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# RESPUESTA CONDUCTUAL DE POSTLARVAS DE CAMARÓN BLANCO *LITOPENAEUS VANNAMEI* FRENTE A LA PRESENCIA DE FILTROS SOLARES EN EL AGUA

## BEHAVIORAL RESPONSE OF WHITE SHRIMP POSTLARVAE *LITOPENAEUS VANNAMEI* TO THE PRESENCE OF SUNSCREENS IN THE WATER

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**RESUMEN:** Los filtros solares son contaminantes emergentes que pueden llegar a los cuerpos de agua por el uso recreativo y por descargas domésticas. El comportamiento locomotor de las postlarvas de *Litopenaeus vannamei* expuestas a 25 y 300 mg/L de protector solar fue el objeto de estudio de esta investigación. Para ello se aplicó un bioensayo estático que contenía un control y dos tipos de tratamientos (25 y 300 mg/L) evaluados tras 24 h y 48 h de exposición. La actividad fue estimada por medio de la distancia recorrida y la estadística fue una complementación de la media de las distancias de desplazamiento, del coeficiente de variación (CV) y del análisis de densidad de Kernel. En cuanto a las diferencias, las pruebas de comparación para la distancia media de desplazamiento no mostraron diferencias estadísticamente significativas ( $p > 0,05$ ). No obstante, a las 24 h el tratamiento de 25 mg/L mostró la mayor variabilidad (CV = 171,3%) y la mayor dispersión de los datos con valores extremos, mientras que a las 48 h los grupos de los tratamientos mostraron una mayor proporción de registros en distancias bajas, lo que anida con una reducción general de la actividad locomotora. En resumen, los resultados reflejan cambios en la variabilidad y en la distribución de la respuesta que no se perciben al comparar solamente las medias. Estos hallazgos aportan evidencia inicial sobre posibles efectos subletales de los filtros solares en postlarvas de *L. vannamei* y respaldan el uso de indicadores conductuales en estudios ecotoxicológicos.

**Palabras clave:** *Litopenaeus vannamei*, filtros solares, comportamiento locomotor, efectos subletales, ecotoxicología, variabilidad conductual

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**ABSTRACT:** Sunscreens are emerging pollutants that can enter water bodies through recreational use and domestic discharges. This study investigated the locomotor behavior of *Litopenaeus vannamei* postlarvae exposed to 25 and 300 mg/L of sunscreen. A static bioassay was conducted, consisting of a control and two treatment groups (25 and 300 mg/L), which were evaluated after 24 and 48 hours of exposure. Activity was estimated based on the distance traveled, and the statistical analysis included the mean displacement distances, the coefficient of variation (CV), and Kernel density analysis. As for the differences, the comparison tests for the mean displacement distance showed no statistically significant differences ( $p > 0.05$ ). However, at 24 h, the 25 mg/L treatment showed the greatest variability (CV = 171.3%) and the widest dispersion of data with extreme values, whereas at 48 h, the treatment groups showed a higher proportion of records at short distances, which is consistent with an overall reduction in locomotor activity. In summary, the results reflect changes in the variability and distribution of the response that are not apparent when comparing only the means. These findings provide initial evidence of possible sublethal effects of sunscreens on *L. vannamei* postlarvae and support the use of behavioral indicators in ecotoxicological studies.

**Keywords:** *Litopenaeus vannamei*, sunscreens, locomotor behaviour, sublethal effects, ecotoxicology, behavioural variability

## INTRODUCTION

The presence of emerging compounds in aquatic ecosystems is related to the daily use of chemical substances and the increase in human activities. Within this group are sunscreens, present in personal care products that can reach coastal and marine areas through recreational activities, domestic discharges and effluents from treatment plants (1, 2, 3, 4, 5). Some of these compounds persist in the environment and have been detected in water, sediments and biological tissues, which favors their interaction with aquatic organisms (1, 2, 6, 7). Sunscreens contain organic and inorganic ultraviolet filters designed to absorb or reflect UV radiation. However, several studies have reported adverse effects of certain compounds, including oxybenzone and octinoxate, on marine organisms (8, 9, 10, 11).

Behavioral ecotoxicology makes it possible to observe early signs of stress before lethal effects appear. Variables such as locomotor activity, swimming patterns, responsiveness, and erratic movements are useful for exploring sublethal effects of chemical contaminants (12, 13, 14, 15, 16). These changes can influence processes relevant to survival, such as foraging, predator evasion, and reproduction (17, 18). The Pacific white shrimp, *Litopenaeus vannamei*, is of great importance for Ecuadorian aquaculture. Their larval and postlarval stages are sensitive to variations in water quality, so they can be used as a model in toxicological and ecotoxicological tests (19, 20, 21).

Although interest in sunscreens in aquatic environments has increased, information on their behavioral effects on crustaceans of aquacultural importance remains limited (8, 21). The

available studies show that the response can change depending on the concentration, exposure time and sensitivity of the individuals, so the analysis of averages does not always allow us to describe all the variability of behavior (15, 21, 22, 23). Therefore, this work aimed to evaluate the effect of 25 and 300 mg/L of sunscreen on the locomotor behavior of *L. vannamei* postlarvae, by analyzing the distance traveled, behavioral variability and the distribution of the locomotor response. The study seeks to provide information on possible sublethal effects of sunscreens on aquatic organisms.

The effects observed in aquatic organisms are not the same for all sunscreens or for all species. They depend on the composition of the product, the concentration, the contact time and the water conditions (6, 7, 8, 11). Thus, laboratory tests should be considered as a controlled approach, not as an exact reproduction of what has happened in an ecosystem. Despite the limitation it entails, they do allow the detection of signals that would justify subsequent studies with environmentally representative concentrations and also greater physicochemical control.

Studying the movement of postlarvae is relevant because movement is part of basic activities such as exploration, feeding and response to environmental stimuli. The present investigation focused on describing whether the concentrations evaluated were associated with changes in distance traveled and behavioral variability. The aim was not to identify the ingredient responsible for the effect, but rather to provide a first description of the response of *L. vannamei* to the experimental exposure.

The analysis of this type of response is especially useful when organisms do not show immediate mortality, but do show changes that may anticipate an alteration in their performance. Distance traveled does not completely summarize behavior; That is why variation measures and distribution graphs were incorporated. This combination allows us to describe in greater detail how individuals behave within each treatment and prevents a single measurement or a single average from determining the interpretation of the study (12, 14, 15, 16).

## MATERIALS AND METHODS

### *Organisms and experimental conditions*

Postlarvae of *Litopenaeus vannamei* at stage PL13, obtained from a commercial larval culture laboratory, were used. They were transported to the experimental site avoiding sudden changes in temperature and salinity. In the laboratory they were kept in 2 L containers with filtered seawater, constant aeration and a cycle of 12 h of light and 12 h of darkness. Salinity was maintained at 33 PSU and temperature at 25 °C, suitable conditions for the cultivation of the species (19). During maintenance, siphoning was carried out every two days to remove organic waste.

Before starting the test, the postlarvae remained in acclimatization for 48 h. This period sought to reduce the effect of the manipulation before the experimental exposure.

### ***Preparation of solutions and concentrations***

The solutions were prepared from a commercial sunscreen and seawater as a dilution medium. A static exposure design was used with three treatments: control (0 mg/L), low concentration (25 mg/L) and high concentration (300 mg/L) (24). For 300 mg/L, 1.8 g of product was dissolved in 6 L of seawater; for 25 mg/L, 0.3 g was dissolved in 12 L. The solutions were stirred for 10 min with a magnetic stirrer before use.

***Table 1. Experimental treatments and calculation of sunscreen concentrations.***

| Parameter                  | Treatment 1 | Treatment 2 | Treatment 3 |
|----------------------------|-------------|-------------|-------------|
| Treatment type             | Control     | Low         | High        |
| SPF                        | 100         | 100         | 100         |
| Concentration (mg/L)       | 0           | 25          | 300         |
| Relative concentration (%) | 0           | 8,3         | 100         |
| Sunscreen quantity (g)     | 0           | 0,3         | 1,8         |
| Volume (L)                 | 6           | 12          | 6           |
| Ratio (g/L)                | 0           | 0,025       | 0,3         |

***Note.*** Concentrations were calculated from the mass/volume ratio and expressed in mg/L. The relative concentration took the treatment of 300 mg/L (100%) as a reference.

### ***Experimental design***

The test was carried out in 200 mL transparent containers, with 90 mL of the corresponding solution in each unit. Postlarvae of similar size were selected to reduce biological variation. The system was direct exposure and did not include spatial gradients; Therefore, it allowed us to evaluate changes in locomotor activity, but not avoidance responses (12, 13, 14, 15, 16).

One postlarva was placed per experimental unit and 12 replicates per treatment were used. The assignment was random. Before recording, each of the organisms was conditioned for 2 min; Next, a 3-min continuous recording was performed. Observations were made after 24 and 48 hours of exposure.

### ***Study variables***

The main variable was the total distance traveled by each of the postlarvae, used as an indicator of locomotor activity. Qualitative observations, such as erratic movements, immobility, decreased activity, and possible escape responses, were also recorded (3, 12).

## Data analysis

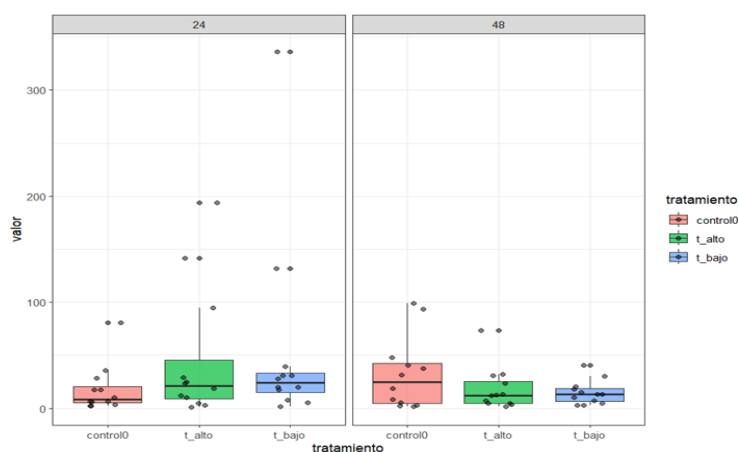
The distance traveled was obtained from video recordings processed with ImageJ and Tracker. Statistical analysis was performed in R (v. 4.5.3). Mean, median, standard deviation and coefficient of variation (CV%) were calculated to describe the dispersion of the data.

Normality and homogeneity of variances were evaluated with the Shapiro-Wilk and Levene tests. Due to the dispersion and the presence of outliers, the non-parametric Kruskal-Wallis test was used. As a descriptive complement, histograms and Kernel density estimates were prepared with ggplot2 (25, 26).

## RESULTS

### 3.1 Locomotor activity and travel distance

The effect of two concentrations of sunscreen (25 mg/L and 300 mg/L) on the locomotor activity of *Litopenaeus vannamei* postlarvae was evaluated. Analysis of the behavioral response using the non-parametric Kruskal-Wallis test did not reveal statistically significant variations in the net movement distance at any of the evaluation times. After 24 hours of exposure, the organisms showed movement patterns comparable to the control group ( $p = 0.28$ ). The average values recorded for the low ( $55.6 \pm 94.7$  mm) and high concentration ( $46.3 \pm 62.8$  mm) treatments were higher than the control ( $18.0 \pm 22.4$  mm). However, the high dispersion of the data prevented establishing a statistical difference (Figure 1). At 48 hours, no significant differences were detected ( $p = 0.58$ ). However, the exposed groups presented lower values than the control. The postlarvae under the low concentration treatment traveled an average of 14.6 mm and those under the high concentration 18.2 mm, while the control group reached 32.3 mm. Boxplots show median, interquartile range, and individual variability ( $n = 12$  per treatment). The Kruskal-Wallis test did not show significant differences between groups ( $p > 0.05$ ).



**Figure 1.** Distance traveled (mm) by *L. vannamei* postlarvae exposed to different concentrations of sunscreens for 24 and 48 h.

### 3.2 Behavioral stability and coefficient of variation (CV%)

Because the magnitude of the displacement did not show significant differences, the coefficient of variation (CV%) was used as a descriptive support to observe the stability of the response. At 24 h, the low concentration group reached the highest value (CV = 171.3%), above the control and the 300 mg/L treatment. At 48 h, CV values decreased, especially by 25 mg/L (77.6%), which coincides with a more concentrated response at low distances.

**Table 2. Descriptive parameters of the locomotor displacement of *L. vannamei*.**

| Time (h) | Treatment       | Average (mm) | Std. Standard ( $\pm$ ) | Variability (CV%) |
|----------|-----------------|--------------|-------------------------|-------------------|
| 24       | Control         | 18.0         | 22.4                    | 125.7%            |
| 24       | Low (25 mg/L)   | 55.6         | 94.7                    | 171.3%            |
| 24       | High (300 mg/L) | 46.3         | 62.8                    | 136.6%            |
| 48       | Control         | 32.3         | 33.9                    | 105.7%            |
| 48       | Low (25 mg/L)   | 14.6         | 11.4                    | 77.6%             |
| 48       | High (300 mg/L) | 18.2         | 20.3                    | 111.6%            |

**Note.** Table 2 shows that, at 24 h, the sunscreen treatments presented average values higher than the control, while at 48 h a decrease in the exposed organisms was recorded. High coefficients of variation show a dispersed response, so the data should be interpreted in conjunction with distribution plots and not just averages.

### 3.3 Qualitative observations and movement patterns

Complementing the quantitative analysis of locomotor activity, qualitative observations allowed us to identify relevant behavioral alterations that were not completely evident through distance traveled metrics. Throughout the experimental days, progressive alterations in the locomotor behavior of the postlarvae subjected to sunscreens were recorded, particularly experienced in the 25 and 300 mg/L treatments, in response to mechanisms linked to chemical stress and/or perception of the pollutant.

In the first measurement carried out at 24 h, the postlarvae that received the 25 mg/L treatment presented episodes of increased activity, developing rapid and sudden movements within the experimental container; In several postlarvae, escape movements, sudden accelerations and erratic trajectories alternating with short episodes of rest were recorded. This pattern can be characterized as behavior as an initial response to the stimulation of the exposure.

In the context of 300 mg/L, the behavioral responses were more heterogeneous: although there were cases of individuals who presented in their movements (initial activation), the majority showed less coordinated shoulders and a behavior relatively associated with remaining in certain places in the container. Circular trajectories, spiral movements and erratic movements, without a specific direction, were recorded, which are considered a sign of the neurobehavioral alteration of aquatic organisms exposed to toxic conditions; In addition, partial loss of stability in movement could be observed, which was visible through sudden changes in body orientation, and difficulties in maintaining continuous swimming patterns.

After 48 hours, behavioral failures became evident in both treatments. After these 48 hours, the exposed postlarvae showed a general decrease in locomotor activity, accompanied by long periods of immobility and a reduction in the frequency of movements; This behavior was more evident in the 300 mg/L treatment, since many individuals remained in a state of immobility for long periods, which was interrupted only by short and infrequent movements. This state suggests a state of motor depression or drowsiness associated with the time of exposure to the pollutant.

Likewise, within some exposed organisms we have seen symptoms of disorientation, evidenced by successive collisions against the walls of the container and sudden changes in the direction of movement. These behaviors reflect, in principle, that the space perception and motor skills systems may be altered. On the contrary, the control group had a clearly and very consolidated pattern over the course of the experiment, characterized not only by more regular displacement trajectories, but also by a lower frequency of the presence of periods of immobility and a more homogeneous displacement between individuals.

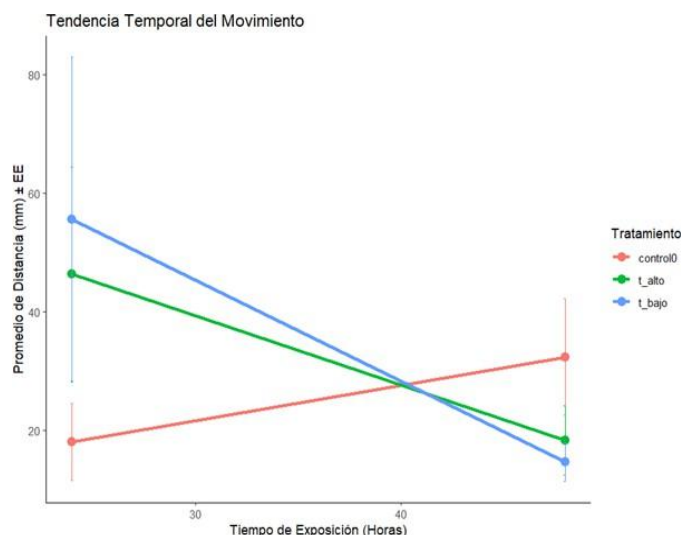
Qualitative observations also indicate a notable intraspecific variability in the response to the pollutant: thus, while some organisms respond with very intense activity, others immediately respond by inhibiting movement, which reveals individual differences in physiological sensitivity and tolerance to chemical stress. This heterogeneity is consistent with the high values observed for the coefficient of variation at 24 h, which corroborates the existence of behavioral fragmentation among the exposed populations.

The observed patterns describe behavioral changes in postlarvae exposed to sunscreens. The response was not uniform between individuals and changed over time, going from more dispersed records at 24 h to a greater concentration of low distances at 48 h. Therefore, rather than talking about a definitive effect, the data allow us to recognize behavioral signals that must be confirmed in subsequent studies.

### 3.4 Nonlinear dose-response relationship

The descriptive data did not show a clear linear dose-response relationship (Figure 2). The 25 mg/L treatment at 24 h presented a higher average distance traveled than the 300 mg/L treatment, suggesting a greater initial activity for the low concentration. This trend was

reversed after 48 h, since the organisms exposed to this concentrate moved less, especially in the treatment with a higher concentration. This result indicates that exposure time has had an effect on the observed response.



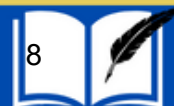
**Figure 2.** Interaction graph showing changes in locomotor activity between treatments and exposure times.

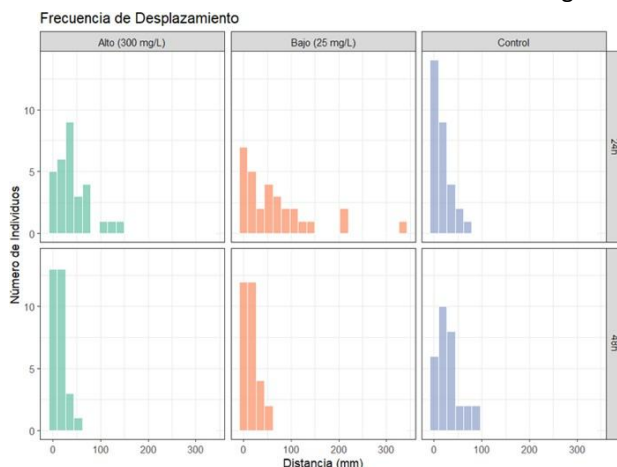
### 3.5 Density analysis and frequency distribution

The analysis of frequency histograms allowed us to evaluate the structure of the locomotor response at the population level, as seen in Figure 3. After 24 h of exposure, the control group exhibited values concentrated in low displacements, which demonstrates a relatively homogeneous behavior. On the contrary, the tested treatments exhibited wider and more dispersed distributions, in addition to the presence of extreme data, in the case of the 25 mg/L treatment, the presence of individuals with large displacements was identified, thus causing the distribution to show a “long tail” in it.

This type of behavior is a non-homogeneous response, where organisms with high and low locomotor activity coexist, which gives rise to a fragmentation of the population response to the pollutant. At 48 h, the histograms show a general shift of the distributions towards low ranges of movement (0-50 mm), reflecting that there is a greater proportion of organisms with reduced activity. This type of pattern suggests a move towards a state of motor inhibition or depression.

The control group has a broader representation of the distributions, which highlights greater stability of locomotor activity. The graphic representation allows us to detect variations in the pattern and dispersion of the responses in the distributions that are not detected with the averages, emphasizing a temporal dynamic in the behavioral response and taking into consideration the importance of evaluating the shape of the population structure to detect sublethal effects.





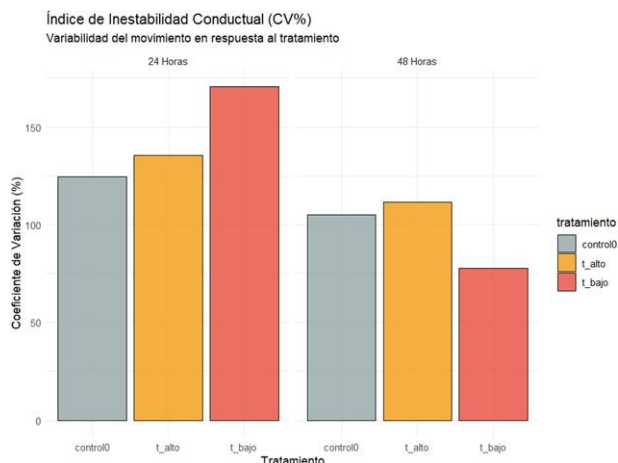
**Figure 3. Histograms of displacement frequency (mm) in *L. vannamei* postlarvae exposed to different concentrations of sunscreen.**

### 3.6 Behavioral instability index (CV%)

The analysis of the coefficient of variation (CV%) made it possible to evaluate the behavioral variability between treatments and exposure times, as seen in Figure 4. At 24 hours, the 25 mg/L treatment presented the highest level of instability (CV = 171.3%), surpassing both the control and the 300 mg/L treatment, indicating a high heterogeneity in the locomotor response of individuals exposed to sublethal concentrations. This trend suggests that organisms show different responses to first exposures, in response to the perception of the harmful substance.

After 48 hours, it can be seen that all treatments show a general decrease in the coefficient of variation (CV%), with the 25 mg/L treatment showing the most pronounced decrease (77.6%). The decrease in variability seems to be a trend towards a more homogeneous general behavior, associated with a decrease in locomotor activity. This pattern reveals the tendency from an initial state of excitement (characterized by high variability) to one of motor depression (where organisms show more similar and scarce movements).

The figure reveals the temporality of the behavioral response, where the high initial variability can be understood as one of the first evidences of stress, and the stabilization of variability as the component of the decrease in activity. In this context, the results support the use of CV% as a sensitive biomarker for the detection of sublethal effects in aquatic organisms.



**Figure 4. Behavioral instability index expressed as coefficient of variation (CV%) in *L. vannamei* postlarvae.**

### 3.7 Detailed analysis of density and behavioral structure

#### 3.7.1 Distribution and dispersion at 24 hours

After 24 h of exposure, the analysis of density and frequency distribution showed descriptive differences in the organization of the locomotor response between the groups (Figure 5). The control showed narrower distributions and distributed in smaller displacements, in contrast, the tested treatments showed broader curves.

Treatments exposed to sunscreens showed broader and more dispersed distributions, showing a not so homogeneous response. In the 25 mg/L treatment, the treatment showed the widest density curve and notable heterogeneity between individuals.

At the same time, treatment at 25 mg/L showed evidence of secondary peaks in the intermediate ranges of displacement (150-200 mm), but indication of a multimodal distribution in the population. In this case, this distribution reflects a fragmentation of the behavioral response into repeated subgroups, as well as the existence of different levels of sensitivity to the pollutant. The existence of these subpopulations is evidence of a certain loss of behavioral synchronization, as well as group homeostasis in the face of chemical stress.

On the other hand, the treatment at 300 mg/L yielded samples with a more compact distribution than that of the treatment at 25 mg/L, but always showing a broader distribution than that presented by the control group. In this case, locomotor activity was concentrated mainly in moderate displacement ranges, with less presence of extreme values, which would indicate that higher concentrations of the contaminant could induce an earlier inhibition of locomotor activity, limiting the presence of hyperactive responses present in the treatment at 25 mg/L.

The widening of the treatment density curves reflects the existence of greater intraspecific variability and a less predictable behavioral response to sunscreen exposure. This type of behavior would be consistent with the high values of the coefficient of variation at 24 hours,

particularly in the treatment with the lowest concentration (CV = 171.3%), which again corroborates that the variability of movement behavior can be a sensitive biomarker of sublethal stress.

On the other hand, from an ecotoxicological perspective, the dispersion we observed may also indicate that the postlarvae must have modified their type of movement upon exposure. The existence of high-glass and low-glass individuals also indicates that the response is not uniform and that therefore it is convenient to have the total distribution of the data.

### **3.7.2 Density shift at 48 hours**

At 48 h of exposure, the density analysis showed a visible modification in the structure of the locomotor response of *Litopenaeus vannamei* postlarvae exposed to sunscreens. Compared to 24 h, the treatment curves shifted toward lower displacement values.

The frequency histograms showed a predominant concentration of organisms in the range of 0 to 10 mm of displacement, particularly in the 300 mg/L treatment. The suggested behavior also indicates that there is a tendency towards states of very low movement, such as, for example, partial immobility or lethargy and the limited movement that characterizes them, short journeys and the existence of long periods of rest. The decrease in the amplitude of the distributions manifests the loss of hyperactivity observed in the first twenty-four hours and reveals the transition towards motor depression responses, consequences of the increase in exposure time.

In the 25 mg/L treatment, the measurements still determine some individuals with moderate movements, but the majority were characterized by very reduced levels of locomotor activity, with a more concentrated (less dispersed) distribution than the initial one, which suggests a progressive homogenization of behavior within the experimental group, where individual responses tend to converge on low levels of mobility, a process that would also be accompanied by the reduction in dispersion observed at 48 hours, which corresponds to the period of time in which a stabilization of the physiological response of individuals to temporary exposure to chemical stress is determined.

On the contrary, the control group offered a broader and more balanced distribution, with individuals distributed in different displacement ranges and without a predominant accumulation at values close to zero. This allows us to conclude that unexposed postlarvae maintained more active and more continuous locomotor patterns, as well as a relatively stable behavioral organization during the development of the trial.

The shift of the density curves towards low values can be interpreted as a decrease in the locomotor performance of the animals under test conditions, but this reading must be cautious, because the bioassay did not yield physiological biomarkers and an analysis of the measurement of the components present in the water was not carried out.

Likewise, the change from broad and heterogeneous distributions to narrower and more concentrated curves shows a temporal variation in the response. In descriptive terms, first more dispersed recordings were observed and then greater grouping at low distances, which coincides with the general reduction in movement.

### 3.8 Relationship between density and variability (CV%)

The structure of the density curves is consistent with the high values of the coefficient of variation observed at 24 hours. The extensive distributions, together with the existence of extreme values, are indicative that individuals did not respond homogeneously, but rather of a high dispersion between individuals.

The curves suggest the probability of occurrence of individuals under different levels of activity, and broader information can be observed in the distributions at 24h of the treatments and a shift towards low values of movement at 48h.

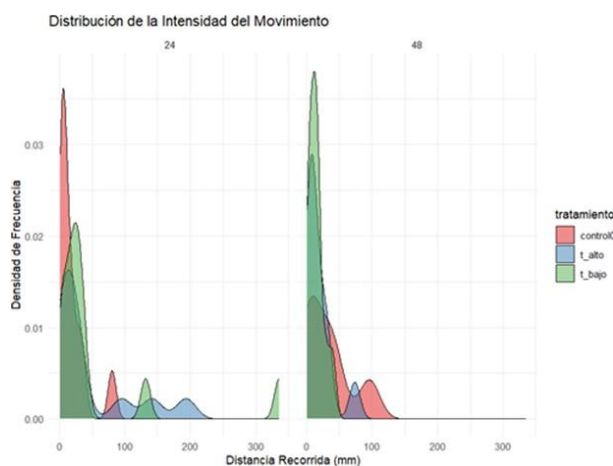


Figure 5. Density distribution of locomotor activity (mm) in *L. vannamei* postlarvae.

## DISCUSSION

The comparison of the mean distances did not show statistically significant differences between treatments. We should not be held responsible for the effect of the concentrations we have evaluated on the average displacement. The descriptive results suggest that the response was not uniform: at 24 h the 25 mg/L treatment produced the highest coefficient of variation and the distance was more distributed, and at 48 h the exposed groups concentrated more recordings at low distances but without revealing the same degree of variability as the control group. In behavioral ecotoxicology studies, these changes in variability can complement, but not replace, the statistical test on means (12, 14, 15, 16).

The extreme values and dispersion observed at 24 h indicate that some organisms moved more than others under the same exposure condition. This heterogeneity may be related

to individual differences, manipulation or exposure to the product. For this reason, it is not possible to attribute variability alone to a specific mechanism. Even so, the use of histograms and Kernel density allowed us to describe an aspect of the data that the average does not clearly show (23, 25, 26).

The general reduction in movement at 48 h deserves cautious interpretation. It may be compatible with lower locomotor activity, but the study did not measure physiological biomarkers or the effective concentration of sunscreen components. It also does not allow the effect of UV filters to be separated from that of other ingredients in the formulation. Therefore, the results should be read as a behavioral response observed under the conditions of the bioassay and not as evidence of a specific neurological, endocrine or metabolic mechanism (8, 9, 10, 11).

The absence of a linear dose-response relationship in the descriptive data should also not be interpreted as evidence of a biphasic response. The greater dispersion at 25 mg/L may be due to a combination of individual variation, sample size, and product exposure. Therefore, the observed pattern must be confirmed with independent replicates and with analyzes designed to simultaneously evaluate concentration and exposure time (22, 23, 25).

The design also does not allow the environmental risk to be estimated by itself. The concentrations were nominal and the study was carried out under controlled conditions, while in natural environments dilution, currents, light, mixing with other contaminants and variations in temperature and salinity intervene. The differences do not invalidate the bioassay because they do not allow us to establish the conclusion that the product tried to cause permanent alterations, but they become a limit to the best conclusions and improvements for subsequent work.

The perception that there is no statistical difference does not indicate that there is no effect, but it does not allow us to conclude that the product has tried to cause permanent alterations. The result must be interpreted within the framework of limits of our design, which we contextualize given the high variability and the convenience of replicating the trial.

From an environmental perspective, locomotor behavior is relevant because it participates in foraging, predator evasion, and habitat use (12, 13, 18). The findings justify continuing with trials that incorporate physicochemical control of water, analytical verification of concentrations, larger sample size and exposures closer to environmental scenarios. It would also be useful to integrate physiological or biochemical variables to relate behavioral changes to other stress indicators (3, 7, 14).

## CONCLUSIONS

Under the conditions of this bioassay, concentrations of 25 and 300 mg/L of sunscreen do not cause significant differences in the average displacement of *L. vannamei* postlarvae at 24 h or 48 h.

The 25 mg/L treatment presented the greatest variability at 24 (CV = 171.3%), and the distribution analyzes showed a more dispersed response than that of the control group. At 48 h, the exposed groups had a greater concentration of recordings at low distances. These descriptive patterns suggest behavioral changes that require confirmation in new trials.

The mean distance, the coefficient of variation, histograms and Kernel density provided complementary information to describe the locomotor response. To establish the ecological importance of the observed patterns, studies with complete physicochemical control, analysis of the components present in the water and greater replication are needed.

For all that has been said, the results should be evaluated as exploratory evidence and not as proof of specific toxicity. The value of the study lies in pointing out that, even when the means do not differ significantly, the form of data distribution can offer useful clues to determine which questions need to be analyzed in a next stage.

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## DECLARATION OF INTEREST

The authors declare that there is no conflict of interest related to the publication of this article. Likewise, no external financing was received that could influence the results obtained.

## REFERENCES

1. Gago-Ferrero P, Díaz-Cruz MS, Barceló D. Occurrence of multiclass UV filters in aquatic environments. *Chemosphere*. 2015;120:578-585.
2. Tsui MMP, Leung HW, Wai TC, Yamashita N, Taniyasu S, Liu W, et al. Occurrence, distribution and ecological risk of UV filters. *Water Res*. 2014;67:55-65.

3. Sánchez-Quiles D, Tovar-Sánchez A. Are sunscreens a new environmental risk associated with coastal tourism? *Environ Int.* 2015;83:158-170.
4. Tovar-Sánchez A, Sánchez-Quiles D, Basterretxea G, Benedé JL, Chisvert A, Salvador A, et al. Sunscreen products as emerging pollutants to coastal waters. *PLoS One.* 2013;8(6):e65451.
5. Langford KH, Thomas KV. Inputs of chemicals from recreational activities into the coastal zone. *J Environ Monit.* 2008;10(7):894-898.
6. Fent K, Kunz PY, Zenker A, Rapp M. A tentative environmental risk assessment of UV filters. *Environ Toxicol Chem.* 2010;29(12):2597-2612.
7. Sharifan H, Ma X, Moore SK, Brownawell BJ. Occurrence and fate of ultraviolet filters in nearshore waters. *Environ Sci Technol.* 2016;50(6):2993-3003.
8. Hodge AA, Hopkins FE, Saha M, Jha AN. Ecotoxicological effects of sunscreen-derived UV filters on marine organisms: a review. *Mar Pollut Bull.* 2025;213:117627.
9. Coronado M, De Haro H, Deng X, Rempel MA, Lavado R, Schlenk D. Estrogenic activity and reproductive effects of oxybenzone in fish. *Aquat Toxicol.* 2008;90(3):182-187.
10. Kunz PY, Fent K. Multiple hormonal activities of UV filters in fish. *Aquat Toxicol.* 2006;79(4):305-324.
11. Kim S, Choi K. Occurrence, toxicity, and ecological risk of benzophenone-3 in aquatic environments. *Environ Int.* 2014;70:143-157.
12. Ribeiro F, Lopes I, Pereira R, Gonçalves F, Soares AMVM. Behavioral responses of aquatic organisms as indicators of environmental contamination. *Ecol Indic.* 2018;95:738-745.
13. Scott GR, Sloman KA. Effects of environmental pollutants on fish behaviour. *Environ Pollut.* 2004;129(2):179-190.
14. Hellou J. Behavioural ecotoxicology, an “early warning” signal to assess environmental quality. *Environ Sci Pollut Res.* 2011;18(1):1-11.
15. Ghalayini M, Hachicho N, Fritsch C, Schäffer A, Hollert H. Behavioral ecotoxicology: a new paradigm for assessing sublethal effects of emerging contaminants. *Sci Total Environ.* 2024;912:168845.
16. Marrone R, Cazenave J, Wunderlin DA. Behavioral variability as an indicator of sublethal stress in aquatic organisms exposed to environmental contaminants. *Ecotoxicology.* 2014;23(3):455-464.
17. Günel AÇ, Tunca SK, Arslan P, Gül G, Dinçel AS. Sublethal effects of permethrin on non-target aquatic organisms. *Environ Sci Pollut Res.* 2021;28:52405-52417.
18. Islam MS, Tanaka M, Yamashita Y. Effects of environmental stressors on aquatic organisms. *Environ Sci Pollut Res.* 2019;26(12):12025-12040.
19. Boyd CE. Water quality: an introduction. Cham: Springer; 2015.
20. Burbano-Gallardo E, Imués-Figueroa MA, Gonzalez-Legarda EA, Brito LO, Olivera Galvez A, Vinatea Arana LA. Supervivencia de poslarvas de *Litopenaeus vannamei* sometidas a la prueba de estrés osmótico y su relación con el estado de muda. *Rev Biol Mar Oceanogr.* 2015;50(2):323-330.
21. Malinowska V, Kuklina I, Grabicová K, Buřič M, Kozák P. Short-term effects of organic UV filters on crayfish locomotor activity. *Ecotoxicol Environ Saf.* 2023;259:115012.

22. Araújo CVM, Rodríguez-Romero A, Fernández M, Sparaventi E, Márquez-Medina M, Tovar-Sánchez A. Repellency and mortality effects of sunscreens on the shrimp *Palaemon varians*: toxicity dependent on exposure method. *Chemosphere*. 2020;257:127190.
23. Vignet C, Joassard L, Lyphout L, Guionnet T, Goubeau M, Le Menach K, et al. Non-monotonic behavioral responses to contaminants. *Environ Sci Pollut Res*. 2014;21(23):13818-13828.
24. Fent K, Weston AA, Caminada D. Ecotoxicology of human pharmaceuticals. *Aquat Toxicol*. 2006;76(2):122-159.
25. Zuur AF, Ieno EN, Elphick CS. A protocol for data exploration to avoid common statistical problems. *Methods Ecol Evol*. 2010;1(1):3-14.
26. Wickham H. *ggplot2: Elegant Graphics for Data Analysis*. 2nd ed. New York: Springer; 2016.

# COMPROMISO ORGANIZACIONAL Y LA RETENCIÓN DEL TALENTO HUMANO EN EL SECTOR FINANCIERO DEL

## CANTÓN PUJILÍ ORGANIZATIONAL COMMITMENT AND HUMAN TALENT RETENTION IN THE FINANCIAL SECTOR OF PUJILI CANTON

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**RESUMEN:** La presente investigación tuvo como objetivo principal determinar la relación entre el compromiso organizacional y la retención del talento humano en los colaboradores del sector financiero del Cantón Pujilí, Ecuador. Metodológicamente, adoptó un enfoque cuantitativo, no experimental, de corte transversal y alcance descriptivo-correlacional, aplicando un censo poblacional al 100% de la plantilla accesible, conformada por 116 profesionales activos de agencias bancarias y cooperativas de ahorro y crédito locales. La recolección de datos se realizó mediante dos cuestionarios validados en Google Forms que mostraron alta consistencia interna y validez: el de compromiso organizacional (17 ítems) alcanzó un Alfa de Cronbach de 0.920 y un KMO de 0.900, mientras que el de retención (9 ítems) obtuvo un Alfa de 0.902 y un KMO de 0.847. Los resultados descriptivos revelaron un escenario favorable donde predominó el nivel alto tanto en el compromiso organizacional (60.3%) como en la retención del talento (55.2%). Tras aplicar la prueba de Kolmogorov-Smirnov y determinar que los datos no siguen una distribución normal ( $p = 0.000$ ), se empleó estadística no paramétrica mediante el coeficiente Rho de Spearman, arrojando un valor de  $Rho = 0.577$  ( $p = 0.000$ ) que evidencia una relación lineal positiva de intensidad moderada, concluyéndose que un mayor compromiso incrementa de manera directa y favorable la retención del personal en la identidad financiera local.

**Palabras clave:** *Compromiso organizacional, retención del talento, sector financiero, modelo no paramétrico, fidelización*

**ABSTRACT:** The main objective of this research was to determine the relationship between organizational commitment and human talent retention among employees in the financial sector of Pujilí Canton, Ecuador. Methodologically, the study adopted a

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quantitative, non-experimental, cross-sectional, and descriptive-correlational design, applying a population census to 100% of the accessible staff, which comprised 116 active professionals from local bank branches and savings and credit cooperatives. Data collection was carried out through two validated questionnaires on Google Forms that demonstrated high internal consistency and validity: the organizational commitment instrument (17 items) achieved a Cronbach's Alpha of 0.920 and a KMO of 0.900, while the retention instrument (9 items) recorded a Cronbach's Alpha of 0.902 and a KMO of 0.847. Descriptive results revealed a favorable scenario where a high level predominated in both organizational commitment (60.3%) and human talent retention (55.2%). Following the Kolmogorov-Smirnov normality test, which determined that the data did not follow a normal distribution ( $p = 0.000$ ), non-parametric statistics were used via Spearman's Rho correlation coefficient; this yielded a value of  $Rho = 0.577$  ( $p = 0.000$ ), demonstrating a moderate positive linear relationship and conclusively leading to the finding that a higher level of commitment directly and favorably increases staff retention within the local financial entity.

**Keywords:** *Organizational commitment, talent retention, financial sector, non-parametric model, loyalty*

## INTRODUCTION

In the contemporary business environment, human talent management has been placed at the center of global corporate strategy. Organizational commitment and talent retention emerge as key constructs for modern management, determining productivity, personnel stability, and institutional sustainability. Within the financial sector, this dynamic is critical because the speed of digital transformation often exceeds the adaptability of internal culture, eroding the psychological bond between employees and their organizations. Therefore, understanding how commitment and loyalty are articulated is essential to mitigate the flight of intellectual capital towards competitive sectors.

At an international level, the reality of banking during the 2024-2025 biennium demonstrates that the retention of strategic profiles no longer depends on traditional economic compensation. In Spain, the central bank emphasizes that the stability of the current financial system depends on cultural cohesion and internal motivation. However, the disconnect between traditional management and digital expectations has weakened the sense of belonging. Reports from Aon Spain place voluntary rotation in strategic profiles at 18%, showing that the projected salary increases of 4% for 2025 are insufficient if organizations do not prioritize flexible environments and comprehensive well-being. Thus, giants such as the Santander Group recognize the need to transcend economic remuneration to effectively manage their staff. At the regional level, the Peruvian financial sector experiences a similar paradox in the period 2024-2025. While institutions reach historic levels of solvency, the human fabric shows fragility due to external pressures such as cybersecurity risks. According to PwC Peru, 54% of employees report a decrease in their

corporate identification due to the absence of connection with institutional values, which raised voluntary rotation in young and technological profiles to 16%, according to the Ministry of Labor and Employment Promotion. Given this, leaders such as the Banco de Crédito del Perú are redefining their models towards digital leadership and labor flexibility. (1) (2) (3) (4) (5) (6) (7) (8) (6)

The Ecuadorian financial sector in the years 2024-2025 reflects identical challenges due to digital and regulatory transformations. The Superintendency of Popular and Solidarity Economy points out that savings and credit cooperatives, despite registering a 12% growth in assets, report increases in personnel turnover in areas of customer service and technological management. At the same time, the Central Bank of Ecuador warned that the voluntary rotation of young and digital talent reached 15%, imposing extraordinary costs in recruitment. This problem is valid in the financial sector of the Pujilí Canton, where studies from the Private Technical University of Loja show that professionals prioritize flexibility, well-being and professional development over traditional economic remuneration. (9) (10) (2) (11)

To scientifically address this problem, it is essential to analyze organizational commitment from the multidimensional model of Meyer and Allen, structured in three components: affective, continuity and normative. Affective commitment refers to the employee's emotional attachment and identification with the company's values; Carrillo maintains that it reduces the intention of voluntary turnover and increases the willingness to make additional efforts, while Chamorro, Vélez and Cedeño highlight that an environment of mutual support and trust favors this emotional bond. Continuance commitment is generated when the employee rationally evaluates the economic and professional costs of leaving the institution based on the accumulated benefits (seniority, experience); Torner explains that the individual with high continuity commitment remains out of necessity or lack of external alternatives, and Sajami and Gonzales associate this link with the accumulated benefits of the position. In turn, De Clerc, Belausteguigoitia and Ohanas point out that continuity reduces psychological exhaustion as employment is perceived as a safe environment. Finally, normative commitment is based on a sense of moral obligation and reciprocity; Gonzáles, Medina and Herrera (2024) state that it develops when workers consider that they must remain loyal to the company as compensation for the incentives and training received. (4) (10) (7) (6) (7)

Regarding the variable retention of human talent, Taruchaín and Revelo (2023) define it as the articulated set of corporate strategies to maintain valuable and qualified collaborators, reducing the costs associated with rotation. De la Cruz, Huaraca, Valdez, Li-Parra and Melgarejo state that managing retention increases competitive advantage and allows efforts to be focused on innovation and sustainable growth, avoiding unnecessary expenses in repetitive personnel selection phases. Skerhskova details that to achieve talent loyalty, critical dimensions such as job security and skills development must be managed, factors that favorably influence technical performance and drastically reduce the staff turnover rate, as pointed out by Matabanchoy and Díaz (11) (9) (12) (5)

Given the pressing need to generate situational scientific data for the local context, the following research question arises: What is the relationship between organizational commitment and employee retention? human talent in the collaborators of the financial sector of the Pujilí Canton? To answer this question, the general objective is established to determine the relationship between organizational commitment and the retention of human talent in employees of the financial sector of the Pujilí Canton. In accordance with the above, it is proposed as an alternative hypothesis of the study (H1) that there is a direct and statistically significant relationship between organizational commitment and the retention of human talent in employees of the local financial sector, directly contrasting it with the null hypothesis (H0) that denies the existence of said association link.

## MATERIALS AND METHODS

This research adopted a quantitative approach with a non-experimental, cross-sectional design and correlational descriptive scope. The population under study was directly made up of professionals and workers who perform their duties in the financial sector of the Pujilí canton, province of Cotopaxi, Ecuador. Because it was a completely finite human group, delimited and completely accessible for the application of the instruments by the work team, a population census was carried out. Therefore, the final sample analyzed coincided exactly with one hundred percent of the members of the local entities, thus including a total of 116 active collaborators belonging to the different banking agencies and savings and credit cooperatives that operate in the aforementioned geographical area.

For the process of collecting field information, two validated data collection instruments were applied, whose methodological origins, operational structure and references are detailed in a summarized manner in Table 1. Both questionnaires were distributed in digital format through the online platform Google Forms to guarantee secure access for the participants.

The first instrument consisted of the scale to evaluate Organizational Commitment, formally adapted from Meyer and Allen's three-dimensional model. It is structured by a total of 17 items distributed in three analytical dimensions: affective commitment (6 items; Cronbach's Alpha = 0.885), continuity commitment (6 items; Cronbach's Alpha = 0.841) and normative commitment (5 items; Cronbach = 0.863). In its overall evaluation, the questionnaire demonstrated excellent internal consistency with a Cronbach's Alpha of 0.920. (13) (10)

To support the construct validity in the studied sample, an Exploratory Factor Analysis (EFA) was executed using the principal components method and Varimax rotation. Sampling adequacy was confirmed by a KMO index of 0.900 and a statistically significant Bartlett's test of sphericity ( $\chi^2 = 1245.32$ ;  $p = 0.000$ ). The factor analysis identified three eigenvalues greater than unity (6.42, 2.15 and 1.38), which together explained 58.5% of the total accumulated variance of the variable.

The second instrument corresponded to the questionnaire adapted from Skerhakova et al. (2022) to evaluate the Retention of Human Talent. This scale consists of 9 items distributed in four operational dimensions: job recognition (2 items; Cronbach's Alpha = 0.812), institutional support (3 items; Cronbach's Alpha = 0.835), mutual trust (2 items; Cronbach's Alpha = 0.798) and personal encouragement (2 items; Cronbach's Alpha = 0.820). The scale had solid overall reliability with a Cronbach's Alpha of 0.902. Construct validity was supported by Exploratory Factor Analysis, obtaining a KMO indicator of 0.847 and a significant Bartlett's sphericity test ( $\chi^2 = 780.45$ ;  $p = 0.000$ ), with four eigenvalues greater than 1.0 (3.85, 1.42, 1.10 and 1.01) representing 62.1% of the explained variance.

**Table 1. Operationalization Matrix of Variables and Measurement Instruments.**

| Variable                         | Dimensions            | Items (Reagents)    | Source / Author of origin |
|----------------------------------|-----------------------|---------------------|---------------------------|
| <b>Organizational Commitment</b> | Affective Commitment  | 1, 2, 3, 4, 5, 6    | Meyer & Allen (1991)      |
|                                  | Continuity Commitment | 7, 8, 9, 10, 11, 12 | Meyer & Allen (1991)      |
|                                  | Normative Commitment  | 13, 14, 15, 16, 17  | Meyer & Allen (1991)      |
| <b>Retention of Human Talent</b> | Job Recognition       | 1, 2                | Skerhakova et al. (2022)  |
|                                  | Soporte Institucional | 3, 4, 5             | Skerhakova et al. (2022)  |
|                                  | Mutual Trust          | 6, 7                | Skerhakova et al. (2022)  |
|                                  | Personal Stimulus     | 8, 9                | Skerhakova et al. (2022)  |

The Kolmogorov-Smirnov normality test, applied prior to the inferential analysis, formally indicated that the data collected do not follow a normal or parametric distribution by registering a significance value of  $p = 0.000$ , which is notably below the critical limit of 0.05. For this reason, the methodological and statistical need to use the non-parametric Spearman correlation test was determined to carry out the corresponding contrast of the hypotheses raised in the research. Statistical processing of all information was carried out in an automated manner using the specialized software package IBM SPSS Statistics. In the first stage, descriptive statistics were applied to classify, order and present the behavior of the variables through frequency tables and percentage graphs. In a second stage, the Spearman correlation calculation was carried out to determine the existence, direction and intensity of the relationship between organizational commitment and the retention of human talent in the workforce.

Finally, specific statistical scales were structured that served to classify the levels of both constructs into three ordered categories of analysis: (low, medium and high).



## RESULTS

The results in table 2 correspond to the descriptive evaluation of the Organizational Commitment variable in the financial entities of the Pujilí Canton. When analyzing the global behavior of this construct in the 116 collaborators, a clear predominance of the high level was observed, which reached 60.3% of the total participation, equivalent to 70 people from the studied workforce. This percentage is followed by the medium level with 34.5%, represented by 40 workers, while the low level registered the lowest representation with only 5.2%, which is equivalent to only 6 professionals. From an institutional perspective, the concentration of more than 90% of employees between the medium and high ranks demonstrates that emotional attachment to organizations, the perception of permanence benefits and the sense of moral loyalty operate very favorably in the sector.

**Table 2. Results of Variable 1.**

| Organizational Commitment |              |            |                  |                       |
|---------------------------|--------------|------------|------------------|-----------------------|
|                           | Frequency    | Percentage | Valid percentage | Cumulative percentage |
| Levels                    | Low Level    | 6          | 5,2              | 5,2                   |
|                           | Medium Level | 40         | 34,5             | 39,7                  |
|                           | High Level   | 70         | 60,3             | 100,0                 |
|                           | Total        | 116        | 100,0            | 100,0                 |

**Note.** Results obtained from the application of the organizational commitment questionnaire processed in SPSS.

On the other hand, the data in the third table details the global results obtained for the variable Retention of Human Talent in the same study group. In this indicator, an equally positive and consolidated trend is evident, highlighting the prevalence of the high level with 55.2% of the cases, which represents 64 census collaborators. Likewise, the medium level obtained a participation of 37.9%, equivalent to 44 people on the staff, while the low level was located at a minimum margin of 6.9%, corresponding to just 8 individuals. These numerical findings demonstrate the solidity of the current human capital loyalty strategies in the area, denoting that factors such as institutional support, recognition of leaders and stability stimuli are perceived excellently by the vast majority of the workforce.

**Table 3. Result of Variable 2.**

| Talent Retention |           |            |                  |                        |
|------------------|-----------|------------|------------------|------------------------|
|                  | Frequency | Percentage | Valid Percentage | Accumulated percentage |
| Levels           | Low Level | 8          | 6,9              | 6,9                    |

|              |     |       |       |       |
|--------------|-----|-------|-------|-------|
| Medium Level | 44  | 37,9  | 37,9  | 44,8  |
| High Level   | 64  | 55,2  | 55,2  | 100,0 |
| Total        | 116 | 100,0 | 100,0 |       |

**Note.** Results obtained from the application of the human talent retention questionnaire processed in SPSS.

The Kolmogorov-Smirnov normality test indicated that the data for both variables do not follow a normal distribution ( $p$  less than 0.05), which justified the use of non-parametric tests for correlational analysis.

**Table 4. Normality test calculation.**

| Normality tests           |             |     |       |
|---------------------------|-------------|-----|-------|
| Kolmogorov-Smirnov        |             |     |       |
|                           | Statistical | gl  | Sig.  |
| Organizational Commitment | 0,378       | 116 | 0,000 |
| Talent Retention          | 0,348       | 116 | 0,000 |

a. Lilliefors Significance Correction

**Note.** Kolmogorov-Smirnov test with Lilliefors significance correction

To carry out the hypothesis contrast and determine the relationship between the analyzed variables, Spearman's Rho correlation coefficient was applied, a technique selected after verifying the absence of normality in the distribution of the data. The results of this statistical test reflected a correlation coefficient of  $Rho = 0.577$  between Organizational Commitment and the Retention of Human Talent in the financial institutions of the canton, a value that represents the existence of a positive linear relationship of moderate intensity, indicating a direct proportionality between both elements. Likewise, the analysis yielded a bilateral significance value of  $p = 0.000$ , a figure that is significantly below the critical significance level of 0.05 and the corporate confidence level of 0.01; Because this indicator is statistically significant ( $p < 0.01$ ), there is sufficient numerical support to strongly reject the null hypothesis ( $H_0$ ) and formally accept the research hypothesis ( $H_1$ ), definitively confirming that a higher level of commitment within the organization directly and favorably influences the increase in the retention of human talent in the workforce.

**Table 5. Correlation calculation.**

| Correlations |                              |
|--------------|------------------------------|
|              |                              |
|              | organizational<br>commitment |
|              | talent retention             |

|                                                                 |                              |                            |        |        |
|-----------------------------------------------------------------|------------------------------|----------------------------|--------|--------|
|                                                                 | organizational<br>commitment | Correlation<br>coefficient | 1,000  | ,577** |
|                                                                 |                              | Sig. (two-sided)           |        | 0,000  |
|                                                                 |                              | N                          | 116    | 116    |
| Spearman's<br>Rho                                               | talent retention             | Correlation<br>coefficient | ,577** | 1,000  |
|                                                                 |                              | Sig. (two-sided)           | 0,000  |        |
|                                                                 |                              | N                          | 116    | 116    |
| . The correlation is significant at the 0.01 level (two-sided). |                              |                            |        |        |

**Note. Spearman Correlation**

## DISCUSSION

The main objective of this research was to determine the relationship between organizational commitment and the retention of human talent in employees of the financial sector of the Pujilí Canton. Statistical findings demonstrated a positive linear relationship of moderate intensity ( $Rho = 0.577$ ;  $p = 0.000$ ). These results align with what was stated by De la Cruz, García & Ramírez and Chiavenato, who maintain that adequate management of intellectual capital works as an indicator of organizational intelligence that increases competitive advantage and prevents the unnecessary loss of financial resources in recruitment processes. (14) (11)

When analyzing the first variable, a clear predominance of the high level of organizational commitment (60.3%) was identified. When delving into the socioeconomic particularities of the Pujilí Canton and the province of Cotopaxi, this finding should not be interpreted in isolation. On the one hand, a significant portion of this commitment responds to factors of cultural and territorial roots specific to the locality, where family closeness, social stability and identification with the impact of local savings and credit cooperatives strengthen the affective and normative commitment. On the other hand, the influence of the local work environment cannot be ruled out, characterized by a limited supply of highly competitive jobs in the formal sector. This scarcity of employment alternatives in the area can tilt the perception of employees towards a commitment to continuity where permanence in the institution responds more to the need to preserve economic stability and accumulated benefits than to a genuine emotional attachment. (15) (8) (7) (16)

Regarding the variable retention of human talent, the trend was equally positive, leading the high level with 55.2%. This shows that factors such as institutional support, recognition of leaders and incentives for permanence, intellectual capital towards larger markets such as Latacunga or Quito. (17) (16)

However, the presence of a significant percentage of the workforce in intermediate ranges (34.5% in commitment and 37.9% in retention) constitutes a critical finding. As Sajami &

Gonzales warn, when workers are located at intermediate levels in delimited geographical contexts, there is a latent risk that they will migrate as soon as a more attractive external job opportunity arises. Faced with this scenario, Pujilí's financial institutions face the strategic challenge of strengthening professional development, emotional salary and comprehensive well-being programs to convert the commitment to continuity into a true affective and sustainable commitment over time. (18)

## CONCLUSIONS

The present research determined a positive linear relationship of moderate intensity between organizational commitment and the retention of human talent in the financial sector of Pujilí, Ecuador. The results ( $Rho = 0.577$ ;  $p = 0.000$ ) validate the research hypothesis, demonstrating that, by strengthening employee commitment, it directly increases the organization's ability to retain its intellectual capital.

From the descriptive diagnosis, 60.3% of the sample presents a high organizational commitment and 55.2% a high level of retention. This consolidation positions local entities in a situation of greater stability compared to the rotation trends observed in other national contexts.

However, the presence of a relevant segment at medium levels of commitment (34.5%) and retention (37.9%) constitutes a critical point of attention. To guarantee long-term sustainability, organizations must transcend traditional strategies, delving into comprehensive well-being programs, transformational leadership and work flexibility. Finally, it is necessary to carry out further studies that involve research in other financial sectors with other categories, to expand the vision of talent management in the financial sector. It is also recommended to conduct longitudinal studies to determine if these variables change over time.

## REFERENCES

1. Ecuador, Banco Central del. eporte analítico de la evolución del mercado laboral e índices de rotación sectorial en el sistema financiero. Quito. 2025.
2. Hernández-Sampieri. Metodología de la investigación: las rutas cuantitativa, cualitativa y mixta. s.l. : McGraw-Hill Education, 2018.
3. España, Aon. Informe global de tendencias en el talento humano y riesgos de capital intelectual. 2024.
4. Meyer JP, Allen NJ. conceptualization of organizational commitment. s.l. : Human Resource Management Review, 1991.
5. Sajami, Amasifuen. Calidad de vida laboral y compromiso organizacional en una institución pública peruana. 2022.

6. Sánchez G, Pérez J. Clima laboral, compromiso y retención: Un estudio correlacional en entornos financieros de libre mercado. s.l. : Revista de Psicología del Trabajo y de las Organizaciones., 2022.
7. B, Avolio. Evaluación del impacto del liderazgo transformacional en el compromiso de la plantilla. 2019.
8. A, Barraza. Compromiso organizacional y rotación laboral en el sector servicios: Un análisis estructural. 2021.
9. MA, Alles. Dirección estratégica de recursos humanos. s.l. : Gestión por competencias. 4.ª ed., 2020.
10. De la Cruz S, Alomoto M, Cruz. I capital intelectual como indicador de inteligencia organizacional y ventaja competitiva en el sector financiero de Cotopaxi. s.l. : Revista Científica de Gestión y Desarrollo Empresarial. , 2023.
11. V, Skerhakova. analysis of the antecedents of talented employees' intention to stay in the organizations. s.l. : European Journal of Interdisciplinary Studies, 2022.
12. TR, Vargas. Estrategias de salario emocional y su efectividad en la retención del talento humano en cooperativas de ahorro y crédito del segmento. s.l. : revista de Gestión Pública y Empresarial Latam, 2024.
13. S, Robbins. Comportamiento organizacional. s.l. : Ciudad de México: Pearson Educación, 2019.
14. Martínez LF, Villamizar. Modelos no paramétricos aplicados al comportamiento organizacional: El uso de Rho de Spearman en la medición de la lealtad laboral. s.l. : Revista Ecuatoriana de Estadística, 2023.
15. García M, Ramírez P. Factores determinantes de la retención del talento humano en la banca cooperativa latinoamericana. s.l. : Revista de Ciencias Sociales, 2023.
16. KS, Cameron. Quinn RE. Diagnóstico y cambio de la cultura organizacional: Basado en el modelo de valores competitivos. Boston : s.n., 2020.
17. I, Chiavenato. Gestión del talento humano: El nuevo papel de los recursos humanos en las organizaciones. s.l. : 5.ª ed. Ciudad de México:, 2021.
18. Solidaria, Superintendencia de Economía Popular y. Informe de estabilidad e inclusión financiera de las cooperativas de ahorro y crédito en el Ecuador. Quito. 2024.

# LA CULTURA TRIBUTARIA EN PEQUEÑOS NEGOCIOS E INFORMALIZACIÓN DE COMERCIANTES AMBULANTES EN LA CIUDAD DE RIOBAMBA

## TAX CULTURE IN SMALL BUSINESSES AND INFORMALIZATION OF STREET VENDORS IN THE CITY OF RIOBAMBA

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**RESUMEN:** El grado de influencia de la cultura tributaria sobre la informalidad del comercio en Riobamba es el punto de partida de esta investigación, centrada en pequeños negocios y vendedores ambulantes de la ciudad. Para ello, se estudió a 194 comerciantes, con el objetivo de conocer su nivel de comprensión de los deberes formales, el comportamiento ante la administración tributaria, las razones de su informalidad y las pautas de cumplimiento de fiscal. Los resultados son de especial interés al constatar que ocho de cada diez comerciantes operan bajo la informalidad. El 76,3 % desconoce sus obligaciones ante el Servicio de Rentas Internas, y el 80,4 % carece de capacitación en la materia. El 83,5 % desconoce las ventajas de registrarse ante el SRI. La falta de trabajo formal (88,1 %) y la falta de recursos económicos (81,4 %) corresponden a los principales motivos de no formalizarse. Un dato que llama la atención es que el 71,6 % no está

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dispuesto a formalizar su actividad económica. El análisis estadístico establece una relación inversa entre cultura tributaria e informalidad ( $r = -0,68$ ;  $p < 0,01$ ). Lo cual demuestra que cuando la cultura tributaria es baja, la informalidad es alta. Por ende, mejorar el conocimiento tributario es una buena alternativa para disminuir la informalidad, así como simplificar los trámites y ofertar más educación tributaria. Los hallazgos de este estudio brindan evidencia que pueda servir al diseño de políticas públicas más efectivas.

**Palabras clave:** *Informalidad, cultura tributaria, políticas fiscales, comerciantes ambulantes, educación tributaria*

**ABSTRACT:** The extent to which tax culture influences commercial informality in Riobamba serves as the starting point for this research, which focuses on the city's small businesses and street vendors. To this end, 194 merchants were studied to assess their understanding of formal obligations, their behavior regarding the tax administration, the reasons for their informality, and their tax compliance patterns. The results are particularly noteworthy, revealing that eight out of ten merchants operate informally. Specifically, 76.3% are unaware of their obligations to the Internal Revenue Service (SRI), and 80.4% lack training in this area. Furthermore, 83.5% are unaware of the benefits of registering with the SRI. A lack of formal employment opportunities (88.1%) and a lack of financial resources (81.4%) are the primary reasons cited for not formalizing operations. A striking finding is that 71.6% of the merchants are unwilling to formalize their economic activities. Statistical analysis establishes an inverse relationship between tax culture and informality ( $r = -0.68$ ;  $p < 0.01$ ), demonstrating that low tax culture correlates with high informality. Consequently, improving tax knowledge alongside simplifying administrative procedures and providing more tax education offers a viable strategy for reducing informality. The study's findings provide evidence that can inform the design of more effective public policies.

**Keywords:** *Informality, tax culture, fiscal policies, street vendors, tax education*

## INTRODUCTION

Tax culture is understood as the set of beliefs, attitudes and values that taxpayers have regarding the payment of taxes. Unlike tax evasion, which are illegal practices to avoid paying taxes generated. Tax compliance is analyzed from two points: deterrence or fear of sanction and tax morale, which is civic duty and trust in the state, the latter better explains the behavior of merchants in contexts of high informality. In Latin America the problem persists due to ignorance, lack of information and resistance to change on the part of informal traders. In countries such as Brazil, Mexico, Argentina and Colombia, simplified tax regimes were implemented in order to promote the formalization of small merchants. In Ecuador, this objective was promoted with the RISE in 2008 and then renamed RIMPE from 2022. In the country, the weak tax culture directly influences the increase in tax evasion,

mainly affecting micro and small businesses, where the informality and complexity of the tax system hinder growth. (1) (1) (2) (3) (4) (5) (6)

In the city of Riobamba, small businesses represented by sales stalls within local markets, as well as street merchants, constitute a large part of the economic lung of the city. According to official figures, in 2022 there were 4,288 formal traders and approximately 2,500 informal traders. Despite the fact that a representative number of these actors carry out their activities outside the legal framework. Previous research indicates that, in the La Condamine market in Riobamba, 86.75% of merchants are unaware of their formal obligations; 76.62% are aware that they must invoice, although they do not know the procedure; and 96% express their willingness to receive training in this regard. (7) (8)

In 2022, the Internal Revenue Service (SRI) launched the Simplified Regime for Popular Businesses and Entrepreneurs (RIMPE), thus giving way to a new tax scheme. The RIMPE contemplates two categories according to income level: Popular Businesses, for those who invoice up to USD 20,000 annually, and Entrepreneurs, for those with income up to USD 300,000. Despite these efforts, challenges remain in incorporating informal traders into the tax system. At the national level, labor informality represents a social problem that has grown in recent years. By 2023, informality in Ecuador covered two-thirds of the country's economically active population, and neither the state nor the private sector provides work for the majority of those who, on their own, seek to generate income to survive. According to results obtained by the National Employment, Unemployment and Underemployment Survey (ENEMDU), corresponding to the year 2023, street vendors have lower incomes, but they work more hours than vendors in small stores, and significant discrepancies are found in terms of gender, educational level and size of the city. In this context, the low tax culture among merchants who operate in market stalls and on public roads directly contributes to the permanence of informality. (9) (10) (11) (12)

The relevance of this study lies in the need to analyze the link between the tax culture of small businesses and the informalization of street merchants in Riobamba. In the framework of development, informality causes contrasting effects. 50% of those surveyed consider that informal trade boosts the economy; 39% believe that it facilitates the population's access to products. (13)

Despite this, it also generates unequal conditions of competition that affect formal sellers. There are few studies that specifically address the relationship between tax culture and informality in the outpatient commerce sector in this city, which shows a gap in knowledge that this research aims to fill. (7)

The general objective is to analyze the relationship between tax culture and the informalization of merchants in markets and street vendors in the city of Riobamba. To this end, three specific purposes were outlined:

1. Evaluate the level of knowledge and tax compliance among small businesses in the Riobamba markets;
2. Identify the administrative, economic and social components that cause the informalization of street vendors
3. Determine the relationship between tax culture and the informalization of street vendors in the city.

The hypothesis states that lower levels of tax culture are associated with higher rates of commercial informalization.

## MATERIALS AND METHODS

The study presents a descriptive, quantitative, and correlational approach. The structure was non-experimental with a cross section, which allowed the variables to be measured at a single moment. Facilitating the determination of the degree of relationship between tax culture and commercial informalization.

The study population was made up of merchants with local market stalls and street merchants from Riobamba. Since we did not have the exact number of street vendors, sampling for infinite populations was applied. The sample calculation started from a confidence level of 94.88% ( $Z = 1.95$ ). We worked with a margin of error of 7%. With an expected proportion of 50% ( $p = q = 0.5$ ), a sample of 194 merchants was obtained.

The 7% margin was due to three reasons: budgetary limitations, temporal nature of field work, and the complexity of accessing street vendors. Given their informal status, it is difficult to expand the sample with these sellers. In inferential studies, 5% is usually used. However, 7% is considered acceptable in descriptive or exploratory research with operational limitations.

When interpreting the results, it should be kept in mind that population estimates carry limited precision. Compared to the ability to generalize to all street vendors in the city of Riobamba, this is more limited than if we had worked with 5%. Even so, the data collected allows us to characterize observable trends. They also serve as a basis for future research with larger samples.

Once the reference sample was defined, the selection of participants was carried out by convenience. This decision was due to the lack of an updated sampling frame and access difficulties. The field work covered various commercial areas of the city. We sought to include the greatest variety of economic lines and levels of experience among the respondents.

The structured survey was used as a collection technique. For its application, a questionnaire designed for the study was used. The instrument was organized in three blocks. In the first, sociodemographic data were collected: sex, age, educational level, time

in the activity and current situation. The second block investigated tax culture, with ten dichotomous questions (yes/no) about tax obligations, advantages of formalization, issuance of receipts, training, compliance and citizen perception. The third block, oriented towards informalization, had ten questions aimed at economic and administrative barriers, difficulties for regularization and the will to do so.

The content validity of the questionnaire was evaluated through the judgment of three experts. The specialists had experience in accounting, taxation and research, reviewing the relevance, clarity, coherence and wording of the items. The specialists' observations were included in the final version.

The pilot test, applied to verify understanding of the questions and make appropriate adjustments, was followed by calculating reliability with the KR-20, which reached 0.965, a sign of high internal consistency.

The instrument was applied in person to the 194 merchants. The surveys were applied in markets and in points of high concentration of street vending in Riobamba. Informed consent was obtained from each of the participants. The confidentiality of the information was assured. The exclusive academic use of the data was guaranteed.

Descriptive statistics were used to process the data. The findings are presented in tables with absolute frequencies and percentages.

## RESULTS

From the processing of the surveys applied to local market merchants and street vendors in Riobamba. The following results were obtained. The information is organized into three sections:

1. Sociodemographic characterization of the sample.
2. Level of tax culture
3. Factors associated with informalization.

The findings are presented in frequency tables and are complemented with graphs.

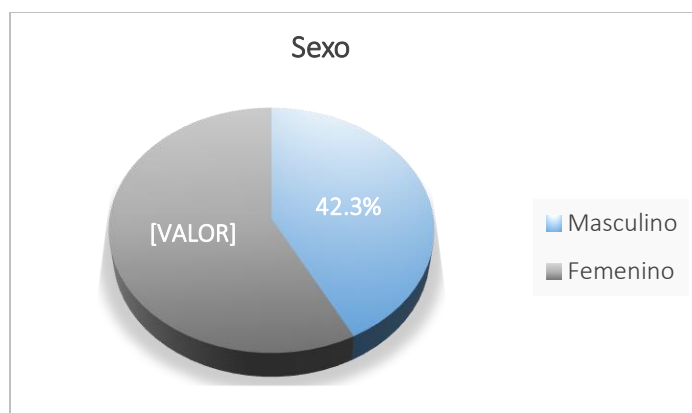
### 1. Caracterización sociodemográfica de la muestra

*Tabla 1. Características sociodemográficas de los comerciantes encuestados.*

|     | Category       | Frequency (n) | Percentage (%) |
|-----|----------------|---------------|----------------|
| Sex | Male           | 82            | 42,3%          |
|     | Female         | 112           | 57,7%          |
| Age | 18 to 25 years | 18            | 9,3%           |

|                                               |                              |     |       |
|-----------------------------------------------|------------------------------|-----|-------|
|                                               | 26 to 35 years               | 39  | 20,1% |
|                                               | 36 to 45 years               | 57  | 29,4% |
|                                               | 46 to 55 years               | 52  | 26,8% |
|                                               | Over 55 years old            | 28  | 14,4% |
| Education level                               | Primary                      | 58  | 29,9% |
|                                               | Secondary                    | 76  | 39,2% |
|                                               | Technical/Technological      | 31  | 16,0% |
|                                               | University                   | 24  | 12,4% |
|                                               | Graduate                     | 5   | 2,5%  |
| Time in commercial activity                   | Less than 1 year             | 15  | 7,7%  |
|                                               | From 1 to 2 years            | 61  | 31,4% |
|                                               | From 2 to 5 years            | 68  | 35,1% |
|                                               | More than 5 years            | 50  | 25,8% |
| Current situation of your commercial activity | Formal (has RUC)             | 42  | 21,6% |
|                                               | Informal (Does not have RUC) | 152 | 78,4% |

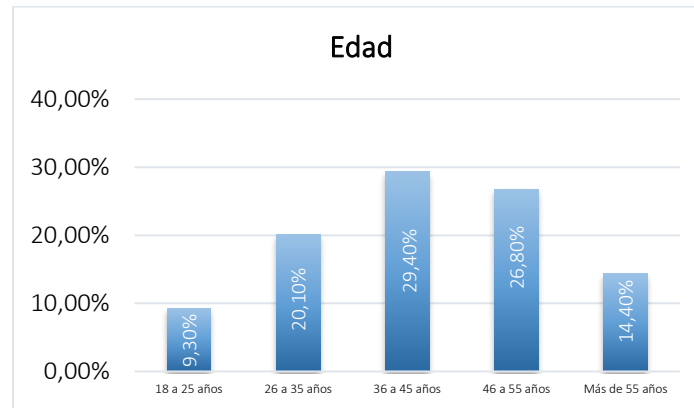
Figure 1 shows the distribution of respondents according to sex. 57.7% are women and 42.3% are men, indicating a female predominance.



**Figure 1. Sex.**

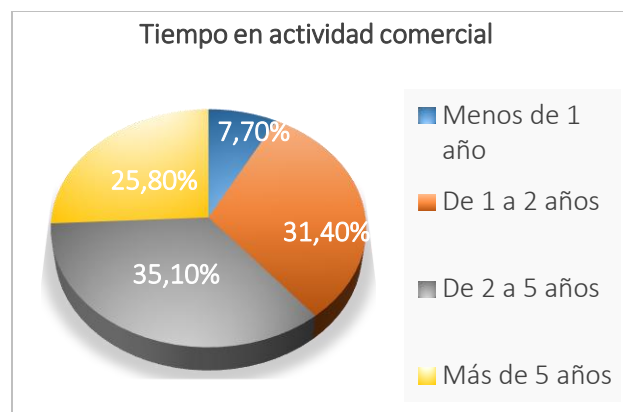
The 36 to 45 year old group is the largest (29.4%), followed by the 46 to 55 year old group (26.8%). They are followed by those between 26 and 35 years old (20.1%) and those over 55 years old (14.4%). The youngest (18-25 years old) barely represent 9.3% (Figure 2).





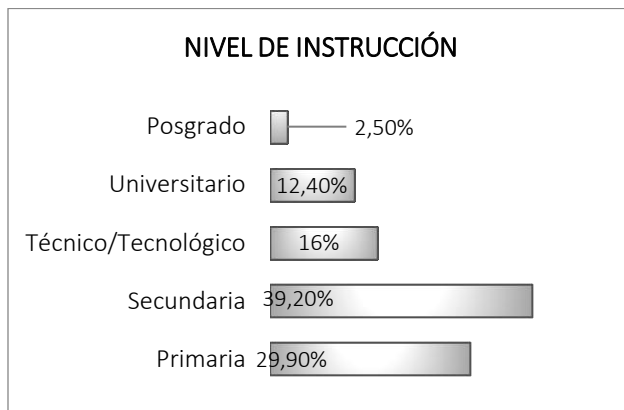
**Figure 2. Age.**

En cuanto a la experiencia, el grupo mayoritario (35,1 %) lleva entre 2 y 5 años, seguido del que tiene 1 a 2 años (31,4 %). Those over 5 years old are 25.8%, and those under 1 year old are 7.7% (Figure 3).



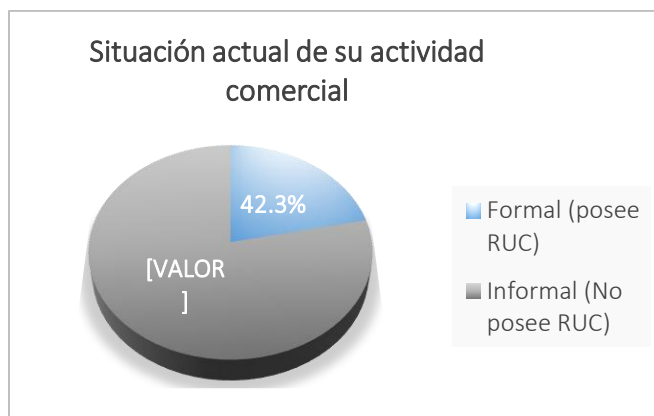
**Figure 3. Activity time.**

La distribución por nivel de instrucción muestra que el 39,2 % tiene secundaria, el 29,9 % primaria, el 16,0 % formación técnica o tecnológica, el 12,4 % estudios universitarios y el 2,5 % posgrado (Figura 4).



**Figure 4. Instruction level.**

Solo el 21,6 % de los comerciantes cuenta con Registro Único de Contribuyentes (RUC), mientras que el 78,4 % carece de esta inscripción (Figura 5).



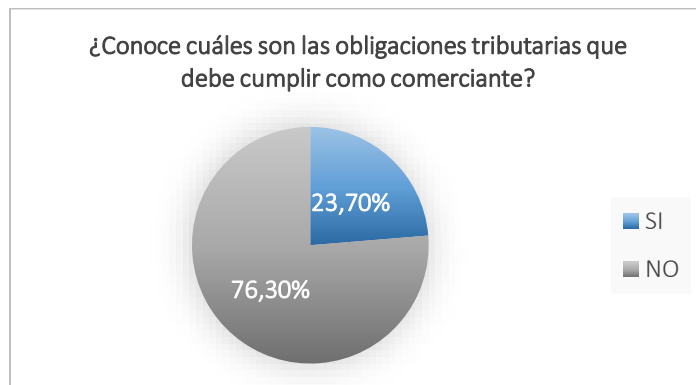
**Figure 5. Current RUC situation.**

## 2. Level of tax culture

*Table 2. Level of tax culture.*

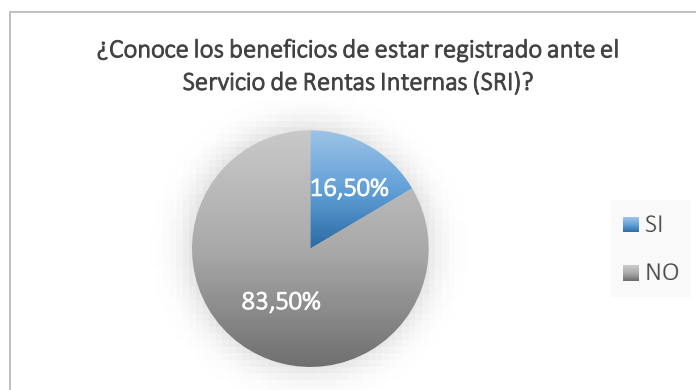
| Question                                                                              | Yes          |                | No           |                |
|---------------------------------------------------------------------------------------|--------------|----------------|--------------|----------------|
|                                                                                       | Frequency(n) | Percentage (%) | Frequency(n) | Percentage (%) |
| Do you know what tax obligations you must comply with as a merchant?                  | 46           | 23,7%          | 148          | 76.3%          |
| Do you know the benefits of being registered with the Internal Revenue Service (SRI)? | 32           | 16,5%          | 162          | 83,5%          |
| Do you know when you should issue sales receipts?                                     | 54           | 27,8%          | 140          | 72,2%          |
| Do you know the necessary requirements to formalize a commercial activity?            | 39           | 20,1%          | 155          | 79,9%          |
| Have you received training on tax issues?                                             | 38           | 19,6%          | 156          | 80,4%          |
| Have you received information from SRI about your tax obligations?                    | 41           | 21,1%          | 153          | 78,9%          |
| Do you comply with your tax obligations in a timely manner?                           | 52           | 26,8%          | 142          | 73,2%          |
| Do you request and provide sales receipts in your commercial transactions?            | 61           | 31,4%          | 133          | 68,6%          |
| Do you keep records of income and expenses of your economic activity?                 | 58           | 29,9%          | 136          | 70,1%          |
| Do you consider that paying taxes is a citizen's responsibility?                      | 79           | 40,7%          | 115          | 59,3%          |

Recognition of obligations is low: 76.3% of respondents do not know them, compared to 23.7% who claim to be aware (Figure 6).



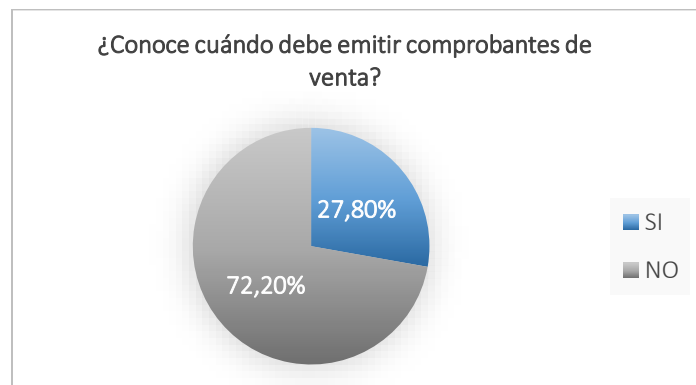
**Figure 6. Knowledge of obligations.**

83.5% of merchants are unaware of the benefits of being registered with the SRI, and only 16.5% recognize them (Figure 7).



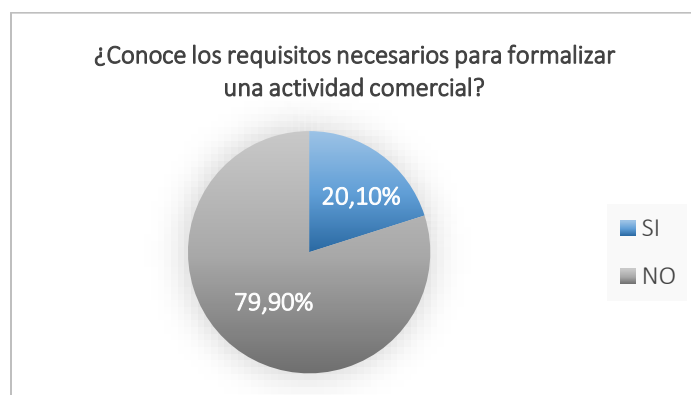
**Figure 7. Benefits of SRI.**

Regarding the issuance of sales receipts, the results show that 72.2% of respondents do not know when sales receipts should be issued, while 27.8% claim to know this tax requirement (Figure 8).



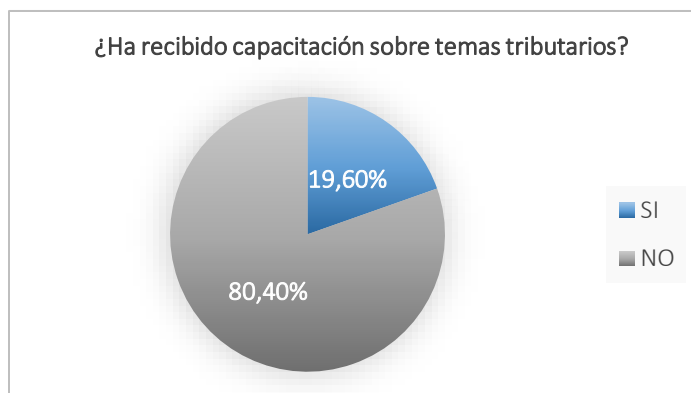
**Figure 8. Issuance of receipts.**

When consulting the participants regarding the requirements for formalization, it was found that 79.9% did not know, and only 20.1% claimed to be informed about it (Figure 9).



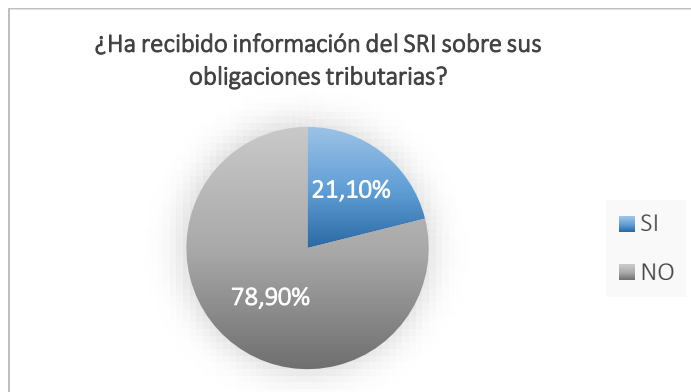
**Figure 9. Formalization requirements.**

Lack of knowledge regarding tax training reaches 80.4% of the study population, while the remaining 19.6% say they have received training in this area (Figure 10).



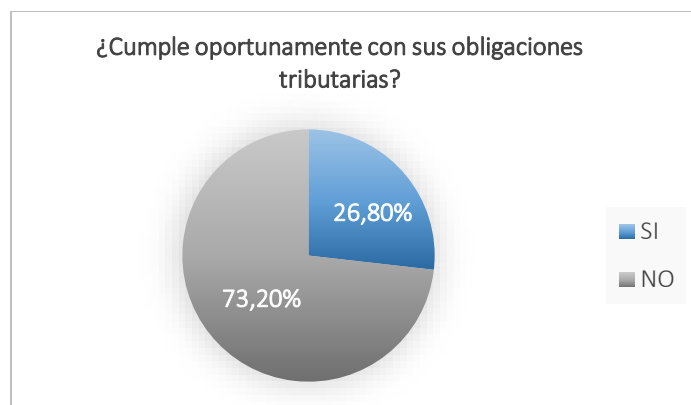
**Figure 10. Tax training.**

Regarding the guidance received from the Internal Revenue Service (SRI), 78.9% of the population studied declares that they have not accessed it, and the remaining 21.1% says they have had information from this entity (Figure 11).



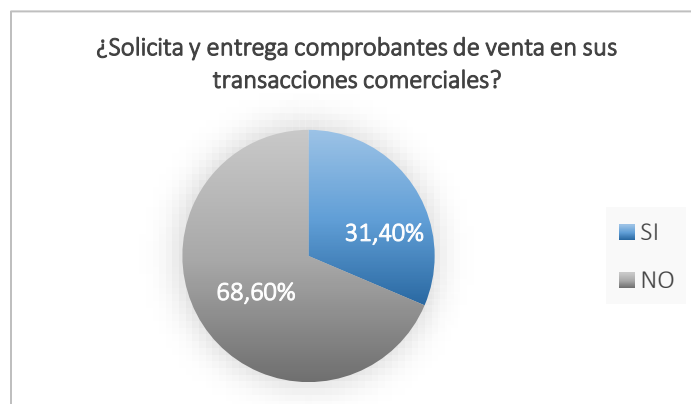
**Figure 11. SRI information.**

Compliance with tax obligations within the established deadlines occurs in only 26.8% of merchants, while the remaining 73.2% do not do so in a timely manner, according to Figure 12.



**Figure 12. Timely compliance.**

The practice of issuing and requesting sales receipts is carried out by 31.4% of the participants, while the remaining 68.6% do not do it (Figure 13).



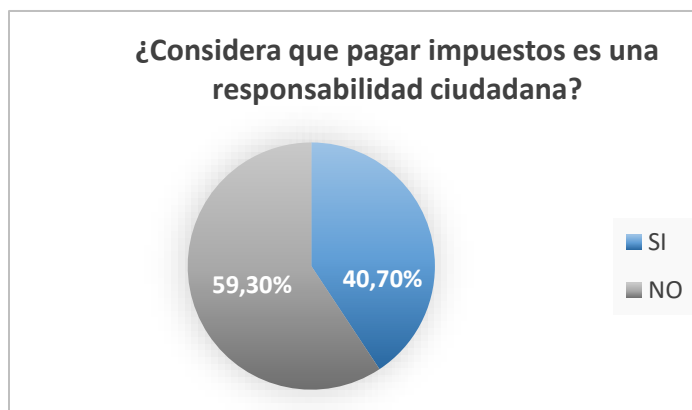
**Figure 13. Sales receipts.**

29.9% of merchants stated that they keep records of their economic movements, while 70.1% do not have controls over their operations, as can be seen from the management of records related to the income and expenses of economic activity (Figure 14).



**Figure 14. Record of income and expenses.**

Only 40.7% of the participants see paying taxes as a citizen's duty, and almost the remaining 59.3% do not share that perspective, according to the data obtained (Figure 15).



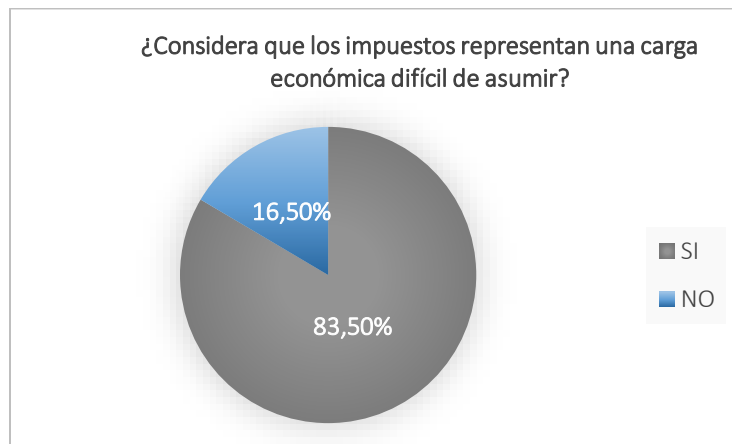
**Figure 15. Citizen responsibility in paying taxes.**

### 3. Factors associated with informalization.

**Table 3. Factors associated with the informalization of merchants in Riobamba.**

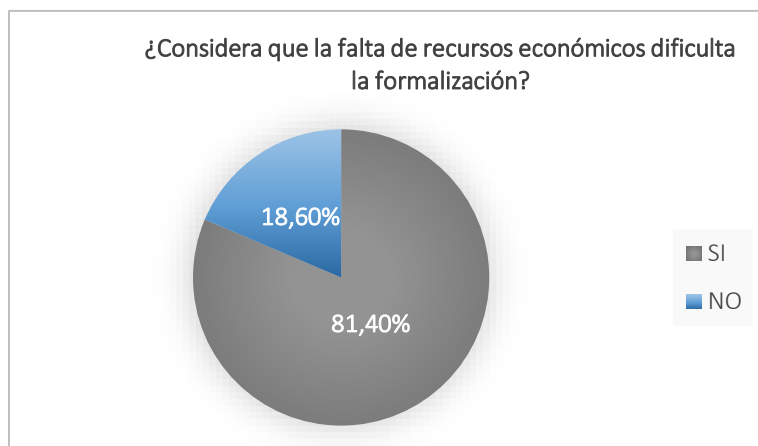
| Question                                                                                                                                                  | Yes          |                | No            |                |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|----------------|---------------|----------------|
|                                                                                                                                                           | Frequency(n) | Percentage (%) | Frequency (n) | Percentage (%) |
| Do you consider that taxes represent a difficult economic burden to assume?                                                                               | 162          | 83,5%          | 32            | 16,5%          |
| Do you think that the lack of financial resources makes formalization difficult?                                                                          | 158          | 81,4%          | 36            | 18,6%          |
| Do you consider the requirements to be formalized excessive?                                                                                              | 149          | 76,8%          | 45            | 23,2%          |
| Have you had difficulties carrying out tax or municipal procedures?                                                                                       | 145          | 74,7%          | 49            | 23,3%          |
| Do you consider the guidance from the control entities to be insufficient?                                                                                | 154          | 79,4%          | 40            | 20,6%          |
| Do you think that the lack of formal employment drives street trading?                                                                                    | 171          | 88,1%          | 23            | 11,9%          |
| Do you think that formalizing your economic activity by registering with the RUC would allow you to generate greater confidence and attract more clients? | 63           | 32,5%          | 131           | 67,5%          |
| Do you think that formalizing your business would help you access credit or financing to expand or improve your venture?                                  | 57           | 29,4%          | 137           | 70,6%          |
| Do you consider that informality is a common practice among merchants?                                                                                    | 167          | 86,1%          | 27            | 13,9%          |

Regarding whether taxes are an economic burden, 83.5% of those consulted consider that they are, while the remaining 16.5% respond that they are not, as reflected in Figure 16.



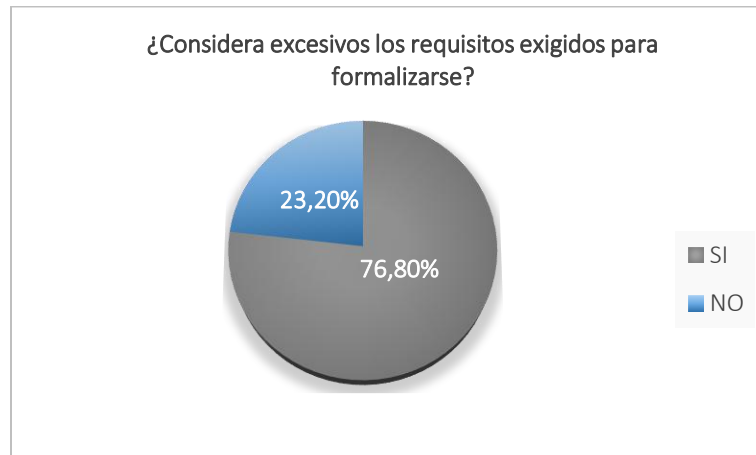
**Figure 16. Economic burden of the tax.**

The lack of financial resources is seen as an obstacle to formalization by 81.4% of those consulted. The remaining 18.6% do not identify it as a difficulty for this process, according to the data collected (Figure 17).



**Figure 17. Economic resources and formalization.**

Only 23.2% of those consulted do not consider the requirements for formalization excessive, while the remaining 76.8% do perceive them as excessive, according to the assessment collected (Figure 18).



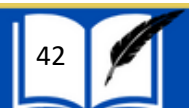
**Figure 18. Excessive requirements.**

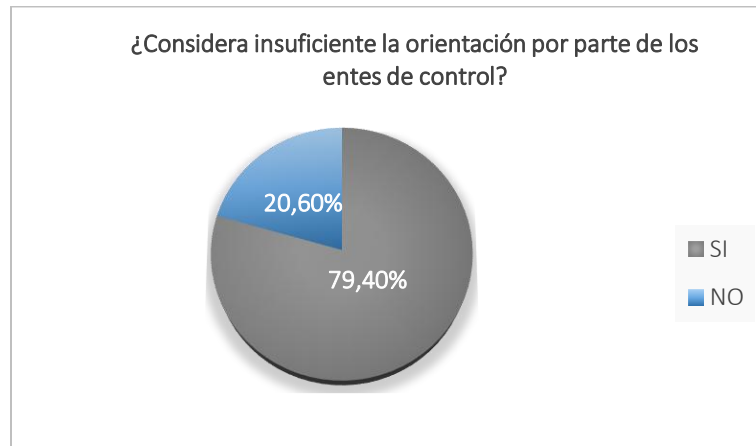
Administrative procedures represented a difficulty for 74.7% of the informants, while the remaining 23.3% said they had not had any problems, according to what can be seen in Figure 19.



**Figure 19. Difficulties in procedures.**

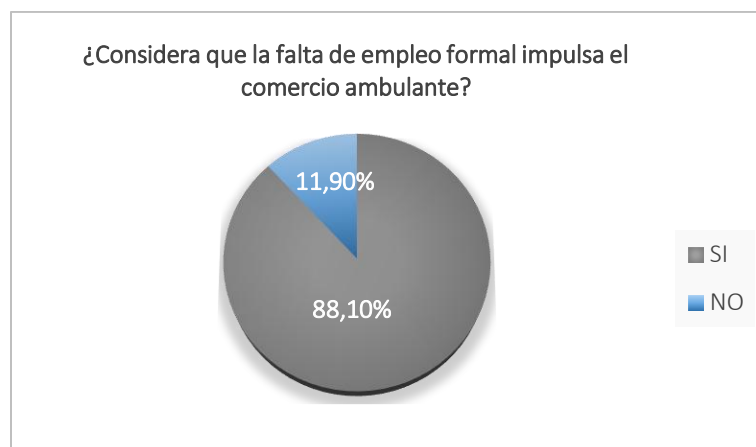
Regarding the orientation of the control entities, 79.4% of the informants believe that it is insufficient, while the remaining 20.6% find it adequate, as reflected in (Figure 20).





**Figure 20. Orientation of the control entities.**

The lack of formal employment is considered by 88.1% of the informants as a factor that increases street trading, while the remaining 11.9% do not relate it to this phenomenon (Figure 21).



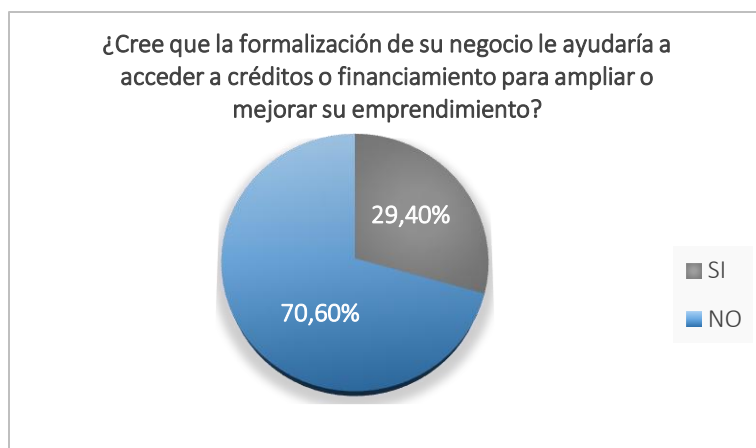
**Figure 21. Formal employment and street commerce.**

32.5% of the informants think that the RUC generates greater trust among clients, while the remaining 67.5% consider that this record does not increase it (Figure 22).



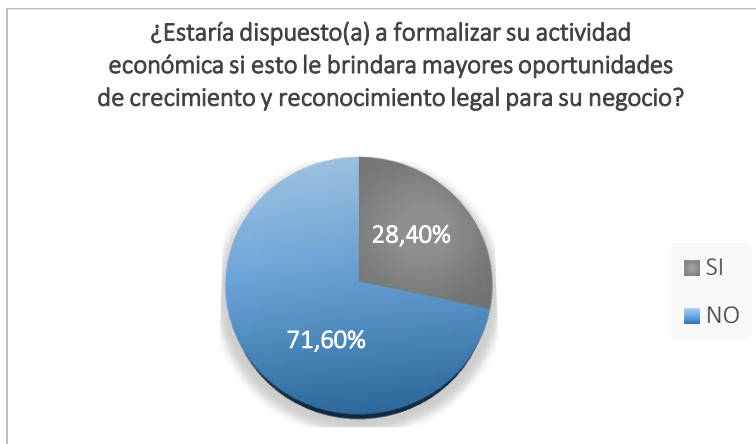
**Figure 22. Trust and RUC.**

Regarding the benefits associated with formalization, 70.6% stated that this does not represent a way to facilitate access to credit, while 29.4% consider that it can favor this opportunity (Figure 23).



**Figure 23. Access to credits.**

Registering with the tax administration as an opportunity for growth: 71.6% of those surveyed said they were willing to take the step, while the remaining 28.4% were not interested (Figure 24).



**Figure 24. Disposition towards formalization.**

Informality as a common practice within commercial activity is recognized by 86.1% of the participants, while 13.9% do not consider this situation to be widespread (Figure 25).



**Figure 25. Presence of informality among merchants.**

## DISCUSSION

The results of this research show a low level of tax culture among the market traders and street vendors of Riobamba, characterized by ignorance of tax obligations (76.3%), lack of training (80.4%) and ignorance of the benefits of the SRI (83.5%). These findings coincide with previous studies developed by Santillán Silva (2022) in the La Condamine market in the city of Riobamba, where the 86.75% of merchants were unaware of their tax obligations, and with Parco Cuje (2023), who identified that 95% of informal merchants in Riobamba do not comply with their formal duties. Studies carried out in Santa Elena (Suárez Pico, 2025), Puyo (Urrutia Guevara et al., 2025) and Quinindé (Velez Ruiz, 2025) confirm that low regulatory knowledge and economic limitations condition tax compliance at the national

level, which suggests that low tax culture is a structural phenomenon in Ecuadorian informal trade. (8) (14) (15) (16) (17)

Regarding the factors that perpetuate non-formalized commerce, 88.1% of those surveyed recognize that the lack of formal employment drives street commerce, coinciding with Ordóñez Córdova (2024), who found that street vendors have lower incomes, but work more hours than formal merchants. The Economic Commission for Latin America and the Caribbean (ECLAC) points out that "high informality and tax evasion have been identified as structural barriers to sustainable growth in Latin America, affecting collection and distributive equity", which confirms the bidirectional relationship observed in Riobamba: the perceived complexity of the state system shows that 76.8% consider the requirements excessive and the insufficient guidance of the control entities (79.40%) fuel the permanence in the activity outside the system. (12) (18)

The implementation of the RIMPE in 2022 has not managed to permeate the most vulnerable sector, since 83.50% of merchants are unaware of the benefits of the SRI. Mosquera Arévalo et al. (2024) support that trust and education in institutions along with citizen participation are essential to change the tax culture in the country. Sánchez Arévalo (2024) found a poor tax culture in small merchants covered by RIMPE in Milagro, and Quiroz Chang (2026) warns that regulatory simplification without support can increase informality, which explains why 78.4% of those consulted operate informally despite the existence of this regime. (19) (20) (21)

The correlational analysis revealed an inverse relationship between tax culture and informalization ( $r = -0.68$ ;  $p < 0.01$ ), confirming the proposed hypothesis. This finding coincides with Remache Páez, who found a correlation of 0.705 between tax culture and formal duties in the Simón Bolívar market in Riobamba, and with Arellano Cepeda et al. (2025), who reported a correlation of 25.8% between tax culture and tax compliance in small businesses in Riobamba. Furthermore, Larrea Cuadrado and Armijos Tandazo (2026) demonstrated a positive and significant relationship with a Spearman's Rho coefficient of 0.901 in businesses in the historic center of Riobamba and Baque Sánchez and Zambrano Quiroz (2024) identified that most of the merchants in Santa Ana do not fulfill their obligations due to lack of guidance. The strongest correlation was observed between tax knowledge and informalization ( $r = -0.62$ ), indicating that the lack of tax information is the most determining component of informality, suggesting that interventions aimed at improving tax knowledge could have a more significant impact on reducing informality. (22) (23) (24) (25)

Two anomalous results deserve attention. The responses obtained allow us to appreciate that a large part of the merchants do not associate tax formalization with palpable benefits. 70.6% express that having the RUC does not influence the possibilities of obtaining a loan and 67.5% indicate that tax registration does not generate greater credibility in their businesses either. The data indicate that respondents do not associate registration with the SRI with immediate economic benefits. Although the RUC allows the commercial activity to

be identified before the tax administration, financial entities evaluate criteria such as payment capacity, income level, guarantees and credit history when evaluating a credit application. Resistance to participating in tax training limits exposure to information that could modify these perceptions. Similarly, the 40% compliance among merchants with less than a year of activity, compared to 23.5% in the 2 to 5 year group, suggests that the length of time spent in non-formalized trade generates a habituation effect that makes formalization difficult, which underlines the importance of early interventions. (22)

This research provides specific empirical evidence for Riobamba by comprehensively analyzing the relationship between tax culture and informalization in market merchants and street vendors, unlike previous studies focused on specific markets. The study quantifies this relationship through a tax culture index, offering concrete inputs for the design of public policies. Future research could address the limitations of the cross-sectional design through longitudinal studies that evaluate the impact of educational interventions on the formalization of popular commerce. (22) (24) (16)

## CONCLUSIONS

Riobamba's commerce shows a fragile tax culture: 76.3% are unaware of their duties, 80.4% have not been trained and 83.5% do not see advantages in the SRI. With only 26.8% punctual compliance and 40.7% citizen awareness, the diagnosis points to a problem of structural deficit.

86.1% already see informality as normal. But this normalization has clear causes: there is a lack of employment (88.1%), there is a lack of resources (81.4%), taxes feel excessive (83.5%). The procedures do not help either (76.8%) and the guidance is scarce (79.4%). The result: informality is no longer experienced as an exception, but as the rule. In other words, it is not that merchants choose to be informal; It is that the system simply does not offer them another route.

The statistics confirm it, the less tax culture, the more informality ( $r = -0.68$ ;  $p < 0.01$ ). In other words, he who doesn't know, doesn't pay. But this finding points to two clear solutions. One, educate on tax matters. Another, simplify the procedures. Because if knowledge is low and processes are cumbersome, informality will not go away on its own.

## REFERENCES

1. Loor Santana C, Sornoza Zamora C. Cultura tributaria y evasión fiscal de las pymes comerciales del cantón Pedernales-Manabí. 2025; <https://doi.org/10.69639/arandu.v12i1.892>

2. Barberán Zambrano N, Yong Amaya L, Bastidas Cabrera T. Confianza gubernamental y moral tributaria. Factores de cumplimiento de los contribuyentes. *European Public & Social Innovation Review*. 2025; 10; <https://doi.org/10.31637/epsir-2025-2238>
3. 3. Castañeda N. Equidad y moral tributaria en los países en desarrollo. *Studies in Compartive international development*. 2024; 59; <https://doi.org/10.1007/s12116-023-09394-z>
4. Agila Saavedra T. Diagnóstico de la cultura tributaria y su efecto en la evasión fiscal de los comerciantes informales en la provincia de Loja, Año 2022. Universidad Católica de Santiago de Guayaquil. 2023; <https://n9.cl/kz7su>
5. Asqui Valladares M. Regímenes tributarios en Latinoamérica y su relación con el RISE, RIM y RIMPE de Ecuador. *Revista Enfoques*. 2022; 6(24); <https://doi.org/10.33996/revistaenfoques.v6i24.148>
6. Ortiz Mayorga M, López Bermello S, Guangasi Laguna , Fiallos Bonilla. Influencia de la cultura tributaria en los niveles de evasión fiscal en Ecuador. *Verdad y derecho*. 2024; 3(1): p. 1 - 15; <https://doi.org/10.62574/63ffeh72>
7. Jimenez Muñoz MS. Estudio económico del sector comercial informal en los mercados municipales de la ciudad de Riobamba, provincia de Chimborazo, año 2022. Escuela Superior Politécnica de Chimborazo. 2024; <https://n9.cl/byzi5>
8. Santillán Silva M. Cultura tributaria en los comerciantes del mercado La Condamine de la ciudad de Riobamba (Ecuador). *Apuntes Contables*. 2022;(30): p. 1-18; <https://doi.org/10.18601/16577175.n30.07>
9. Arias Vidal L. Evaluación del comportamiento tributario en comerciantes informales en la ciudad de Guayaquil año 2022. Universidad Católica de Santiago de Guayaquil. 2023; <https://n9.cl/kbz144>
10. Servicio de Rentas internas. RIMPE - Negocios Populares y Emprendedores. 2022; <https://www.sri.gob.ec/rimpe>
11. Enríquez Bermeo F. El comercio informal en Quito. *Mundos plurales*. 2024; 11(2); <https://doi.org/10.17141/mundosplurales.2.2024.6307>
12. Ordóñez Córdova MD. La informalidad y el bienestar : análisis de las características de trabajadores informales. Escuela Politécnica Nacional. 2024; <https://n9.cl/bxyv42>
13. Salazar Zúñiga C. Implicaciones del Comercio Informal en el contexto del modelo de Desarrollo Local en la ciudad de Riobamba. Universidad Nacional de Chimborazo. 2023; <https://n9.cl/xbtwb>
14. Parco Cuje KM. El comercio informal en medios digitales y el cumplimiento de los deberes formales tributarios. Universidad Nacional de Chimborazo. 2023; <https://n9.cl/1zhw1>
15. Suárez Pico HM. Cultura tributaria en los negocios del barrio Puerto Nuevo, cantón La Libertad, provincia de Santa Elena, año 2024. Universidad Estatal Península de Santa Elena. 2025; <https://n9.cl/iicy9>
16. Durán Maldonado , Urrutia Guevara J, Lach Tenecota W. Cultura tributaria de los comerciantes informales de prendas de vestir en la ciudad de Puyo. *Noesis*. ; 7(1); <https://doi.org/10.35381/noesisin.v7i1.407>

17. Velez Ruiz JD. Análisis de la cultura tributaria y cumplimiento de deberes formales de los comerciantes minoristas del cantón Quinindé, provincia de Esmeraldas. Universidad Central Del Ecuador. 2025; <https://n9.cl/36437>
18. CEPAL. Panorama Fiscal de América Latina y el Caribe 2023: Política fiscal para el crecimiento, la redistribución y la transformación productiva. Comisión Económica para América Latina y el Caribe (CEPAL). 2023; <https://n9.cl/6y0ten>
19. Mosquera Arévalo , Carranza Quimi , Sandoval Cují , Pozo Calero. Diseño de estrategias para mejorar la cultura contable y tributaria de los comerciantes de Quevedo. Revista REMCA. 2024; 7(3): p. 306; <https://doi.org/10.62452/kt7nbf81>
20. Sánchez Arévalo S. Impacto de la cultura tributaria en la economía de pequeños comerciantes pertenecientes al Régimen RIMPE Negocio Popular del cantón Milagro durante el año 2023. Universidad Católica de Santiago de Guayaquil. 2024; <https://n9.cl/0buuy>
21. Quiroz Chang A. La gobernanza tributaria simplificada en el Régimen RIMPE: un análisis de eficiencia administrativa y transparencia en Ecuador. Revista Minerva. 2026; 7(19); <https://doi.org/10.47460/minerva.v7i19.264>
22. Remache Páez KD. La cultura tributaria y su influencia en los deberes formales de los contribuyentes del mercado Simón Bolívar de Riobamba, en el cantón Riobamba 2024. Universidad Nacional de Chimborazo. 2025; <https://n9.cl/33k5sd>
23. Arellano Cepeda OE, Ayaviri Nina , Villa Villa VM, Rodríguez E. Cumplimiento y cultura tributaria en pequeñas empresas comerciales de la ciudad de Riobamba. Perspectivas Sociales Y Administrativas. 2025; 3(2); <https://doi.org/10.61347/psa.v3i2.92>
24. Larrea Cuadrado PL, Armijos Tandazo A. Cultura tributaria y su efecto en el cumplimiento de las obligaciones fiscales en los negocios del centro histórico de Riobamba, 2025. Universidad nacional de Chimborazo. 2026; <https://n9.cl/1eusj>
25. Baque Sánchez. La cultura tributaria en el cumplimiento de las obligaciones fiscales de los comerciantes abastecedores del mercado central de Santa Ana”. Universidad Estatal del Sur de Manabí. 2024; <https://n9.cl/1l1z1y>

# RELACIÓN ENTRE PRÁCTICAS DE CONTABILIDAD AMBIENTAL Y RENTABILIDAD EN LAS COOPERATIVAS DE AHORRO Y CRÉDITO

## RELATIONSHIP BETWEEN ENVIRONMENTAL ACCOUNTING PRACTICES AND PROFITABILITY IN SAVINGS AND CREDIT COOPERATIVES

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**RESUMEN:** El surgimiento por este estudio nació al identificar que, en muchas cooperativas del sector financiero popular, los temas ambientales suelen presentarse más como parte de la imagen institucional que como información integrada a los estados financieros. En respuesta a esta situación, la investigación tuvo como objetivo analizar la relación entre la contabilidad ambiental y la rentabilidad en las cooperativas de ahorro y crédito de los segmentos 1 y 2 de Ambato, Ecuador. Para ello, se desarrolló un estudio con enfoque mixto y diseño transversal, mediante un censo aplicado a directivos y contadores de las 17 cooperativas de la ciudad. La información recopilada se analizó con el coeficiente Rho de Spearman, lo que permitió examinar la relación entre las variables del estudio. Los resultados mostraron en un 53% el manejo adecuado de los recursos naturales y el registro de los impactos ambientales que contribuyen a mejorar la toma de decisiones internas y favorecen una mejor gestión de los costos operativos. No obstante, cuando se examinó los indicadores financieros de rendimiento sobre el patrimonio y de rendimiento sobre los activos, se encontró que no existe vínculo estadístico con la rentabilidad, por lo que fue rechazada la hipótesis inicial. En conclusión, en las cooperativas en un 67% se contribuye al manejo de la contabilidad ambiental mediante el control de gastos y a la eficiencia operativa, obteniendo beneficios en la gestión diaria. No obstante, su impacto en los resultados financieros finales no refleja resultados positivos. Esto implica el desafío de fortalecer la preparación del personal, acoger herramientas analógicas e integrar la sostenibilidad como parte esencial de la información financiera.

**Palabras clave:** Rentabilidad, cooperativas de ahorro y crédito, contabilidad ambiental, optimización de recursos

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**ABSTRACT:** This study originated from the observation that, in many cooperatives within the popular financial sector, environmental issues tend to be presented more as part of the institutional image than as information integrated into financial statements. In response to this situation, the research aimed to analyze the relationship between environmental accounting and profitability in savings and credit cooperatives classified as Segments 1 and 2 in Ambato, Ecuador. To this end, a study employing a mixed-methods approach and a cross-sectional design was conducted, utilizing a census of executives and accountants from the city's 17 cooperatives. The collected data were analyzed using Spearman's Rho coefficient, allowing for an examination of the relationship between the study variables. The results indicated that 53% of the cooperatives demonstrated proper management of natural resources and the recording of environmental impacts, factors that contribute to improved internal decision-making and better operational cost management. However, an examination of financial indicators—specifically return on equity and return on assets—revealed no statistical link to profitability, leading to the rejection of the initial hypothesis. In conclusion, while 67% of the cooperatives contribute to environmental accounting management through expense control and operational efficiency—thereby gaining benefits in day-to-day operations—this does not translate into a positive impact on final financial results. This highlights the challenge of strengthening staff training, adopting analytical tools, and integrating sustainability as an essential component of financial information.

**Keywords:** *Profitability, Savings and credit cooperatives, Environmental accounting, Resource optimization*

## INTRODUCTION

### Background of the study problem

Currently, environmental accounting goes beyond its informative function, as it is consolidated as an essential pillar of strategic competitiveness. In Spain, an example is mentioned related to green bonds, which shows a positive relationship between environmental performance and emissions reduction (1). In the Latin American context, it responds to an urgency to maintain the economy in the face of the growing demands of responsible capital (2).

The lack of environmental accounting information prevents us from knowing the real effect of the projects and their contribution to the ecosystem. The International Financial Reporting Standards (IFRS) offer a clear technical structure; they ignore the recording of social and ecological facts, which forces risks to be evaluated using financial data that are insufficient to measure environmental vulnerability (3).

This problem becomes critical, since the lack of sustainability indicators generates incomplete files and facilitates the delivery of resources to companies with poor ecological management. Only under this qualitative rigor will it be possible to promote

transparent management models that leave behind the use of environmental reports as mere corporate image tools.

In this context, the application of International Financial Reporting Standards (IFRS) presents inconsistencies in the measurement, recognition and disclosure of financial information, expenses and risks related to environmental accounting. This occurs in segment 1 and 2 cooperatives in the city of Ambato, since there are inherent limitations to the application of the standard. As a regulatory framework focused strictly on the reasonableness of traditional financial statements, IFRS lacks standardized metrics to quantify environmental impact, its current accounting systems fail to capture how its partners' ecological risks affect their long-term solvency, or how capital allocation is impacting the local environment. Consequently, the need arises to adopt a model that integrates environmental accounting to correct the technical gaps that traditional financial regulations omit.

Given this situation, this research asks the following question: How is environmental accounting related to the profitability of savings and credit cooperatives belonging to segments 1 and 2 in the city of Ambato, Ecuador? In order to test the hypothesis:  $H_1$ , environmental accounting is positively related to the profitability of savings and credit cooperatives belonging to segments 1 and 2 of the city of Ambato, Ecuador.

### **Conceptual foundations of environmental accounting in savings and credit cooperatives**

Environmental accounting refers to a management model within the sustainability accounting approach (4). From a broader perspective, environmental accounting has been gaining importance in the current business environment, since it has become a tool that allows integrating both financial and non-financial information into management and decision-making processes (5).

In this sense, environmental management is oriented towards the collection and analysis of information data that occurs with the use of natural resources and the impact generated by human activity, such as carbon dioxide emissions, water use, waste generation and renewable energy. The information facilitates the diagnosis of environmental impact through indicators, such as efficiency in energy use and emissions mitigation (2).

This study covers the use of natural resources, waste management and energy consumption, fundamental elements for responsible decision making (6). In this sense, it refers to the strategy aimed at preserving the environment and strengthening institutional sustainability. Likewise, the social dimension is related to the way in which the organization's activities influence people and the community that surrounds it (7). However, under the framework of the International Financial Reporting Standards (IFRS) with the recent incorporation of the S1 and S2 sustainability standards, which are incomplete, because it maintains a predominantly financial vision oriented to the investor. This technical and regulatory limitation means that essential operational and community activities, such as internal recycling processes and collective waste

management, are not tangibly reflected in the organizations' balance sheets, causing certain operational and community activities, such as internal recycling processes, collective waste management and social welfare initiatives, to not be tangibly manifested within the financial statements (3)(5).

Ethics and corporate responsibility go hand in hand, because they reflect a company's real commitment to acting with integrity and being aware of its role in society (8). Furthermore, business ethics is considered as a guide for management towards values such as honesty, transparency and objectivity (9). At the same time, profitability continues to be seen as a fundamental pillar in strategic planning, since it shows the ability of an organization to convert its resources into real profits. This metric helps measure how efficient the company is in managing everything it has, both tangible and intangible, and also allows us to see its potential to generate value (10). This is advantageous when evaluating financial performance and deciding where to direct the business.

This is essential, because it allows for a complete evaluation of both administrative performance and the way in which capital is strategically deployed (11). They are two key pillars to ensure that the entity is sustainable and that its assets are strengthened over time. From there, profitability is nothing more than a reflection of how the business is being managed (12). For example, when we look at the gross margin, we can clearly see how efficient operations are, it shows us whether we are taking care of costs and whether the value we assign to our products is adequate to sustain the structure of the company.

In relation to the above, operational efficiency is achieved when cost reduction and quality care merge as forces that drive production (13). Under this approach, raising quality standards makes it possible to stop the trickle of errors and the waste of inputs, which ensures full use of resources and strengthens the position of the business over time (14). The objective of the research is to analyze the relationship between environmental accounting and profitability in savings and credit cooperatives belonging to segments 1 and 2 in the city of Ambato, Ecuador.

## MATERIALS AND METHODS

The research was supported by the positivist paradigm, the reality of the savings and credit cooperatives belonging to segments 1 and 2 of the city of Ambato, Ecuador was considered as the base context for the development of the research that was objective, measurable and susceptible to empirical analysis, and at the same time sought to explain the causal relationships between the study variables. In this framework, environmental accounting was considered as the independent variable and profitability as the dependent variable, both operationalized in quantifiable indicators that allowed their measurement and statistical analysis. In this way, the study not only allowed us to test the hypothesis raised about the positive relationship between both variables, but also explain how environmental accounting practices influenced the financial performance

of savings and credit cooperatives, providing empirical evidence that contributed to the understanding of the phenomenon investigated (15).

The present investigation was developed through a non-experimental design, since the phenomenon was developed in its natural environment without the deliberate manipulation of the independent variables, thus responding to the integrity of the observed data. A mixed approach was used that combines qualitative-quantitative methods, which led to a fusion of a strategy that allowed the psychometric precision of the numerical indicators and the interpretive depth of the qualitative information obtained in the field. The study was designed with a correlational-causal scope, with the purpose of not only identifying, but also explaining the degree of association and dependence between the study variables. The methodology was based on a hypothetical-deductive, analytical-synthetic approach; which allowed us to verify the hypothesis and organize the information. In this way, it was ensured that the findings are reliable, valid and the study can be replicated in other contexts.

The survey technique was used to collect data. Carried out to the management or direction staff, accounting or financial department and operations or administration area in the 17 savings and credit cooperatives, which validated the information to understand the phenomenon studied. The instrument was subjected to an approval process through the evaluation of specialists, who examined its relevance and relevance to evaluate the proposed topic (16).

In this framework, the Content Validity Index (CVI) applied using the formula, based on Lawshe's classic proposal:

$$IVC = \frac{N_e - \frac{N}{2}}{\frac{N}{2}}$$

The content validation of the 20-item instrument reaches a global Content Validity Index (CVI) of 0.87, a result that exceeds the minimum of 0.80 recommended for a panel of five judges  $N = 5$  and confirms a strong theoretical alignment, since only three items received objections. This index is calculated from Lawshe's formula, which contrasts the variable  $N$ , the total number of participating experts, which is five in this case, with the variable that represents the number of judges who evaluated each item; This mathematical relationship is used to measure the degree of consensus and determine if the agreement exceeds that expected by chance, providing the validity of the instrument. Methodologically, although it is a small qualitative sample (5 experts), it is adequate and widely accepted in descriptive-causal instrument validation studies (22).  $N_e$

The present investigation adopted a census approach covering all the entities of segments 1 and 2 located in the city of Ambato, Ecuador. This non-random selection includes 17 institutions, which facilitates a detailed analysis of the local reality without the need to apply random sampling methods. The evaluated group is mainly made up of the cooperatives: OSCUS, San Francisco, El SAGRARIO, Educadores de Tungurahua,

Mushuc Runa, Indígena SAC, Maquita Cushun, Ambato, Kullki Wasi, Chibuleo, Vencedores, Kisapincha, Acción Tungurahua, Sumak Samy, Credi Ya, Sisa and Interandina (17).

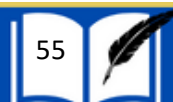
*Table 1. Variable operationalization matrix.*

| Independent Variable Environmental Accounting |                                     |                                                                                                                                                                                                                      |
|-----------------------------------------------|-------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Variable                                      | Dimensions                          | Indicators                                                                                                                                                                                                           |
| Environmental accounting                      | Dimension environmental             | <ul style="list-style-type: none"> <li>Accounting record of environmental impacts</li> <li>Measurement of CO2 emissions and energy consumption</li> <li>Accounting management of natural resources</li> </ul>        |
|                                               | Social dimension                    | <ul style="list-style-type: none"> <li>Register of social investments</li> <li>Information on labor well-being</li> <li>Inclusion of social criteria in accounting reports</li> </ul>                                |
|                                               | Environmental economic dimension    | <ul style="list-style-type: none"> <li>Evaluation of long-term financial performance</li> <li>Integration of sustainability criteria in profitability</li> <li>Efficient allocation of resources</li> </ul>          |
|                                               | Ethics and corporate responsibility | <ul style="list-style-type: none"> <li>Application of ethical principles in accounting information</li> <li>Existence of codes of ethics</li> <li>Compliance with financial and environmental regulations</li> </ul> |
| Profitability Dependent Variable              |                                     |                                                                                                                                                                                                                      |
| Variable                                      | Dimensions                          | Indicators                                                                                                                                                                                                           |
| Profitability                                 | Financial profitability             | <ul style="list-style-type: none"> <li>Return on assets (ROA)</li> <li>Return on equity (ROE)</li> <li>Financial margin</li> </ul>                                                                                   |
|                                               | Operational efficiency              | <ul style="list-style-type: none"> <li>Reduction in operating costs</li> <li>Optimization of resource use</li> <li>Cost-income ratio</li> </ul>                                                                      |
|                                               | Long-term profitability             | <ul style="list-style-type: none"> <li>Sustained profit growth</li> <li>Financial stability</li> <li>Sustainability of economic performance</li> </ul>                                                               |

*Note. Matrix for operationalization of variables, dimensions and indicators of the study.*

## RESULTS

Distribution of respondents according to age: the analysis of table 1 shows that 41.2% of respondents are between 25 and 35 years old, followed by the group over 45 years old with 29.4%, while the ranges from 36 to 45 years old and under 25 years old represent 17.6% and 11.8%. This distribution shows a greater participation of personnel



in the productive stage, which can favor the adoption of accounting practices linked to sustainability according to table 2.

**Table 2. Frequencies for age.**

| Age                | Frequency | Percentage | Valid Percentage | Cumulative Percentage |
|--------------------|-----------|------------|------------------|-----------------------|
| 25-35 years        | 7         | 41.2       | 41.2             | 41.2                  |
| 36-45 years        | 3         | 17.6       | 17.6             | 58.8                  |
| Less than 25 years | 2         | 11.8       | 11.8             | 70.6                  |
| Over 45 years old  | 5         | 29.4       | 29.4             | 100.0                 |
| Absent             | 0         | 0.0        |                  |                       |
| Total              | 17        | 100.0      |                  |                       |

**Note.** Frequency and percentage of responses obtained regarding the age of the respondents (n=17).

Labor well-being in accounting reports according to gender: the descriptive results show that 47.1% of respondents indicate that information on labor well-being is completely included in the accounting reports, followed by 29.4% who indicate that very little is incorporated, 17.6% who state that it is presented and 5.9% who indicate that it is not included. In the analysis by gender, the female group presents greater dispersion in the responses with 40% in complete inclusion, 30% in very little, 20% in partial inclusion and 10% in not included, while in the male group complete inclusion predominates with 57.1%, followed by 28.6% in very little and 14.3% in partial inclusion, with no records in the not included category. Regarding the Chi-square contrast, the value  $p=0.792$  with 3 degrees of freedom indicates that there is no evidence to establish an association between gender and the inclusion of labor well-being information in the accounting reports in the cooperatives analyzed, as evidenced in table 3-4.

**Table 3. Workplace well-being in accounting reports by gender.**

| Is information on workplace well-being included in accounting reports? |             |              |                 |                |       |
|------------------------------------------------------------------------|-------------|--------------|-----------------|----------------|-------|
| Genre:                                                                 | Very little | Not included | Yes, completely | Yes, partially | Total |
| Female                                                                 | 3           | 1            | 4               | 2              | 10    |
| Male                                                                   | 2           | 0            | 4               | 1              | 7     |
| Total                                                                  | 5           | 1            | 8               | 3              | 17    |

**Note.** Frequency and percentage of responses on the inclusion of workplace well-being information in accounting reports by gender

**Table 4. Chi-square contrasts.**

| Value | Gl | p |
|-------|----|---|
|-------|----|---|



**Table 3. Workplace well-being in accounting reports by gender.**

| Is information on workplace well-being included in accounting reports? |             |              |                 |                |       |
|------------------------------------------------------------------------|-------------|--------------|-----------------|----------------|-------|
| Genre:                                                                 | Very little | Not included | Yes, completely | Yes, partially | Total |
| X <sup>2</sup>                                                         | 1.036       | 3            | .792            |                |       |
| N                                                                      | 17          |              |                 |                |       |

**Note.** Chi-square test to evaluate the relationship between gender and the inclusion of workplace well-being information in accounting reports.

The registration of environmental impacts and control of natural resources: They show that 52.9% of respondents indicate that environmental impacts are recorded, and within this group, 66.7% also indicate that accounting control of natural resources is maintained, which reflects a more consistent application of these practices. In contrast, 35.3% state that these records are carried out sometimes, with a predominance of 66.7% in this group who rarely keep control of the resources, which shows certain limitations in the integration of both processes. The never and rarely categories present a reduced participation of 5.9% each. In relation to the statistical analysis, the value  $p=0.228$  obtained in the Chi-square test indicates that a relationship is not identified between the record of environmental impacts and the accounting control of natural resources in the cooperatives evaluated as shown in table 5 and 6.

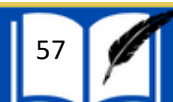
**Table 5. Record of environmental impacts and control of natural resources.**

| Does your cooperative record the environmental impacts of its operations? | Is there accounting control of the natural resources used by the cooperative? |        |        |       |
|---------------------------------------------------------------------------|-------------------------------------------------------------------------------|--------|--------|-------|
|                                                                           | Sometimes                                                                     | Rarely | Always | Total |
| Sometimes                                                                 | 1                                                                             | 4      | 1      | 6     |
| Never                                                                     | 0                                                                             | 0      | 1      | 1     |
| Rarely                                                                    | 0                                                                             | 1      | 0      | 1     |
| Always                                                                    | 2                                                                             | 1      | 6      | 9     |
| Total                                                                     | 3                                                                             | 6      | 8      | 17    |

**Note.** Frequency and percentage of responses about the recording of environmental impacts and the accounting control of natural resources ( $n=17$ ).

**Table 6. Record of environmental impacts and control of natural resources.**

|                | Value | gl | p    |
|----------------|-------|----|------|
| X <sup>2</sup> | 8.146 | 6  | .228 |
| N              | 17    |    |      |



**Note. Relationship between combined variables evaluated with Chi-square ( $p < 0.05$ ;  $n = 17$ )**

Registration of social investments and incorporation of social criteria in financial reports: the results show that 52.9% of respondents indicate that social investments are always recorded, and within this group 77.8% also indicate that social criteria are always incorporated in financial reports, while 11.1% do so sometimes and 11.1% rarely, which reflects greater consistency in these practices. On the other hand, 47.1% state that social investments are sometimes recorded, where 50% also incorporate social criteria sometimes, followed by 25% who always do so and 25% rarely, which shows a less consistent application. In relation to the statistical analysis, the value  $p = 0.088$  indicates that a relationship between both variables is not identified, despite the fact that a certain tendency of association is observed in the cooperatives as evident in table 7 and 8.

**Table 7. Record of social investments and incorporation of social criteria in financial reports.**

| Are the social investments made by the cooperative recorded? | Does the cooperative incorporate social criteria in its financial reports? |        |        | Total |
|--------------------------------------------------------------|----------------------------------------------------------------------------|--------|--------|-------|
|                                                              | Sometimes                                                                  | Rarely | Always |       |
| Sometimes                                                    | 4                                                                          | 2      | 2      | 8     |
| Always                                                       | 1                                                                          | 1      | 7      | 9     |
| Total                                                        | 5                                                                          | 3      | 9      | 17    |

**Note. Frequency and percentage of responses about the registration of social investments and the incorporation of social criteria in financial reports**

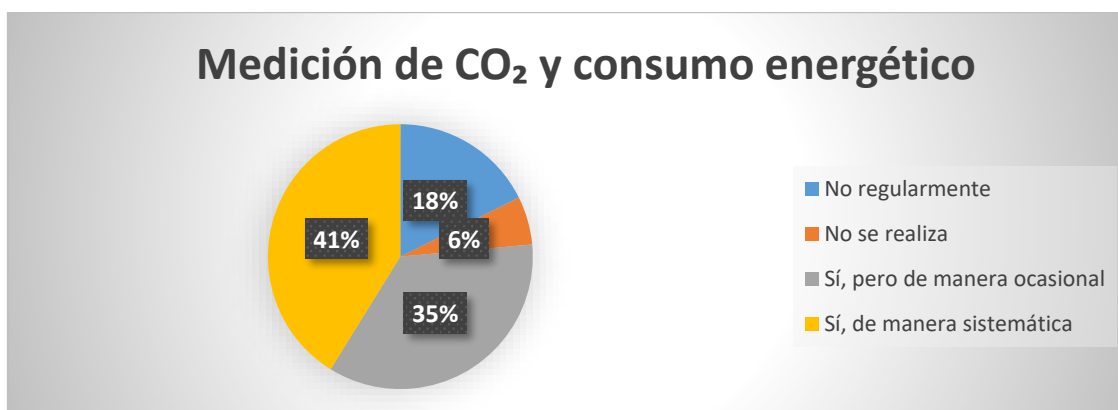
**Table 8. Relationship between social investments and social criteria in financial reports.**

|          | Value | Gl | P    |
|----------|-------|----|------|
| $\chi^2$ | 4.869 | 2  | .088 |
| N        | 17    |    |      |

**Note. Relationship between the record of social investments and the incorporation of social criteria evaluated with Chi-square ( $p < 0.05$ ;  $n = 17$ ).**

Measurement of CO<sub>2</sub> and energy consumption: the results show that the measurement of CO<sub>2</sub> emissions and energy consumption is already part of the management in several cooperatives, since 41.2% carry it out systematically and 35.3% occasionally, adding up to 76.5% that apply this type of practices at some level. This shows progress in the incorporation of the environmental approach within institutional management. However, there are still weaknesses, since 17.6% indicate that the measurement is carried out irregularly and 5.9% that it is not carried out, which reflects a lack of continuity and standardization. However, there is progress, the application is still not homogeneous, which can limit the quality of environmental accounting information and its usefulness for financial decision making (see figure 1)

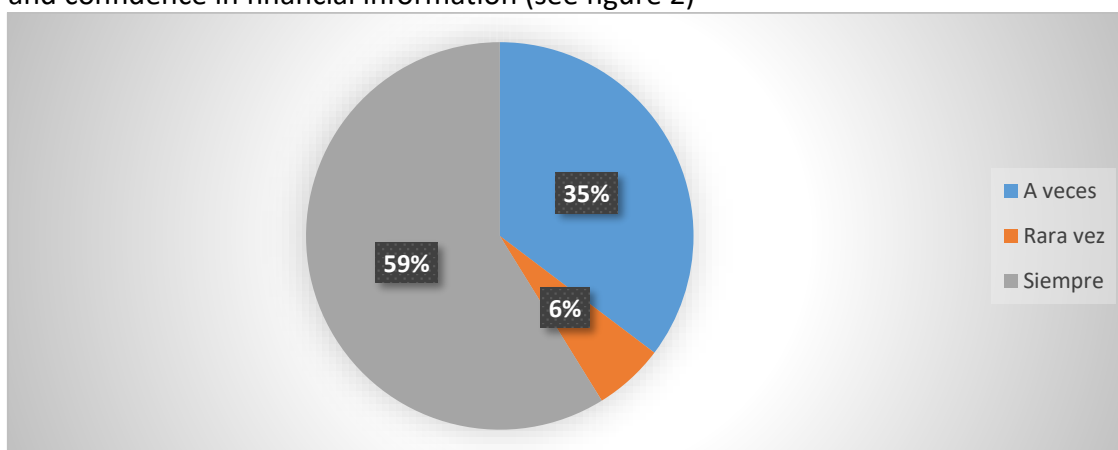




**Figure 1. Measurement of CO<sub>2</sub> and energy consumption.**

**Note.** Most cooperatives measure CO<sub>2</sub> emissions and energy consumption with differences in their frequency and level of application.

Application of ethical accounting principles: the results show that the application of ethical principles in the preparation of accounting information is a fairly widespread practice in the cooperatives analyzed, because 58.8% indicate that they are always applied and 35.3% that they are used on some occasions, reaching a total of 94.1%. This reflects a clear trend towards the use of ethical criteria in accounting processes. However, 5.9% indicate that they are rarely applied, which shows that there are still certain gaps in their constant application. In general, accounting ethics is present in most cases, it is still necessary to reinforce its continuous use to achieve greater consistency and confidence in financial information (see figure 2)



**Figure 2. Application of ethical accounting principles.**

**Note.** The application of ethical principles in accounting information predominates with variations in its frequency.

#### Variable normality analysis using the Shapiro-Wilk test

The normality analysis using the Shapiro-Wilk test shows that all the variables evaluated have p values lower than 0.05, ranging between <0.001 and 0.018, which leads, with statistical rigor, to the systematic rejection of the null hypothesis of normality in each of

the items analyzed. This behavior is consistent both in sociodemographic variables (age, gender, level of education, position and experience) and in those related to accounting, environmental and sustainability practices. The W statistics, which vary between 0.611 and 0.865, reinforce the evidence of deviations from a normal distribution, which can be attributed, in part, to the ordinal nature of the variables (Likert-type scales) and the small sample size ( $n=17$ ) (see annex 1)

### Relationship between variables using non-parametric statistics

This section examines the relationship between the study variables, environmental accounting and profitability, with the objective of determining both the intensity and the direction of their association. For this, Spearman's Rho correlation coefficient was used (see table 5)

The interpretation of the results of the Spearman's Rho coefficient ( $\rho$ ) is based on two fundamental elements: the strength and direction of the relationship and its statistical significance. The value of  $\rho$  ranges between -1 and +1; values close to +1 indicate a positive relationship (both variables increase), values close to -1 reflect a negative relationship (one variable increases while the other decreases), and values close to 0 show no relationship. Regarding magnitude, coefficients between 0.00–0.29 are considered weak, 0.30–0.59 moderate, and  $\geq 0.60$  strong. However, to determine if this relationship is statistically valid, the p value is analyzed: if  $p < 0.05$ , the correlation is significant and can be generalized to the population; Otherwise, there is not enough evidence to affirm a real relationship as shown in Table 9.

**Table 9. Relationship between environmental accounting, management and profitability.**

| Variable 1                          | Variable 2                                  | $\rho$ (Spearman) | p     |
|-------------------------------------|---------------------------------------------|-------------------|-------|
| P8: Control of natural resources    | P6: Record of environmental impacts         | 0.429             | 0.086 |
| P8: Control of natural resources    | P18: Profitability (ROA/ROE)                | 0.115             | 0.660 |
| P8: Control of natural resources    | P9: Social investments                      | 0.248             | 0.337 |
| P8: Control of natural resources    | P20: Environmental information in decisions | 0.680             | 0.005 |
| P8: Control of natural resources    | P19: Optimization of resources              | 0.619             | 0.008 |
| P6: Record of environmental impacts | P18: Profitability (ROA/ROE)                | 0.243             | 0.348 |
| P6: Record of environmental impacts | P9: Social investments                      | 0.441             | 0.076 |
| P6: Record of environmental impacts | P20: Environmental information in decisions | 0.612             | 0.015 |
| P6: Record of environmental impacts | P19: Optimization of resources              | 0.234             | 0.367 |
| P18: Profitability (ROA/ROE)        | P9: Social investments                      | 0.088             | 0.736 |
| P18: Profitability (ROA/ROE)        | P20: Environmental information in decisions | 0.407             | 0.132 |
| P18: Profitability (ROA/ROE)        | P19: Optimization of resources              | 0.138             | 0.598 |
| P9: Social investments              | P20: Environmental information in decisions | 0.377             | 0.165 |
| P9: Social investments              | P19: Optimization of resources              | 0.485             | 0.049 |

|                                             |                                |       |       |
|---------------------------------------------|--------------------------------|-------|-------|
| P20: Environmental information in decisions | P19: Optimization of resources | 0.579 | 0.024 |
|---------------------------------------------|--------------------------------|-------|-------|

**Note.** Spearman's Rho coefficient ( $\rho$ ); Relationships with  $p < 0.05$  are considered significant.

By carefully examining the results presented in Table 5, a fairly obvious pattern can be identified. On the one hand, there is a connection between the variables that are related to both environmental and operational management.

For example, when the cooperative carries out adequate management of its natural resources (P8), it also tends to use more environmental information when making decisions (P20) and to optimize its resources (P19). These connections are not only favorable, but also relevant, suggesting that they are not the result of chance, but reflect actual practices within organizations. In the same way, the environmental record (P6) is linked to the decision-making process, which shows that environmental accounting effectively adds value to internal management. However, when profitability is analyzed (P8), the situation transforms. However, some correlations are favorable, they are not of great relevance, which shows that it cannot be assured that environmental accounting is affecting economic results. In other words, cooperatives may be working with environmental and management aspects, but this still does not reflect a better level of profitability. Collectively, the findings indicate that environmental accounting improves and optimizes resources and helps cooperatives' administrative decision-making, although its impact on profit is not directly manifested in the economic parameters. The quantitative study, through the use of Spearman's Rho coefficient, validates the connection between ecological accounting and profitability, but does not present statistical significance, which results in the rejection of the proposed hypothesis. However, the connections of variables and the favorable trends between internal management show us that its contribution is located at the intermediate level of organizational performance, where it reinforces the processes to influence the final results.

**Table 10. Technical approach.**



**Note. Logistic regression model ( $p > 0.05$ ).**

## Qualitative Analysis

In order to strengthen the research and verify the proposed hypothesis, the qualitative study provided the understanding of this management through the actions in the cooperatives under study, who examine environmental accounting through the control of inputs and monitoring the use of resources such as paper, plastics and electricity. This

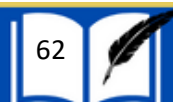
| Independent Variable                        | Coefficient ( $\beta$ ) | Standard Error | z value | p-value | Odds Ratio (OR) | 95% CI (Bootstrapped) |
|---------------------------------------------|-------------------------|----------------|---------|---------|-----------------|-----------------------|
| P8: Control of natural resources            | 0.312                   | 0.248          | 1.258   | 0.208   | 1.367           | [0.812 - 2.014]       |
| P6: Record of environmental impacts         | 0.187                   | 0.221          | 0.846   | 0.398   | 1.206           | [0.765 - 1.892]       |
| P20: Environmental information in decisions | 0.456                   | 0.239          | 1.908   | 0.056   | 1.578           | [0.987 - 2.451]       |
| P19: Resource optimization                  | 0.274                   | 0.255          | 1.075   | 0.282   | 1.315           | [0.793 - 2.087]       |
| P9: Social investments                      | 0.098                   | 0.214          | 0.458   | 0.647   | 1.103           | [0.712 - 1.689]       |
| Constant (Threshold 1)                      | -1.872                  | 0.612          | -3.059  | 0.002   | -               | -                     |
| Constant (Threshold 2)                      | 0.245                   | 0.598          | 0.410   | 0.682   | -               | -                     |

method promotes effectiveness and produces savings, which aligns with internal administration results. In a complementary manner, when applying the Ordinal Logistic Regression Model, several models were evaluated, the most relevant being the one that takes profitability as the dependent variable (P18) and the main dimensions of environmental accounting as explanatory variables (P8, P6, P20 and P19).

The results of the ordinal logistic regression model indicate that there is no statistically significant relationship between the majority of environmental accounting practices and the level of profitability of the companies analyzed. Specifically:

The coefficient of P8 (Control of natural resources) presented a positive value, but not significant ( $p > 0.05$ ), suggesting that it cannot be stated that greater control of natural resources significantly increases the achievement of higher levels of profitability, although there is a positive trend.

The P20 variable of environmental information in decisions showed a strong coefficient close to significance, indicating that a better integration of environmental information in decision making could increase the probabilities of obtaining greater profitability, although this relationship does not reach the conventional principle of significance in the sample studied. The variables P6 recording of environmental impacts and P19



Resource optimization did not show significant effects on profitability. The bootstrapped confidence intervals confirmed the stability of the estimates, reinforcing the conclusion that the relationship between environmental accounting and profitability is weak in this context.

However, there is a disconnection with strategic processes and the lack of a broader evaluation of impacts that limit its scope, which helps to understand why its contribution does not translate into profitability. Jointly, a process is determined in which environmental accounting strengthens the operational base and opens possibilities for financial effects that need further evolution to be consolidated.

The analysis of the research reveals that the ecological requires importance when adding productivity. The deduction of costs becomes the main link between ecological actions and economic results, which relates this experience to eco-efficiency methods. Under this context, the focus is on immediate economic benefits, while a broader perspective of sustainability loses relevance. Environmental accounting is more often used as a resource for monitoring expenditures than as an aid in planning or formulating strategic decisions. Restrictions on the evaluation and measurement of information about the environment are observed within the inferential analysis. The overuse of paper shows established habits that have not yet been replaced by digital methods. This element shows obstacles related to culture in organizations and change management. The lack of advanced guides and guidelines prevents environmental information from playing a fundamental role in management, limiting its contribution to financial planning.

The results show that environmental accounting needs to be improved within the framework of the accounting system. The placement of indicators and the use of digital technologies would increase their effectiveness. The training of personnel, carrying out team training and the inclusion of these aspects in organizational planning would facilitate progress towards a more harmonious management where the economic and ecological are connected, have a broader focus and are assisted with decisions.

## DISCUSSION

By synthesizing findings between the general business environment and cooperative management, it is established that the use of environmental accounting is no longer just an administrative burden, but rather comes from economic success. This positive synergy indicates that being able to detect the costs of ecology will allow optimizing the use of resources and correcting operating expenses. Environmental accounting has ceased to be a purely ethical issue and has become a direct driver of profitability and efficiency in production processes, where sustainability and economic benefit act as complementary dimensions (19). The ecology of financial statements not only strengthens the theoretical accounting framework, but also offers guidance so that these decisions are appropriate to ensure the value of the entity in the long term (20).

However, the empirical results of the research in the 17 savings and credit cooperatives of Ambato openly refute this theoretical position, by statistically demonstrating the absence of a significant relationship between environmental management and traditional financial profitability indicators (ROA and ROE).

This contrast with previous literature finds its explanation in the regulatory conditions and the market structure of the Ecuadorian cooperative sector. In Ecuador, the Superintendency of Popular and Solidarity Economy (SEPS) and current legislation impose fixed cost structures and rate regulations that curb the direct short-term benefit of operational efficiency on profitability. Thus, although the Ambato cooperatives manage to optimize operating expenses through resource management, this cost savings does not have a proportional effect on the ROA or ROE.

Internal efficiency manages to establish the basis of the operation, but its final financial impact is neutralized by regulatory rigidity, the lack of direct fiscal incentives for green accounting and a fragile strategic articulation that connects environmental savings with the generation of financial value (21).

Added to this market limitation is the structural problem of the "profile" of the traditional accountant. Under the framework of the International Financial Reporting Standards (IFRS) applied in the national context, socio-environmental facts continue to be neither standardized nor formally made visible in the balance sheets.

In this context, a phenomenon of neutralization of operational savings is evident, although companies manage to optimize internal resources through environmental accounting practices such as: better control of natural resources or optimization of consumption, this saving does not translate into a significant increase in Return on Assets (ROA). This occurs mainly because active and passive interest rates are strongly regulated by the Central Bank of Ecuador (BCE).

These regulations establish reduced and inflexible margins between the rates of raising and placing resources, which limits the ability of companies to financially capitalize on their operational efficiencies. In other words, although operating costs are reduced through more efficient environmental management, the low interest rate differential prevents these savings from being converted into greater financial profitability, neutralizing the expected positive impact on asset performance.

The explanatory distance for the effective implementation of environmental accounting in Ambato is not the disinterest of management, but the lack of cutting-edge internal policies and the lack of specific technical training in sustainable finance. Even so, the problem persists of transforming the usual "profile" of the accountant, which traditionally, due to many standards towards which the reports revolve, among them, the International Financial Reporting Standards (IFRS), still does not have standardized social and environmental facts or events. In fact, it seems that the explanatory distance for the implementation of environmental accounting is not disinterest, but rather the lack of types of internal policies or specific technical training on the environmental issue.

Consequently, information on social and environmental impacts, although it contributes to transparency, institutional reputation and long-term viability in an increasingly demanding and competitive environment, cannot be fully materialized in traditional financial indicators due to these structural restrictions of the Ecuadorian financial system (23).

The coincidence of these works indicates that environmental accounting has left aside what is expressed as a technical record to become a space for strategic and political dispute: in the cooperative field it is recognized as a generator of profitability and operational efficiency and in the social field it constitutes a tool of resistance known as counter-accounts, put into practice with respect to what social movements would be with regard to the questioning of official information and the inability of territorial damages.

The sample including environmental metrics not only responds to parameters for improving financial results, but also responds to an ethical request for transparency (18).

The integration of results shows that environmental accounting is no longer subject to being a purely technical record, but rather becomes the core of the political legitimacy and efficiency of the operation. But a key alignment is generated: although cooperatives and medium-sized companies optimize operating expenses through resource management, cost savings do not have a proportional effect on ROA or ROE, suggesting that progress in internal efficiency contributes to the foundation of the operation, but its financial impact is diluted due to the lack of strategic articulation and the rigidity of regulations (21).

The drive to use "counter-accounts" and thus give visibility to territorial impacts also shows that sustainability should not be considered dead weight, but rather an administrative benefit that protects reputation in critical markets. The challenge is to change environmental accounting from a basic input control tool to a value generation tool. Only through technical training is there the possibility of converting operational resilience into measurable financial resilience, in accordance with the democratic responsibility of the organization.

## CONCLUSIONS

The promotion of operational management and internal decision making through environmental accounting does not translate into a direct improvement in financial profitability in the cooperatives studied. The positive connections between the control of natural resources and the use of environmental data for strategic decisions for resource optimization are not carried over to asset and equity performance indicators. This finding shows and refutes the initial hypothesis and shows that the internal efficiency formed by environmental practices is not yet shown in measurable financial results. From this perspective, sustainability tends to be a set of independent works that, as a global approach, since labor well-being and social investment are indicated in the reports without a real connection with financial management. This lack of articulation is

common in the environmental area, where energy and CO<sub>2</sub> emissions measurements are carried out without clear criteria and in an irregular manner, making it difficult for accounting records to show true control over natural resources. In short, as long as this information remains fragmented and lacks continuity, it cannot be incorporated into decision-making in the environmental or social area, limiting sustainability to specific actions that lose trustworthy and strategic notability.

Ethics in accounting, which is manifested in the creation of financial data, does not become an ecological metric which supports strategic planning. Currently, the ecological approach allows reducing the use of basic inputs through their supervision, without relating it to long-term financial decision processes. This lack of coherence between the ethical principle and daily operations highlights an opportunity for improvement in the consistency of the methods used.

Environmental accounting in Ecuadorian cooperatives is used as a means to promote short-term efficiency and expenses, not as a driver of profitability. In order for this practice to have a financial impact, it is necessary to train staff in sustainable management, develop environmental indicators linked to financial statements and replace manual processes with digital systems. This change would allow environmental accounting to become a great support for strategic decision making.

## REFERENCES

1. García C, Herrero B, Miralles J, Miralles M. Exploring the determinants of corporate green bond issuance and its environmental implication: The role of corporate board . Rev Technol. Forecast Soc Change. 2023;(189):2-12. Disponible en: doi:<https://doi.org/10.1016/j.techfore.2023.122379>
2. Ortiz P, Haydeé K. Responsabilidad social como motor de la sostenibilidad en economías emergentes. Rev Cienc Soc.2025; 31(1):107-119. Disponible en: <https://doi.org/10.31876/racs.v31i1.43488>
3. Rubio G, Hernández L, Bermeo K, Meneses N. Análisis de las normas internacionales de información financiera y su relación con la responsabilidad social empresarial. Rev Econ Polít.2020;(31): 31-157. Disponible en: doi:<https://doi.org/10.25097/rep.n31.2020.08>
4. González A. Contabilidad ambiental: desarrollo sostenible y responsabilidad empresarial. Rev Contab Ambient. 2022:195-210. doi:<https://doi.org/10.7476/9789978108178.0011>
5. Corredor A. Importancia de los reportes de sostenibilidad en la gestión del revisor fiscal. Rev. Cubana Contab Finanz, 2024;18(2):1-13. Disponible en: <https://revistas.uh.cu/cofinhab/article/view/10413>
6. Sarmiento A, Orellana D, Perez P. La contabilidad ambiental en empresas industriales de línea blanca en la provincia del Azuay-Ecuador. Rev Interdiscip Human Educ Cienc Tecnol.2020; 6(2):370-396. Disponible en: doi:DOI 10.35381/cm.v6i2.370
7. García V. Valores, principios, fines e interpretación constitucional. Rev Derecho y Soc.2003;21(2003):190-209. Disponible en:

- doi:<https://revistas.pucp.edu.pe/index.php/derechoysociedad/article/view/17370/17654>
8. Franco C. & Velásquez, F. Cómo mejorar la eficiencia operativa utilizando el trabajo en equipo. *Rev Estud Gerenc.*2000;(76):27-35. Disponible en: <https://www.redalyc.org/articulo.oa?id=21207602>
  9. Sarmiento B, Puquio A, García N, Bringas I, Ruiz K. Ética empresarial y responsabilidad social en las Mypes en el Perú. *Rev Lider.* 2023;(18): 15-25. Disponible en: <https://revistas.pucp.edu.pe/index.php/revistalidera/article/view/28545>
  10. Gaytán J. Indicadores financieros y económicos. *Rev Merc Neg.*2019;(39):161-172. Disponible en: <https://www.redalyc.org/articulo.oa?id=571860887009>
  11. Ramos E, Delgado S, Ortiz V, Arbulú M. La rentabilidad financiera de las empresas en tiempos de pandemia: una revisión sistemática. *Cofin Habana.*2024;18(1): 1-13. Disponible en: <https://revistas.uh.cu/cofinhab/article/view/9939>
  12. Conforme M, Zambrano J. Análisis de la estructura de capital en el apalancamiento financiero de las empresas farmacéuticas de Guayaquil, Ecuador. *Rev Univ Soc,* 2023;15(2): 467-474. Disponible en: [https://www.uteg.edu.ec/wp-content/uploads/2023/09/04\\_art.2023.pdf](https://www.uteg.edu.ec/wp-content/uploads/2023/09/04_art.2023.pdf)
  13. León, G, Romero E. Gestión operativa y su impacto en la eficiencia de la Coordinación de Servicios de Atención al Ciudadano IESS Manabí. *Rev Cient.*2023;8(2):150-177. Disponible en: 10.23857/pc.v8i2
  14. Nuñez L, Alfaro J, Aguado A, González E. Toma de decisiones estratégicas en empresas: Innovación y competitividad. *Rev Venez GerenC.*2023;28(9):628-641. Disponible en: doi:<https://doi.org/10.52080/rvgluz.28.e9.39>
  15. Villegas, D., Vilca, A., Saavedra, P., Felices, L., Baños, N., Ortiz, A., . . . Acosta, S. (2023). Los paradigmas de investigación en las Ciencias Sociales. Maracaibo: INDICAP Pacífico. 2023: 62-79. Maracaibo: INDICAP Pacífico. doi:<https://doi.org/10.53595/eip.007.2023.ch.4>
  16. Herrera J, Calero J, González M, Collazo M, Travieso Y. El método de consulta a expertos en tres niveles de validación. *ReV Habanera Cienc Med.*2022;1:11-18. Disponible en: <https://www.redalyc.org/journal/1804/180473621013/html/>
  17. Superintendencia de Economía Popular y Solidaria (SEPS). Actualización de registro de directivos de organizaciones de la economía popular y solidaria. 2025. Disponible en: <https://www.gob.ec/seps/tramites/actualizacion-registro-directivos-organizaciones-economia-popular-solidaria>
  18. Cabrera A, Quinche F. Movimientos sociales y contabilidad social y ambiental: el rol de las contracuentas como ejercicio de la crítica. *Rev Innor,* 2023;31(82): 125-144. Disponible en: doi:<https://doi.org/10.15446/innovar.v31n82.98428>
  19. García D, Tapia B, Aguilar A. Relación Entre el uso de la Contabilidad Ambiental y el Desempeño Financiero de la Empresa. *Rev Eur Sci J.*2023;19(37):143-157. Disponible en: doi:<https://doi.org/10.19044/esj.2023.v19n37p143>
  20. Hennings J, Yaguache D. La gestión financiera como factor de la rentabilidad en las cooperativas de ahorro y crédito del Ecuador 2016-2020. *Rev Mundo Investig Conoc.*2021;5(4): 356-371. doi:10.26820/recimundo/5.(4).dic.2021.356-371
  21. Escobar J, Martínez A. Validez de contenido y juicio de expertos: una aproximación a su utilización. *Rev Avan Medi,* 2008;(6):27-36. Disponible en:



[https://www.researchgate.net/publication/302438451\\_Validez\\_de\\_contenido\\_y\\_juicio\\_de\\_expertos\\_Una\\_aproximacion\\_a\\_su\\_utilizacion](https://www.researchgate.net/publication/302438451_Validez_de_contenido_y_juicio_de_expertos_Una_aproximacion_a_su_utilizacion)

22. Acosta S, Romero C, Villalba A. Prácticas Contables con Enfoque Social y Ambiental. Cienc Lat Rev Cient Multidiscip, 2023;7(5):2797-2816. Disponible en: doi:[https://doi.org/10.37811/cl\\_rcm.v7i5.7920](https://doi.org/10.37811/cl_rcm.v7i5.7920)

## Anexo 1

|                         | Edad  | Género: | Nivel de estudios: | Cargo que desempeña en la cooperativa: | Años de experiencia en la cooperativa: | ¿Su cooperativa registra contablemente los impactos ambientales de sus operaciones? | ¿Se realiza la medición de emisiones de CO <sub>2</sub> y consumo energético? | ¿Se lleva un control contable de los recursos naturales utilizados por la cooperativa? |
|-------------------------|-------|---------|--------------------|----------------------------------------|----------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Válido                  | 17    | 17      | 17                 | 17                                     | 17                                     | 17                                                                                  | 17                                                                            | 17                                                                                     |
| Ausente                 | 0     | 0       | 0                  | 0                                      | 0                                      | 0                                                                                   | 0                                                                             | 0                                                                                      |
| Media (Aritmética)      | 2.647 | 1.588   | 3.353              | 1.941                                  | 2.176                                  | 1.647                                                                               | 1.882                                                                         | 1.882                                                                                  |
| Desviación típica       | 1.057 | 0.507   | 0.493              | 0.556                                  | 1.131                                  | 0.862                                                                               | 0.928                                                                         | 0.928                                                                                  |
| Shapiro-Wilk            | 0.852 | 0.632   | 0.611              | 0.732                                  | 0.845                                  | 0.742                                                                               | 0.833                                                                         | 0.739                                                                                  |
| Valor P de Shapiro-Wilk | .011  | < .001  | < .001             | < .001                                 | .009                                   | < .001                                                                              | .006                                                                          | < .001                                                                                 |
| Mínimo                  | 1.000 | 1.000   | 3.000              | 1.000                                  | 1.000                                  | 1.000                                                                               | 1.000                                                                         | 1.000                                                                                  |
| Máximo                  | 4.000 | 2.000   | 4.000              | 3.000                                  | 4.000                                  | 4.000                                                                               | 4.000                                                                         | 3.000                                                                                  |

|                         | ¿Se registran las inversiones sociales realizadas por la cooperativa? | ¿Se incluye información sobre bienestar laboral en los informes contables? | ¿La cooperativa incorpora criterios sociales en sus reportes financieros? | ¿Se evalúa el desempeño financiero considerando criterios de sostenibilidad? | ¿Se integran criterios de sostenibilidad en la rentabilidad y planificación financiera? | ¿La cooperativa realiza una asignación eficiente de recursos considerando impactos ambientales? |
|-------------------------|-----------------------------------------------------------------------|----------------------------------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Válido                  | 17                                                                    | 17                                                                         | 17                                                                        | 17                                                                           | 17                                                                                      | 17                                                                                              |
| Ausente                 | 0                                                                     | 0                                                                          | 0                                                                         | 0                                                                            | 0                                                                                       | 0                                                                                               |
| Media (Aritmética)      | 1.471                                                                 | 1.941                                                                      | 1.647                                                                     | 1.412                                                                        | 1.412                                                                                   | 1.765                                                                                           |
| Desviación típica       | 0.514                                                                 | 1.029                                                                      | 0.786                                                                     | 0.618                                                                        | 0.618                                                                                   | 0.664                                                                                           |
| Shapiro-Wilk            | 0.642                                                                 | 0.802                                                                      | 0.752                                                                     | 0.678                                                                        | 0.678                                                                                   | 0.792                                                                                           |
| Valor P de Shapiro-Wilk | < .001                                                                | .002                                                                       | < .001                                                                    | < .001                                                                       | < .001                                                                                  | .002                                                                                            |
| Mínimo                  | 1.000                                                                 | 1.000                                                                      | 1.000                                                                     | 1.000                                                                        | 1.000                                                                                   | 1.000                                                                                           |
| Máximo                  | 2.000                                                                 | 4.000                                                                      | 3.000                                                                     | 3.000                                                                        | 3.000                                                                                   | 3.000                                                                                           |

|                         | ¿Se aplican principios éticos en la elaboración de la información contable? | ¿Existe un código de ética que guíe las prácticas contables y ambientales de la cooperativa? | ¿La cooperativa cumple con normativas financieras y ambientales vigentes? | ¿Cómo evalúa la rentabilidad de la cooperativa sobre activos (ROA) y patrimonio (ROE)? | ¿La cooperativa optimiza sus recursos y costos considerando criterios ambientales? | ¿La información ambiental influye en las decisiones estratégicas y en la planificación financiera? |
|-------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| Válido                  | 17                                                                          | 17                                                                                           | 17                                                                        | 17                                                                                     | 17                                                                                 | 15                                                                                                 |
| Ausente                 | 0                                                                           | 0                                                                                            | 0                                                                         | 0                                                                                      | 0                                                                                  | 2                                                                                                  |
| Media (Aritmética)      | 1.471                                                                       | 1.588                                                                                        | 1.471                                                                     | 2.176                                                                                  | 1.765                                                                              | 1.933                                                                                              |
| Desviación típica       | 0.624                                                                       | 1.004                                                                                        | 0.624                                                                     | 0.951                                                                                  | 0.752                                                                              | 0.799                                                                                              |
| Shapiro-Wilk            | 0.714                                                                       | 0.631                                                                                        | 0.714                                                                     | 0.865                                                                                  | 0.709                                                                              | 0.782                                                                                              |
| Valor P de Shapiro-Wilk | < .001                                                                      | < .001                                                                                       | < .001                                                                    | .018                                                                                   | < .001                                                                             | .002                                                                                               |
| Mínimo                  | 1.000                                                                       | 1.000                                                                                        | 1.000                                                                     | 1.000                                                                                  | 1.000                                                                              | 1.000                                                                                              |
| Máximo                  | 3.000                                                                       | 4.000                                                                                        | 3.000                                                                     | 4.000                                                                                  | 4.000                                                                              | 4.000                                                                                              |

# DISEÑO Y CONSTRUCCIÓN DE UNA ESCALERA DE SEGURIDAD INDUSTRIAL MANUAL DE PELDAÑOS PLANOS PARA REDUCIR LA FATIGA FÍSICA EN LA FUNDACIÓN ECOSUR - ECUADOR

## DESIGN AND CONSTRUCTION OF A MANUAL INDUSTRIAL SAFETY LADDER WITH FLAT STEPS TO REDUCE PHYSICAL FATIGUE AT FUNDACIÓN ECOSUR - ECUADOR

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**RESUMEN:** El presente trabajo describe el diseño y construcción de una escalera de seguridad industrial manual de peldaños planos, desarrollada para el Departamento de Reconstrucción de Vivienda de la Fundación EcoSur - Ecuador, con sede en Riobamba, en el marco del "Proyecto de Mejoramiento de la Calidad de Vida de los Sectores más Vulnerables". El diseño tomó como referencia el modelo KENDO TOOLS, bajo los requisitos de la norma europea EN 131, integrando principios ergonómicos orientados a minimizar el estrés físico en piernas y espalda. Se priorizó el uso de materiales de larga vida útil y bajo peso, optimizando la movilidad, transporte y versatilidad en entornos de construcción, respetando los más altos estándares de calidad conforme al Control Estadístico 6 Sigma. La investigación se orientó a determinar cómo afecta el diseño y construcción de esta escalera en la reducción de la fatiga física y la mejora de la seguridad laboral dentro del sector de la construcción. Se establecieron tres objetivos específicos: diseñar la escalera mediante software CAD para determinar los parámetros geométricos más adecuados; construir el prototipo con base en el diseño CAD y una simulación tensodeformacional; y validar el producto mediante un análisis estadístico multivariado y un control de calidad 6 Sigma, con la elaboración de un manual técnico de uso y mantenimiento. La implementación de la escalera en los sitios de intervención de la Fundación EcoSur arrojó resultados altamente favorables, evidenciando mejoras en el bienestar general del trabajador, reducción del ausentismo por fatiga, incremento de la productividad y disminución de accidentes e incidentes laborales, tanto en Riobamba como en las demás localidades donde se desarrollan los proyectos en ejecución.

**Palabras clave:** *ergonomía, seguridad industrial, peldaños planos, construcción, bienestar.*

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**ABSTRACT:** This paper describes the design and construction of a manual flat-rung industrial safety ladder, developed for the Housing Reconstruction Department of the EcoSur - Ecuador Foundation, headquartered in Riobamba, within the framework of the "Project for Improving the Quality of Life of the Most Vulnerable Sectors." The design was based on the KENDO TOOLS model, following the requirements of European standard EN 131, and incorporated ergonomic principles aimed at minimizing physical stress on the legs and back. Priority was given to the use of long-lasting, lightweight materials, optimizing mobility, transportation, and versatility in construction environments, while meeting the highest quality standards in accordance with 6 Sigma Statistical Process Control. The research sought to determine how the design and construction of this ladder affects the reduction of physical fatigue and the improvement of occupational safety within the construction sector. The alternative hypothesis proposed that the use of the ladder significantly reduces physical fatigue among workers compared to a conventional ladder. To verify this, three specific objectives were established: to design the ladder using CAD software in order to determine the most suitable geometric parameters; to build the prototype based on the CAD design and a stress-strain simulation; and to validate the product through a multivariate statistical analysis and 6 Sigma quality control, along with the development of a technical manual for use and maintenance. The implementation of the ladder at EcoSur Foundation intervention sites yielded highly favorable results, evidencing improvements in workers' overall well-being, reduced absenteeism due to fatigue, increased productivity, and a decrease in occupational accidents and incidents, both in Riobamba and in the other localities where ongoing projects are being carried out.

**Keywords:** *ergonomics, industrial safety, flat rungs, construction, well-being*

## INTRODUCTION

Industrial safety constitutes a technical discipline aimed at identifying, evaluating and controlling occupational risks with the purpose of preventing accidents and occupational diseases. Its historical evolution has moved from corrective approaches to systematic prevention models, supported by international reference organizations such as the International Labor Organization (ILO), the Occupational Safety and Health Administration (OSHA) and the International Organization for Standardization (ISO). Despite these advances, hundreds of thousands of deaths from workplace accidents are documented each year worldwide, a figure that highlights the persistent need for solid occupational health and safety management systems, particularly in high-risk sectors such as construction and housing reconstruction.

In the Ecuadorian context, safety and health at work is regulated by Executive Decree No. 255 of May 2, 2024, which strengthens the current regulatory framework together with the Labor Code, Decision 584 of the Andean Instrument for Safety and Health at Work, and the resolutions of the Ecuadorian Social Security Institute (IESS). This regulatory framework classifies occupational risks into six categories: physical, chemical, biological, safety, ergonomic and psychosocial. For its management, the ISO 45001 standard proposes a five-level hierarchy of controls that includes

elimination, substitution, engineering controls, administrative controls and the use of personal protective equipment. However, the effective application of these principles in small-scale entities dedicated to social reconstruction remains limited.

Since 2007, the EcoSur - Ecuador Foundation, based in the city of Riobamba, has been developing projects aimed at improving the quality of housing in vulnerable sectors. The institution has a department specialized in housing reconstruction, made up of ten workers, whose work focuses on the structural and functional rehabilitation of homes to improve habitability conditions and social well-being. However, there is evidence of limited implementation of occupational risk prevention standards in said department, as well as the use of rudimentary and improvised work equipment. One of the main problems identified is the technical lack of knowledge regarding industrial safety and the construction and use of equipment such as ladders and scaffolding, which generates the urgency of implementing innovative solutions that prioritize the safety and well-being of the worker.

In the reconstruction industry, a recurring problem is the physical fatigue of workers, caused by intensive physical demands and prolonged use of inadequate equipment. The use of ladders with traditional circular tube steps generates a negative impact on the productivity, safety and well-being of operators, since these steps do not offer a stable or ergonomic surface. This fact increases the effort necessary to maintain balance and, consequently, increases the pressure on specific points of the body, increasing the risk of workplace accidents. In the long term, the use of this equipment can lead to occupational diseases such as musculoskeletal disorders in the lower extremities.

Faced with this problem, the fundamental principle of ergonomics establishes that the work must be adapted to the worker and not the worker to the work. In this sense, the technical intervention of this project is oriented towards the redesign of the work equipment - the ladder - and not towards actions that directly involve the reconstruction workers. The specialized literature on ergonomics applied to vertical access equipment indicates that the design of flat steps, non-slip surfaces and geometric dimensions adjusted to anthropometric parameters allows the pressure to be evenly distributed on the worker's foot, significantly reducing physical fatigue and the risk of falls. Studies such as those by Chaffin et al. and Karwowski have documented that the geometry of the step is one of the variables with the greatest impact on the biomechanical load of the lower limb during ascent and descent in height. In this framework, the European standard EN 131 establishes the technical reference criteria for the design of safe manual ladders, being applicable to this study as a regulatory basis for design.

In methodological terms, previous studies in the field of industrial safety and work equipment design have demonstrated the usefulness of combining computer-aided modeling (CAD), finite element analysis (FEA) and quality control methodologies such as Six Sigma to validate the performance of prototypes before their implementation. Likewise, the REBA (Rapid Entire Body Assessment) method has been widely used to evaluate postural load in tasks that involve the use of access equipment at height, constituting a valid instrument to compare ergonomic performance between conventional and proposed equipment. Depending on the frequency of

use in reconstruction projects, the staircase has been selected as a priority object of technical intervention over other access equipment such as scaffolding, the installation of which implies greater logistical and structural complexity.

In this context, the present investigation raises the following research question: how does the design and construction of a manual industrial safety ladder with flat steps affect the reduction of physical fatigue and the improvement of occupational safety in the construction sector within the EcoSur Foundation - Ecuador? As a tentative response, the alternative hypothesis is formulated that the use of the proposed ladder significantly reduces the physical fatigue of Housing Reconstruction Department workers compared to a conventional ladder. To verify this hypothesis, the following specific objectives are defined: (i) design the staircase using CAD software to determine the most appropriate geometric parameters; (ii) build the prototype based on the CAD design and a stress-deformational simulation; and (iii) validate the ladder through multivariate statistical analysis and 6 Sigma quality control, with the subsequent preparation of a technical manual for use and maintenance.

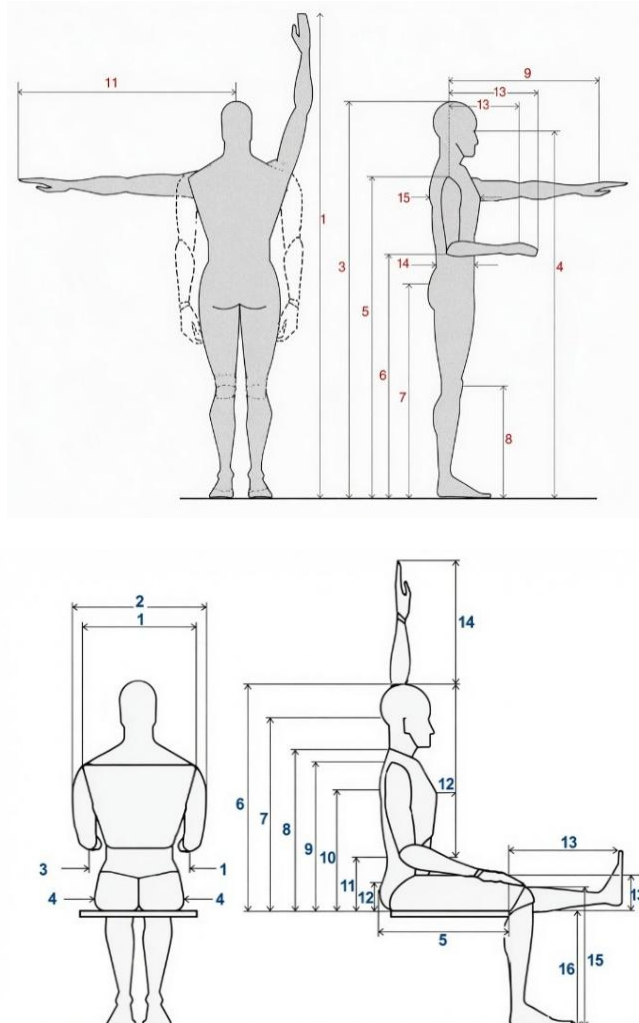
## MATERIALS AND METHODS

The present study adopted a quantitative experimental approach, with a controlled and randomized design, aimed at evaluating the effect of a manual industrial safety ladder with flat steps on the reduction of physical fatigue (1). It was a prospective trial with a control group (conventional staircase with circular steps) and experimental group (proposed staircase), following a scheme of repeated measures in the same subject (2). The level of research was explanatory, with a deductive modality (3).

The population was made up of 10 workers from the Housing Reconstruction Department of the EcoSur Foundation - Ecuador, Riobamba headquarters (average age 40.6 years, average mass 66.6 kg) (4). Census sampling was used (N=10), with random assignment of the order of use of the stairs. The study was developed in the real context of work in the El Altar parish and surrounding areas, province of Chimborazo, Ecuador, in socioeconomic conditions of vulnerable sectors and approximate altitudes of 2488 meters above sea level (5).

The interventions consisted of the standardized use of both stairs for 15 minutes per session, replicating real reconstruction activities (4). The proposed staircase was designed in AutoCAD 2026 demo version with flat steps 0.150 m wide × 0.400 m long (6063-T5 aluminum), spacing of 0.280 m and inclination angle of 75.5°. Its construction followed the EN 131 and ANSI A14.2 (6.7) standard. Finite element analysis was performed in Autodesk Inventor demo version 2026 to validate Von Mises stresses, displacement and safety factor.

Anthropometric variables (Figure 1) (8) and physiological tests were measured: vertical jump, heart rate, systolic pressure and static squat.



**Figure 1. Anthropometric measurements.**

**Source: (8).**

Each test was performed for 60 days over a period of 6 months. REBA methodology was applied for ergonomic evaluation (8) and 6 Sigma Statistical Quality Control (9) whose starting point is shown in Table 1.

**Table 1. Quality criteria of the proposed staircase.**

| Item | Quality Criterion      | Qualification |
|------|------------------------|---------------|
| 1    | Construction Material  | 9.3           |
| 2    | Distance between Steps | 9.1           |

|    |                               |     |
|----|-------------------------------|-----|
| 3  | Shape and surface of the step | 9.2 |
| 4  | Load capacity                 | 9.2 |
| 5  | Tilt angle                    | 9.3 |
| 6  | Stringers                     | 9.3 |
| 7  | Ergonomic comfort             | 9.4 |
| 8  | Anchorage                     | 9.5 |
| 9  | Condition                     | 9.5 |
| 10 | Certification                 | 9.6 |

Statistical analysis was performed in Wolfram Mathematica version 14.3 (10). Normality was verified using the Kolmogorov-Smirnov test. For normal data, Student's T test was used; for non-normals, Wilcoxon. 6 Sigma analysis included Cp, Cpk, DPMO and sigma level according to Equations 1-7 (11, 12). All procedures followed regulatory principles established in Executive Decree 255 and ISO 45001 (13,14).

$$Cp = \frac{ES - EI}{6\sigma} \quad (1)$$

$$Cpi = \frac{\mu - EI}{3\sigma} \quad (2)$$

$$Cps = \frac{ES - \mu}{3\sigma} \quad (3)$$

$$Cpk = \text{Mínimo} \left[ \frac{\mu - EI}{3\sigma}, \frac{ES - \mu}{3\sigma} \right] \quad (4)$$

$$PPM = \exp \left[ \frac{29.37 - (Z - 0.8406)^2}{2.221} \right] \quad (5)$$

$$\text{sigmalevel} = 3(Cpk) + 1.5 \quad (6)$$

$$Z = 0.8406 + \sqrt{29.37 - 2.221 \times \ln(PPM)} \quad (7)$$

Where is the process capacity, the lower capacity, the upper capacity, the actual capacity, the upper specification, the lower specification, the process mean, the standard deviation, the parts per million out of specification and , are the sigma level.  $C_p C_{pi} C_{ps} C_{pk} ESEI \mu \sigma PPM Z \text{sigma level}$

## RESULTS

In the population studied, made up of 10 workers, with an average age of 40.6 years and average body mass of 66.6 kg, the proposed ladder showed consistent and statistically significant improvements in all indicators of physical fatigue compared to the conventional ladder with circular steps.

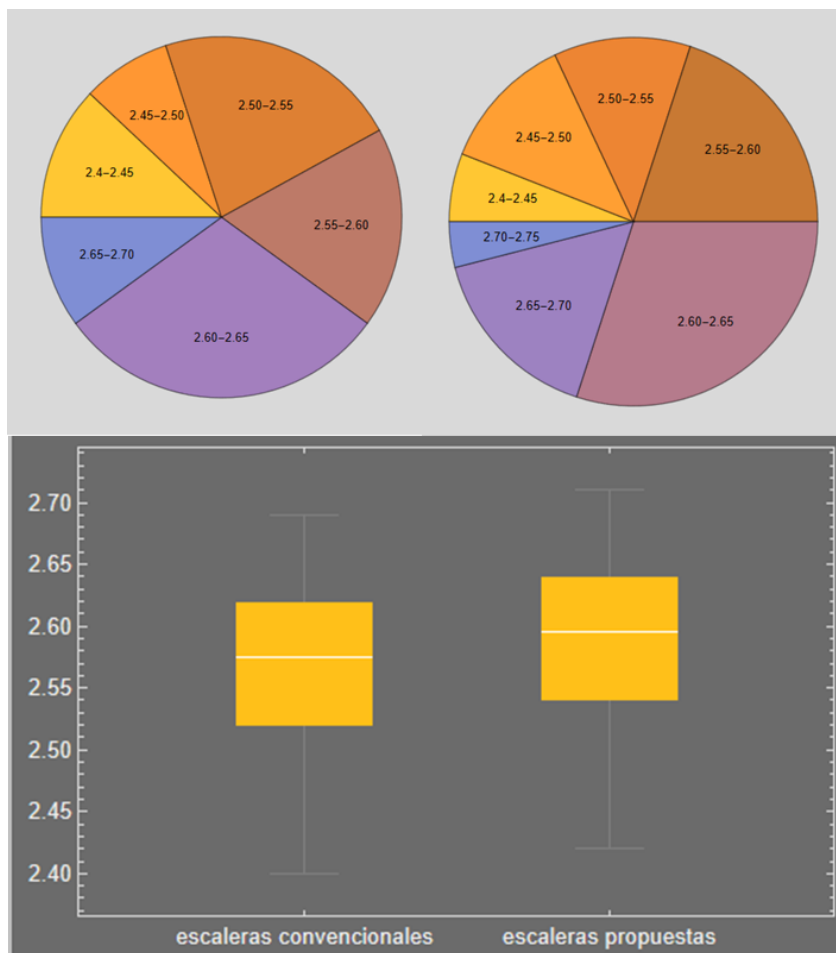
In the vertical jump test (Table 2, 3, Figure 2), the median reach increased from 2.575 m with the conventional ladder to 2.595 m with the proposed ladder, representing a difference of 0.020 m. This improvement indicates greater preservation of muscle power in the lower extremities. The Student's T test rejected the null hypothesis ( $p=0.0338$ ), confirming that the observed difference is not due to chance.

**Table 2. Count vertical jump values on conventional stairs.**

| Range     | Count |
|-----------|-------|
| 2.40-2.45 | 12    |
| 2.45-2.50 | 8     |
| 2.50-2.55 | 22    |
| 2.55-2.60 | 18    |
| 2.60-2.65 | 30    |
| 2.65-2.70 | 10    |

**Table 3. Count vertical jump values for proposed staircase.**

| Range     | Count |
|-----------|-------|
| 2.40-2.45 | 6     |
| 2.45-2.50 | 12    |
| 2.50-2.55 | 12    |
| 2.55-2.60 | 20    |
| 2.60-2.65 | 30    |
| 2.65-2.70 | 16    |
| 2.70-2.75 | 4     |



**Figure 2. Diagrams of the vertical jump test.**

**Note:** The top panels present pie charts for the conventional staircase (left) and the proposed one (right). The lower panel shows the comparison using box plots for both conditions.

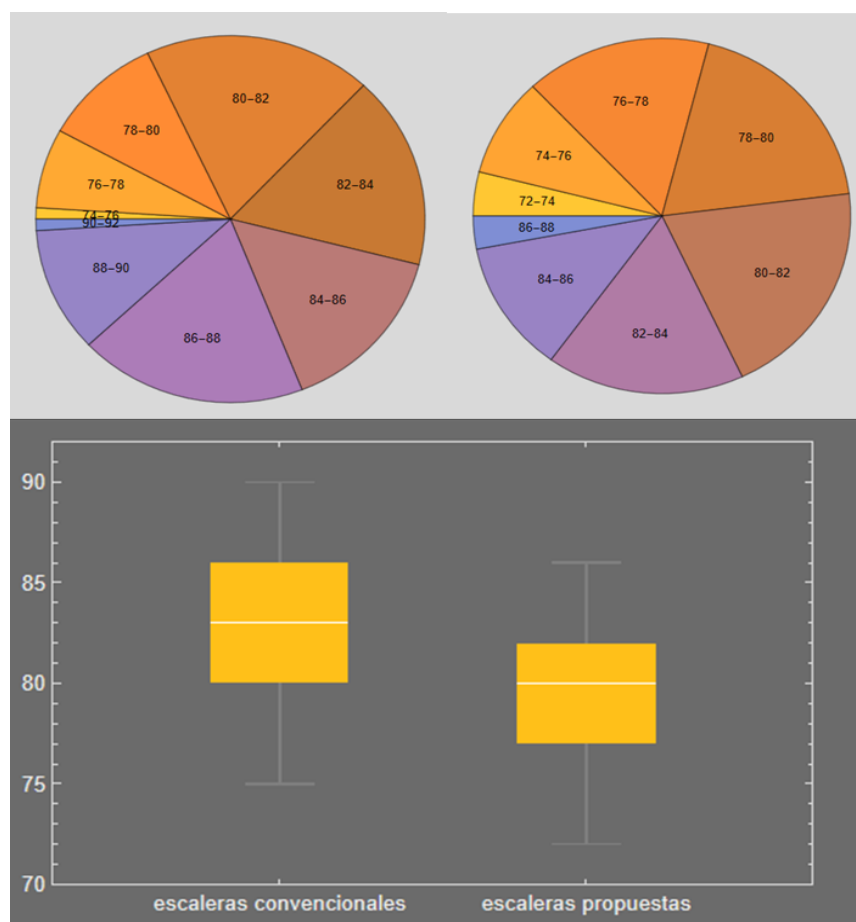
Regarding heart rate (Table 4, 5, Figure 3), the median decreased from 83 to 80 bpm (difference of 3.4 bpm). This result reflects a lower cardiovascular demand during the use of the flat-step ladder. The Wilcoxon test yielded a p-value of  $4.31 \times 10^{-20}$ , highly significant.

**Table 4. Conventional staircase heart rate count values.**

| Range | Count |
|-------|-------|
| 74-76 | 1     |
| 76-78 | 7     |
| 78-80 | 10    |
| 80-82 | 19    |
| 82-84 | 17    |
| 84-86 | 15    |
| 86-88 | 19    |

**Table 5. Count heart rate values proposed staircase.**

| Range | Count |
|-------|-------|
| 72-74 | 4     |
| 74-76 | 9     |
| 76-78 | 16    |
| 78-80 | 19    |
| 80-82 | 20    |
| 82-84 | 17    |
| 84-86 | 12    |
| 86-88 | 3     |



**Figure 3. Diagrams of the heart rate test.**

**Note:** The top panels present pie charts for the conventional staircase (left) and the proposed one (right). The lower panel shows the comparison using box plots for both conditions.

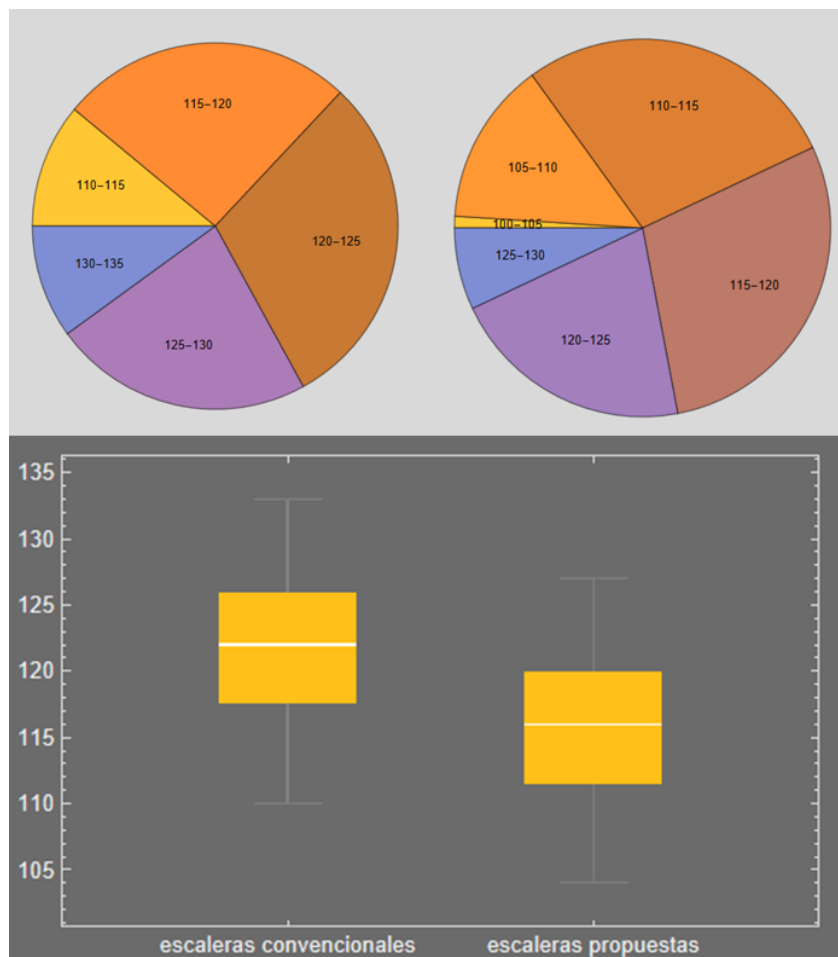
In the systolic pressure test (Table 6, 7, Figure 4), the median decreased from 122 to 116 mmHg (difference of 6.02 mmHg). This reduction suggests less hemodynamic overload associated with physical effort. The Student's T test showed a p-value of  $6.45 \times 10^{-13}$ , confirming the statistically significant difference.

**Table 6. Count conventional staircase pressure values.**

| Range   | Count |
|---------|-------|
| 110-115 | 11    |
| 115-120 | 26    |
| 120-125 | 30    |
| 125-130 | 23    |
| 130-135 | 10    |

**Table 7. Count of proposed staircase pressure values.**

| Range   | Count |
|---------|-------|
| 100-105 | 1     |
| 105-110 | 14    |
| 110-115 | 28    |
| 115-120 | 29    |
| 120-125 | 21    |
| 125-130 | 7     |



**Figure 4. Systolic pressure test diagrams.**

**Note:** The top panels present pie charts for the conventional staircase (left) and the proposed one (right). The lower panel shows the comparison using box plots for both conditions.

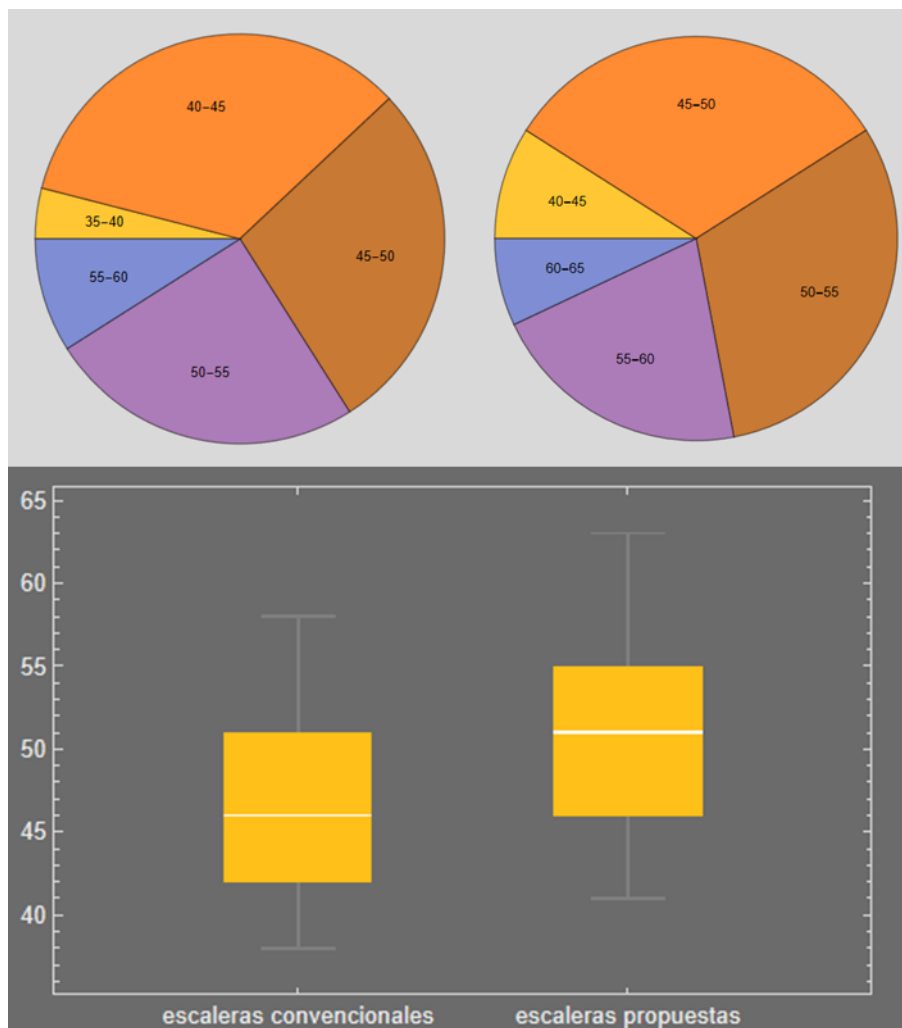
In the static squat test (Table 8, 9, Figure 5), the median endurance time increased from 46 to 51 seconds (difference of 4.01 s). This finding shows a better preservation of the muscular strength and resistance of the lower body after the use of the proposed staircase. The Wilcoxon test presented a p-value of 0.0, clearly rejecting the null hypothesis.

**Table 8. Count values for conventional stair squat.**

| Range | Count |
|-------|-------|
| 35-40 | 4     |
| 40-45 | 34    |
| 45-50 | 28    |
| 50-55 | 25    |
| 55-60 | 9     |

**Table 9. Count of proposed stair squat values.**

| Range | Count |
|-------|-------|
| 40-45 | 9     |
| 45-50 | 32    |
| 50-55 | 31    |
| 55-60 | 21    |
| 60-65 | 7     |



**Figure 5. Diagrams of the static squat test.**

**Note:** The top panels present pie charts for the conventional staircase (left) and the proposed one (right). The lower panel shows the comparison using box plots for both conditions.

The 6 Sigma analysis carried out on ten quality criteria of the proposed ladder (Table 1) gave an average of 9.34, with a real capacity index (Cpk) of 1.39, defects per million opportunities (DPMO)

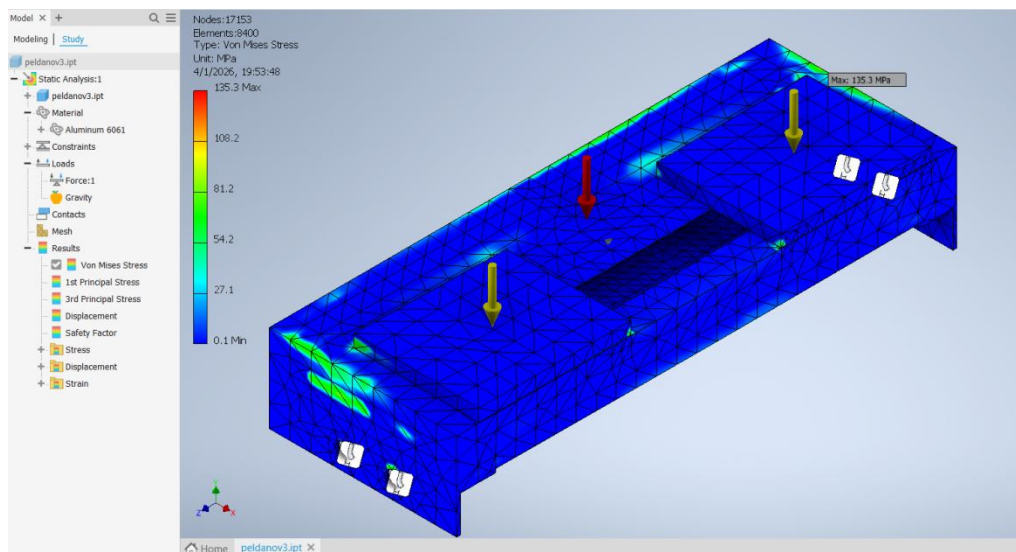
of 14.3 and a sigma level of 5.68 (Table 10). These values indicate an excellent level of design quality and reproducibility. The analysis showed a variation of 5.27% with respect to 6 sigma quality.

**Table 10. Base statistics of 6 sigma analysis.**

| Statistical    | Meaning                  | Value  |
|----------------|--------------------------|--------|
| n              | data number              | 10.0   |
| LSL            | lower limit              | 7.00   |
| USL            | upper limit              | 10.0   |
| T (nominal)    | value ideal              | 8.50   |
| x              | mean                     | 9.34   |
| s <sup>2</sup> | variance                 | 0.0249 |
| s              | standard deviation       | 0.15   |
| cv             | coefficient of variation | 1.69%  |
| Cp             | potential capacity       | 3.17   |
| Cpu            | higher capacity          | 1.39   |
| Cpl            | lower capacity           | 4.94   |
| Cpk            | actual capacity          | 1.39   |
| Cpm            | Taguchi index            | 0.585  |
| DPMO           | defects per million      | 14.3   |
| Z              | Sigma level              | 5.68   |

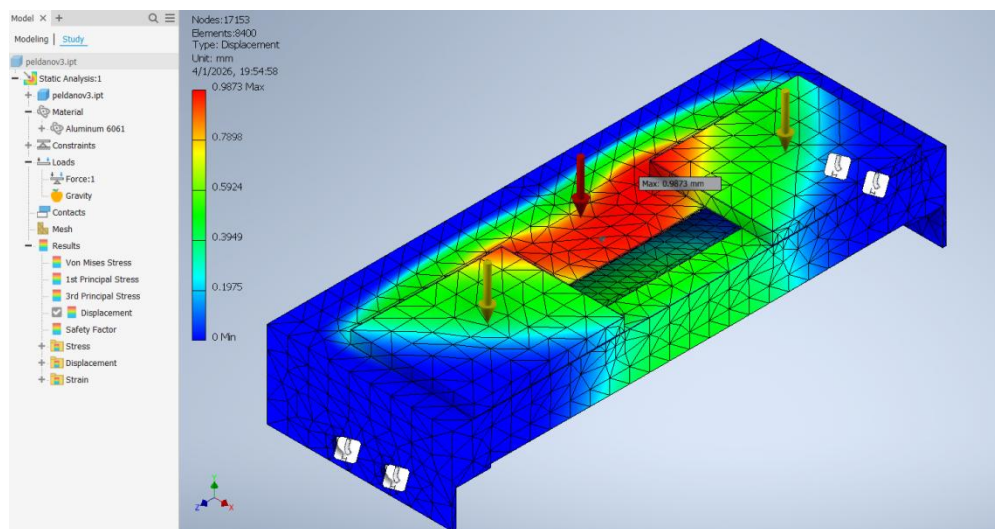
**Source: (10).**

Finite element analysis validated the structural safety of the prototype. For the individual step, a maximum Von Mises stress of 135.3 MPa, a maximum displacement of 0.98 mm and a safety factor of 2.03 were obtained (Figures 6, 7, 8) (15). In the complete ladder assembly, the values were: maximum Von Mises stress of 35.98 MPa, maximum displacement of 0.621 mm and minimum safety factor of 7.64 (Figures 9, 10, 11) (15). Both far exceed regulatory requirements.



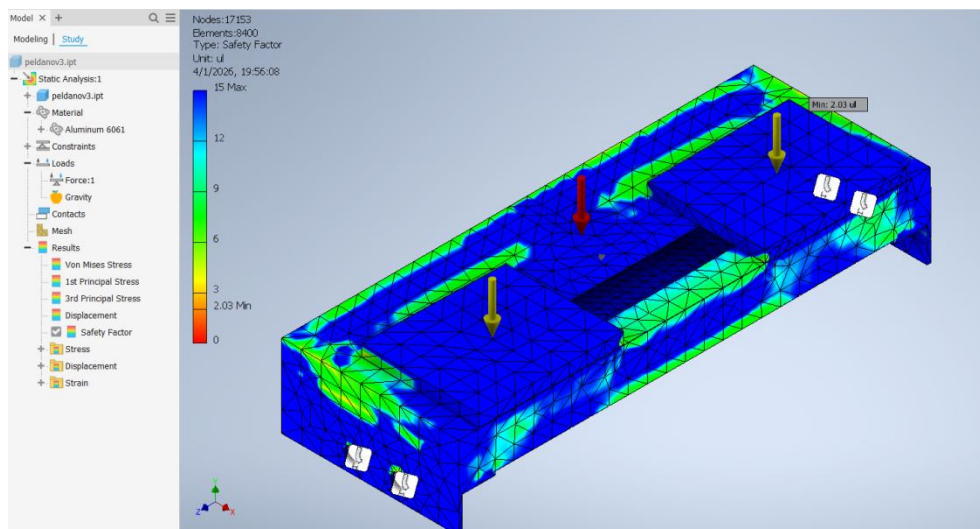
**Figure 6. Von Mises stress result in step (maximum: 135.3 MPa).**

**Source: (15).**



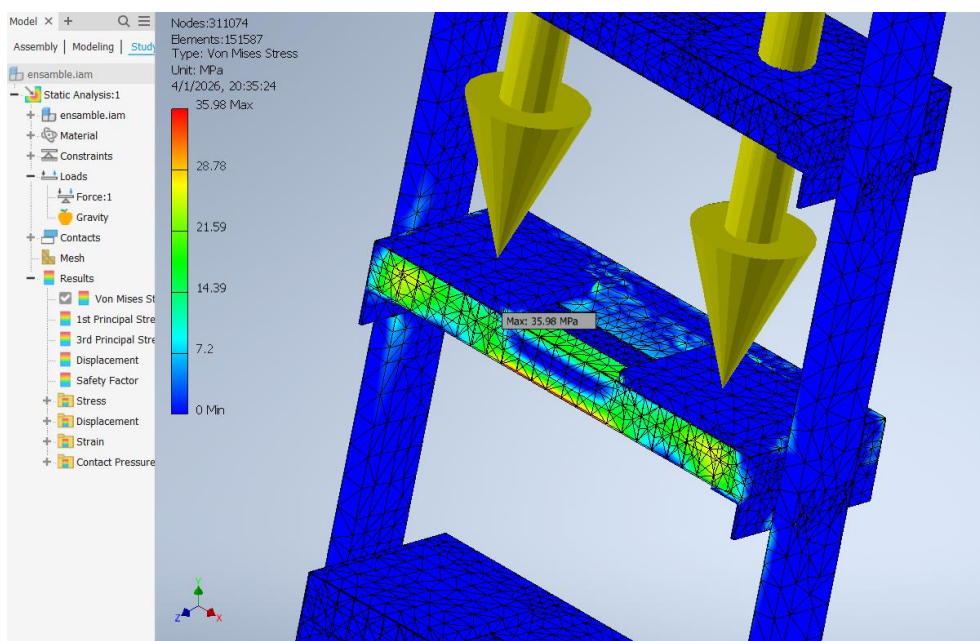
**Figure 7. Step displacement result (maximum: 0.98 mm).**

**Source: (15).**



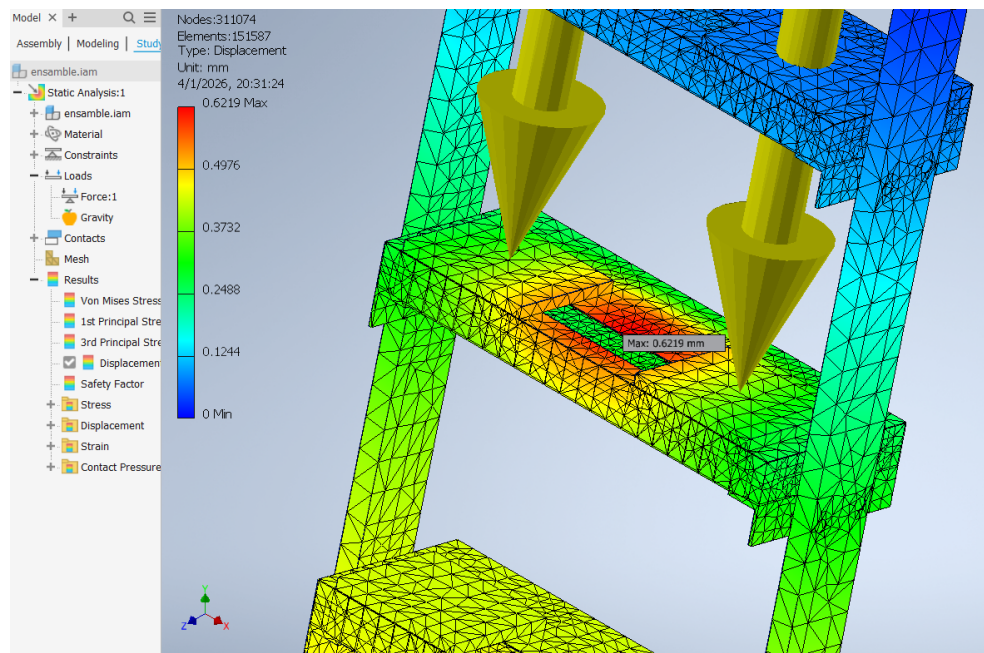
**Figure 8. Safety factor result in step (2.03).**

**Source: (15).**



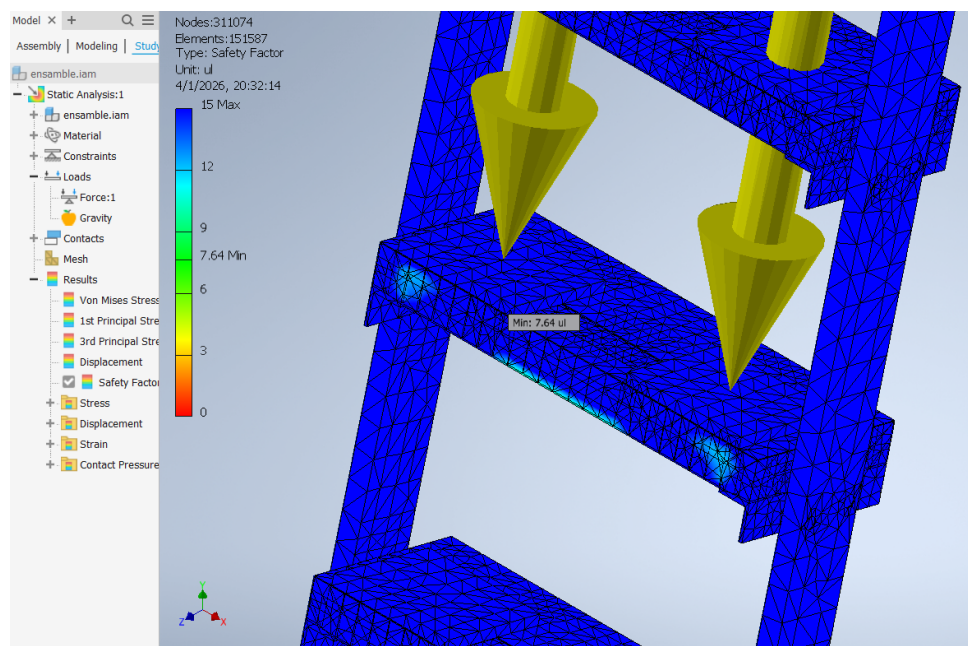
**Figure 9. Von Mises stress result on stairs – approach to the step (maximum: 35.98 MPa).**

**Source: (15).**



**Figure 10. Stair displacement result (maximum: 0.621 mm).**

**Source: (15).**



**Figure 11. Stair safety factor result (minimum: 7.64)**

**Source: (15).**



The detailed geometry of the proposed staircase is presented in Tables 11 and 12, with steps 0.150 m wide and 0.400 m long.

**Table 11. Geometry of the proposed staircase based on a maximum structure height (y) of 2.93 m.**

| Geometric Element                                                                 | Value  |
|-----------------------------------------------------------------------------------|--------|
| Distance to the upper support (x)                                                 | 3.02 m |
| Separation space with respect to the structure (x/4)                              | 0.76 m |
| Angle of inclination of the staircase with respect to the horizontal ( $\alpha$ ) | 75.50° |
| Total length of staircase (considering an excess of 3 feet or 0.91 m)             | 3.94 m |

**Table 12. Geometry of the proposed staircase.**

| Geometric Element                        | Normal Rung | Small Rung |
|------------------------------------------|-------------|------------|
|                                          | Value       | Value      |
| Step width                               | 0.150 m     | 0.0750 m   |
| Step length (distance between stringers) | 0.400 m     |            |
| Flap width                               | 0.0380 m    |            |
| Step spacing                             | 0.2800 m    |            |
| Stringer width                           | 0.0600 m    |            |

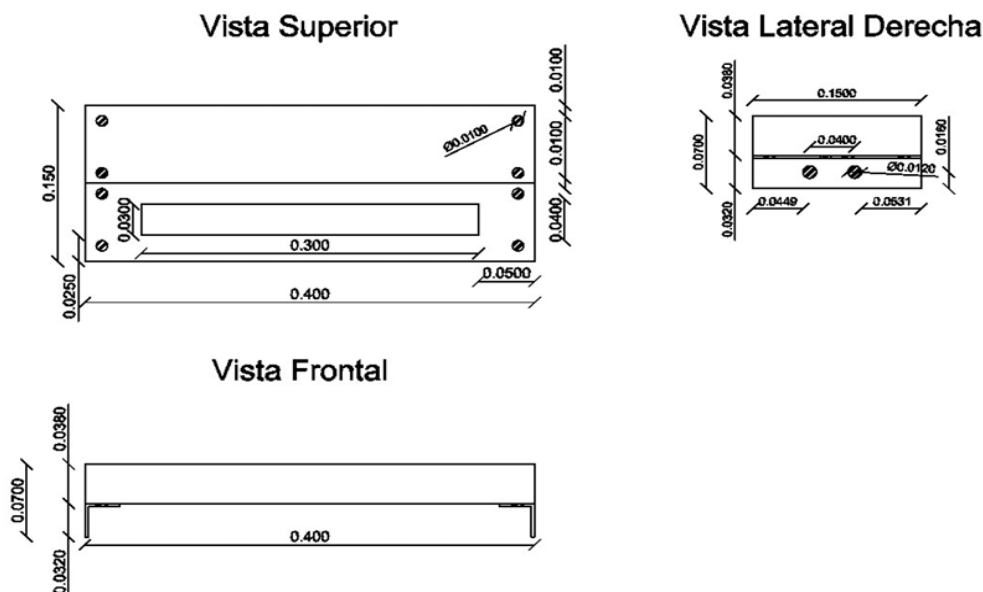
Specialized literature supports the design parameters adopted in the proposed staircase. The adoption of separation between steps, with respect to the ANSI standards of 35 cm and EN 131 of 28 cm, significantly reduces the average heart rate during the climb and improves the worker's stay, with the spacing of 28 cm adopted in the proposed staircase being consistent with these recommendations (16). 6063-T5 aluminum presents predictable mechanical properties and adequate rigidity for moderately loaded structures, which validates its selection for the construction of steps and stringers of industrial stairs (17). The safety factors obtained through finite element analysis are representative of the real behavior of hollow sections of 6063-T5 aluminum under static loading, an aspect directly applicable to the structural validation of the proposed step (18). The REBA method was designed to evaluate musculoskeletal risk in tasks with unpredictable postures such as activities at height on stairs, establishing that scores less than 4 indicate low risk without the need for immediate intervention (19). A Cpk value greater than 1.33 guarantees an acceptable level of processes, a threshold that the proposed ladder exceeds with a Cpk of 1.39, confirming the safety of its use (20). The calculation of DPMO and the sigma level constitutes an internationally recognized standard methodology for the evaluation of quality in

the design of engineering prototypes, with the 5.68 sigma level obtained being indicative of a performance superior to that of most conventional industrial processes (21).

Finally, the prototype of the staircase was delivered to the EcoSur Foundation - Ecuador, the technical manual for use and the plan of the staircase step (Figure 12,13).



**Figure 12. Delivery of the proposed ladder and dissemination of the user manual.**



**Figure 13. Step plan of the proposed staircase.**

Source: (22).

## DISCUSSION

The results of the vertical jump indicate less muscle fatigue in the lower extremities with the flat rung ladder. The difference of 0.020 m is clinically relevant for repetitive tasks in construction.

The reduction in heart rate (3.4 bpm) suggests less cardiovascular demand during safety checks on stairs. This finding strengthens the ergonomic hypothesis of flat design.

The decrease of 6.02 mmHg in systolic pressure in the proposed stairs reduces hemodynamic risk in elderly workers.

The increase of 4.01 s in static squat confirms better preservation of muscle strength. The novelty lies in the implementation of flat steps, 6 Sigma analysis and finite elements. Through the study, the safety and protection of occupational risks of the workers of the EcoSur Foundation - Ecuador is increased.

The 5.68 sigma level is within industrial quality standards and validates the reproducibility of the design. The safety factors (2.03 and 7.64) exceed the requirements of the EN 131 standard.

In summary, all the results obtained support the rejection of the null hypothesis and the acceptance of the alternative hypothesis in the four physiological tests carried out, demonstrating the ergonomic and functional superiority of the flat-step ladder.

## CONCLUSIONS

The designed and built manual industrial safety ladder with flat steps significantly reduced the physical fatigue of workers at the Housing Reconstruction Department of the EcoSur Foundation - Ecuador, evidenced by statistically significant improvements ( $p < 0.05$ ) in vertical jump (+0.020 m), heart rate (-3.4 bpm), systolic pressure (-6.02 mmHg) and static squat (+4.01 s), fulfilling the general objective.

The geometric design (AutoCAD 2026 demo version), structural validation (Inventor 2026 demo version) and 6 Sigma quality control (Wolfram Mathematica version 14.3) produced a safe (safety factor  $> 2$ ) and ergonomic prototype, superior to conventional stairs, complying with EN 131, ANSI and OSHA standards (4, 6, 7).

The implementation of the prototype and technical manual represents a practical contribution to the prevention of occupational risks in social construction in Ecuador, improving well-being, productivity and safety.

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## REFERENCES

1. Batista E. Escaleras portátiles dieléctricas extensibles, requisitos de diseño y seguridad durante su uso. 2022.
2. Ramos-Galarza C. Diseños de investigación experimental. CienciAmérica [Internet]. 2021 [citado 2025]; 10(1):1-7. ISSN: 1390-9592. Disponible en: <http://cienciamerica.uti.edu.ec/openjournal/index.php/uti/article/view/356>. DOI: 10.33210/ca.v10i1.356
3. Cejas Martínez MF, Liccioni EJ, Aldaz Hernández SM, Murillo Naranjo M, Venegas Álvarez G. Enfoque cuantitativo y cualitativo: Una mirada de los métodos mixtos. Barinas: Fundación Editorial de la Universidad Nacional Experimental de los Llanos Occidentales Ezequiel Zamora (FEDUEZ); 2023.
4. Mondelo PR, Gregori E, Barrau P. Ergonomía 1: Fundamentos. 3a ed. Barcelona: Edicions UPC; 1999. ISBN: 84-8301-315-0
5. GADM del Cantón Penipe. Información General del Cantón Penipe [Internet]. Penipe; 2026 [citado 2026]. Disponible en: <https://www.penipe.gob.ec>
6. Comité Europeo de Normalización (CEN). EN 131-1: Escaleras – Parte 1: Terminología, tipos y dimensiones funcionales. Bruselas: CEN; 2015.
7. American National Standards Institute (ANSI). ANSI A14.2: American National Standard for Ladders - Portable Metal - Safety Requirements. Nueva York: ANSI; 2017.
8. Hignett S, McAtamney L. Rapid Entire Body Assessment (REBA). Appl Ergon. 2000; 31(2):201-5. ISSN: 0003-6870. DOI: 10.1016/S0003-6870(99)00039-3
9. Allen TT. Introduction to engineering statistics and six sigma. Londres: Springer; 2006. ISBN: 978-1-85233-955-5. DOI: 10.1007/1-84628-200-4
10. Wolfram Research, Inc. Mathematica, Version 14.3 [software]. Champaign, IL: Wolfram Research; 2025.
11. Gutiérrez Pulido H, de la Vara Salazar R. Control estadístico de la calidad y Seis Sigma. 3a ed. México: McGraw-Hill Interamericana; 2013. ISBN: 978-607-15-0929-1
12. Park SH. Six Sigma for quality and productivity promotion. Tokio: Asian Productivity Organization; 2003. ISBN: 92-833-1722-X
13. Noboa D. Decreto Ejecutivo N.º 255: Reglamento de Seguridad y Salud en el Trabajo del Ecuador. Quito: Presidencia de la República del Ecuador; 2024.
14. Organización Internacional de Normalización (ISO). ISO 45001:2018: Sistemas de gestión de la seguridad y salud en el trabajo – Requisitos con orientación para su uso. Ginebra: ISO; 2018.
15. Autodesk, Inc. Autodesk Inventor, Version 2026 [software]. San Francisco, CA: Autodesk; 2025.

16. Duraj V, Fathallah F. Ergonomic Evaluation of Orchard Ladders with Shorter Rung Spacing. *Proc Hum Factors Ergon Soc Annu Meet.* 2020; 64(1):1077-81. ISSN: 1071-1813. DOI: 10.1177/1071181320641218
17. Ho M, Lee P, Ye C, Lin C, Huang C. Experiment and finite element analysis study on the deflection of aluminum extruded 6063-T5 hollow structural beam. *IOP Conf Ser Mater Sci Eng.* 2020; 711(1):012075. ISSN: 1757-899X. DOI: 10.1088/1757-899X/711/1/012075
18. Gardner L, Ashraf M. Structural design for non-linear metallic materials. *Eng Struct.* 2006; 28(6):926-34. ISSN: 0141-0296. DOI: 10.1016/j.engstruct.2005.11.001
19. Hignett S, McAtamney L. Rapid Entire Body Assessment (REBA). *Appl Ergon.* 2000; 31(2):201-5. ISSN: 0003-6870. DOI: 10.1016/S0003-6870(99)00039-3
20. Bhargava M, Gaur S. Process improvement using Six-Sigma (DMAIC process) in bearing manufacturing industry: A case study. *IOP Conf Ser Mater Sci Eng.* 2021; 1017(1):012034. ISSN: 1757-899X. DOI: 10.1088/1757-899X/1017/1/012034
21. Allen TT. *Introduction to engineering statistics and six sigma.* Londres: Springer; 2006. ISBN: 978-1-85233-955-5. DOI: 10.1007/1-84628-200-4
22. Autodesk, Inc. *AutoCAD, Version 2026 [software].* San Francisco, CA: Autodesk; 2025.

# CAJAS DE AHORRO INFORMAL COMO ALTERNATIVA DE INCLUSIÓN FINANCIERA EN EL CANTÓN LA MANÁ, ECUADOR

## INFORMAL SAVINGS GROUPS AS A FINANCIAL INCLUSION ALTERNATIVE IN LA MANÁ CANTON, ECUADOR

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**RESUMEN:** La presente investigación tiene como objetivo principal evaluar la contribución de la caja de ahorro y crédito familiar "Familia Unida" como modelo alternativo de inclusión financiera frente a las barreras del sistema financiero formal, mediante un análisis socioeconómico en el cantón La Maná, provincia de Cotopaxi, durante el período 2021–2025, esta indagación permitió determinar que el acceso limitado al crédito continúa representando uno de los principales obstáculos para la inclusión financiera en las zonas rurales, situación que ha favorecido el desarrollo de mecanismos comunitarios de ahorro y préstamo basados en la cooperación y la confianza entre sus integrantes, esta investigación se desarrolló bajo la estrategia metodológica de estudio de caso integrando información obtenida mediante un censo aplicado a los 19 socios activos, entrevistas semiestructuradas y el análisis de los registros administrativos y financieros correspondientes al período 2021–2025. La evidencia documental permitió constatar un funcionamiento financiero estable, respaldado por aportaciones acumuladas de USD 11.210,00, ingresos por intereses de préstamos de USD 8.679,51 e ingresos complementarios de USD 5.182,90, lo que permitió mantener un valor USD 2.311,84 resultado de la diferencia entre los ingresos complementarios y los egresos registrados” además los datos de las encuestas coinciden con estos resultados reflejando una valoración favorable en cuanto a la rapidez en el acceso al crédito, flexibilidad de las condiciones de financiamiento y el modelo de gestión sustentado en la confianza mutua, estos hallazgos sugieren que las cajas de ahorro informal pueden complementar la oferta del sistema financiero formal en contextos rurales al reducir las barreras de acceso al crédito, pero su sostenibilidad dependerá del fortalecimiento de la gestión administrativa, del control interno y de mecanismos que contribuyan a consolidar su funcionamiento a largo plazo.

**Palabras clave:** barreras financieras, capital social, cajas de ahorro, economía popular y solidaria, inclusión financiera, microfinanzas comunitarias

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**ABSTRACT:** The main objective of this research is to evaluate the contribution of the "Familia Unida" family savings and credit group as an alternative model for financial inclusion against the barriers of the formal financial system, through a socioeconomic analysis in La Maná canton, Cotopaxi province, during the 2021–2025 period. This inquiry determined that limited access to credit continues to represent one of the primary obstacles to financial inclusion in rural areas—a situation that has fostered the development of community-based savings and loan mechanisms rooted in cooperation and mutual trust among members. The study was conducted using a case study methodological strategy, integrating data obtained through a census applied to all 19 active members, semi-structured interviews, and the analysis of administrative and financial records covering the 2021–2025 period. Documentary evidence confirmed a stable financial operation, supported by accumulated contributions of USD 11,210.00, loan interest income of USD 8,679.51, and supplementary income of USD 5,182.90, resulting in a net balance of USD 2,311.84 from the difference between supplementary income and recorded expenditures. Furthermore, survey data align with these results, reflecting a favorable assessment regarding the speed of credit access, the flexibility of financing terms, and a management model based on mutual trust. These findings suggest that informal savings groups can complement the formal financial system in rural contexts by reducing barriers to credit access; however, their long-term sustainability will depend on strengthening administrative management, internal control, and consolidation mechanisms.

**Keywords:** *financial barriers, social capital, savings banks, popular and solidarity economy, financial inclusion, community microfinance*

## INTRODUCTION

Financial inclusion is widely recognized as an essential component of sustainable economic development, because it facilitates access and effective use of financial services under adequate conditions of cost, opportunity and security(1,2). Various studies have indicated that greater financial inclusion contributes to improving the economic resilience of households, reducing their vulnerability to adverse events and strengthening financial stability, particularly during periods of crisis and economic recovery (3,4).

Having a formal financial system does not guarantee that the entire population can access its services on equal terms. For example, in rural areas and in economies with high levels of informality, barriers persist related to documentary requirements, credit history, required guarantees, costs associated with financing and the times required for loan approval(5); These limitations mainly affect households with variable incomes and small businesses, for which timely access to credit constitutes a determining element for the development of their economic activities(4,6).

In Ecuador, various initiatives have been promoted aimed at strengthening the popular and supportive financial system, but gaps in access to financing are still observed, especially in rural territories and in sectors with low levels of economic formalization

according to the Central Bank of Ecuador (7), a significant part of the population still faces difficulties in obtaining credit through traditional mechanisms, a situation that has favored the development of community forms of savings and loans adapted to the economic and social characteristics of each locality. (8.9).

Within these alternatives, community-based family savings banks stand out, whose operation is based on the cooperation, trust and self-management of their members, allowing financial resources to be mobilized through simpler procedures and with fewer administrative demands than those observed in traditional financial institutions. Various studies indicate that these experiences constitute a practical manifestation of the principles of the popular and solidarity economy and represent a financing option for communities where the supply of formal credit is limited (10).

Beyond facilitating access to credit, the permanence of these organizations depends on their ability to adequately manage the resources they manage with a timely recovery of loans, transparency in financial management, risk management and the existence of reliable administrative records are aspects that directly affect their sustainability. operations.

Although the literature recognizes the contribution of savings banks to financial inclusion, there are still limited studies that integrate documentary evidence of their financial performance with the perception of their own members to jointly analyze their functioning and sustainability in small-scale community organizations, making it difficult to understand how these mechanisms respond to financing needs in rural contexts and what their contribution is in the face of the restrictions of the formal financial system (11–14).

Under this context, this research was developed with the objective of evaluating the financial and socioeconomic performance of the family savings bank "Familia Unida" and analyzing its contribution as an alternative for financial inclusion in the face of the limitations of the formal financial system in the canton of La Maná, using a case study with a mixed approach that integrated the review of the administrative and financial records corresponding to the period 2021–2025. This analysis allowed us to examine the evolution of the contributions, the income derived from credit activity, the administration of resources and the perception of the participants regarding the functioning of the system. Unlike research focused solely on the perception of participants or on isolated financial indicators, this study integrates documentary information, financial records and perception of members to offer a characterization of the operation of a community savings bank from a socioeconomic and financial perspective.

## MATERIALS AND METHODS

The research was developed under the methodological strategy of case study, because the main interest consisted in understanding in depth the functioning of a community savings and credit organization within its real context, according to Yin (15) mentions that this design is pertinent when the phenomenon analyzed cannot be separated from

the conditions in which it occurs and when it is required to integrate different sources of evidence, in addition Stake (16) points out that the case study allows understanding particular social processes rather than obtaining statistical generalizations, in addition the research is complemented with a scope descriptive-explanatory, integrating quantitative and qualitative information used in the analysis of financial performance and the contribution of a family savings bank as a mechanism of financial inclusion, with respect to the documentary component, a retrospective field and observational study was carried out with longitudinal analysis of the administrative and financial records generated between February 2021 and December 2025. In addition, information on the perception of the participants was collected through a non-experimental design applied to all the active members of the organization.

The present study was carried out in the canton of La Maná, province of Cotopaxi, Ecuador, taking as reference the family savings bank “Familia Unida”, made up of 19 active members who are the total of the samples obtained in the information collection process, respecting the ethical principles applicable to these studies, for which the 19 active members were informed about the objectives of the research, the academic nature of the study, the exclusive use of the information with scientific purposes and their right to participate voluntarily, obtaining the informed consent of all participants, with regard to the documentary analysis of the administrative and financial records of the savings bank “Familia Unida”, there was authorization from those responsible for the organization, these data were processed in an aggregate manner, under confidentiality criteria during all stages of the study without individually identifying the partners or disclosing personal or economic information that would allow their recognition.

The collection of information was developed with three complementary techniques, first a structured survey was carried out applied to the members, using a five-level Likert-type scale (1 = strongly disagree and 5 = strongly agree), with the purpose of evaluating the dimensions of accessibility to credit, perceived costs, trust between members, preference for the community system and socioeconomic impact, second was to apply semi-structured interviews aimed at those responsible for the administration and members with greater participation in the management of the organization, in order to understand aspects related to operational functioning. decision making, resource management and system sustainability and third was the documentary analysis of the administrative and financial records generated by the savings bank during the period between February 1, 2021 and December 31, 2025, examining records of monthly contributions, normal and emerging credit operations, internal payment vouchers, interest records, financial balances, complementary income and administrative minutes related to the approval and monitoring of financial operations. The cut-off date for the information corresponded to December 31, 2025, the closing date of the financial year analyzed. It is also noted that the surveys and interviews were carried out between January and February 2026, once the administrative closing of the 2025 financial year had concluded and the financial information used in the study had been consolidated.

To guarantee the traceability and consistency of the information, a documentary extraction matrix was prepared in which all the financial variables used in the study were

systematized. The data were then subjected to a cross-verification process between the contribution records, the registered cash movements, the credit records and the interest income. It is also important to emphasize that the interest income was recorded in accordance with the administrative information of the organization and the individual values were not necessarily uniform among the partners, because their distribution responded to the criteria established in the internal regulations and the decisions adopted by the assembly of the savings bank, these identified differences were contrasted with the original documentation and verified together with the administrative managers of the organization, emphasizing that only the information supported by documentary records was incorporated into the analysis, while the data that could not be verified documentary was excluded from the analysis.

The variables analyzed included the contributions of the partners, the interest income generated by loans, the complementary income, the organization's expenses and the perception indicators related to accessibility to credit, trust, perceived costs, preference for the community system and socioeconomic impact, with the purpose of integrating into a single indicator variables expressed in different units of measurement, previously a normalization process was carried out using the Min–Max method. This procedure transforms each variable to a dimensionless scale between 0 and 1, preserving the relative differences between observations and allowing direct comparison between indicators of a different nature with the following formula, where  $X_i$  is the value of the indicator,  $X_{min}$  is the minimum value recorded,  $X_{max}$  is the maximum value recorded, and  $X_i^*$  is the normalized value.

$$X_i^* = \frac{X_i - X_{min}}{X_{max} - X_{min}} X_i^*$$

Once the variables were normalized, the Socioeconomic Efficiency Index (IESE) was obtained through the simple arithmetic average of the normalized indicators that allowed the comparison between the community system and the formal financial system, which was obtained through the simple average of the three normalized indicators considered in the study: accessibility to credit (0.89), perceived costs (0.83) and socioeconomic impact (0.87). Each dimension was previously normalized on a scale between 0 and 1 and subsequently added using a simple arithmetic average, according to the following expression: , where  $Y_i$  represents the normalized value of each dimension and  $n$  corresponds to the number of variables incorporated in the index. This procedure allowed the quantitative information to be synthesized into a comparable indicator of the socioeconomic performance of the community model. It should be noted that the simple arithmetic average was chosen because there was not enough empirical evidence to assign differentiated weights between the analyzed indicators. Under these conditions, it was assumed that all the dimensions evaluated contributed the same relative importance to the socioeconomic performance of the savings bank. Furthermore, this procedure has been widely used in the construction of composite indicators when objective criteria are not available to establish specific weights.

$$IESE = \frac{\sum_{i=1}^n Y_i}{n}$$

Regarding the processing of the quantitative information, it was carried out through descriptive statistics, using absolute frequencies, percentages, means and standard deviations to summarize the information obtained in the surveys and in the financial

records. The qualitative information was analyzed through thematic coding, grouping the testimonies into categories related to accessibility to credit, trust, administrative management, organizational functioning and financial sustainability. To validate the results, methodological triangulation was applied between the documentary information, the results of the survey and the semi-structured interviews. The reliability of the questionnaire was evaluated using Cronbach's Alpha coefficient, obtaining a value of 0.958, an indicator of a very high internal consistency between the items used to measure the dimensions of the study. Finally, the research respected the ethical principles applicable to studies with human participation, guaranteeing the informed consent of the participants and the confidentiality of the information provided.

## RESULTS

### 3.1 Financial structure and operational basis of the system

The records obtained show that during the period 2021–2025 the savings bank maintained a constant participation of 19 active members, generating accumulated values of USD 11,210.00 in reference to contributions and a total of USD 25,072.41 of resources managed throughout the period analyzed.

*Table 1. Consolidated movement of managed resources (2021–2025).*

| Concept                            | Value (USD)      |
|------------------------------------|------------------|
| Partner contributions              | 11.210,00        |
| Interest on loans                  | 8.679,51         |
| Complementary income               | 5.182,90         |
| <b>Managed resources</b>           | <b>25.072,41</b> |
| Amount placed in credits           | 24.350,00        |
| Administrative and social expenses | 2.871,06         |
| Surplus complementary income       | 2.311,84         |

Source: Own elaboration based on the individual contributions and interest records of the “Familia Unida” savings bank.

Interest income presented a variable behavior, increasing from USD 456.00 in 2021 to USD 2,711.11 in 2024 and decreasing to USD 1,813.55 in 2025. These records allow us to describe this annual variation, although they do not contain sufficient information to individually identify the effect of the number, amount or term of the loans granted.

*Table 2. Annual evolution of partner contributions and interest income generated by loans (2021–2025).*

| Year                | Active members | Annual contributions (USD) | Interest (USD)  | income | Annual total (USD) |
|---------------------|----------------|----------------------------|-----------------|--------|--------------------|
| As of February 2021 | 19             | 2.090,00                   | 456,00          |        | 2.546,00           |
| 2022                | 19             | 2.280,00                   | 1.435,07        |        | 3.715,07           |
| 2023                | 19             | 2.280,00                   | 2.263,78        |        | 4.543,78           |
| 2024                | 19             | 2.280,00                   | 2.711,11        |        | 4.991,11           |
| 2025                | 19             | 2.280,00                   | 1.813,55        |        | 4.093,55           |
| <b>Total</b>        | —              | <b>11.210,00</b>           | <b>8.679,51</b> |        | <b>19.889,51</b>   |

Source: Own elaboration based on the individual contributions and interest records of the "Familia Unida" savings bank.

It is noted that the partners' contributions and interest income represented USD 19,889.51, constituting the main source of financial resources for the savings bank.

### 3.2 Complementary income and expenses

During the period 2021–2025, the complementary income of the savings bank was USD 5,182.90, coming mainly from raffles, contribution certificates and fines for late payment registered by the organization. In the same period, expenses reached USD 2,871.06, corresponding to social and mortuary aid, integration activities, acquisition of uniforms and administrative expenses.

*Table 3. Complementary income, expenses and annual balance of the savings account, 2021–2025.*

| Year                   | Complementary income (USD) | Expenditures (USD) | Annual (USD)    | balance |
|------------------------|----------------------------|--------------------|-----------------|---------|
| 2021                   | 961,50                     | 833,53             | 127,97          |         |
| 2022                   | 1.011,90                   | 613,00             | 398,90          |         |
| 2023                   | 1.031,50                   | 355,00             | 676,50          |         |
| 2024                   | 1.024,00                   | 380,00             | 644,00          |         |
| 2025                   | 1.154,00                   | 689,53             | 464,47          |         |
| <b>Total 2021–2025</b> | <b>5.182,90</b>            | <b>2.871,06</b>    | <b>2.311,84</b> |         |

Source: Own elaboration based on the records of complementary income and expenses of the "Familia Unida" savings bank.

According to the data in table 3, at the end of the 2025 fiscal year, the organization records a net remainder of the social fund of USD 2,311.84, which exclusively covers operational planning, integration activities and mortuary aid. This item is independent of the Operating Capital Fund (Savings and Interest), which is analyzed in a consolidated manner to safeguard the total assets of the partners."

It should be noted that due to the informal and self-managed nature of the 'Familia Unida' savings bank, the administrative records do not have a statement of financial position under international accounting standards, even so the reconciliation of cash flows executed in this investigation demonstrates a Net Equity of USD 22,201.35 at the end of 2025, given that the recovery rate of the credit portfolio was 100% at the end of each year, this total capital does not represent a loss or expense, but rather constitutes the available liquidity of the organization accumulated for the benefit of its 19 associates."

*Table 4. Expenditures by type of expense of the "Familia Unida" savings bank, 2021–2025.*

| Type of discharge                   | 2021          | 2022          | 2023          | 2024          | 2025          | Total           |
|-------------------------------------|---------------|---------------|---------------|---------------|---------------|-----------------|
| Social aid                          | 100,00        | 300,00        | 220,00        | 200,00        | 200,00        | 1.020,00        |
| Mortuary aid                        | 0,00          | 0,00          | 100,00        | 50,00         | 10,00         | 160,00          |
| Integration activities              | 668,53        | 173,00        | 0,00          | 100,00        | 0,00          | 941,53          |
| Uniforms and institutional identity | 0,00          | 110,00        | 0,00          | 0,00          | 115,00        | 225,00          |
| Administrative expenses             | 65,00         | 30,00         | 35,00         | 30,00         | 364,53        | 524,53          |
| <b>Annual total</b>                 | <b>833,53</b> | <b>613,00</b> | <b>355,00</b> | <b>380,00</b> | <b>689,53</b> | <b>2.871,06</b> |

Source: Own elaboration based on the expenditure records of the "Familia Unida" savings bank.

The expenditure structure shows that social aid represented the main accumulated component, with USD 1,020.00, followed by integration activities, with USD 941.53. Administrative expenses amounted to USD 524.53 over the five years. The composition of the expenditures confirms that a relevant part of the complementary resources was allocated to social and organizational purposes, in addition to administrative functioning.

In relation to the financial indicators, the Operational Self Sufficiency (OSS) formula was adapted, which is calculated using the formula. Due to the community and informal nature of the organization studied, the Operational Self Sufficiency indicator was adapted considering only the income generated by the financial activity and the expenses actually recorded in the administrative books. It was not possible to incorporate provisions for portfolio at risk or external financial costs because the organization does not maintain third-party financing or record accounting provisions in accordance with the regulations applicable to the formal financial system. Based on the formula, operating income was used, the sum of interest generated by the loans (USD 8,679.51) and complementary income from raffles, contribution certificates and fines for late payment (USD 5,182.90), which together totaled USD 13,862.41. The administrative and social expenses recorded during the same period (USD 2,871.06) were considered operating expenses, reaching an approximate value of 4.83 (483%), which indicates that the income generated by the organization was sufficient to broadly cover its operating costs during the analyzed period. 
$$OSS = \frac{\text{ingresos operativos}}{\text{gastos operativos}}$$

### 3.3 Evolution of the credit portfolio and recovery

The analysis of the credit activity of the "Familia Unida" savings bank during the period 2021-2025 reveals a trend of accelerated growth in the placement of resources, as seen in Table 5, the number of loans granted annually quintupled, going from 3 operations in 2021 to 15 in 2025, reflecting proportionally in the total amount lent per year, which started at USD 900.00 and reached USD 10,550.00 at the end of fiscal year 2025. Regarding the late fees collected, they showed a decreasing behavior in relative terms, decreasing drastically from 4.17% in 2021 to 0.22% in 2024, experiencing a slight rebound at 0.43% in 2025. This dynamic suggests a maturation in the internal control and compliance mechanisms on the part of the partners as the organization consolidated over time.

Table 5. Evolution of loans granted and late fees (2021–2025).

| Year | Credits | Capital placed | Interest generated | Total Default | Recovery (%) |
|------|---------|----------------|--------------------|---------------|--------------|
| 2021 | 3       | 900            | 456,00             | 37,5          | 100          |
| 2022 | 7       | 1500           | 1.435,07           | 53,9          | 100          |
| 2023 | 11      | 4500           | 2.263,78           | 22,5          | 100          |
| 2024 | 14      | 6900           | 2.711,11           | 15            | 100          |

|      |    |       |          |    |     |
|------|----|-------|----------|----|-----|
| 2025 | 15 | 10550 | 1.813,55 | 45 | 100 |
|------|----|-------|----------|----|-----|

**Source:** Own elaboration based on the administrative records of the "Familia Unida" savings bank.

According to the reviewed administrative records, all the credits granted during the period were recovered at the close of each financial year. Therefore, the organization did not record a past-due portfolio outstanding as of December 31, 2025. It also presents a total of 50 credits granted with a total value of USD 24,350.00 and a total of USD 8,679.51 of interest generated

### ***3.4 Comparison of access conditions to credit between the savings bank and the formal financial system***

Based on the information collected through interviews with the main cooperatives and banks of La Maná and through the operating records of the "Familia Unida" savings bank, differences were identified in the conditions of access to credit between both systems. The main differences are related to the approval time, the documentary requirements, the guarantees required, the costs associated with the credit and the degree of flexibility during the credit process. granting.

**Table 6. Comparison between formal financial system and savings bank.**

| Variable         | Formal financial system              | Family savings bank                                                 |
|------------------|--------------------------------------|---------------------------------------------------------------------|
| Interest rate    | 11.25% – 22% annually                | 1% – 2% monthly                                                     |
| Approval time    | 5 – 8 days                           | 1 – 3 days                                                          |
| Requirements     | ≥ 5 documents                        | Simplified documentation and internal validation between partners   |
| Guarantees       | Mortgage or guarantor                | Solidarity guarantee based on trust and commitment between partners |
| Additional costs | (receipts, insurance, contributions) | Fixed contribution of 1% according to the amount                    |
| Flexibility      | Low                                  | High                                                                |

**Source:** Own elaboration based on information collected in local financial institutions and the administrative records of the "Familia Unida" savings bank.

The results show that the main difference between both models lies in the mechanisms of access to credit because formal financial institutions require documentation, guarantees and previously established evaluation processes, the savings bank bases the approval of loans on mutual knowledge between partners, the trust built within the organization and compliance with internal agreements.

### ***3.5 Characteristics of the credit offered by the formal financial system***

The review of the credit conditions given by local financial institutions allowed us to identify that the minimum financing amount corresponds to USD 1,000, with minimum terms of 12 months and annual interest rates between 11.25% and 22%, recording an average of 16.09% also approved times ranged between 5 and 8 days, with an average of 5.5 days. Additionally, average accessory costs of USD 87.07 were identified,

equivalent to 8.71% of the requested amount, mainly associated with insurance, mandatory contributions and other administrative charges.

**Table 7. Conditions and accessory costs of credit in the formal financial system.**

| Indicator                                    | Result       |
|----------------------------------------------|--------------|
| Minimum observed amount                      | \$1000       |
| Minimum observed term                        | 12 months    |
| Annual interest (min-max)                    | 11.25% – 22% |
| Average annual interest                      | 16.09%       |
| Approval time (min-max)                      | 5 – 8 days   |
| Average approval time                        | 5 days       |
| Average accessory costs (individual credits) | \$87.07      |
| Average accessory costs over the amount      | 8.71%        |
| Range of accessory costs (individual)        | 4.5% – 13%   |
| Range of accessory costs (group)             | 0.7% – 24%   |

*Source: Own elaboration*

The results show that in addition to the interest rate, formal credit incorporates complementary costs that increase the effective cost of financing. In individual credits, these costs represented on average 8.71% of the requested amount, while in group products a greater variability was observed, with values between 0.7% and 24%. These differences reflect the heterogeneity of the credit policies applied by the financial institutions included in the study.

### **3.6 Comparison of financing scenarios for a loan of USD 1,000**

With the purpose of illustrating the differences in the cost and conditions of access to financing, a credit scenario of USD 1,000 with a term of 12 months was compared, using information collected from the “Familia Unida” savings bank, from the Grupo Solidario product of the Bank Pichincha and the Futuro Lamanense Savings and Credit Cooperative. The comparison considered the total amount paid, the approval time, the documentary requirements and the type of guarantee required for each financing alternative.

**Table 8. Comparison of a \$1000 loan for 12 months.**

| Concept          | Savings bank | Group Solidario Pichincha | Banco Cooperativa Lamanense | Futuro |
|------------------|--------------|---------------------------|-----------------------------|--------|
| Amount requested | 1000         | 1000                      | 1000                        |        |
| Deadline         | 12 months    | 12 months                 | 12 months                   |        |
| Nominal rate     | 2% monthly   | depending on product      | depending on product        |        |
| Total payment    | 1144,68      | 1275                      | 1350                        |        |

|               |                                 |                                                  |                                      |
|---------------|---------------------------------|--------------------------------------------------|--------------------------------------|
| Monthly fee   | 94.56 + contribution<br>= 95.39 | —                                                | —                                    |
| Approval time | 1–3 days                        | 5–8 days                                         | 5–8 days                             |
| Guarantee     | Trust                           | Mutual trust between the<br>members of the group | Guarantor with financial<br>solvency |

**Source:** Own elaboration based on information collected from the “Familia Unida” savings bank, Cooperativa Futuro Lamanense and Banco Pichincha.

Table 6 shows that the total cost of financing continues to be lower in the savings bank, while maintaining advantages related to the speed of approval and the reduction of documentary requirements, indicating that the main strength of the community model does not lie solely in the interest rate, but in the combination of accessibility, operational flexibility and lower costs associated with the process of obtaining credit. The comparative simulation of the credit was prepared using the financial simulator used by the “Familia Unida” savings bank itself, based on an amortization scheme with monthly installments, a nominal rate of 2% per month and an additional contribution of 1% annually destined to strengthen the social fund of the organization. This contribution does not constitute a financial interest, but rather an internal capitalization mechanism approved by the partners.

### 3.7 Member perception results

The survey applied to the 19 members shows a broadly favorable assessment of the functioning of the family savings bank in all the dimensions evaluated. These scores reflect a positive perception regarding the accessibility of credit, trust among the members, the costs associated with financing and the impact generated on the family economy.

**Table 9.** Aggregate results of members' perception of the functioning of the savings bank.

| Dimension              | Medium      | Dev. Standard | Index (0–100) | Interpretation          |
|------------------------|-------------|---------------|---------------|-------------------------|
| Credit accessibility   | 4.56        | 0.42          | 89.0          | Very favorable          |
| Perceived costs        | 4.32        | 0.48          | 83.0          | Favorable               |
| Trust between partners | 4.72        | 0.36          | 93.0          | Very high               |
| Financial preference   | 4.40        | 0.51          | 85.0          | Favorable               |
| Socioeconomic impact   | 4.48        | 0.45          | 87.0          | Very favorable          |
| <b>Overall average</b> | <b>4.50</b> | <b>0.44</b>   | <b>87.5</b>   | <b>Highly favorable</b> |

**Source:** Own elaboration

The trust dimension between partners obtained the highest rating (mean = 4.72), which shows the importance of cooperative relationships and collective commitment as elements that support the functioning of the organization, thus explaining that the approval of loans can be carried out through mechanisms of mutual trust, reducing the

need for formal guarantees. Regarding accessibility to credit, it reached an average of 4.56, indicating that participants perceive an agile, flexible financing process with fewer administrative requirements than those observed in the formal financial system.

In relation to the socioeconomic impact, the average obtained (4.48) demonstrates that the members' perception is that the family savings and credit model has contributed to strengthening their savings capacity, meeting unforeseen economic needs and improving their financial stability.

The dimensions financial preference (4.40) and perceived costs (4.32) also presented favorable evaluations, which confirms that the participants consider the savings bank as a competitive alternative to the formal financing options available in the canton, in general the perception reached 87.5 points out of 100, reflecting a broadly favorable evaluation of the operation of the organization and the benefits perceived by its members.

The documentary results and the information obtained through the survey show a high coherence between the financial performance of the organization and the perception of its members, thus evidencing the high levels of trust, accessibility and satisfaction with the operation of the community model. The high internal consistency of the questionnaire ( $\alpha = 0.958$ ) supports the reliability of the results obtained based on the normalized dimensions of accessibility, perceived costs and socioeconomic impact. The Socioeconomic Efficiency Index (IESE) reached a value of 0.86, a result that summarizes the favorable assessment of the performance of the community model by its members.

## DISCUSSION

The administrative records of the “Familia Unida” savings bank show that during the period 2021–2025, accumulated contributions reached USD 11,210.00 and interest income amounted to USD 8,679.51. alone, it does not allow us to affirm that the organization has achieved financial sustainability given that; The permanence of community savings systems depends on multiple factors, including portfolio recovery, membership stability, quality of governance, and administration of financial resources (17,18). The complementary income amounted to USD 5,182.90 and the expenses totaled USD 2,871.06, with an accumulated difference of USD 2,311.84. This result corresponds only to the difference between the complementary income and the recorded expenses, without representing a comprehensive financial balance. The distribution of expenditures shows that USD 1,020.00 were allocated to social aid and USD 941.53 to community integration activities, reflecting that the organization fulfills social functions in addition to facilitating savings and access to credit, a characteristic of popular and solidarity economy organizations described by Dávila Pinto et al. (19) Hidalgo Romero et al. (12), who point out that these entities direct part of their resources to strengthening collective well-being and social cohesion.

The partners' responses support the information obtained in the administrative records, emphasizing that trust reached the highest average rating, followed by accessibility to credit and the perceived socioeconomic impact, demonstrating that social capital

constitutes one of the main assets of the organization. Salinas Vásquez et al. (10) identified similar results in Ecuadorian cooperatives, where trust between members reduces risk perception and facilitates credit management. Dávila Pinto et al. (19) maintain that solidarity finance strengthens local development processes through cooperative relationships between its members, while Hidalgo Romero et al. (12) highlight that the popular and solidarity economy preserves management mechanisms based on the participation and co-responsibility of the partners. The positive assessment expressed by the participants represents a perception of the organization's functioning and not a direct measurement of the economic impact generated. The absence of formal procedures to evaluate the payment capacity and document the recovery of the portfolio constitutes an aspect that can be strengthened, especially if the number of financial operations or the number of associates increases.

The savings bank has more agile approval processes, fewer administrative requirements and greater proximity between those who request and approve loans, conditions that favor the financial inclusion of people with difficulties accessing the formal financial system (20). Karim et al. (4) point out that community financial organizations reduce access barriers through internal evaluation mechanisms based on direct knowledge of the applicants. Ozili (5) maintains that financial inclusion depends on both the availability of services and the ease of access and the costs associated with the financing process. The Central Bank of Ecuador (7) and Sierra Lara et al. (8) recognize that popular and solidarity economy organizations play a relevant role in expanding access to credit for sectors traditionally excluded from the financial system. The monthly nominal rate of 2% applied by the savings bank may appear higher than that offered by some financial institutions when expressed in annual terms; However, the effective cost of the credit is also conditioned by the amortization system, the required guarantees, additional charges and the time required to complete the approval process. These transaction costs can represent a greater economic burden than the interest rate itself for liquidity-constrained households (4–6,21).

The results obtained correspond to an organization made up of 19 partners, where the closeness between the participants favors the monitoring of agreements and compliance with financial obligations. An increase in membership to 50 or 100 partners would modify the current operating conditions and would require more structured administrative processes, standardized procedures for credit evaluation, stronger internal controls and supervision mechanisms that guarantee transparency in the management of resources. The evidence presented by Aganze et al. (17), Atahau et al. (22) and Mamun and Várallyai (18) indicates that the permanence of community financial organizations depends on the ability to strengthen their governance as the volume of operations and the number of participants increases. Organizational growth requires balancing trust between partners with technical tools that preserve administrative efficiency and financial sustainability.

Credit risk management constitutes another relevant aspect for the continuity of the organization. During the period analyzed, no losses were recorded that compromised the operation of the fund; However, the lack of provisions intended to cover possible bad debts represents a potential vulnerability to default scenarios. The accumulation of

operations increases exposure to financial risk, so it is advisable to incorporate policies for portfolio classification, systematic monitoring of loans and the gradual constitution of preventive reserves. Gutiérrez-Nieto et al. (6) highlight that adequate credit risk management favors the sustainability of microfinance institutions, while Salinas Vásquez et al. (10) show that social capital reduces part of the risk of non-compliance, although it does not replace formal financial control mechanisms. The incorporation of these practices would contribute to strengthening the organization's ability to maintain liquidity and guarantee the continuity of financial services offered to its members.

The results must be interpreted considering the methodological characteristics of the study. The research was developed through a case study applied to a single community savings bank made up of 19 active members, a condition that limits the generalization of the findings to other organizations with different organizational structures, sizes or territorial contexts. Further research could incorporate comparative analyzes between various savings banks and cooperatives of popular and solidarity economy, as well as longitudinal studies that allow evaluating the evolution of financial sustainability, risk management and socioeconomic impact in different organizational growth scenarios.

## CONCLUSIONS

The “Familia Unida” savings bank constitutes for its members as a complementary mechanism for access to financing. Its internal functioning is characterized by simpler validation processes and shorter response times based on regulations and internal decisions of its organization, unlike those identified in the financial products consulted in the town of La Maná. In addition, the results of the survey applied to the members showed a favorable assessment of the functioning of the fund, especially in the dimensions of trust and accessibility to credit. demonstrating the importance that partners attribute to cooperation and mutual knowledge, but these perceptions obtained do not replace the objective measurement of variables such as portfolio recovery, delinquency, profitability or impact on family income and it is emphasized that this conclusion is limited to the case studied and does not imply that all savings banks present the same conditions.

It can be seen that during the 2021–2025 period, accumulated contributions of USD 11,210.00 and interest income of USD 8,679.51 were recorded, in addition, complementary income reached USD 5,182.90 and expenses associated with social, organizational and administrative activities totaled USD 2,871.06, generating a cumulative difference of USD 2,311.84 value that corresponds to the net result of complementary income less social and administrative expenses, so it should not be interpreted as a comprehensive financial balance of the organization.

El alcance de los resultados está limitado por el estudio de una sola organización, el reducido número de participantes y la disponibilidad de registros administrativos consolidados para fortalecer el funcionamiento de la caja se recomienda mejorar el registro individual de las operaciones de crédito, documentar la recuperación de capital e intereses, establecer controles contables periódicos y definir procedimientos internos para el tratamiento de posibles incumplimientos.

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## REFERENCES

1. Basnayake D, Naranpanawa A, Selvanathan S, Bandara J. Financial inclusion through digitalization and economic growth in Asia-Pacific countries. *Int Rev Financ Anal*. 2024;96:103596.
2. Kattan-Rodríguez G, Galindo-Manrique A. From access to impact: How digital financial inclusion drives sustainable development. *Sustainability*. 2025;17(23):10799.
3. Demirgüç-Kunt A, Singer D, Ansar S, Klapper L, Hess J. La base de datos Global Findex 2017: Medición de la inclusión financiera y la revolución de la tecnología financiera [Internet]. Washington, DC: World Bank; 2018. Disponible en: <http://hdl.handle.net/10986/29510> doi:10.1596/978-1-4648-1259-0
4. Karim N, Tarazi M, Reille X. Microfinance and community-based finance: Lessons for financial inclusion. *World Dev*. 2022;153:105806.
5. Ozili P. Financial inclusion research around the world: A review. *Forum Soc Econ*. 2021;50(4):457-79.
6. Gutiérrez-Nieto B, Serrano-Cinca C, Cuéllar-Fernández B. Microfinance institutions and sustainable development goals: The moderating role of credit risk. *Sustainability*. 2021;13(2):786.
7. Banco Central del Ecuador. Inclusión financiera en Ecuador, barreras, avances y efectos socioeconómicos: Una revisión sistemática [Internet]. Quito: BCE; 2026 [citado 23 de julio de 2026]. Disponible en: <https://www.bce.fin.ec/economiaticolor/publicaciones/investigaciones/inclusion-financiera-en-ecuador-barreras-avances-y-efectos-socioeconomicos-una-revision-sistemica/>
8. Sierra Lara Y, Alonzo Villacis MA, Cajas Beltrán MA. Cooperativas de Ahorro y Crédito e inclusión financiera. *Coop Desarro*. 2024;12(1).
9. Superintendencia de Economía Popular y Solidaria. Actualidad y cifras EPS – Abril 2024 [Internet]. Quito: SEPS; 2024 [citado 23 de julio de 2026]. Disponible en: <https://www.seps.gob.ec/wp-content/uploads/Actualidad-y-Cifras-EPS-reducido-feb2024.pdf>
10. Salinas Vásquez J, Sarmiento Jara J, Urgilés Salinas M, Oña Avendaño D. Social capital and credit risk in a financial cooperative of Ecuador. *J Co-op Organ Manag*. 2024;12(2):100247.

11. López-Sánchez A, Valdivieso M. Gestión contable y control financiero en organizaciones de economía solidaria en América Latina. *Rev Cienc Soc.* 2023;29(4):55-72.
12. Hidalgo Romero P, Pulgar Salazar M, Coral Guerrero C. El ADN de la economía popular y solidaria en Ecuador: Explorando las características clave de un sistema económico alternativo. *REVESCO Rev Estud Coop.* 2024;146:e93671.
13. Choudhary P, Ghosh C, Thenmozhi M. Impact of fintech and financial inclusion on sustainable development goals: Evidence from cross country analysis. *Finance Res Lett.* 2025;72:106573.
14. Crowe S, Cresswell K, Robertson A, Huby G, Avery A, Sheikh A. The case study approach. *BMC Med Res Methodol.* 2011;11:100.
15. Yin R. Case study research and applications: Design and methods. 6th ed. Thousand Oaks (CA): Sage Publications; 2018.
16. Stake R. The art of case study research. Thousand Oaks (CA): Sage Publications; 1995.
17. Aganze R, Mersland R, D'Espallier B, Andersson K. Determinants of sustainability of informal community-based financial groups: Insights from a survival analysis approach. *J Dev Stud.* 2025;61:1-23.
18. Mamun A, Várallyai L. Advancing sustainability through financial inclusion and sustainable finance: A systematic literature review. *Digit Finance.* 2025;7(4):853-70.
19. Dávila Pinto P, Ortuño-Pérez S, Mantilla Garcés D, Albuja Centeno V. The role of solidarity finance in sustainable local development in Ecuador. *Economies.* 2025;13(8):227.
20. World Bank. The little data book on financial inclusion 2022. Washington (DC): World Bank; 2022.
21. Ozili P, Mhlanga D. Why is financial inclusion so popular? An analysis of development buzzwords. *J Int Dev.* 2024;36(1):231-53.
22. Atahau A, Sakti I, Hutar A, Huruta A, Kim M. Financial literacy and sustainability of rural microfinance: The mediating effect of governance. *Cogent Econ Finance.* 2023;11(2):2230725.

# EMPLEO DE INTELIGENCIA ARTIFICIAL PARA SÍNTESIS DE MATERIALES BASADOS EN FÍSICA EN RECONSTRUCCIÓN PATRIMONIAL

## AI-DRIVEN SYNTHESIS OF PBR MATERIALS FOR VIRTUAL HERITAGE RECONSTRUCTION

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**RESUMEN:** La digitalización del patrimonio arquitectónico evoluciona desde la documentación hacia un instrumento transversal de investigación, conservación preventiva y divulgación, donde la visualización 3D con renderización se basa en la demanda de materiales digitales plausibles para sostener la credibilidad de la representación. Sin embargo, la paradoja metodológica de las técnicas reality-based (fotogrametría y TLS) capturan con alta fidelidad geométrica el estado actual del bien, así como el registro de deterioros, pátinas y alteraciones que dificultan la materialidad histórica original como el caso de la erosión y las alteraciones cromáticas del granito fino ornamentado que oscurecen la apariencia primigenia de la Iglesia de Santa María de Sar en Santiago de Compostela. Por ello, este trabajo aborda la brecha entre lo existente-degradado y lo original-perdido mediante un método aplicado que desarrolla y documenta un flujo de trabajo integral para la síntesis de materiales PBR asistida por IA multimodal, integrado en un pipeline profesional (GIMP + Blender/Cycles). Los hallazgos técnicos muestran que la generación del albedo toma aproximadamente tres minutos, el resto de mapas PBR se derivan sistemáticamente en GIMP y se integran posteriormente en Blender. Desde la ética, se identifica que los modelos de IA crean debido a sus datos de entrenamiento, lo que exige una documentación explícita de parámetros, así los resultados demuestran que, bajo dirección experta la IA produce materiales PBR plausibles, concluyendo que el método es técnicamente viable y estéticamente coherente para divulgación e hipótesis de restitución, sin sustituir a la captura directa ni exime de la transparencia metodológica.

**Palabras clave:** *patrimonio cultural, patrimonio cultural digital, modelado 3D, materiales PBR, ingeniería de instrucciones*

**ABSTRACT:** The digitization of architectural heritage is evolving from mere documentation into a cross-cutting tool for research, preventive conservation, and dissemination, where 3D visualization with rendering relies on the demand for plausible digital materials to support the credibility of the representation. However, a

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methodological paradox arises with reality-based techniques (photogrammetry and TLS), which capture the current state of the asset with high geometric fidelity, including the recording of deterioration, patinas, and alterations that obscure the original historical materiality—as in the case of erosion and chromatic alterations of fine ornamental granite that mask the original appearance of the Church of Santa María de Sar in Santiago de Compostela. Therefore, this work addresses the gap between the existing-degraded and the original-lost through an applied method that develops and documents a comprehensive workflow for the synthesis of PBR materials assisted by multimodal AI, integrated into a professional pipeline (GIMP + Blender/Cycles). The technical findings show that albedo generation takes approximately three minutes, the remaining PBR maps are systematically derived in GIMP and subsequently integrated into Blender. From an ethical perspective, AI models are found to introduce biases due to their training data, requiring explicit paradata documentation. Thus, the results demonstrate that, under expert guidance, AI produces plausible PBR materials, concluding that the method is technically viable and aesthetically coherent for dissemination and restitution hypotheses, without replacing direct capture or exempting methodological transparency.

**Keywords:** *cultural heritage, digital cultural heritage, 3D modeling, PBR materials, prompt engineering*

## INTRODUCTION

The digitization of architectural heritage expands the virtual scope from registration to a transversal instrument for research, preventive conservation and public access. In this context, physics-based rendering (PBR) flows become widespread in heritage 3D visualization associated with the search for materially credible representations; The credibility of the visualization depends critically on the quality and plausibility of the digital materials applied to the model (1, 2, 3, 4).

However, there is a fundamental methodological paradox: while techniques such as photogrammetry and terrestrial laser scanning (TLS) allow the generation of reality-based 3D models with high geometric fidelity to document the current state of heritage assets, said state usually incorporates deterioration and interventions that make the inference of the original historical materiality difficult (5, 6, 7, 8, 9, 10). This discordance is manifested with particular acuity in the Church of Santa María de Sar, where ornamental elements in fine granite present surface erosion and chromatic alterations that obscure their original appearance.

Contemporary theory of digital heritage recognizes that all digital representation is inherently interpretive, placing itself between the documentation of the existing state and the hypothesis of disappeared states (11, 12, 13). This spectrum requires methodological transparency through paradata, a fundamental ethical requirement according to the London Charter (2009) (14) and the Seville Principles (2017) (15) because it implies a double challenge: technical and interpretive.



Conventional methods of creating digital heritage materials have two categories: (1) photogrammetry which is the standard for documenting existing heritage by producing textures that record pathologies and degradation (16, 17, 18) although, Vico-García et al. (2025) (19) point out that cleaning these textures of anachronistic elements is complex and destructive. Therefore, in cases of substantial material loss, photogrammetry would lack reliable data (11). Consequently, (2) manual modeling is the alternative of creating hypothetical materials with the synthesis of historical information and architectural analogues (20). Although this approach is time intensive, its quality will depend on the subjective skill of the creator because its process would rarely be reproducible or transparent, since it would have the risk of reflecting contemporary aesthetic conceptions (11, 21).

Contextually, generative Artificial Intelligence (AI) models, in particular multimodal systems conferring natural language processing and image synthesis, propose new possibilities for cultural heritage (22). Models that operate as statistical inference systems because they learn probability distributions over millions of text-image pairs to originate new images corresponding to textual descriptions (23). Therefore, the initial applications of AI in cultural heritage focus on virtual restoration of images, categorization of artifacts or production of stylistic variants (11, 22). However, the specific application to PBR texture synthesis for virtual architectural reconstruction represents a theoretically unexplored domain with obstacles such as the scarcity of paired data sets and multichannel coherence problems (24, 25, 26).

This application must take into account fundamental precautions, as generative AI models turn out to be biased by their training data extracted from the contemporary internet, suggesting the risk of generating anachronistic views of heritage (27). Furthermore, their stochastic nature clashes with the ideal of scientific reproducibility (28), and critical digital heritage theory emphasizes that these technologies reconfigure relations of interpretive authority (29).

In response, the research proposes a dual objective: to develop and document a comprehensive workflow that employs multimodal AI models (GPT-4 with DALL-E 3) to create PBR materials intended for virtual heritage reconstruction; and apply this protocol to the synthesis of textures of the original fine granite of the Church of Santa María de Sar. The research is articulated around the question of what level of aesthetic coherence and technical feasibility is necessary for the process to be considered methodologically valid when deployed within a rigorous protocol that starts from a contextually anchored historical specification, follows an iterative prompt engineering process and culminates in specialized post-processing.

The validity evaluation operates in two interdependent dimensions: contextual aesthetic coherence, defined as the degree to which a generated texture is perceived as plausible and integrable in a 3D model according to expert evaluation based on historical-material knowledge; and reproducible technical feasibility, referring to the ability of an AI output to be processed and integrated into a standard PBR production workflow to generate a physically coherent renderable material (30). These criteria are intertwined with the concept of heritage prompt engineering, understood as the systematic process of translating historical-material knowledge into precise instructions



to direct a generative model, an emerging practice as a specialized competence at the intersection between historical research, materials science and computational linguistics.

The fundamentality of this research lies in its methodological contribution, closing the gap between the emerging capabilities of AI and the needs of heritage visibility through a structured and reproducible workflow to technically demonstrate the integration of AI outputs in professional pipelines (Blender/Cycles) and theoretically advance the discussion of the validity criteria for the evaluation of digital reconstructions that use generative technologies and, open a debate of the intersection of digital heritage and computational ethics (31, 32).

## MATERIALS AND METHODS

This research takes an applied method approach, given that the central objective is to design, document and evaluate a specific technical procedure for the resolution of a practical problem, such as the efficient generation of hypothetical PBR materials for digital heritage.

While a methodology constitutes the framework that justifies the why of the research, a method describes the operational how (33). In this case, the what is the evaluation of the viability of AI for synthesis of heritage textures; the why is exposed in the theoretical framework, based on an interpretive-critical paradigm; and the how is the five-phase workflow. It is a method for developing and evaluating prototypes in digital humanities that follows a linear and descriptive logic, common in technological feasibility studies applied to heritage, where rigor lies in the descriptive transparency and reproducibility of the process (34).

The nature of the problem is not amenable to standardized quantitative measurement, as there are no universally accepted metrics to measure the historical coherence of a texture. Validation is based on an expert qualitative evaluation, taking into account criteria of aesthetic-historical coherence and technical functionality, through direct observation and critical analysis of the visual results, an approach consistent with design-based research (35). The validity of the method is derived from the observed feasibility of the process and the credibility of the results before a specialized audience.

The implementation required three tools. ChatGPT Plus (GPT-5.2 with DALL-E 3) was used for image synthesis. Image processing was performed in GIMP 3.0.6. Materials integration and visual validation were carried out in Blender 4.5 with its Cycles engine to evaluate physical properties under controlled lighting (Table 1).

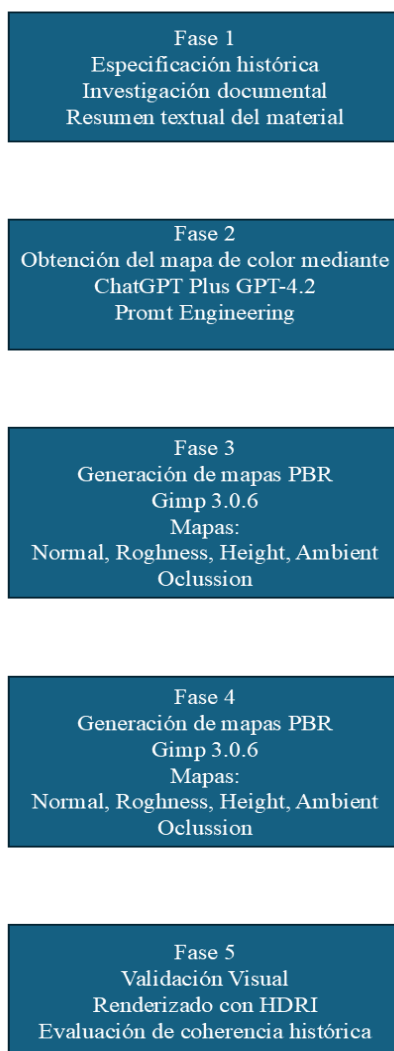
*Table 1. Technical specifications of the programs and computer used.*



| <i><b>Component</b></i>                    | <i><b>Specification</b></i> |
|--------------------------------------------|-----------------------------|
| Image synthesis                            | ChatGPT plus (DALL-E 3)     |
| Texture processing                         | GIMP 3.0.6                  |
| 3D modeling and texturing                  | Blender 4.5 / Cycles        |
| <i><b>Minimum recommended hardware</b></i> |                             |
| Processor                                  | Ryzen 7 3700X               |
| Ram Memory                                 | 16 GB DDR4                  |
| Graphics card                              | NVIDIA RTX 2060 6GB         |
| Storage                                    | SSD 256 GB                  |
| Internet connection                        | Used by ChatGPT             |

The applied method is articulated in five consecutive phases, illustrated in Figure 1, which transform a historical specification into a digital material. Below, each phase is broken down with its intermediate outputs and the difficulties encountered.





**Figure 1. Diagram of the proposed workflow for the synthesis of PBR materials.**

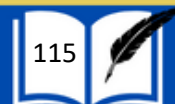
*Source: own elaboration.*

## **2.1 Phase 1: Historical specification and documentary research**

This phase represents the first stage of the workflow used, which translates the historical research into a textual description, in this case it will define the characteristics of the original fine beige granite, excluding patinas and documented deterioration, in addition to selecting the images that will serve as a reference for the material.

## **2.2 Phase 2: Base texture synthesis using AI**

The next phase is the adaptation of the generated textual description to obtain an approximate result, since the reference images include damage from patina, moss and shadows, it is necessary to overcome them with the adjustment due to the prompt. The textual description used to solve this was: "Based on the images provided, create a seamless, 2k, albedo map of fine granite sandstone for the base of a PBR material."



### 2.3 Phase 3. Generation of PBR maps in GIMP

The result obtained after the synthesis process using ChatGPT will be intervened using GIMP, focused on deriving the complementary maps. For the normals map, the albedo was converted to grayscale and the Normals Map filter was applied, adjusting the depth to obtain subtle micro-surface relief.

The roughness map was obtained by manipulating the same grayscale image; The tones were inverted and the contrast was adjusted to assign low roughness values to light areas and high values to dark areas. The height map was derived from the gray version of the albedo, applying Gaussian Blur and enhancing the contrast. The ambient occlusion map was generated from the height map; Gaussian Blur was applied and Levels were adjusted to selectively darken cracks and seams. Each map was adjusted to maintain physical and visual consistency with the albedo.

### 2.4 Phase 4: Integration into Blender

The 5 maps generated, both by AI and by GIMP, are integrated into Blender following the standard flow established for PBR materials. Thus, these maps make up a digital material that is applied to the corresponding 3D model, configuring the UV coordinates and texture scale to guarantee realistic use.

### 2.5 Phase 5: Visual validation

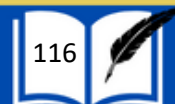
The last phase corresponds to visual validation using test renders with HDRI lighting, which allows evaluating the visual coherence of the material, its physical response to light and its integration into a rendered virtual environment.

It should be noted that this study adopts an applied method whose central purpose is to document and evaluate a specific technical procedure designed to solve a practical problem in heritage visualization. The method is based on the observed viability of the process and the qualitative evaluation of the result based on criteria of aesthetic-historical coherence and technical functionality in a PBR environment. Figure 1 schematizes the operational sequence of the five phases that make up this workflow, from the conceptual definition of the material to its final validation as a digital asset, where each phase represents a specific functional module within the production pipeline.

## RESULTS

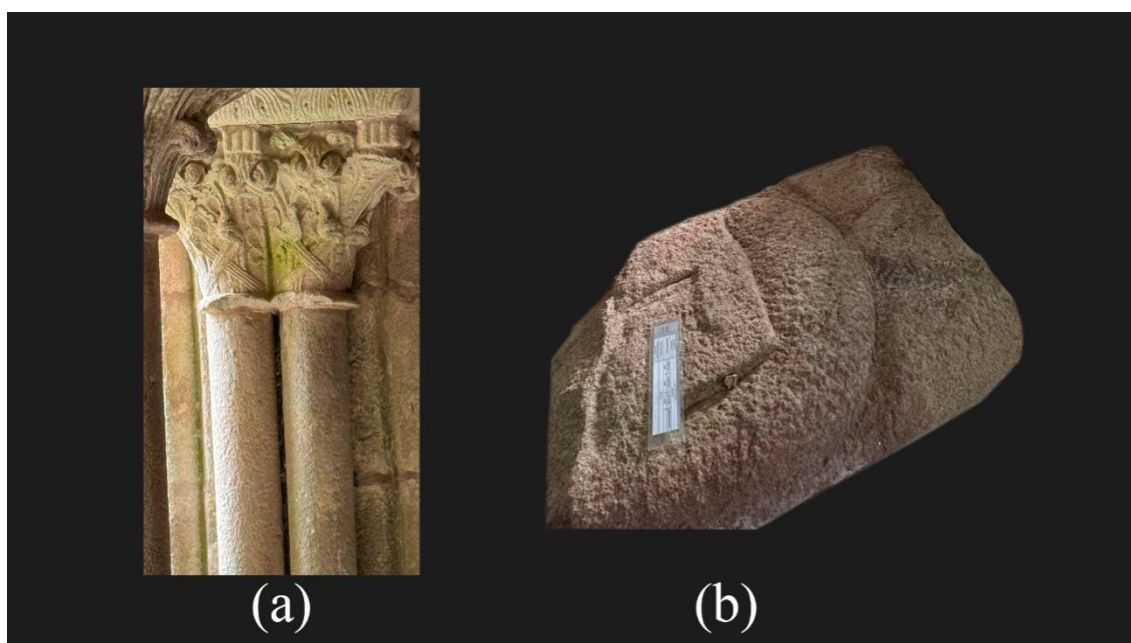
This section presents the visual results obtained in each phase of the workflow, demonstrating the feasibility of the proposed method to generate heritage PBR materials using AI.

The execution began in the ChatGPT interface, which introduced a specific textual description and a prompt that combined technical production requirements (2K resolution, seamless format, albedo map type) with a specific detail of historical material ("fine granite sandstone").



To visually support this specification, two reference images were provided to the model: 1) a sample of pure granite that defined the target texture, and 2) a photograph of an existing medieval arch in Santa María de Sar, built with the same material, which provided architectural context and historical validation. This multimodal prompt engineering approach allowed the DALL-E 3 model to be directed towards the generation of a base image conceptually aligned with the heritage restitution objectives (Figures 2 and 3).

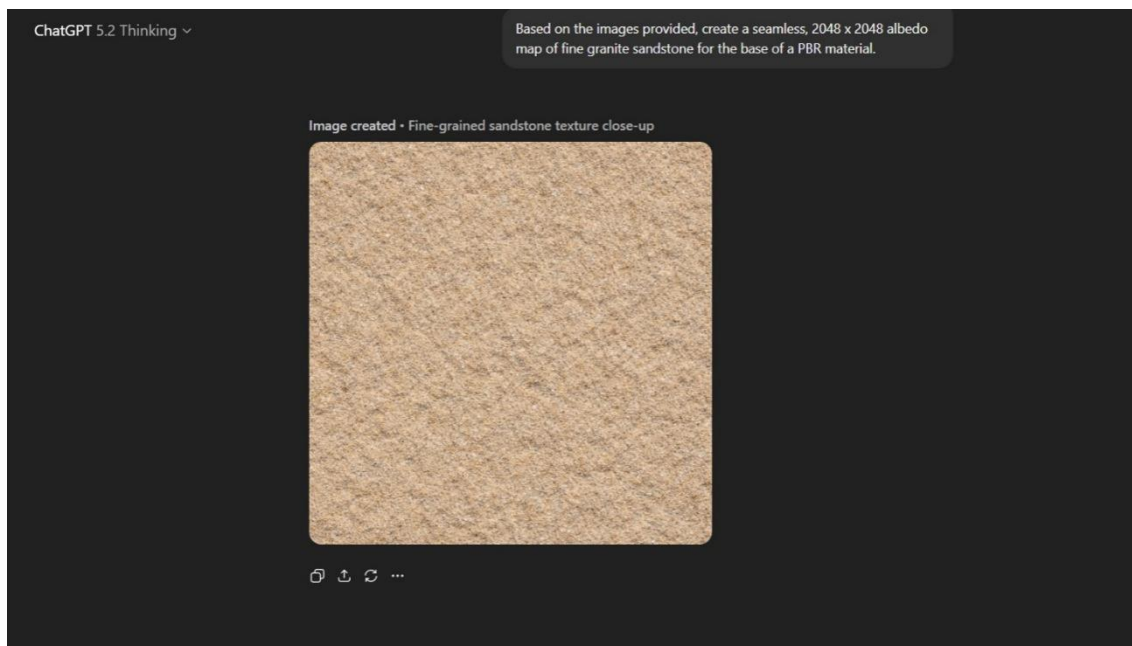
Figure 2a shows a detail of the medieval arch of Santa María de Sar, built with the sandstone granite that constitutes the case study, while 2b is a reference sample of the same material, which defines the target texture. Both images were provided to the AI as visual context to guide the generation of the albedo map technically specified in the textual prompt.



**Figure 2. Reference images.**

**Source: own elaboration.**

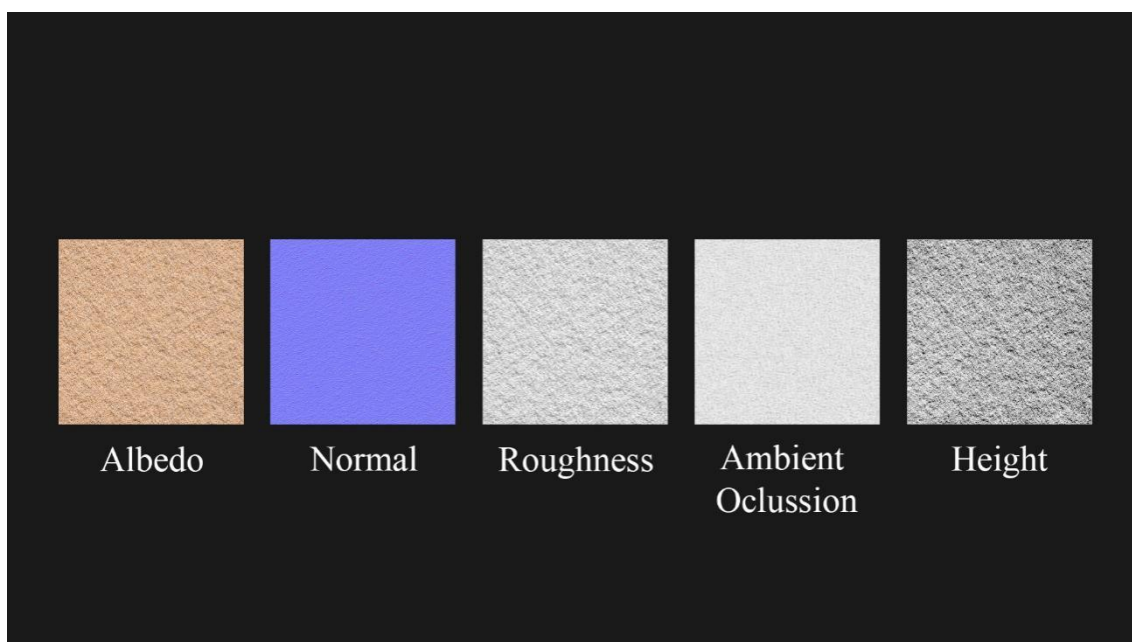
Figure 3 documents the result of the AI synthesis phase, and by capturing the ChatGPT interface it shows the exact prompt that specified the technical requirements and material context. The generated image, produced in approximately three minutes, corresponds to an albedo map with the requested characteristics, received in seamless format and with neutralized lighting, ready for subsequent processing.



**Figure 3. AI synthesis process in ChatGPT.**

*Source: own elaboration.*

In this way, based on the albedo map synthesized by the AI, we proceeded to generate the complete set of maps that make up a physically coherent PBR material within the GIMP environment. This critical derivation step converted the base image into a material system ready for realistic rendering (Figure 4).



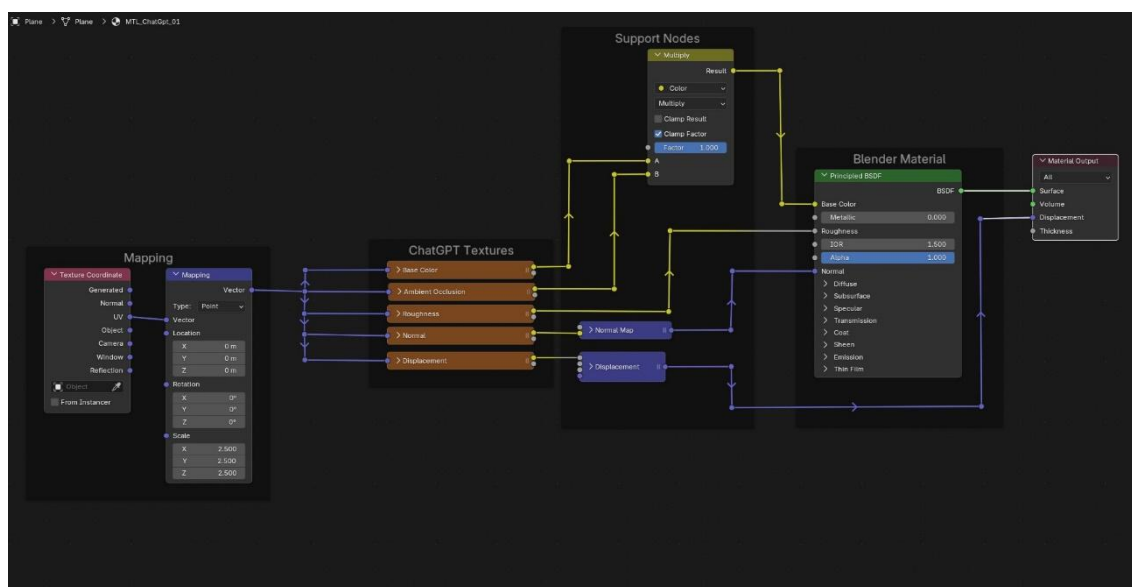
**Figure 4. Resulting maps after post-processing in Gimp.**

*Source: own elaboration.*

Figure 4 shows the set of PBR maps derived by Gimp from the AI-synthesized Albedo. The figure shows the entire set of maps that together make up the physically based material: Albedo, which gives the color to the material; Normal, which is responsible for the surface micro-geometry of the granite; Roughness, which defines the variation of specular gloss; Ambient occlusion (AO), which simulates shading in concavities and joints; and Height map, intended for displacement or parallax effects. The visual consistency between the maps confirms the validity of the AI-generated albedo as a basis for a physically plausible derivation.

After obtaining all the maps that make up the PBR material, albedo, normals, roughness, height and ambient occlusion, the next phase consisted of its technical integration within the Blender environment. To do this, a material was configured under the Cycles rendering engine within the node editor, where it is evident how these five maps are systematically connected to the corresponding inputs of the Principal BSDF shader.

This nodal configuration is fundamental, since it establishes the precise physical relationships between the surface properties defined by each texture, transforming the set of independent images into a unified digital material, physically coherent and ready to be applied to the geometry of the heritage model (figure 5).



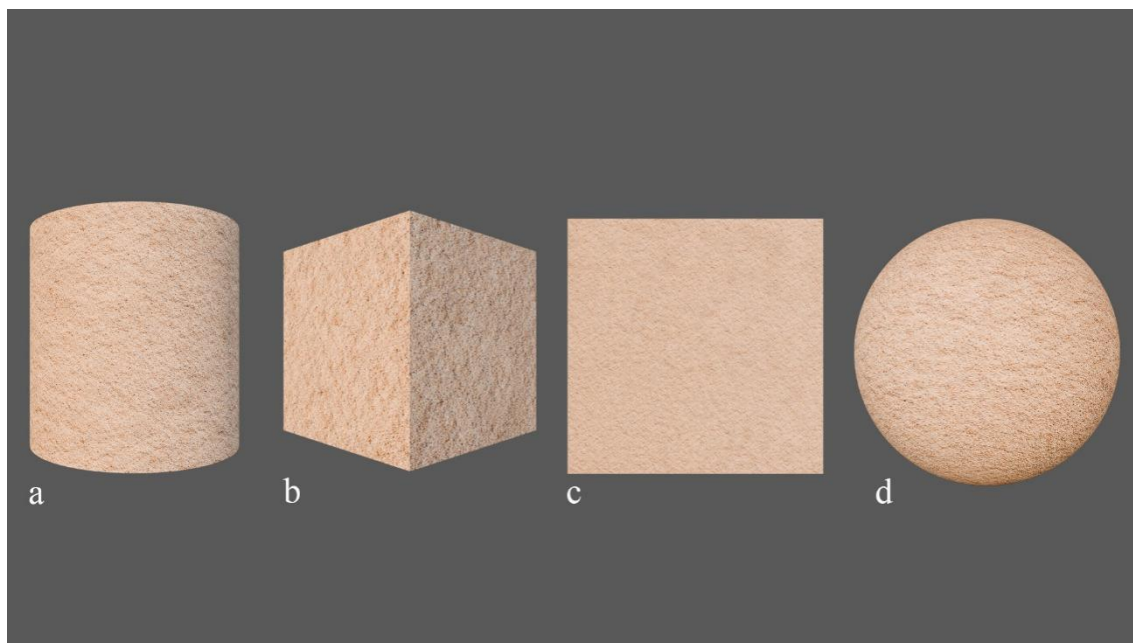
**Figure 5. Material nodal configuration in Blender.**

*Source: own elaboration.*

Screenshot of the node editor showing the systematic connection of the five generated texture maps (Figure 5) (albedo, normal, roughness, height and ambient occlusion) to their corresponding input sockets in a Principled BSDF shader. This configuration establishes the physical relationships between surface properties, transforming the independent images into a unified digital material ready for application in the heritage 3D model.

After the creation of the material and its correct configuration in the node editor, a preliminary validation phase was carried out by assigning it to primitive test geometries

– a plane, a cube and a cylinder. This step allowed the physical behavior of the material to be verified in situ under different surface orientations and lighting conditions, ensuring the coherence of the PBR maps and the absence of visual artifacts before their final application to the historic ornamental element of the Church of Saint Mary of Sar (figure 6).

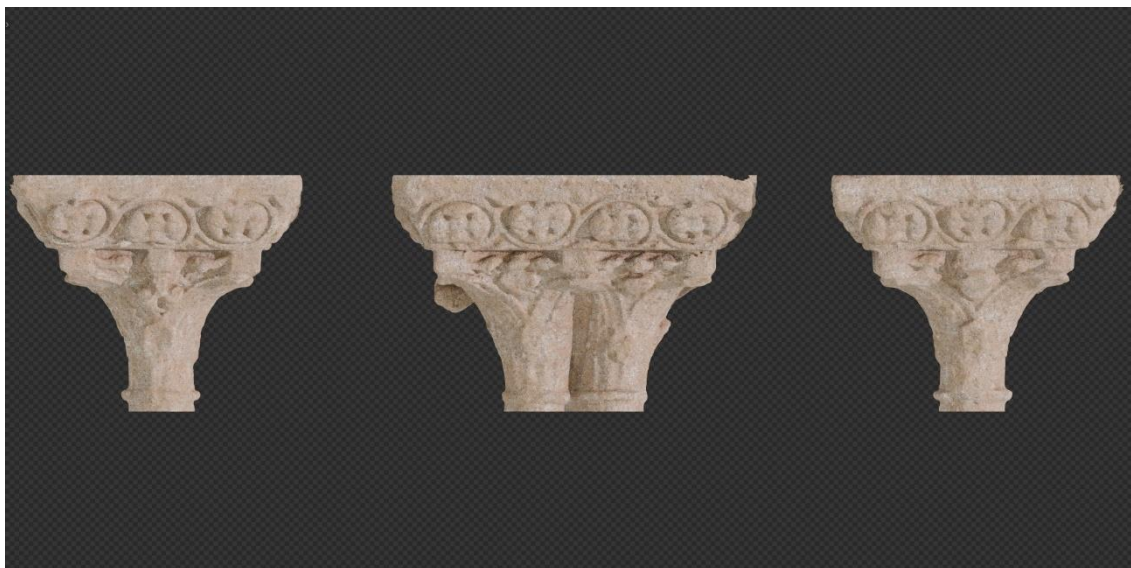


**Figure 6. Preliminary validation in primitive geometries.**

*Source: own elaboration.*

Figure 6 shows the render of the final PBR material applied to basic 3D models (cylinder, cube, plane, sphere) to evaluate its physical behavior under different surface orientations and controlled lighting conditions. This stage allowed us to verify the coherence of the maps, the correct projection of the textures and the unified visual response of the material before its assignment to the historical heritage element.

After preliminary verification in test geometries, the final visual validation was carried out by assigning the material to a specific heritage element: an ornate capital located in the interior ceiling of the central nave of the Church of Santa María de Sar. For this evaluation, HDRI ambient lighting was used, which simulates realistic lighting conditions and allows a comprehensive evaluation of the physical response of the material, its interaction with light, specular behavior and relief perception, as well as its visual coherence within the historical architectural context for which it was conceived (Figure 7).



*Figure 7. Final validation in heritage context.*

*Source: own elaboration*

Figure 7 is a render of an ornate capital from the interior of the church of Santa María de Sar with the PBR material applied. The evaluation was carried out under HDRi lighting, which made it possible to analyze in situ the physical response of the material, its realistic interaction with light, specular behavior and the perception of relief and its visual coherence within the historical architectural context for which it was conceived.

The final integration of the synthesized material into the target heritage element, together with the complete set of PBR maps and their documented technical configuration, constitutes the tangible result of the proposed workflow. These visual and technical results, however, open a series of questions about the effectiveness, limitations and methodological significance of the process carried out, aspects that will be critically analyzed in the following discussion section.

## DISCUSSION

The successful implementation of the workflow poses an affirmative, albeit nuanced, answer to the research question regarding the technical feasibility and aesthetic coherence of integrating generative AI into the production of heritage PBR materials. The technical feasibility is demonstrated not only in the temporal efficiency with the generation of the albedo in minutes radically contrasting with the hours or days of subjective manual modeling (24) or with the complex processing of photogrammetry to clean degraded textures, but in the perfect integration of the synthetic output in a standard industrial PBR pipeline.

However, this efficiency comes with a transfer of workload: while traditional methods such as photogrammetry, although accurate, inevitably capture current deterioration, requiring hours or days of manual texture cleaning to remove patinas and anachronistic alterations (16, 17, 19). For its part, manual modeling allows greater creative control,

but its quality depends critically on the subjective skill of the digital artist, with production times that can extend to several days per material (20, 21). In contrast, the method proposed here shifts the critical effort from the technical execution to the historical specification and prompt engineering phase, reducing the generation of the albedo to minutes, although transferring the expertise to the domain of historical research and the management of the AI model (23, 27).

Thus, aesthetic coherence reaches a level of contextualized historical plausibility, that is, a criterion different from the documentary quality of traditional methods. Well, photogrammetry provides an accurate representation of the current state of deterioration; Therefore, manual modeling often promises a historically accurate recreation that is limited by the creator's subjective skill and interpretation.

Then, AI guided by site-specific visual references (Fig. 2) created a texture that contextually evoked the historical material to fill a gap between the existing and the hypothesis of the lost; although this capacity has been structurally limited by the stochastic nature and biases of diffusion models. Thus, unlike a laser scanner and/or a metric camera, DALL-E 3 which does not measure or usually replicate; was interpreted based on statistical distributions of the training set. This makes it prone to generating anomalies or generic textures ("average stone") when the references are ambiguous or the prompt is imprecise, a risk that does not exist in direct capture methods.

These technical limitations are intrinsically linked to profound ethical implications. The use of generative AI in cultural heritage reactivates classic debates about authenticity and interpretive authority (29). A model trained predominantly with internet data perpetuates and amplifies contemporary cultural and aesthetic biases, potentially generating an anachronistic or Westernized view of historical materials.

Therefore, transparency (paradata) is an ethical imperative that any application of this method must specifically declare the synthetic and/or interpretive nature of the textures by differentiating them from the direct capture data and/or documented during the prompt engineering process, as well as the references used. Which causes alignment with the principles of the London Charter (2009) (14) to avoid the creation of a speculative heritage with the false authority of a historical document.

The practical implications are dual because, on the one hand, this technology partially democratizes the origin of high-fidelity materials, since it allows teams with fewer resources specialized in digital art to create visual prototypes for feasibility studies with financing proposals and/or educational experiences. Thus, on the other hand, a new dependence on platforms and commercial models arises whose algorithms, costs and conditions of use tend to change arbitrarily with the vulnerability that it does not affect traditional methods based on open source software and/or autonomous photogrammetric techniques.

The future of this line of work should focus only on developing domain-specific models trained with ethically curated heritage corpora, and integrating AI hybridly; for example, by using photogrammetry to provide geometry and macrotextual structure, and by using AI to infer and synthesize micro-texture and missing original colors. In this way, AI would



not replace methodologies, but would be integrated to overcome their respective limitations under a framework of transparency and critical rigor for the researcher and/or creator, and not the algorithm as an authority in the interpretation of the past.

## CONCLUSIONS

This study developed and validated an operational workflow that integrated AI synthesis into the production of PBR materials for historical heritage visualization. The results demonstrated that, under a framework of precise historical specification and prompt engineering, it is possible to create digital materials with correct aesthetic-historical plausibility for dissemination contexts, preliminary studies and/or restitution hypotheses.

The main answer to the research question was affirmative because the integration of generative AI in this pipeline was technically feasible and, aesthetically, coherent, although its value did not lie in automation, but in the formalization of a new translation process.

Thus, the method became expert knowledge and a replicable history protocol that can direct the future and synthetic generation towards a specific heritage objective by surpassing mere random generation.

However, as evidence, this capacity remains, which does not replace material evidence or direct capture; On the contrary, it reconfigured the role of the researcher and/or creator from manual executor to AI director because his critical authority was exercised in the specification and validation phase, not in the execution phase.

Therefore, the ultimate contribution of this work transcended as the specific technical result by offering a methodologically transparent model that documented step by step its adaptability and improvement by the community. It is then that he raises and also asks a fundamental question for the future of digital humanity: how will AI tools be designed that not only accelerate processes, but also amplify and formalize the interpretive rigor of the specialist?

Therefore, it is recommended that future research explores (1) the development of standardized prompts for categories of historical heritage materials, (2) hybrid integration with photogrammetry data to guide the synthesis geometrically, and the (3) creation of domain-specific models trained with curated heritage corpora.

Because only in this way will AI stop representing a unitary creative black box and become a critical, analytical, reproducible and ethical instrument that will serve the interpretation and communication of digital historical heritage.

In short, this research is presented as a complementary tool to a digital kit for the historical heritage specialist because it validates contexts where the balance between efficiency, historical plausibility and methodological transparency of the space is explicit and ethically managed.

## ACKNOWLEDGEMENTS

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## REFERENCES

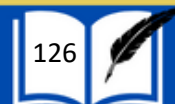
1. Storeide MB, George S, Sole A, et al. Standardization of digitized heritage: A review of implementations of 3D in cultural heritage. *Herit Sci.* 2023;11:249. doi: 10.1186/s40494-023-01079-z.
2. Markiewicz J, Kot P, Georgopoulos A, et al. Transforming architectural heritage documentation: Developing integrated European recommendations for safeguarding and preservation. *npj Herit Sci.* 2025;13:622. doi: 10.1038/s40494-025-02200-0.
3. Lang M, Salcedo Paparoni V. Scanning authenticity: On the limits of 3D representation in museums. *ISPRS Ann Photogramm Remote Sens Spat Inf Sci.* 2025; X-M-2-2025:193-199. DOI: 10.5194/isprs-annals-X-M-2-2025-193-2025.
4. Wu L, Yu R, Su W, Ye S. Design and implementation of a metaverse platform for traditional culture: The chime bells of Marquis Yi of Zeng. *Herit Sci.* 2022;10:193. doi: 10.1186/s40494-022-00828-w.
5. Alshawabkeh Y, Baik A. Integration of photogrammetry and laser scanning for enhancing scan-to-HBIM modeling of Al Ula heritage site. *Herit Sci.* 2023;11:147. doi: 10.1186/s40494-023-00997-2.
6. Stamnas A, Kaimaris D, Georgiadis C, Patias P. Comparing 3D digital technologies for archaeological fieldwork documentation: The case of Thessaloniki Toumba excavation, Greece. *Int Arch Photogramm Remote Sens Spat Inf Sci.* 2021;XLVI-M-1-2021:713-720. doi: 10.5194/isprs-archives-XLVI-M-1-2021-713-2021.
7. Llabani A, Abazaj F. 3D documentation of cultural heritage using terrestrial laser scanning. *J Appl Eng Sci.* 2024;22(2):267-271. doi: 10.5937/jaes0-50414.
8. Sanmartín P, Sanjurjo-Sánchez J, Prieto B. Covering layers on granite buildings of Northwestern Iberian Peninsula: When observable characteristics and lab characterization do not match. *Coatings.* 2020;10(2):137. doi: 10.3390/coatings10020137.
9. Mishra M, Lourenço PB. Artificial intelligence-assisted visual inspection for cultural heritage: State-of-the-art review. *J Cult Herit.* 2024;66:536-550. doi: 10.1016/j.culher.2024.01.005.
10. Jáidar Benavides Y, Magar Meurs V, Ruiz Martín MC, editors. *Criterios de conservación del patrimonio en piedra.* México: Secretaría de Cultura / INAH / UNAM-IIE / ICCROM; 2025. Disponible en: <https://www.iccrom.org/es/publication/criterios-de-conservaci%C3%B3n-del-patrimonio-en-piedra>



11. Pietroni E, Ferdani D. Virtual restoration and virtual reconstruction in cultural heritage: Terminology, methodologies, visual representation techniques and cognitive models. *Information*. 2021;12(4):167. doi: 10.3390/info12040167.
12. Apollonio FI. The three-dimensional model as a "scientific fact": The scientific methodology in hypothetical reconstruction. *Heritage*. 2024;7(10):5413-5427. doi: 10.3390/heritage7100255.
13. Fallavollita F, Foschi R, Apollonio FI, Cazzaro I. Terminological study for scientific hypothetical 3D reconstruction. *Heritage*. 2024;7(9):4755-4767. doi: 10.3390/heritage7090225.
14. The London Charter. The London Charter for the computer-based visualisation of cultural heritage. Version 2.1. 2009. Disponible en: [https://londoncharter.org/fileadmin/templates/main/docs/london\\_charter\\_2\\_1\\_en\\_edits.pdf](https://londoncharter.org/fileadmin/templates/main/docs/london_charter_2_1_en_edits.pdf)
15. The Seville Principles. The Seville Principles: International principles of virtual archaeology. 2017. Disponible en: <https://icomos.es/wp-content/uploads/2020/06/Seville-Principles-IN-ES-FR.pdf>
16. Xing Y, et al. A scoping review of photogrammetry in cultural building heritage. *Electronics*. 2025;14(18):3666. doi: 10.3390/electronics14183666.
17. Brúha L, et al. Reconstruction of lost cultural heritage sites and landscapes: Context of ancient objects in time and space. *ISPRS Int J Geo-Inf*. 2020;9(10):604. doi: 10.3390/ijgi9100604.
18. De Fino M, Galantucci RA, Fatiguso F. Condition assessment of heritage buildings via photogrammetry: A scoping review from the perspective of decision makers. *Heritage*. 2023;6(11):7031-7066. doi: 10.3390/heritage6110367.
19. Vico-García D, Mozas-Calvache AT, et al. Proposal of radiometric correction for the in-situ modelling of polychrome religious carvings. *Int Arch Photogramm Remote Sens Spat Inf Sci*. 2025;XLVIII-M-9-2025:1563-1568. doi: 10.5194/isprs-archives-XLVIII-M-9-2025-1563-2025.
20. González ER. La reconstrucción virtual aplicada al patrimonio como herramienta para la investigación y la divulgación: El ejemplo del sacrificio ritual del patio del yacimiento de Casas del Turuñuelo (Guareña, Badajoz, España). *Cuad Prehist Arqueol Univ Granada*. 2024;34:85-114.
21. Chen Y, Nie Y, Ummenhofer B, Birkl R, Paulitsch M, Nießner M. PBR-SR: Mesh PBR texture super resolution from 2D image priors. *arXiv*. 2025. doi: 10.48550/arXiv.2506.02846.
22. Spennemann DHR. Generative artificial intelligence, human agency and the future of cultural heritage. *Heritage*. 2024;7(7):3597-3609. doi: 10.3390/heritage7070170.
23. Rombach R, Blattmann A, Lorenz D, Esser P, Ommer B. High-resolution image synthesis with latent diffusion models. En: *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*. 2022. p. 10684-10695. doi: 10.1109/CVPR52688.2022.01042.
24. Witte J, Lee E, Brausem L, Shillabeer V, Bonacchi C. Generative AI in heritage practice: Improving the accessibility of heritage guidance. *Heritage*. 2025;8(12):513. doi: 10.3390/heritage8120513.



25. Xu J, Yan L, Zhang R, Zhou M. A review of the development and application of generative technology in digital museums. *npj Herit Sci.* 2025;13(1):589. doi: 10.1038/s40494-025-02164-1.
26. Chen G, Tong Y, Wu Y, Wu Y, Liu Z, Huang J. Reconstruction of cultural heritage in virtual space following disasters. *Buildings.* 2025;15(12):2040. doi: 10.3390/buildings15122040.
27. Bender EM, Gebru T, McMillan-Major A, Shmitchell S. On the dangers of stochastic parrots: Can language models be too big? En: *Proceedings of the 2021 ACM Conference on Fairness, Accountability, and Transparency (FACCT '21).* 2021. p. 610-623. doi: 10.1145/3442188.3445922.
28. Pineau J, Vincent-Lamarre P, Sinha K, Larivière V, Beygelzimer A, d'Alché-Buc F, Fox E, Larochelle H. Improving reproducibility in machine learning research: A report from the NeurIPS 2019 reproducibility program. *arXiv.* 2020. doi: 10.48550/arXiv.2003.12206.
29. Champion EM, editor. *Virtual heritage: A guide.* London: Ubiquity Press; 2021.
30. Pescarin S, Cerato I, Ciortan IM, Città G, Clay A, Spotti S, Sotiropoulou S, Trumpy G. Authenticity in the design of digital heritage applications. En: *Chromatic Visions. Lecture Notes in Computer Science.* Vol. 15750. Cham: Springer; 2025. p. 81-127. doi: 10.1007/978-3-032-07792-9\_3.
31. Pansoni S, Tiribelli S, Paolanti M, Di Stefano F, Frontoni E, Malinverni ES, Giovanola B. Artificial intelligence and cultural heritage: Design and assessment of an ethical framework. *Int Arch Photogramm Remote Sens Spat Inf Sci.* 2023; XLVIII-M-2-2023:1149-1155. doi: 10.5194/isprs-archives-XLVIII-M-2-2023-1149-2023.
32. Tiribelli S, Pansoni S, Frontoni E, Giovanola B. Ethics of artificial intelligence for cultural heritage: Opportunities and challenges. *IEEE Trans Technol Soc.* 2024;5(3):293-305. doi: 10.1109/TTS.2024.3432407.
33. Creswell JW, Poth CN. *Qualitative inquiry and research design: Choosing among five approaches.* 4th ed. Thousand Oaks: SAGE Publications; 2018.
34. Münster S, Apollonio FI, Bluemel I, Fallavollita F, Foschi R, Grellert M, Ioannides M, Jahn PH, Kurdiyovsky R, Kuroczyński P, Lutteroth JE, Messemer H, Schelbert G. Scholarly method. En: *Handbook of digital 3D reconstruction of historical architecture.* Cham: Springer; 2024. p. 41-64. doi: 10.1007/978-3-031-43363-4\_3.
35. McKenney S, Reeves TC. *Conducting educational design research.* 2nd ed. London: Routledge; 2019. doi: 10.4324/9781315105642.



# VALORIZACIÓN BIOTECNOLÓGICA DE RESIDUOS AGROINDUSTRIALES ECUATORIANOS PARA BIOINSUMOS Y BIOPRODUCTOS: REVISIÓN APLICADA CON MATRIZ DE DECISIÓN

## BIOTECHNOLOGICAL VALORIZATION OF ECUADORIAN AGROINDUSTRIAL RESIDUES FOR BIOINPUTS AND BIOPRODUCTS: AN APPLIED REVIEW WITH A DECISION MATRIX

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**RESUMEN:** La agroindustria ecuatoriana genera subproductos asociados a las cadenas de banano, cacao, arroz, caña de azúcar, maíz, cítricos y camarón, muchos de los cuales se descartan sin aprovechamiento. Estos materiales contienen fibras, carbohidratos, proteínas, compuestos fenólicos, pectinas, polisacáridos y quitina susceptibles de transformación mediante rutas biotecnológicas. Se desarrolló una investigación documental, no experimental, de alcance descriptivo-comparativo, orientada a analizar su potencial para obtener bioinsumos y bioproductos. La búsqueda reproducida en Scopus para 2022–2026 recuperó 459 resultados en la interfaz y 455 registros únicos en el archivo exportado; el corpus final integró 45 fuentes científicas seleccionadas por pertinencia y trazabilidad. La información se organizó en una matriz de decisión con cinco criterios: disponibilidad del residuo, potencial biotecnológico, diversidad de productos, aplicabilidad productiva y aporte ambiental. Los residuos se agruparon en materiales lignocelulósicos, subproductos con contenido funcional relevante y residuos acuícolas orientables hacia biopolímeros. Banano y cacao alcanzaron la mayor prioridad; caña de azúcar, camarón, cítricos y arroz también se clasificaron como de prioridad alta, mientras que maíz obtuvo prioridad media. Se concluye que los residuos agroindustriales ecuatorianos presentan un potencial de valorización diferenciado; dentro del alcance documental y de la matriz empleada, banano y cacao constituyen las alternativas iniciales más favorables, aunque su implementación debe confirmarse mediante caracterización local y evaluaciones técnicas, económicas y ambientales.

**Palabras clave:** *Biotecnología industrial, biomasa residual, economía circular, fermentación, biofertilizantes, sostenibilidad productiva*

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**ABSTRACT:** Ecuadorian agroindustry generates by-products from banana, cocoa, rice, sugarcane, maize, citrus and shrimp chains, many of which are discarded without recovery. These materials contain fibers, carbohydrates, proteins, phenolic compounds, pectins, polysaccharides and chitin that can be transformed through biotechnological routes. A non-experimental documentary study with a descriptive-comparative scope was conducted to analyze their potential for producing bioinputs and bioproducts. The reproducible Scopus search for 2022–2026 retrieved 459 results in the interface and 455 unique records in the exported file; the final corpus comprised 45 scientific sources selected for relevance and traceability. The information was organized in a decision matrix using five criteria: residue availability, biotechnological potential, product diversity, productive applicability and environmental contribution. Residues were grouped into lignocellulosic materials, by-products with relevant functional content and aquaculture residues suitable for biopolymer production. Banana and cocoa achieved the highest priority; sugarcane, shrimp, citrus and rice were also classified as high priority, whereas maize obtained medium priority. It is concluded that Ecuadorian agroindustrial residues have differentiated valorization potential; within the documentary scope and the matrix applied, banana and cocoa are the most favorable initial alternatives, although their implementation requires local characterization and specific technical, economic and environmental assessments.

**Keywords:** *Industrial biotechnology, residual biomass, circular economy, fermentation, biofertilizers, productive sustainability*

## INTRODUCTION

Dentro de la estructura productiva del Ecuador, la agroindustria vinculada al banano, cacao, arroz, caña de azúcar, maíz, cítricos y camarón genera, además de sus productos comerciales, una cantidad significativa de subproductos que no ingresan a ningún canal de aprovechamiento posterior. Cáscaras, bagazos, cascarillas, pseudotallos, raquis, pulpas, mucílagos y exoesqueletos quedan fuera del producto final en cada ciclo productivo. Aunque su manejo habitual los sitúa como material de descarte, análisis fisicoquímicos de estos subproductos revelan la presencia de fibras, carbohidratos, proteínas, compuestos fenólicos, pectinas y polisacáridos cuya utilidad en procesos agrícolas e industriales ha sido confirmada en distintos estudios (1,2).

When a recovery mechanism is not established, this biomass can affect soils and water sources or be lost without its components having a subsequent use.. The linear scheme of extraction, processing and disposal of waste maintains environmental pressures in productive areas. This problem has been described in international and regional literature on agroindustrial waste and its transformation into resources (2–4).

The proportion and characteristics of the waste vary depending on the production chain, the fraction of the material processed and the technological level used. In Ecuador, rice husks, sugarcane bagasse, cocoa shells and other biomasses have been studied; However, these works usually analyze a residue or a route in isolation, which makes a joint comparison difficult(1–3,5,6).

Among the documented alternatives to modify this situation, applied biotechnology has gained relevance because it allows, through controlled biological processes, to convert waste materials into products with a specific application. Routes such as solid state fermentation, submerged fermentation, enzymatic hydrolysis, anaerobic digestion and microbial bioconversion have shown the capacity to generate biofertilizers, biopesticides, enzymes, biopolymers, bioethanol, biogas and antioxidant compounds from different types of biomass. The choice of one or another route does not only respond to the type of waste available, but is also conditioned by its physicochemical stability, the regularity with which it can be obtained and the intended use for the final product (7–10).

Waste does not behave in the same way when it comes to its use, since its response depends on the composition of each waste. Materials such as bagasse, husk, straw and pseudostems, of a lignocellulosic nature, can be used as fermentation substrates or as a source for energy generation (4,11,12). However, using them directly is inefficient due to the recalcitrance that characterizes the lignocellulosic matrix. Within these materials, cellulose is arranged in microfibrils whose crystalline areas are held together by a network of hydrogen bonds, and all of this is embedded in a matrix formed by hemicellulose and lignin. This structural organization decreases the porosity of the material and makes it difficult for microorganisms and hydrolytic enzymes to reach the glycosidic bonds. Added to this is that lignin operates as a physical barrier and can cause enzymes to adsorb in a non-productive way. For these reasons, these biomasses usually require physical, chemical or biological pretreatments and subsequent hydrolysis, so that their carbohydrates can be efficiently transformed into fermentable sugars (1,4,11–13).

Cocoa and citrus peels present a different profile: they highlight the presence of bioactive compounds, pectins and antioxidant fractions with possible pharmacological and agri-food applications. In the case of cocoa mucilage, its soluble portion is composed mainly of glucose, fructose and sucrose, low molecular weight molecules that yeasts and bacteria can assimilate without extensive depolymerization. This availability facilitates fermentation, although the high water content, rapid microbiological deterioration and composition variability can complicate storage and standardization of the process (14,15).

The waste from the shrimp industry offers a different panorama. The chitin, proteins and minerals present in them allow us to obtain chitosan, protein hydrolysates and biomaterials useful in agriculture, food and water treatment. Chitin is a linear polysaccharide of N-acetyl-D-glucosamine with  $\beta$ -(1→4) bonds, high crystallinity and low solubility. In the exoskeleton it is associated with proteins and calcium carbonate, so its recovery requires demineralization and deproteinization; Deacetylation is subsequently applied to obtain chitosan or hydrolysis to generate oligomers and amino sugars. These procedures consume reagents and energy and can generate effluents that must be treated (16–19). Thus, while mucilage can be used as a fermentation substrate with less conditioning, shrimp residue requires separation and structural modification.

Ecuador presents favorable conditions because several chains generate byproducts for a good part of the year and some waste is concentrated in packing plants, mills, pilers

or processing plants. However, operational availability is not uniform: it depends on seasonality, humidity, territorial dispersion and storage capacity. Banana and cocoa offer a relatively regular generation, while corn and citrus present more marked variations that must be incorporated into the sizing of the processes (5,20–23).

The problem persists at another level. The information available on the use of these wastes appears distributed in research that addresses specific materials or processes, without there yet being a synthesis that allows linking the type of biomass with the applicable technology and the product that can be obtained. For those who make decisions in the productive sector or design lines of research, this dispersion represents a specific obstacle when establishing priorities.

Starting from this gap, this work maintains that agroindustrial waste from Ecuador presents a potential for biotechnological valorization differentiated according to its composition and the technologies available for each type of biomass. For this purpose, the available scientific literature on transformation processes applicable to different types of residual biomass was reviewed and a comparative tool was built that allows each waste to be related to its processing route and the products that can be obtained from it. The results seek to support the identification of priority alternatives, guide future lines of research and provide concrete elements for the design of circular economy strategies within the Ecuadorian agroindustry.

## MATERIALS AND METHODS

A descriptive and comparative documentary review was carried out to identify biotechnological recovery routes applicable to banana, cocoa, rice, sugar cane, corn, citrus and shrimp waste. These chains were selected for their productive relevance, recurrent generation of byproducts and availability of scientific evidence on their transformation (3,5,7,16,21,22,24–30).

The literature search was updated and reproduced in Scopus on July 14, 2026. The following equation was run on the title, abstract, and keyword fields:

*TITLE-ABS-KEY(("agro-industrial waste\*" OR "agroindustrial residue\*" OR "agricultural by-product\*" OR "residual biomass") AND (banana OR cocoa OR cocoa OR rice OR sugarcane OR maize OR corn OR citrus OR shrimp) AND ("biotechnological valorization" OR bioconversion OR fermentation OR "enzymatic hydrolysis" OR biofertilizer\* OR biopolymer\* OR chitosan OR pectin OR bioethanol OR biogas)) AND PUBYEAR > 2021 AND PUBYEAR < 2027 AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re")) AND (LIMIT-TO(LANGUAGE,"English") OR LIMIT-TO(LANGUAGE,"Spanish"))*

The search was limited to the period 2022-2026, to original articles and reviews published in scientific journals, in their final state and written in English or Spanish. With these parameters, 459 records were recovered.

The query returned 459 results in the Scopus interface. The exported CSV contained 455 unique titles; 454 had DOI and EID, and one lacked both identifiers. Comparison by DOI,

EID, and title showed no duplicates. Documents without directly extractable information on composition, process, product, performance or application, as well as thematically redundant ones, were excluded from the synthesis.

The comparison between the export and the bibliography identified 16 publications in the final corpus from the reproduced search. 29 sources were added from previous searches and retrospective tracing to cover Ecuadorian context, multi-criteria analysis and experimental performances. The final corpus brought together 45 unique sources, organized by residue, composition, process, product, performance and application (1,7).

Traceability was verified using the source consistency index (SCI), defined as:

$$ICF_k = \frac{D_k + T_k + F_k + R_k + E_k}{5} \quad 1)$$

In the equation,  $D_k$  indicated the presence of DOI or persistent identifier;  $T_k$ , the fulfillment of the time interval;  $F_k$ , the final publication in a scientific journal;  $R_k$ , the direct relationship with the object studied; and  $E_k$ , the availability of extractable information. Each component received 0 or 1 and  $ICF_k \geq 0.80$  was required. Forty-one sources reached 1.00; The references (21.31–33) obtained 0.80 for being before 2022, but were retained for their quantitative balances. The ICF evaluated documentary traceability, not risk of bias.

The decision matrix included five criteria: availability, biotechnological potential, product diversity, productive applicability and environmental contribution, taking as reference multi-criteria approaches applied to agricultural waste (34,35). The  $s_{ij}$  scores were assigned on an ordinal scale from 1 to 3 according to Table 1. In the event of insufficient or contradictory evidence, the lower level was adopted.

**Table 1. Criteria and operational rules used for the decision matrix.**

| Criterion                  | 1 = Low                                    | 2 = Medium                               | 3 = High                                                               |
|----------------------------|--------------------------------------------|------------------------------------------|------------------------------------------------------------------------|
| Availability               | Limited, localized or irregular generation | Seasonal or regional generation          | Continuous or high-scale generation, supported by documentation        |
| Biotechnological potential | A preliminary exploitation route           | Two routes or mainly laboratory evidence | Three or more differentiated routes, supported by at least two sources |
| Product diversity          | One product family                         | Two or three product families            | Four or more product families                                          |

| Criterion                  | 1 = Low                    | 2 = Medium                                          | 3 = High                                                                     |
|----------------------------|----------------------------|-----------------------------------------------------|------------------------------------------------------------------------------|
| Productive applicability   | One conceptual application | Application in two sectors or laboratory validation | Documented application in three or more sectors or pilot/productive evidence |
| Environmental contribution | Unproven benefit           | A documented benefit or qualitative evidence        | Two or more benefits supported by at least two sources                       |

**Source: Own elaboration based on multi-criteria and environmental approaches (34,35).**

For diversity, bioethanol, biogas and bioenergy were counted as a family; chitin, chitosan and derived biomaterials were grouped as biopolymers, avoiding duplicating products from the same route.

The scores were normalized in the range of 0 to 1 using the expression:

$$z_{ij} = \frac{s_{ij} - 1}{2} \quad 2)$$

No Delphi queries were performed nor were statistical methods applied to estimate the relative importance of the criteria. Because there was not enough empirical evidence to establish a hierarchy between them, the uniform weighting vector was adopted:

$$w = (0,20; 0,20; 0,20; 0,20; 0,20) \quad 3)$$

The priority index of each residue was calculated by:

$$P_i = \sum_{j=1}^5 w_j z_{ij} \quad 4)$$

High priority was established when  $P_i \geq 0.70$ , equivalent to an original score of 12 to 15; medium priority when  $0.30 \leq P_i < 0.70$ , equivalent to 8-11 points; and low priority when  $P_i < 0.30$ , equivalent to 7 points or less.

Stability was examined with 10,000 iterations and seed 20260714. Weights were generated uniformly between 0.16 and 0.24 and renormalized to sum to 1. The procedure was run in Python 3.12.13 with NumPy 2.3.5.

Finally, a comparative matrix was prepared that related each biomass to its transformation route, product and application. The priority was established based on documented availability, biotechnological potential, applicability and environmental contribution, within a circular economy perspective (1,7,34,35).

## RESULTS

The agro-industrial waste analyzed does not follow the same pattern compared to the available biotechnological recovery routes. What determines the potential of each material is its composition, the regularity with which it is generated within the production chain and the quantity of products that can be derived from it. Based on this logic, the reviewed waste was grouped into three categories: lignocellulosic materials, waste with relevant functional content and by-products of aquaculture origin that can be directed towards biopolymers.

Within the first group were cane bagasse, rice husks and straw, banana pseudostems and rachis, and corn residues. They all share a matrix based on cellulose, hemicellulose and lignin, suitable for fermentation, hydrolysis, anaerobic digestion and production of biodegradable materials. Their abundance and low cost are advantages, but they typically require pretreatments to release fermentable sugars and improve enzymatic or microbial action (1,4,7,11–13,30).

Cocoa and citrus residues made up the second group. Its peels, mucilage and albedos contain pectins, phenolic compounds, fermentable sugars and antioxidant fractions that allow obtaining functional ingredients and agri-food products (14,15,24,25,36,37). In Ecuador, cocoa shell and mucilage deserve attention due to their availability in producing areas and due to the evidence on fermentation and circular bioeconomy (14,22,38).

The third group corresponded to shrimp waste. Chitin, proteins and minerals guide them towards chitosan, protein hydrolysates and biomaterials. The processes of demineralization, deproteinization, and deacetylation differ from the energetic fermentation of lignocellulosic materials, and their products have applications in agriculture, food, and water treatment (16–19).

**Table 2. Biotechnological routes identified for Ecuadorian agroindustrial waste.**

| String productive | Residue main                | Composition predominant                       | Biotechnological route possible                                    | Product expected                                            | Application end                                 |
|-------------------|-----------------------------|-----------------------------------------------|--------------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------|
| Banana            | Pseudostem, rachis and peel | Fiber, cellulose, hemicellulose and sugars    | Fermentation, hydrolysis and anaerobic digestion                   | Biofertilizers, bioethanol, biogas, fibers and biomaterials | Agriculture, energy and biodegradable materials |
| Cocoa             | Shell and mucilage          | Fiber, phenolic compounds, sugars and pectins | Fermentation, extraction of functional compounds and bioconversion | Antioxidants, bio-inputs, pectin and fermented products     | Agribusiness, food and agriculture              |

| String productive | Residue main                               | Composition predominant                              | Biotechnological route possible                                                 | Product expected                                        | Application end                       |
|-------------------|--------------------------------------------|------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------|---------------------------------------|
| Rice              | Husk and straw                             | Lignocellulose, silica and fiber                     | Pretreatment, fermentation, anaerobic digestion and thermobiological conversion | Bioenergy, biochar, adsorbent materials and substrates  | Energy, environment and agriculture   |
| Sugar cane        | Bagasse and cachaça                        | Lignocellulose, residual sugars and organic matter   | Hydrolysis, fermentation and enriched composting                                | Bioethanol, enzymes, biofertilizers and energy          | Energy, agriculture and industry      |
| Corn              | Stubble, stubble and processing waste      | Lignocellulose and residual starches                 | Saccharification, fermentation and composting                                   | Bioethanol, organic acids and biofertilizers            | Energy, agriculture and bioprocesses  |
| Citrus            | Peel and albedo                            | Pectin, essential oils, fiber and phenolic compounds | Extraction, fermentation and hydrolysis                                         | Pectin, antioxidants, essential oils and bioethanol     | Food, agribusiness and bioproducts    |
| Shrimp            | Exoskeletons, heads and processing remains | Chitin, proteins and minerals                        | Demineralization, deproteinization, deacetylation and hydrolysis                | Chitin, chitosan, protein hydrolysates and biomaterials | Agriculture, food and water treatment |

**Source: Own elaboration based on bibliographic review (12–18,21–30,36–43).**

Table 2 confirms that there is no single valuation path. Banana, cane, rice and corn converge in lignocellulosic use; cocoa and citrus allow the recovery of functional compounds and pectins; and shrimp is oriented towards biopolymers. This differentiation forces each biomass to be related to the process it can sustain according to its composition (4,11–18,22,24,25,27–30,36–38).

To complement this qualitative comparison, a theoretical-documentary mass balance per ton of waste was constructed. In the lignocellulosic routes, the theoretical mass of ethanol was estimated by the expression:

$$m_{\text{EtOH,teórico}} = M(0,568f_C + 0,581f_H) \quad 5)$$

where M represents the dry mass of the residue and  $f_C$  and  $f_H$  correspond to the mass fractions of cellulose and hemicellulose. The coefficients 0.568 and 0.581 are obtained by considering the stoichiometric hydration of glucan to glucose (180/162) and of xylan

to xylose (150/132), followed by the theoretical yield of 0.511 kg of ethanol per kilogram of monosaccharide. The effective yield was expressed as:

$$m_{\text{EtOH,efectivo}} = m_{\text{EtOH,teórico}} \times \eta_p \times \eta_h \times \eta_f \quad 6)$$

where  $\eta_p$ ,  $\eta_h$  and  $\eta_f$  represent the efficiencies of pretreatment, hydrolysis and fermentation. To convert the mass of ethanol to volume, a density of 0.789 kg L<sup>-1</sup> was used. In cocoa mucilage, the conversion of directly fermentable sugars was considered. For pectin and chitosan, the following was applied:

$$m_{\text{producto}} = M \times Y_{\text{extracción}} \quad 7)$$

The equations were used as a theoretical reference; The values in Table 3 correspond to performances documented in the original sources (14,19,20,30–33,44,45).

Because the publications did not provide equivalent time profiles for all seven chains, it was not possible to calculate a common kinetic constant. When the studies reported the final concentration and processing time, an average productivity was calculated using:

$$Q_P = \frac{C_P}{t} \quad 8)$$

In the other cases, the overall yield per unit of residue was maintained, without assuming kinetic behaviors that had not been demonstrated experimentally.

**Table 3. Mass balances and documentary yields by agroindustrial chain.**

| Chain  | Base of the balance     | Condition processing                                                  | Performance documented                                                                                              | Equivalent per ton          | Main limitation                                                                                                     |
|--------|-------------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-----------------------------|---------------------------------------------------------------------------------------------------------------------|
| Banana | 1 t of dried pseudostem | Simultaneous saccharification and fermentation for approximately 72 h | 112 L of ethanol t <sup>-1</sup> ; approximate specific productivity of 1.56 L t <sup>-1</sup> h <sup>-1</sup> (20) | 112 L or 88.4 kg of ethanol | The high humidity of the fresh pseudostem increases the mass transported and the energy required for stabilization. |

| Chain         | Base of the balance                                                | Condition processing                                                                         | Performance documented                                                                                                                           | Equivalent per ton                                              | Main limitation                                                                            |
|---------------|--------------------------------------------------------------------|----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| Cocoa         | 1 t of fresh mucilage; approximate density of 1 kg L <sup>-1</sup> | Fermentation with <i>Saccharomyces cerevisiae</i> at 25 °C for 96 h                          | 71.91 g L <sup>-1</sup> ethanol; average productivity of 0.75 g L <sup>-1</sup> h <sup>-1</sup> (14)                                             | Approximately 71.9 kg or 91 L of ethanol                        | The concentration of sugars changes with the variety, maturity and post-harvest handling.  |
| Rice          | 1 t dry straw                                                      | Combined pretreatment, enzymatic hydrolysis and fermentation                                 | 214 mg ethanol g <sup>-1</sup> biomass and bioconversion efficiency of 72.5 % (33)                                                               | 214 kg or approximately 271 L of ethanol                        | The presence of silica and lignin determines the efficiency of the pretreatment.           |
| Sugar cane    | 1 t of dried bagasse                                               | Acid pretreatment, hydrolysis and fermentation of C5 and C6 sugars                           | 191.96 kg of ethanol; pentose fermentation yield of 86.11% (44)                                                                                  | 243.3 L ethanol                                                 | The balance depends on the recovery and co-fermentation of hexoses and pentoses.           |
| Corn          | 1 t of dry stubble                                                 | Pretreatment, saccharification and fermentation                                              | 480 L t <sup>-1</sup> theoretical maximum; 240 L t <sup>-1</sup> as a process estimate and 45 L t <sup>-1</sup> in an experimental study (31,45) | Between 45 and 240 L compared to a theoretical maximum of 480 L | The yield changes with the cultivar, humidity, harvest and hydrolysis efficiency.          |
| Citrus fruits | 1 t of pulverized dry peel                                         | Acid extraction at 80 °C, pH 2, for 90 min                                                   | 21.63% pectin in orange peel and 32.53% in lime peel (32)                                                                                        | Between 216 and 325 kg of pectin                                | The yield depends on species, maturity, drying, acid and extraction time.                  |
| Shrimp        | 1 t of dried exoskeleton                                           | Demineralization, deproteinization and deacetylation; approximately 52 h of chemical contact | 13.96 % chitosan relative to the dry shell (19)                                                                                                  | 139.6 kg per dry ton                                            | The species, humidity, mineral content and degree of deacetylation affect the performance. |

**Source: Own elaboration based on experimental results and documentary balances (14,19,20,31–33,44,45).**

The balance sheets show that a high stoichiometric potential does not ensure an equivalent effective performance. In lignocellulosics, losses during pretreatment, hydrolysis and fermentation explain the distance between the theoretical maximum and the recovered product. 112 L of ethanol per dry ton of banana pseudostem, 243.3 L t<sup>-1</sup> of sugarcane bagasse and approximately 271 L t<sup>-1</sup> of rice straw were documented (20,33,44).

The difference was greater for corn: compared to a theoretical maximum of 480 L t<sup>-1</sup> of dry stubble, the process estimates and the revised experimental result were 240 and 45 L t<sup>-1</sup>, respectively (31,45). For other chains, cocoa mucilage produced 71.91 g L<sup>-1</sup> of ethanol after 96 h; dried citrus peel allowed recovery of 216–325 kg of pectin per ton; and the dry shrimp exoskeleton reached 139.6 kg t<sup>-1</sup> of chitosan (14,19,32).

To organize this information and establish priorities, the decision matrix defined in the methodology was applied, evaluating five criteria per residue: availability, biotechnological potential, product diversity, productive applicability and environmental contribution. The normalized results are shown in Tables 4a and 4b.

**Table 4a. Scoring of the criteria for prioritizing Ecuadorian agroindustrial waste.**

| Residue agroindustrial | Available bility | Potential biotechnological | Diversity of products | Applicability productive | Contribution environmental | Score total |
|------------------------|------------------|----------------------------|-----------------------|--------------------------|----------------------------|-------------|
| Banana waste           | 3                | 3                          | 3                     | 3                        | 3                          | 15          |
| Cocoa waste            | 3                | 3                          | 3                     | 3                        | 3                          | 15          |
| Sugar cane waste       | 3                | 3                          | 2                     | 3                        | 3                          | 14          |
| Shrimp waste           | 3                | 3                          | 2                     | 3                        | 3                          | 14          |
| Citrus waste           | 2                | 3                          | 3                     | 3                        | 3                          | 14          |
| Waste rice             | 3                | 2                          | 2                     | 3                        | 3                          | 13          |
| Corn waste             | 2                | 2                          | 2                     | 2                        | 2                          | 10          |

**Table 4b. Normalized index, priority and backup sources per residue.**

| Agroindustrial waste | Pi Index | Priority | Supporting Sources |
|----------------------|----------|----------|--------------------|
| Banana Residues      | 1,00     | High     | (20,21,23,39,40)   |
| Cocoa Residues       | 1,00     | High     | (14,15,22,24)      |
| Sugarcane Residues   | 0,90     | High     | (12,13,26,41,44)   |
| Shrimp Residues      | 0,90     | High     | (16–19)            |
| Citrus residues      | 0,90     | High     | (25,32,36–38)      |
| Rice residues        | 0,80     | High     | (27,33,42,43)      |
| Corn residues        | 0,50     | Medium   | (28–31,43,45)      |

Source: Own elaboration from the sources indicated for each chain

Banana and cocoa topped the classification with 15 points and  $Pi = 1.00$ . Sugar cane, shrimp and citrus reached 14 points and  $Pi = 0.90$ ; rice obtained 13 points and  $Pi = 0.80$ ; and corn was located in medium priority with 10 points and  $Pi = 0.50$ . The scores do not represent national experimental measurements, but rather an ordinal synthesis of the evidence cited in the last column of Table 4b.

The sensitivity analysis maintained the priority category of the seven residues in 100% of the 10,000 iterations. Banana and cocoa remained at  $Pi = 1.00$ ; cane and shrimp varied between 0.868 and 0.926; citrus, between 0.871 and 0.926; rice, between 0.756 and 0.841; and corn remained at  $Pi = 0.50$ . Therefore, the classification was stable against small variations in the weights, although this robustness does not replace technical and economic validation.

Yearly availability is not equivalent to a consistent monthly offer. Corn and citrus have greater seasonality and dispersion; On the other hand, bagasse, rice husks and shrimp exoskeletons are usually concentrated in processing facilities. Humidity, low bulk density, collection distance, and the need for stabilization can reduce the viability of a technically promising route. Therefore, the matrix should be interpreted as an initial technological prioritization and not as a demonstration of profitability.

## DISCUSSION

The results confirm that the biotechnological valorization of Ecuadorian agroindustrial waste cannot be proposed through a uniform route. The potential of each biomass depends on its composition, the way it is generated and the relationship between the

transformation process and the expected product. This interpretation coincides with studies that indicate that waste acquires value when its chemical and structural characteristics are linked to specific technologies and applications (1,2,7–9,34,35). The matrix allowed these differences to be ordered, although its scores should be understood as a documentary prioritization and not as a demonstration of industrial feasibility.

Bananas and cocoa achieved the highest priority, but for different reasons. Banana pseudostems, rachises, and peels combine availability with routes to fibers, nanocellulose, bioenergy, biofertilizers, and biodegradable materials (20,21,23,39,40). However, its lignocellulosic structure requires conditioning, pretreatment and hydrolysis. For reference, one ton of dried pseudostem could generate around 112 L of ethanol through simultaneous saccharification and fermentation (20); This figure should not be applied to fresh material, whose high water content increases transportation and conditioning needs. Cocoa responds to a functional logic: the shell and mucilage contain phenolic compounds, pectins and fermentable sugars (14,15,22,24). In the mucilage, 71.91 g L<sup>-1</sup> of ethanol were reported after 96 h, equivalent to approximately 91 L per fresh ton (14). Its advantage is the direct availability of sugars; Its limitations are microbiological deterioration and composition variability.

Sugarcane and rice also showed high priority, although their use is conditioned by lignocellulosic recalcitrance. For sugarcane bagasse, 191.96 kg of ethanol per dry ton were documented, equivalent to 243.3 L, when hexoses and pentoses are recovered and fermented (44). In rice straw, 214 mg of ethanol per gram, approximately 271 L per dry ton, was recorded after combined pretreatment (33). These yields show the potential of both chains, but depend on the efficiency of pretreatment, hydrolysis, enzyme consumption, and the microbial capacity to use the released fractions (12,13,26,27,33,41–44).

Corn was placed in medium priority because evidence shows a gap between theoretical potential and achievable yield. For dry stubble, a maximum of close to 480 L of ethanol per ton was estimated, compared to a process estimate of approximately 240 L t<sup>-1</sup> and an experimental result of 45 L t<sup>-1</sup> (31,45). These differences respond to the composition, humidity, pretreatment and microorganisms used. Although there are also routes to biosurfactants, cellulosic materials and biohydrogen (28–30,43), it is still necessary to define which waste and process would be most appropriate for Ecuadorian conditions.

Citrus fruits and shrimp show that valorization should not be limited to energy production. The acid extraction of citrus peels allowed the recovery of between 21.63 and 32.53% of pectin on a dry basis, equivalent to 216–325 kg per ton (32), in addition to there being alternatives for essential oils, packaging and functional compounds (25,36–38). In shrimp waste, a chitosan yield of 13.96% was reported with respect to the dry shell, equivalent to 139.6 kg per dry ton (19). However, obtaining it requires demineralization, deproteinization and deacetylation, with consumption of reagents and generation of effluents that must be incorporated into the environmental evaluation (16–19).

The matrix also showed that annual abundance does not equate to operational availability. Corn and citrus fruits have greater seasonality and dispersion, while bagasse, rice husks and shrimp exoskeletons tend to be concentrated in sugar mills, mills or processing plants. Humidity, low bulk density, collection distance, and the need for stabilization can reduce the benefit of a technically viable route (3,5,22,23). This interaction explains why selection must simultaneously consider productive, technological and environmental variables, as proposed by multi-criteria approaches applied to agricultural waste (34,35).

The stability observed in the sensitivity analysis supports the general classification against small variations in the weights, but does not eliminate the limitations of the study. The collected yields come from different experimental conditions and calculation bases, so they function as orders of magnitude and not as industrial predictions for Ecuador. Nor were costs, monthly availability or impacts evaluated through life cycle analysis. Consequently, banana and cocoa constitute initial alternatives of greatest interest, while the implementation of any of the routes must be confirmed with local characterization, mass balances, techno-economic evaluation and laboratory and pilot scale tests.

## CONCLUSIONS

The evaluated Ecuadorian agroindustrial waste does not present a uniform potential for biotechnological recovery. Its use depends on the composition of the material, the regularity with which it is generated, the technological complexity of the transformation route and the type of final product that can be obtained. Lignocellulosic waste, such as sugarcane bagasse, rice husks and straw, banana pseudostems and rachis, show potential for fermentative processes, bioenergy, biofertilizers and biomaterials; However, its transformation may require pretreatments that condition technical and economic feasibility. On the other hand, cocoa and citrus residues are better oriented towards the recovery of functional compounds, pectins, antioxidant fractions and molecules of industrial interest. Shrimp waste follows a different logic, focused on obtaining chitin, chitosan and protein hydrolysates from the exoskeleton.

The decision matrix made it possible to organize dispersed information and establish an initial prioritization based on comparable criteria. Banana and cocoa obtained the highest scores, although for different reasons: banana stood out for its availability, diversity of residual fractions and breadth of possible routes, while cocoa stood out for the functional value of its by-products. Sugar cane, shrimp, citrus fruits and rice were also placed in high priority, but their use requires a more precise selection of the process, the final product and the operating conditions. Corn was classified as medium priority, not due to lack of potential, but due to the need to better define the type of waste, the biotechnological route and the expected application.

The biotechnological valorization of agroindustrial waste should not be interpreted only as a waste management strategy, but as a productive, environmental and technological opportunity within chains already consolidated in the country. However, the abundance of biomass does not by itself guarantee the feasibility of its use. The decision on which

waste to prioritize must also consider transformation barriers, conditioning costs, product stability, potential demand and local processing capabilities.

In this sense, the comparative matrix and the theoretical-documentary balances constructed in this work constitute initial guidance tools to select waste and recovery routes with greater relevance for the Ecuadorian context. The balances allow establishing orders of magnitude for bioethanol, pectin and chitosan, but should not be interpreted as yields obtained directly in national facilities. The next steps should focus on trials with waste collected in Ecuador and pilot tests that allow evaluating composition, humidity, effective performance, stability, scalability, collection and operation costs, reagent consumption and environmental impact of the prioritized routes.

## REFERENCES

1. Prado-Acebo I, Cubero-Cardoso J, Lu-Chau TA, Eibes G. Integral multi-valorization of agro-industrial wastes: A review. *Waste Management*. 2024 Jun 30;183:42–52. doi:10.1016/j.wasman.2024.05.001
2. Bala S, Garg D, Sridhar K, Inbaraj BS, Singh R, Kamma S, et al. Transformation of Agro-Waste into Value-Added Bioproducts and Bioactive Compounds: Micro/Nano Formulations and Application in the Agri-Food-Pharma Sector. *Bioengineering*. 2023 Feb;10(2):152. doi:10.3390/bioengineering10020152
3. Weldesemayat Sileshi G, Barrios E, Lehmann J, Tubiello FN. An organic matter database (OMD): consolidating global residue data from agriculture, fisheries, forestry and related industries. *Earth System Science Data*. 2025 Feb 3;17(2):369–91. doi:10.5194/essd-17-369-2025
4. Escudero-Curiel S, Giráldez A, Pazos M, Sanromán Á. From Waste to Resource: Valorization of Lignocellulosic Agri-Food Residues through Engineered Hydrochar and Biochar for Environmental and Clean Energy Applications—A Comprehensive Review. *Foods*. 2023 Jan;12(19):3646. doi:10.3390/foods12193646
5. Bermúdez JMS, Varela GAZ, Cedeño REC, Riera MA. Estudio de residuos biomásicos agrícolas para la instalación de una biorefinería de pequeña escala. *La Granja*. 2025 Aug 26;42(2):136–53. doi:10.17163/lgr.n42.2025.09
6. Nicolás García M, Borrás Enríquez A, González Escobar J, Calva Cruz O, Pérez Pérez V, Sánchez Becerril M. Phenolic Compounds in Agro-Industrial Waste of Mango Fruit: Impact on Health and Its Prebiotic Effect – a Review. *Pol J Food Nutr Sci*. 2023 Feb 21;5–23. doi:10.31883/pjfn/159361
7. Ezeorba TPC, Okeke ES, Mayel MH, Nwuche CO, Ezike TC. Recent advances in biotechnological valorization of agro-food wastes (AFW): Optimizing integrated approaches for sustainable biorefinery and circular bioeconomy. *Bioresource Technology Reports*. 2024 Jun 1;26:101823. doi:10.1016/j.biteb.2024.101823
8. Burbano-Cuasapud JM, Solarte-Toro JC, Restrepo-Serna DL, Cardona Alzate CA. Process Sustainability Analysis of Biorefineries to Produce Biofertilizers and Bioenergy from Biodegradable Residues. *Fermentation*. 2023 Sep;9(9):788. doi:10.3390/fermentation9090788
9. Yafetto L, Odamtten GT, Wiafe-Kwagyan M. Valorization of agro-industrial wastes into animal feed through microbial fermentation: A review of the global and

- Ghanaian case. Heliyon. 2023 Apr 1;9(4):e14814. doi:10.1016/j.heliyon.2023.e14814
10. Sundaram T, Govindarajan RK, Vinayagam S, Krishnan V, Nagarajan S, Gnanasekaran GR, et al. Advancements in biosurfactant production using agro-industrial waste for industrial and environmental applications. *Front Microbiol.* 2024 Feb 5;15:1357302. doi:10.3389/fmicb.2024.1357302
  11. Jayanthi B, Vinoth S, Hariharan M, Raja RK, Kamaraj C, Narayanan M. Valorization of agro-industry wastes for nanocellulose fabrication and its multifunctional applications. *Biocatalysis and Agricultural Biotechnology.* 2024 Apr 1;57:103124. doi:10.1016/j.bcab.2024.103124
  12. Matsueda Y, Antunes E. A review of current technologies for the sustainable valorisation of sugarcane bagasse. *Journal of Environmental Chemical Engineering.* 2024 Dec 1;12(6):114900. doi:10.1016/j.jece.2024.114900
  13. Kamboj A, Sadh PK, Yadav B, Kumari A, Kumar R, Surekha, et al. Unravelling the potential of sugarcane bagasse: An eco-friendly and inexpensive agro-industrial waste for the production of valuable products using pretreatment processes for sustainable bio-economy. *Journal of Environmental Chemical Engineering.* 2024 Dec 1;12(6):114461. doi:10.1016/j.jece.2024.114461
  14. Zambrano A, Cobos V, Luna T, Duarte J, Barzallo D. Optimization of Bioethanol Production from Cocoa Mucilage (*Theobroma cacao*) Using a Commercial and a Genetically Modified Strain of *Saccharomyces cerevisiae*. *International Journal of Agriculture and Biosciences.* 2026 Feb 12. doi:10.47278/journal.ijab/2026.039
  15. Guzmán-Armenteros TM, Guerra LS, Ruales J, Ramos-Guerrero L. Ecuadorian Cacao Mucilage as a Novel Culture Medium Ingredient: Unveiling Its Potential for Microbial Growth and Biotechnological Applications. *Foods.* 2025 Jan;14(2):261. doi:10.3390/foods14020261
  16. Pérez WA, Marín JA, López JN, Burgos MA, Rios LA. Development of a Pilot-ecofriendly Process for Chitosan Production from Waste Shrimp Shells. *Environmental Processes.* 2022 Sep 2;9(3):55. doi:10.1007/s40710-022-00605-8
  17. Lakshmi DS, Ravindran L, Mary PJM, Rathika G, Sreekala MS, Munisamy S. Valorization of Crustacean Shells: Preparation, Characterization, and Chemical Modification of Nano-Chitin Biopolymer Membrane for Application in Water Purification. *Waste Biomass Valor.* 2024 Nov 1;15(11):6067–90. doi:10.1007/s12649-024-02601-5
  18. Bautista-Hernández I, Gómez-García R, Martínez-Ávila GCG, Pintado M. Solid state fermentation (SSF) on marine biomasses and their by-products - a new research biorefinery frontier for the obtention of innovative and novel value-added compounds towards industrial applications. *Journal of Environmental Management.* 2026 Jun 15;410:129973. doi:10.1016/j.jenvman.2026.129973
  19. Aberoumand A, Chabavi M. Extraction and Quality Control of Chitin and Chitosan from Shrimp (Vanami) *Litopenaeus Vanamei* Shells Wastes. *Natural Product Communications.* 2024 Oct 1;19(10):1934578X241291383. doi:10.1177/1934578X241291383
  20. Guerrero AB, Ballesteros I, Ballesteros M. The potential of agricultural banana waste for bioethanol production. *Fuel.* 2018 Feb 1;213:176–85. doi:10.1016/j.fuel.2017.10.105

21. Kumar V, Chakraborty P, Janghu P, Umesh M, Sarojini S, Pasrija R, et al. Potential of banana based cellulose materials for advanced applications: A review on properties and technical challenges. *Carbohydrate Polymer Technologies and Applications*. 2023 Dec 1;6:100366. doi:10.1016/j.carpta.2023.100366
22. Alava C, Moncayo S, Galarza L. Cocoa husk in the circular bioeconomy: a perspective from Ecuador and other producer countries. *Front Food Sci Technol*. 2025 Dec 18;5. doi:10.3389/frfst.2025.1726187
23. Hazarika U, Saikia P, Choudhury M, Das M. Unlocking the potential of banana peel waste – A multi-faceted review emphasizing its nutrient profile, extraction strategies, and prospective utility within the context of circular waste bioeconomy. *Applied Food Research*. 2026 Jun;6(1):101675. doi:10.1016/j.afres.2026.101675
24. Sánchez M, Laca A, Laca A, Díaz M. Cocoa Bean Shell: A By-Product with High Potential for Nutritional and Biotechnological Applications. *Antioxidants*. 2023 May;12(5):1028. doi:10.3390/antiox12051028
25. Sharma P, Vishvakarma R, Gautam K, Vimal A, Kumar Gaur V, Farooqui A, et al. Valorization of citrus peel waste for the sustainable production of value-added products. *Bioresource Technology*. 2022 May 1;351:127064. doi:10.1016/j.biortech.2022.127064
26. Ntunka MG, Makhathini TP, Khumalo SM, Bwapwa JK, Tshibangu MM. Recent Developments in the Valorization of Sugarcane Bagasse Biomass via Integrated Pretreatment and Fermentation Strategies. *Fermentation*. 2025 Nov;11(11):632. doi:10.3390/fermentation11110632
27. Li Z, Zheng Z, Li H, Xu D, Li X, Xiang L, et al. Review on Rice Husk Biochar as an Adsorbent for Soil and Water Remediation. *Plants*. 2023 Jan;12(7):1524. doi:10.3390/plants12071524
28. Nunes HMAR, Vieira IMM, Santos BLP, Silva DP, Ruzene DS. Biosurfactants produced from corncob: a bibliometric perspective of a renewable and promising substrate. *Preparative Biochemistry & Biotechnology*. 2022 Feb 1;52(2):123–34. doi:10.1080/10826068.2021.1929319 PubMed PMID: 34081569.
29. Gutiérrez P, Aldas M, Gavilanes D, Cadena F, Valle V. Corn cob valorization: Synthesis of a polymer based on crystalline cellulose with poly(ethylene glycol) diacrylate and N-vinylcaprolactam. *Cleaner Engineering and Technology*. 2025 Jul;27:101019. doi:10.1016/j.clet.2025.101019
30. Aghaei S, Karimi Alavijeh M, Shafiei M, Karimi K. A comprehensive review on bioethanol production from corn stover: Worldwide potential, environmental importance, and perspectives. *Biomass and Bioenergy*. 2022 Jun 1;161:106447. doi:10.1016/j.biombioe.2022.106447
31. Mensah MB, Jumpah H, Boadi NO, Awudza JAM. Assessment of quantities and composition of corn stover in Ghana and their conversion into bioethanol. *Scientific African*. 2021 Jul;12:e00731. doi:10.1016/j.sciaf.2021.e00731
32. Akhter MostJ, Sarkar S, Sharmin T, Mondal SC. Extraction of pectin from powdered citrus peels using various acids: An analysis contrasting orange with lime. *Applied Food Research*. 2024 Dec;4(2):100614. doi:10.1016/j.afres.2024.100614
33. Sawhney D, Vaid S, Bangotra R, Sharma S, Dutt HC, Kapoor N, et al. Proficient bioconversion of rice straw biomass to bioethanol using a novel combinatorial pretreatment approach based on deep eutectic solvent, microwave irradiation

- and laccase. *Bioresour Technol.* 2023 May;375:128791. doi:10.1016/j.biortech.2023.128791 PubMed PMID: 36871702.
34. Lombardi P, Todella E. Multi-Criteria Decision Analysis to Evaluate Sustainability and Circularity in Agricultural Waste Management. *Sustainability.* 2023 Jan;15(20):14878. doi:10.3390/su152014878
35. Orlandella I, Fiore S. Life Cycle Assessment of the Production of Biofertilizers from Agricultural Waste. *Sustainability.* 2025 Jan;17(2):421. doi:10.3390/su17020421
36. Frosi I, Balduzzi A, Moretto G, Colombo R, Papetti A. Towards Valorization of Food-Waste-Derived Pectin: Recent Advances on Their Characterization and Application. *Molecules.* 2023 Jan;28(17):6390. doi:10.3390/molecules28176390
37. Díaz-Muñoz LL, Castañeda-Aude JE, Landín-Sandoval VJ, Lozano-Álvarez JA, Escárcega-González CE. Valorization and Harnessing Citrus Waste: Focus on Green Synthesis of Metal Nanoparticles with Antimicrobial Applications and Other Potential Uses. *Food Reviews International.* 2026 Mar 31;42(4):2116–61. doi:10.1080/87559129.2025.2541849
38. Revathi V, Bora S, Afzia N, Ghosh T. Orange peel composition, biopolymer extraction, and applications in paper and packaging sector: A review. *Sustainable Chemistry and Pharmacy.* 2025 Feb 1;43:101908. doi:10.1016/j.scp.2025.101908
39. Fiallos-Cardenas M, Gavin C, Huilcarema-Enríquez K, Cumbicus-Bravo A, Pozo F. Innovation in obtaining bacterial nanocellulose from banana rachis: Effects of ozone treatment. *Case Studies in Chemical and Environmental Engineering.* 2025 Jun;11:101044. doi:10.1016/j.csee.2024.101044
40. Romero-Cárdenas E, Romero-Romero BR, Tapia-Núñez DW, Zúñiga-Santillán XL, Valenzuela-Cobos JD. Sustainable paper from agricultural residues: differentiating treatment effects in banana pseudostem fibers using X-STATIS multiblock analysis. *Front Sustain.* 2025 Jul 23;6:1628095. doi:10.3389/frsus.2025.1628095
41. Pérez-Contreras S, Hernández-Rosas F, Lizardi-Jiménez MA, Herrera-Corredor JA, Baltazar-Bernal O, Avalos-de la Cruz DA, et al. Sugarcane Industry By-Products: A Decade of Research Using Biotechnological Approaches. *Recycling.* 2025 Aug;10(4):154. doi:10.3390/recycling10040154
42. Liang D, Wei C, Liu D, Liu X, Xiao S, Wang Y, et al. Research Progress Review on the Activation of Bioactive Substances by Targeted Fermentation of Rice Bran. *Foods.* 2026 Jan;15(11):1881. doi:10.3390/foods15111881
43. Prado ERL, Rial RC. Biohydrogen production from residual biomass: The potential of wheat, corn, rice, and barley straw – recent advances. *Bioresource Technology.* 2025 Sep 1;432:132638. doi:10.1016/j.biortech.2025.132638
44. Dionísio SR, Santoro DCJ, Bonan CIDG, Soares LB, Biazzi LE, Rabelo SC, et al. Second-generation ethanol process for integral use of hemicellulosic and cellulosic hydrolysates from diluted sulfuric acid pretreatment of sugarcane bagasse. *Fuel.* 2021 Nov 1. doi:10.1016/j.fuel.2021.121290
45. Kadam KL, McMillan JD. Availability of corn stover as a sustainable feedstock for bioethanol production. *Bioresour Technol.* 2003 May;88(1):17–25. doi:10.1016/s0960-8524(02)00269-9 PubMed PMID: 12573559.

# IMPACTO DE LA INTELIGENCIA ARTIFICIAL GENERATIVA EN LOS PROCESOS DE ENSEÑANZA- APRENDIZAJE Y EL DESARROLLO DE COMPETENCIAS EN EDUCACIÓN SUPERIOR: REVISIÓN SISTEMÁTICA Y METAANÁLISIS

## THE IMPACT OF GENERATIVE ARTIFICIAL INTELLIGENCE ON TEACHING AND LEARNING PROCESSES AND SKILL DEVELOPMENT IN HIGHER EDUCATION: A SYSTEMATIC REVIEW AND META-ANALYSIS

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**RESUMEN:** La inteligencia artificial generativa (IAGen) ha emergido como una de las innovaciones tecnológicas que mayor potencial transformador presenta para la educación superior en la última década, ofreciendo herramientas de producción de texto, imágenes y código a partir de instrucciones en lenguaje natural. Realizar una síntesis y análisis crítico de la evidencia científica que entre 2016 y 2026 se ha publicado sobre los efectos de la IAGen en los procesos de enseñanza-aprendizaje y en el desarrollo de competencias del alumnado universitario. Se llevó a cabo una revisión sistemática, con un enfoque de metaanálisis siguiendo las guías de PRISMA 2020, en las bases de datos Scopus, Web of Science, SciELO y ERIC. Se completó con un total de 27 fuentes publicadas en revistas de alto impacto, que incluían revisiones sistemáticas, metaanálisis y estudios empíricos. La evidencia agregada muestra un efecto positivo de la IAGen con una magnitud moderada-alta en relación con el rendimiento académico, con tamaños de los efectos que oscilan entre  $g = 0,57$  (mediados por diseño experimental) y  $g = 1,14$  (mediados por el diseño explícito de una disciplina). Se encontraron efectos positivos consistentes para la personalización del aprendizaje, el feedback inmediato y el desarrollo de competencias digitales, junto con efectos negativos que afectan a la integridad académica, a la dependencia cognitiva y a la brecha digital institucional. La IAGen se convierte en una herramienta pedagógica de alto potencial si es implementada junto con acompañamiento docente, marcos de ética claros y estrategias de evaluación auténtica; su implementación sin

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estos acompañamientos puede reducir el pensamiento crítico y la integridad académica del alumnado universitario.

**Palabras clave:** *Inteligencia artificial, aprendizaje, educación superior, competencias, revisión sistemática*

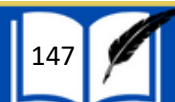
**ABSTRACT:** Generative artificial intelligence (GAI) has emerged over the past decade as one of the technological innovations with the greatest transformative potential for higher education, offering tools for generating text, images, and code based on natural language instructions. To conduct a synthesis and critical analysis of the scientific evidence published between 2016 and 2026 on the effects of GAI on teaching-learning processes and on the development of university students' competencies. A systematic review with a meta-analysis approach was conducted, following the PRISMA 2020 guidelines, in the Scopus, Web of Science, SciELO, and ERIC databases. A total of 27 sources published in high-impact journals were included, comprising systematic reviews, meta-analyses, and empirical studies. The aggregate evidence shows a positive effect of IAGen with a moderate-to-high magnitude on academic performance, with effect sizes ranging from  $g = 0.57$  (mediated by experimental design) to  $g = 1.14$  (mediated by the explicit design of a discipline). Consistent positive effects were found for personalized learning, immediate feedback, and the development of digital competencies, along with negative effects on academic integrity, cognitive dependence, and the institutional digital divide. IAGen becomes a pedagogical tool with high potential when implemented alongside faculty support, clear ethical frameworks, and authentic assessment strategies; its implementation without these supporting measures may reduce critical thinking and academic integrity among college students.

**Keywords:** *Artificial intelligence, learning, higher education, competencies, systematic review*

## INTRODUCTION

The introduction of artificial intelligence (AI) systems in educational contexts is not a new phenomenon since 1960, when intelligent tutoring applications were already developed that sought to adapt teaching and, at the same time, automate evaluation procedures. Notwithstanding the above, reality took a spectacular and radical turn starting in 2022 with the arrival of large-scale language models capable of original generation of text, images, audio and code from instructions formulated using natural language, thus establishing the framework of generative artificial intelligence (IAGen). In this sense, tools such as ChatGPT, Gemini, Copilot or Claude have gone from being technological curiosities to being elements of daily use in university classrooms in just three years, which has conditioned an urgent reaction from the international scientific community to address their pedagogical, ethical and cognitive implications.(1)(2)(3)

At the international level, different systematic reviews agree that IAGen has great possibilities of transforming university teaching since it optimizes the creation of



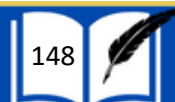
teaching materials for different learning rates, allows the generation of immediate feedback systems and offers the possibility of accessing academic help outside of class hours. A bibliometric analysis of more than three hundred articles indexed in Scopus showed that, from 2017 to 2023, scientific production on IAGen in higher education multiplied by more than seven, with scientific publications presenting three main thematic lines: academic integrity, personalization of learning and intelligent tutoring systems. Following a similar line, an article that explored the challenges and opportunities of the IAGen from the perspective of university professors demonstrated that its pedagogical value depends, to a large extent, on the existence of clear institutional policies and their level of digital literacy.(4)(5)(6)

Going from general to specific, the most recent empirical evidence has begun to narrow down the mechanisms by which IAGen affects learning. From a review of the aspect of the responses, attitudes and behaviors of students towards these types of tools, it was found that, although the majority of students perceive a beneficial effect in the understanding of complex content, there remains a tension between the instrumental use of AI as a cognitive aid and its substitute use, a risk for the autonomous elaboration of knowledge; A systematic review study in the Latin American field of digital transformation of higher education found that one hundred and twenty-nine investigations document improvements in the personalization of teaching and the efficiency of administrative processes, but are also aware of the technological infrastructure gaps that persist between public and private institutes.(7)(8)

The construction of competencies is the other axis of the discussion. Different authors point out that the IAGen can represent a scaffolding of thinking that can promote critical thinking, problem-solving and written communication skills when it is consciously applied within a curricular design; on the contrary, the unguided use of the IAGen generates a cognitive dependency that slows down reflection and self-regulation of learning. This tension of empowerment or substitution structures the axis of the debate that is currently taking place on the inclusion of the IAGen in the field of university education.(9)(10)(11)

An element that runs through it is academic integrity. Recent studies warn that the ease with which IAGen produces coherent and structured text increases the risk of disguised plagiarism practices, and an emerging form of academic dishonesty designated by some authors as "IA-plagiarism". In the Ecuadorian environment in this case, a study that included a sample of 4, 8, 11 students from eight universities determined the existence of a statistically significant association between trust in the information generated by ChatGPT and the amount of self-reported plagiarism, in the same way that greater critical knowledge regarding the limitations of IAGen tools was associated with academic behaviors of greater responsibility. The above emphasizes that the impact of IAGen is not produced by the technology itself, but depends on the digital and ethical education one has to use it.(12)(13)

Despite the increase in primary research, the available evidence is poorly corroborated because it is divided between case studies, perception surveys and short-term trials with little integration based on the reported effect size.



Evidence of its need is given by various authors at the same time that this evidence would need to be systematized through replicable procedures that allow estimating the real magnitude of the effect of the IAGen on learning beyond the subjective assessments of teachers and students. Likewise, there is little evidence of standard institutional frameworks on the use of this type of tools, which makes it difficult to compare results between different university contexts.(14)(15)

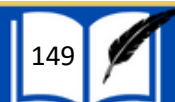
In summary, the justification of the present review consists of: i) offering the academic community a rigorous and updated synthesis that accounts, through systematic procedures, for the scattered evidence on the effects of IAGen on university learning; ii) the convenience of identifying both the pedagogical opportunities it offers and its ethical and cognitive risks so that the results can guide the development of institutional policies and teaching actions based on evidence, and iii) the limited availability of reviews that quantitatively integrate the effect sizes reported in recent literature, which hinders the possibility of making decisions on the part of academic authorities and teaching bodies. In accordance with the above, we constructed the following justification for the present study: the objective of our review was to analyze, using a systematic meta-analysis type review, the impact of generative artificial intelligence on the teaching-learning processes and development of competencies of university students from the indexed scientific evidence that emerged between 2016 and 2026.

## MATERIALS AND METHODS

The present work was developed within the framework of a bibliographic-documentary approach in its quantitative aspect, corresponding to a systematic review with part of a meta-analysis; The guidelines of the PRISMA 2020 declaration (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) were followed, an internationally recognized methodological instrument as a guarantee of transparency, replicability and the level of rigor in the processes of identification, selection, evaluation and synthesis of scientific evidence. This design option responds appropriately to the fact that it does not comment on the collection of primary data, but rather on the critical analysis and quantitative integration of the results obtained in already published indexed sources.

The reference population was composed of the indexed scientific production on generative artificial intelligence in higher education between the months of January 2016 and July 2026. After the detection, screening and eligibility evaluation phase, a final sample was established consisting of 27 sources such as systematic reviews, meta-analysis, quantitative empirical studies and normative reference documents (framework of teaching digital competencies) all published in journals indexed in Scopus, in Web of Science or in SciELO or in equivalent bases.

The search was carried out in a digital documentary environment using access to internationally recognized academic databases such as Scopus, Web of Science, SciELO, ERIC and open access institutional repositories (PubMed Central, ScienceDirect, SpringerLink, MDPI, Taylor & Francis Online). Considering that there was no field work listing information or direct intervention on human beings, this study did not require approval from a human research ethics committee.

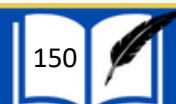


The interest in the variables revolved around two fundamental dimensions: (a) the impact of IAGen on academic performance and the learning process itself, ATOMIZED through the effect sizes presented (Hedges'  $g$ ) in the included studies, both primary and meta-analyses; and (b) the development of competencies such as the changes recorded in critical thinking, digital competence, self-regulation of one's own learning and academic integrity. Moderating variables such as academic discipline, duration of the intervention and the methodological design of the primary studies were also extracted.

Taking into account that the sample used in the present synthesis included already published meta-analyses, a second-order synthesis (meta-analysis synthesis) was chosen, extracting the effect sizes (Hedges'  $g$ ) and the 95% confidence intervals reported in each study, in such a way that an own aggregate model was not calculated or estimated, but rather the double weighting of overlapping primary studies between reviews was avoided. Regarding qualitative and descriptive studies, an inductive thematic analysis of the data was used to identify recurring categories linked to the benefits, risks, or competencies related to the use of the IAGen. The heterogeneity between studies was reviewed narratively, taking into account the differences sustained in the design of the study itself, the discipline, or the duration of the intervention reported by the authors of the studies themselves.

**Table 1. Applied methodology.**

| PRISMA Phase           | Procedure applied                                                                                                                                                                              | Criteria / Tools                                                                                                                  |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| <b>Identification</b>  | Systematic search in Scopus, Web of Science, SciELO and ERIC with the descriptors "generative artificial intelligence" AND "higher education" AND "learning" and their equivalents in Spanish. | 547 records identified (2016-2026); boolean operators AND/OR; language filters (Spanish/English).                                 |
| <b>Screening</b>       | Removal of duplicates and review of titles and abstracts according to predefined inclusion and exclusion criteria.                                                                             | 198 duplicate records removed; 349 evaluated by title/abstract.                                                                   |
| <b>Eligibility</b>     | Full text reading of the preselected studies to verify thematic relevance, methodological rigor and affiliation to indexed journals.                                                           | 61 articles evaluated in full text; Studies without peer review, thematic duplicates, and one retracted article were excluded.    |
| <b>Inclusion</b>       | Final selection of sources that met all quality and indexing criteria.                                                                                                                         | 27 sources included: 8 systematic reviews/meta-analyses, 15 empirical studies and 4 normative or theoretical reference documents. |
| <b>Data extraction</b> | Standardized recording of author, year, country, design, sample size, effect size and main findings in an emptying matrix.                                                                     | Structured spreadsheet; double cross-checking of the extracted data.                                                              |
| <b>Synthesis</b>       | Narrative and quantitative integration (synthesis of effect sizes) organized by thematic axes: academic performance, competencies and ethical risks.                                           | Inductive thematic analysis; comparison of effect sizes between meta-analyses.                                                    |



The table summarizes the methodological flow followed according to the PRISMA 202018 diagram, for which it was constructed from the initial identification of 547 records to the inclusion of 27 relevant sources that met the quality, indexing and thematic relevance criteria. This systematic and structured procedure made it possible to minimize selection bias and guarantee that the synthesized evidence came from publications that had been subjected to peer review, explicitly excluding an article whose retraction status was verified during the eligibility phase. It was proposed that a combination of narrative analysis and synthesis of effect sizes was the most appropriate measure given that the sample included previous meta-analyses with only partially overlapping samples, which could have led to double counting bias if a single overall aggregate effect had been estimated.

## RESULTS

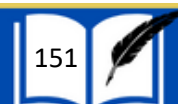
The results of the systematic review presented here are grouped into three axes, which include: (a) the effect of generative artificial intelligence on academic performance, the data for which were synthesized from the meta-analyses that have been included; (b) the competencies that have been affected or developed by its use; and (c) the ethical risks and challenges that already appear in the reviewed literature. All tables will be accompanied by an interpretive analysis rooted in the evidence reviewed.

### Effect of the IAGen on academic performance

Before presenting the quantitative data, it is pertinent to comment that the meta-analyses in this review are characterized by the different numbers of primary studies that comprise them, as well as by the chronological and disciplinary range, which will explain the variability that appears in the effect sizes. In summary, Table 1 presents the results of a total of five meta-analyses published between 2024 and 2026 that evaluated the effect of ChatGPT and related tools on learning indicators in higher education.(16)(17)

**Table 2. Synthesis of effect sizes reported in meta-analysis on the impact of generative artificial intelligence on university academic performance.**

| Study (year)                                | No. of studies / participants  | Variable evaluated                                    | Effect size (g)              | Interpretation                    |
|---------------------------------------------|--------------------------------|-------------------------------------------------------|------------------------------|-----------------------------------|
| Mo et al. (2025)(16)                        | 66 studies / n.d.              | Undergraduate learning achievement (129 effect sizes) | <b>g = 1.14</b>              | Large effect                      |
| Liu, Zuo, and Lu (2025)(17)                 | 22 studies                     | Overall academic performance                          | <b>g = 0.58</b>              | Moderate effect                   |
| Study of 35 experiments (2022-2024)         | 35 studies / 4193 participants | Cognitive and non-cognitive skills                    | <b>g = 0.67</b>              | Moderate effect                   |
| Perception and attitudes review (2020-2024) | 99 studies                     | Perception and usage behavior                         | <b>Qualitative synthesis</b> | Prevalence of positive perception |



Review of  
teaching  
practice  
(2017-2023)

355 studies

Teaching and  
learning practices

**Qualitative  
synthesis**

Benefits in  
feedback and  
personalization

The content of Table 2 illustrates that there is a trend towards positive effects, reaching medium to high magnitudes with Hedges'  $g$  values ranging from 0.58 to 1.14. The heterogeneity observed from the studies could be explained by the type of course considered, the duration of the intervention more than 5 weeks and the instructional model, considered relevant moderators in the literature. It is worth noting that the meta-analysis with more integrated effect sizes reported the largest effect size, which suggests that the integration of the IAGen in the training process in a sustained and non-punctual manner causes the effect on learning to increase. However, this relationship must be interpreted with caution, given that the primary studies have significant methodological heterogeneity and, in some, absence of randomized control groups.(16)(17)

### Developed competencies and modalities of pedagogical integration

A second axis of analysis focused on identifying which specific competencies of university students are favored through the pedagogical use of the IAGen, as well as the modalities of pedagogical integration that are the most frequent in the reviewed literature, . Table 2 organizes this information based on the frequency with which each competency was reported as benefiting in the included studies.(9)(10)(18)

**Table 3. University competencies associated with the pedagogical use of generative artificial intelligence and its integration modalities.**

| Competence / dimension                            | Pedagogical integration modality                                                   | Relative frequency in the literature |
|---------------------------------------------------|------------------------------------------------------------------------------------|--------------------------------------|
| <b>Teacher and student digital competence</b>     | Training in prompt engineering, critical use of AI tools and algorithmic literacy. | High                                 |
| <b>Feedback and formative assessment</b>          | Automated generation of personalized feedback and adaptive rubrics.                | High                                 |
| <b>Critical thinking and analysis</b>             | Cross-checking AI-generated answers, contrasting with primary sources.             | Medium-high                          |
| <b>Self-regulated learning</b>                    | Use of conversational assistants as scaffolding for task planning.                 | Medium                               |
| <b>Written communication and academic writing</b> | Support in text structuring and style correction, with subsequent teaching review. | Medium-high                          |
| <b>Academic integrity and ethics</b>              | Establishment of declared use and citation policies for AI tools.                  | High (as risk to be mitigated)       |

The results in Table 3 show us that digital competence and formative feedback are the dimensions that are most documented as benefiting from the IAGen, which coincides with what was mentioned in studies that highlight its ability to generate personalized comments on a massive scale without increasing the teaching load proportionally. Self-regulation of learning, on the other hand, shows an intermediate frequency, thus indicating that its development depends to a greater extent on the instructional design than on the autonomous use of the tool by the student 9. Likewise, academic integrity



appears transversally in the literature, not as a competence from which the IAGen generates a direct benefit, but as a dimension that requires explicit pedagogical intervention to avoid its deterioration.(18)(12)(13)

### Risks, challenges and implementation conditions

Finally, the main dangers and institutional requirements were systematized that, according to the evidence reviewed, determine whether the IAGen functions as an enhancer or an impediment to university learning, . Table 4 shows these results and the approximate proportion of studies that show them.(11)(15) (19)

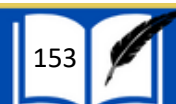
**Table 4. Risks and institutional conditions associated with the implementation of generative artificial intelligence in higher education.**

| Identified risk/challenge                                      | Associated institutional condition                                           | Prevalence in the reviewed studies |
|----------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------|
| <b>Covert plagiarism and academic dishonesty</b>               | Absence of clear institutional policies for the declared use of AI.          | Very high                          |
| <b>Cognitive dependence and decreased reflective effort</b>    | Lack of redesign of evaluation tasks towards authentic formats.              | High                               |
| <b>Institutional digital divide</b>                            | Inequality in access to connectivity and payment tools between universities. | Medium-high                        |
| <b>Insufficient teacher training in AI</b>                     | Limited offer of continuous training on digital skills.                      | High                               |
| <b>Biases and errors in generated content (hallucinations)</b> | Lack of information cross-verification strategies.                           | Medium                             |

Examination of Table 4 shows that the dangers identified are not attributable to the technology itself, but rather that there are no institutional requirements that guide its responsible use. Academic dishonesty and insufficient teaching preparation are the challenges that appear most frequently in the reviewed literature, in line with the evidence, previously discussed in the introduction, which showed that uncritically trusting the information generated by AI results in higher levels of self-reported plagiarism. In summary, the three resulting axes suggest that the impact of the IAGen on university learning is conditional: its pedagogical potential is present when teaching support is provided, explicit institutional policies are established and evaluation strategies are redesigned, while its absence tends to enhance the identified dangers.(13)(20)

## DISCUSSION

The results of the present review corroborate, in general terms, the trend evidenced by the most current international literature: generative artificial intelligence shows a moderate-high positive effect on university academic performance. The highest effect size provided in this synthesis ( $g = 1.14$ ) corresponds to those described by studies addressing the use of ChatGPT in a problem-based learning context where the tool acted as a fully available tutor. Even so, this result is discrepant with the more modest effect sizes found in meta-analyses with smaller samples, which denotes that the magnitude



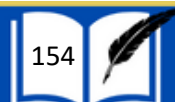
of the impact is more related to the number of integrated studies, the disciplinary variety of the sample and the methodological quality of the primary designs, rather than with a generic effect independent only of the technology.(21)(16)(1)(17)

Regarding the development of competences, the results of this review agree with previous studies that indicate that digital competence and formative feedback are the dimensions most frequently favored through the IAGen, but they differ in part in relation to research that concludes that critical thinking is systematically nourished by the use of these tools itself. The evidence reviewed here suggests, however, that this is rather a conditional relationship in which critical thinking is fueled by the use of the IAGen as a starting point for the verification and contrast of information, but converges in the fact that it is not fueled by it, but is weakened when the tool is used as the sole and undisputed source of answers. This distinction is consistent with the approach in which IAGen can act as an "amplifier" of previous pedagogical provisions, rather than as a determining cause in itself.(18)(9)(12)(14)(4)

The outcome in relation to academic integrity deserves detailed discussion. The findings of the present review are consistent with the study carried out in Ecuadorian universities that already warned of the existence of a positive association between trust in the information that had been generated from AI and self-reported levels of plagiarism<sup>13</sup>, as well as with those studies that already warned about the existence of other forms of academic dishonesty that were not detectable through traditional plagiarism detection systems, . However, unlike different positions that attribute this phenomenon exclusively to culture (technology), the use of the evidence analyzed in this article suggests that the determining element is the absence of explicit institutional policies on the use of these tools. This last aspect coincides with research that indicates that media and information literacy, rather than restricted access to technology, is the most effective strategy when it comes to preventing practices of improper use of IAGen, .(12)(14)(15)(22)(13)(23)

Regarding regional differences, the evidence analyzed on Latin America shows a pattern that is partially different from that shown by studies carried out in North American, European and Asian contexts. Thus, while international literature tends to influence the cognitive effect of the IAGen, in the face of this pattern, the Latin American studies reviewed emphasize, both actively and passively, the institutional digital divide as a structural condition, which precedes any discussion on pedagogical effectiveness. This difference does nothing more than suggest that the conclusions obtained in contexts of high connectivity cannot be directly extrapolated to institutions with more limited technological resources, at the same time that it reinforces the need for teacher training in digital skills to do so before the curricular implementation of these tools.(8)(10)(24)

Finally, it should be said that most of the primary studies that make up the reviewed meta-analyses have a short, quasi-experimental design, which restricts the possibility of establishing powerful causal relationships and evaluating the sustainability of the observed effects in the medium and long term. This limitation, also recognized by other authors, is a line of research to be built: longitudinal studies are necessary that examine whether the positive effects collected in interventions of a few weeks are sustainable throughout an academic program or research that delves into the differential effect of



the IAGen depending on the socioeconomic level and the training discipline of the students.(16)(17)(25)(26)

## CONCLUSIONS

The evidence synthesized in this systematic review allows us to affirm that generative artificial intelligence produces a positive effect, of a moderately high to high magnitude, on the academic performance of higher education students, with effect sizes ranging between 0.57 and 1.14 depending on the discipline, the duration of the intervention and the methodological design of the primary studies analyzed. This finding responds directly to the previously formulated objective, since it is proven that the impact that these tools have on learning has been empirically proven and that it would not only be a subjective perception of the teaching or the students.

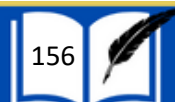
As a result of the reflections on the development of the different types of competencies, it is proposed that, to the extent that generative artificial intelligence works in the classroom associated with an intentional pedagogical design, it will favor digital competence, formative feedback and, conditionally, critical thinking and written communication. In the absence of this design, however, cognitive dependence tends to be generated, affecting the autonomous elaboration of knowledge. In this sense, technology, without a doubt, is the effect of Classroom Design and, therefore, of educational technology, showing that the effect of technology is not simple, but rather it is mandatory that we highlight the fact that the impact of technology has to do decisively with the institutional and didactic conditions in which the sessions are carried out. Obviously, the last conclusion refers to the fact that academic integrity appears as the most pressing and transversal challenge of those that have been detected in the reviewed literature, in contexts where institutional regulatory gaps persist.

The evidence from Latin America and the Ecuadorian evidence, in particular, reveal that uncritical trust in the information generated by these tools is associated with a concern in terms of self-reported plagiarism, while critical knowledge about instrumental limitations acts as a protective factor, a fact that accounts for the need to include digital and ethical literacy as the central axis of the design of any curricular integration strategy. This leads us to propose that higher education institutions develop explicit policies in relation to the declared use of generative artificial intelligence, that they strengthen the training processes of teachers in digital skills, that they reformulate the evaluation strategies towards authentic formats that value the process of knowledge construction and not just the final product. Similarly, it is necessary to raise the need to promote longitudinal research that allows contrasting the sustainability of the described effects and that explores their differential behavior depending on the academic discipline affected and the socioeconomic context of the students, all with a view to generating evidence that supports sustained curricular and institutional decisions.

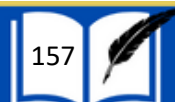
## REFERENCES



1. Ogunleye B, Zakariyyah KI, Ajao O, Olayinka O, Sharma H. A Systematic Review of Generative AI for Teaching and Learning Practice. *Educ Sci (Basel)*. 2024 Jun 13;14(6):636. doi:10.3390/educsci14060636
2. Zhu C SMLJLTWM. How to harness the potential of ChatGPT in education? *Knowledge Management & E-Learning: An International Journal*. 2023 Jun 10;133–52. doi:10.34105/j.kmel.2023.15.008
3. Kasneci E, Sessler K, Küchemann S, Bannert M, Dementieva D, Fischer F, et al. ChatGPT for good? On opportunities and challenges of large language models for education. *Learn Individ Differ*. 2023 Apr;103:102274. doi:10.1016/j.lindif.2023.102274
4. Tlili A, Shehata B, Adarkwah MA, Bozkurt A, Hickey DT, Huang R, et al. What if the devil is my guardian angel: ChatGPT as a case study of using chatbots in education. *Smart Learning Environments*. 2023 Feb 22;10(1):15. doi:10.1186/s40561-023-00237-x
5. Bahroun Z, Anane C, Ahmed V, Zacca A. Transforming Education: A Comprehensive Review of Generative Artificial Intelligence in Educational Settings through Bibliometric and Content Analysis. *Sustainability*. 2023 Aug 29;15(17):12983. doi:10.3390/su151712983
6. Michel-Villarreal R, Vilalta-Perdomo E, Salinas-Navarro DE, Thierry-Aguilera R, Gerardou FS. Challenges and Opportunities of Generative AI for Higher Education as Explained by ChatGPT. *Educ Sci (Basel)*. 2023 Aug 23;13(9):856. doi:10.3390/educsci13090856
7. Wu F, Dang Y, Li M. A Systematic Review of Responses, Attitudes, and Utilization Behaviors on Generative AI for Teaching and Learning in Higher Education. *Behavioral Sciences*. 2025 Apr 4;15(4):467. doi:10.3390/bs15040467
8. Quiroz Martinez MR. Inteligencia Artificial Generativa (IA Gen) en la Transformación Digital de la Educación Superior una Revisión Sistemática de Literatura. *Ciencia Latina Revista Científica Multidisciplinar*. 2025 May 7;9(2):6339–78. doi:10.37811/cl\_rcm.v9i2.17370
9. Ali D, Fatemi Y, Boskabadi E, Nikfar M, Ugwuoke J, Ali H. ChatGPT in Teaching and Learning: A Systematic Review. *Educ Sci (Basel)*. 2024 Jun 14;14(6):643. doi:10.3390/educsci14060643
10. Ng DTK, Leung JKL, Su J, Ng RCW, Chu SKW. Teachers' AI digital competencies and twenty-first century skills in the post-pandemic world. *Educational technology research and development*. 2023 Feb 21;71(1):137–61. doi:10.1007/s11423-023-10203-6
11. Yusuf A, Pervin N, Román-González M. Generative AI and the future of higher education: a threat to academic integrity or reformation? Evidence from multicultural perspectives. *International Journal of Educational Technology in Higher Education*. 2024 Mar 25;21(1):21. doi:10.1186/s41239-024-00453-6
12. Cotton DRE, Cotton PA, Shipway JR. Chatting and cheating: Ensuring academic integrity in the era of ChatGPT. *Innovations in Education and Teaching International*. 2024 Mar 3;61(2):228–39. doi:10.1080/14703297.2023.2190148
13. Torres-Diaz JC, Duarte J, Rivera D, Flandoli AB. Artificial intelligence and academic integrity: exploring plagiarism in Ecuadorian universities. *International Journal for Educational Integrity*. 2025 Dec 26;21(1):35. doi:10.1007/s40979-025-00209-3



14. Farrokhnia M, Banihashem SK, Noroozi O, Wals A. A SWOT analysis of ChatGPT: Implications for educational practice and research. *Innovations in Education and Teaching International*. 2024 May 3;61(3):460–74. doi:10.1080/14703297.2023.2195846
15. Pudasaini S, Miralles-Pechuán L, Lillis D, Llorens Salvador M. Survey on AI-Generated Plagiarism Detection: The Impact of Large Language Models on Academic Integrity. *J Acad Ethics*. 2025 Sep 4;23(3):1137–70. doi:10.1007/s10805-024-09576-x
16. Mo F, Huang J, Yang Y, Özen Z, Maeda Y, Olenchak FR. Undergraduate students' learning outcomes with ChatGPT: A meta-analytic study. *Computers and Education: Artificial Intelligence*. 2026 Jun;10:100536. doi:10.1016/j.caeai.2025.100536
17. Liu Z, Zuo H, Lu Y. The Impact of <scp>ChatGPT</scp> on Students' Academic Achievement: A Meta-Analysis. *J Comput Assist Learn*. 2025 Aug 15;41(4). doi:10.1111/jcal.70096
18. Banihashem SK, Noroozi O, van Ginkel S, Macfadyen LP, Biemans HJA. A systematic review of the role of learning analytics in enhancing feedback practices in higher education. *Educ Res Rev*. 2022 Nov;37:100489. doi:10.1016/j.edurev.2022.100489
19. Al-Ghonmein AM, Al-Moghrabi KG. The potential of ChatGPT technology in education: advantages, obstacles and future growth. *IAES International Journal of Artificial Intelligence (IJ-AI)*. 2024 Jun 1;13(2):1206. doi:10.11591/ijai.v13.i2.pp1206-1213
20. Strzelecki A, Cicha K, Rizun M, Rutecka P. Acceptance and use of ChatGPT in the academic community. *Educ Inf Technol (Dordr)*. 2024 Dec 18;29(17):22943–68. doi:10.1007/s10639-024-12765-1
21. Page M, McKenzie J, Bossuyt P. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;(372):71.
22. Lund BD, Lee TH, Mannuru NR, Arutla N. AI and Academic Integrity: Exploring Student Perceptions and Implications for Higher Education. *J Acad Ethics*. 2025 Sep 20;23(3):1545–65. doi:10.1007/s10805-025-09613-3
23. Guillén-Gámez FD, Sánchez-Vega E, Colomo-Magaña E, Sánchez-Rivas E. Incident factors in the use of ChatGPT and dishonest practices as a system of academic plagiarism: the creation of a PLS-SEM model. *Res Pract Technol Enhanc Learn*. 2024 Sep 16;20:028. doi:10.58459/rptel.2025.20028
24. Redecker C, Punie Y. Digital Competence of Educators DigCompEdu.
25. Galindo-Domínguez H, Campo L, Delgado N, Sainz de la Maza M. Relationship between the use of ChatGPT for academic purposes and plagiarism: the influence of student-related variables on cheating behavior. *Interactive Learning Environments*. 2025 Jul 3;33(6):4047–61. doi:10.1080/10494820.2025.2457351
26. Balalle H, Pannilage S. Reassessing academic integrity in the age of AI: A systematic literature review on AI and academic integrity. *Social Sciences & Humanities Open*. 2025;11:101299. doi:10.1016/j.ssaho.2025.101299



# EVALUACIÓN Y MITIGACIÓN DE RIESGOS LABORALES MEDIANTE SISTEMAS DE SEGURIDAD INDUSTRIAL EN UNA PLANTA AGROINDUSTRIAL DE PROCESAMIENTO DE

## VEGETALES Y ALIMENTOS EVALUATION AND RISK MITIGATION THROUGH INDUSTRIAL SAFETY SYSTEMS IN A VEGETABLE AND FOOD PROCESSING AGRO-INDUSTRIAL PLANT

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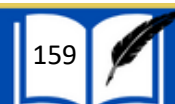
**RESUMEN:** La industria agroalimentaria de procesamiento de vegetales presenta entornos laborales complejos donde coexisten riesgos mecánicos por maquinaria de corte, riesgos biológicos, superficies húmedas propensas a caídas y exposición a bajas temperaturas. El objetivo de este estudio fue evaluar el impacto de la implementación de un Sistema de Gestión de Seguridad Industrial, alineado a la norma ISO 45001, en una planta procesadora de alimentos preparados para mitigar la siniestralidad laboral y asegurar la continuidad operativa. La metodología adoptada contiene un enfoque cuantitativo, de alcance descriptivo correlacional, estructurada en tres fases: diagnóstico de línea base mediante matrices de Identificación de Peligros y Evaluación de Riesgos (IPERVR), diseño del sistema documental operativo, y medición post-intervención de indicadores de gestión. Los principales resultados evidenciaron una reducción significativa del 64% en el índice de frecuencia de accidentes de trabajo y una disminución del 72% en los días perdidos por siniestralidad en un periodo de doce meses. Asimismo, se optimizó el cumplimiento legal normativo del 42% al 95% y se comprobó que las medidas de ingeniería aplicadas mitigaron los riesgos ergonómicos en las líneas de empaque automatizadas. Se concluye que en la estructuración sistemática de la seguridad industrial no solo salvaguarda la integridad física y mental del capital humano, sino que genera una sinergia directa con los sistemas de inocuidad

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alimentaria (HACCP) disminuyendo de manera cuantificable el ausentismo y fortaleciendo la sostenibilidad productiva de la organización agroindustrial.

**Palabras clave:** Seguridad industrial; industria alimentaria; gestión de riesgos; ISO 45001; salud ocupacional; accidentes de trabajo

**ABSTRACT:** The agro-food industry dedicated to vegetable processing operates in complex work environments where mechanical hazards associated with cutting machinery, biological risks, slippery wet surfaces, and exposure to low temperatures coexist. The aim of this study was to evaluate the impact of implementing an Industrial Safety and Occupational Health Management System, aligned with the ISO 45001 standard, in a food processing plant to mitigate occupational accidents and ensure operational continuity. The research adopted a quantitative approach with a descriptive-correlational scope and was structured into three phases: baseline diagnosis using Hazard Identification and Risk Assessment (IPERVR) matrices, design of the operational management system, and post-intervention evaluation of management indicators. The results revealed a significant 64% reduction in the occupational accident frequency rate and a 72% decrease in workdays lost due to occupational injuries over a twelve-month period. Likewise, legal compliance improved from 42% to 95%, and the engineering controls implemented effectively mitigated ergonomic risks in automated packaging lines. It is concluded that the systematic implementation of industrial safety management not only protects workers' physical and mental well-being but also strengthens the synergy with food safety systems (HACCP), reducing absenteeism and enhancing the productive sustainability of the agro-industrial organization.

**Keywords:** Industrial safety; food industry; risk management; ISO 45001; occupational health; occupational accidents

## INTRODUCTION

The global agri-food industry represents one of the most dynamic and essential productive sectors for supplying supply chains; However, their operating environments harbor a complex matrix of hazards that compromise the occupational health and safety of human capital (1). Specifically, plants dedicated to the processing of vegetables and prepared foods configure critical work scenarios where high-speed automation lines, handling of sharp tools, continuous exposure to low temperatures in post-harvest areas and cold rooms, and the persistence of humid surfaces derived from the washing and sanitizing phases coexist simultaneously (2). These factors exponentially increase the probability of occurrence of occupational accidents, such as entrapments, amputations, falls at the same level and musculoskeletal disorders derived from repetitive movements and forced postures in the selection and packaging stations (3). According to data from the International Labor Organization (ILO), both incidents and occupational diseases not only undermine the integrity of the worker, they also impose financial burdens on organizations, which impacts productivity and intersectoral competitiveness (4).



In Latin America, risk management in the agroindustrial sector presents additional challenges related to the heterogeneous compliance with current legal frameworks and the limited adoption of systematic preventive methods (5). Historically, food processing companies have prioritized the implementation of rigorous food safety schemes, such as Hazard Analysis and Critical Control Points (HACCP) and the ISO 22000 standard, relegating operator safety to a secondary or reactive level (6). However, contemporary scientific literature demonstrates that a work accident in an agri-food production line not only paralyzes the manufacturing flow, but also introduces potential vectors of biological or cross contamination in the product, evidencing a direct interdependence between work safety and the final quality of the food (7, 8). Consequently, migration towards proactive management models that unify both protection criteria is essential.

During the last five years, international developments in occupational health have established the ISO 45001 standard as the global reference standard for the structuring of Occupational Health and Safety Management Systems (SGSST) (9). This framework bases its operation on the continuous improvement cycle PHVA (Plan, Do, Check, Act) and requires rigorous identification of hazards, risk assessment and determination of controls through a technical hierarchy that prioritizes elimination, replacement and engineering controls over the use of Personal Protective Equipment (PPE) (10). In plant processing plants, the systematic application of Hazard Identification and Risk Evaluation with Results Assessment (IPERVR) matrices allows quantitative mapping of the criticality of each operational position, facilitating the efficient allocation of financial resources for technological mitigation and ergonomic redesign of jobs (11, 12).

Despite the conceptual advantages offered by these integrated management systems, there is a gap in local empirical research regarding the exact quantification of their effectiveness after being implemented in agroindustrial SMEs in the region. Several authors maintain that the success of risk mitigation depends on the organizational culture and the adequacy of controls to the biological and hygienic particularities of food manufacturing, where many conventional engineering materials cannot be used due to sanitation regulations (13, 14). Therefore, empirically evaluating the impact of an industrial safety system adapted to these restrictions becomes a scientific and corporate imperative.

The justification of this research is based on the need to provide metric evidence that is reproducible that demonstrates how the technical structuring of an industrial safety system can statistically significantly reduce accidents within a vegetable processing plant. The study directly addresses the problem of high frequency with minor incidents and absenteeism on packaging lines. To guide the development of the research, the following hypothesis is proposed: the implementation of a safety management system focused on engineering controls and IPERVR matrices significantly reduces the frequency and severity rates of workplace accidents compared to the initial operational baseline.

Although there are methodologies that are widely used for the management of occupational health and safety, their implementation within the food industry presents specific limitations. Many organizations maintain reactive approaches that were based on the investigation of accidents that have occurred, instead of developing preventive



strategies based on the systematic identification of hazards. The conditions inherent to food processing, such as the permanent presence of humidity, slippery surfaces, strict hygiene protocols, thermal variations and continuous operation of automated equipment, make the application of some conventional safety controls difficult. These characteristics generate the obligation to adapt risk assessment tools to the particular conditions of the food sector, prioritizing engineering controls compatible with safety and production requirements.

Based on the above, the general objective of this study is to evaluate the effectiveness of the implementation of an industrial safety and occupational health management system for the mitigation of occupational risks in an agroindustrial vegetable and prepared food processing plant. The specific objectives include: 1) Diagnose the initial situation of the plant through the legal compliance index and the qualitative assessment of risks by position; 2) Design and implement technical mitigation measures and standardized operating procedures under the ISO 45001 standard; and 3) Monitor and statistically contrast the ex-ante and ex-post intervention accident rate indicators over a twelve-month time horizon.

## MATERIALS AND METHODS

This research was structured under a quantitative approach, with a descriptive-correlational scope and a quasi-experimental longitudinal ex-ante and ex-post design (15). This design allowed us to evaluate the behavior of the dependent variables, represented by the accident rates, before and after the introduction of the independent variable, corresponding to the industrial safety management system based on the ISO 45001 standard (11, 15). The study scenario consisted of a medium-sized agroindustrial plant dedicated to the processing and packaging of fresh vegetables and prepared foods, with an active working population of 120 operators distributed in three rotating shifts. Due to the size of the population and in order to avoid sampling errors, a complete census was chosen, including all workers who performed direct operational functions in the areas of raw material reception, washing, automated cutting, packaging lines and storage in freezing chambers (15).

To guarantee the homogeneity of the analyzed population, inclusion and exclusion criteria were established. Only operational workers with an active contract and a minimum stay of six months in the plant were included, because they had continuous exposure to the risks inherent to the production process. Interns, administrative personnel without regular entry to production areas, occasional contractors and workers with prolonged medical disabilities or pre-existing pathologies that could alter the accident rate indicators related to the work activity carried out during the study period were excluded.

The methodological development was executed sequentially over a time horizon of 12 months, which is divided into three well-defined operational phases. The first phase consisted of the baseline diagnosis and hazard survey. Therefore, a checklist was applied based on current national legal regulations regarding occupational health and safety, which determined the initial percentage of technical compliance of the company.



Simultaneously, the Hazard Identification and Risk Evaluation with Results Assessment Matrix (IPERVR) method was used, methodologically adapted from the Colombian technical standard NTC 45 and the ILO guidelines for food manufacturing (11, 12). Using this tool, quantitative values were assigned to the level of deficiency, level of exposure and level of consequence to calculate the Risk Level (NR), which categorized the dangers detected into four acceptability scales: trivial, tolerable, moderate and intolerable.

Prior to their application, both the checklist and the IPERVR matrix were subjected to a validation process through the judgment of three experts with experience in industrial safety, occupational health and risk management in the food industry, who evaluated the relevance, clarity and consistency of each criterion. Subsequently, agreement between evaluators was determined using the Fleiss Kappa coefficient, obtaining a value of 0.84, considered an almost perfect level of agreement, which demonstrated adequate reliability of the instrument and reduced possible bias during risk assessment.

The second phase included the design and implementation of the technical mitigation measures of the management system. Strictly following the hierarchy of controls established by international security standards, engineering solutions were prioritized over administrative ones (10). Specifically, the cutting machinery was intervened by placing fixed physical guards and emergency stop switches with interconnected magnetic sensors. To counteract the risk of falls on wet surfaces, a non-slip epoxy coating treatment with high mechanical and chemical resistance was applied to the floors in the washing areas. In the packaging lines, an ergonomic redesign of the workstations was carried out by installing height-adjustable tables and rest platforms to mitigate musculoskeletal disorders due to prolonged standing and repetitive movements. Overall, there was a standardization of the document management system through the creation of Standard Operating Procedures (SOP) for high-risk tasks with technical training programs and the provision of Personal Protective Equipment (PPE) that contains specific certification for humid and low-temperature environments.

The third and final phase consisted of monitoring with statistical evaluation of the results after a system maturation period of twelve months. Safety key performance indicators were calculated monthly using formulas standardized by the International Labor Organization. The Frequency Index (IF) was determined by the relationship between the total number of work accidents multiplied by a factor of  $10^6$  and divided by the total man-hours actually worked during the period. The Severity Index (GI) was calculated by dividing the number of days lost due to accidents multiplied by the same factor of  $10^6$  on the man-hours that were worked. Finally, the work absence rate was calculated by subtracting the days of medical absence from the total planned days.

The comparative analysis of all the data collected in the ex-ante and ex-post phases was processed using the statistical software SPSS version 25. To validate the research hypothesis by determining whether the differences between both periods were statistically significant, Shapiro-Wilk normality tests were applied. Subsequently, the parametric Student's t test for related samples was implemented for the indicators that presented a normal distribution, and the non-parametric test of Wilcoxon signed ranks for the non-linear behavioral variables, setting a confidence level of 95% and a statistical significance value of  $p < 0.05$ .



## RESULTS

### Baseline Diagnosis and Percentage of Initial Legal Compliance

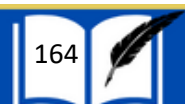
The initial technical diagnosis carried out in the agro-industrial vegetable processing plant made it possible to quantitatively determine the level of compliance with the legal regulatory framework in occupational safety and health. The application of the structured checklist showed that the organization operated under a markedly reactive scheme, registering a global compliance rate of only 42% with respect to technical obligations. The greatest deficiencies were concentrated in the document management axes with 15% compliance, where there was evidence of the non-existence of Standard Operating Procedures (SOPs) for critical tasks, the absence of a plan with structuring of training and the lack of auditable records of the delivery of personal protective equipment. In the axis of physical and engineering conditions, compliance has a scope of 35%, detecting cutting machinery deprived of physical guards with the absence of accessible emergency stop systems and a general deterioration of the non-slip coating in the washing and sanitizing areas, which increased the continuous risk of falls at the same level due to the accumulation of constant humidity and organic plant residues. The only axis that showed an acceptable level of compliance was the formation of the joint security body (80%), although its monthly minutes showed a punitive and not preventive approach to the reported incidents.

### Hazard Identification and Initial Risk Assessment (IPERVR Matrices)

The quantitative diagnosis phase using the Hazard Identification and Risk Evaluation Matrix with Results Assessment (IPERVR) method allowed mapping the criticality of a total of 45 jobs evaluated in the three operational shifts. The ex-ante analysis obtained an identification of a predominance of risks categorized as Intolerable and Moderate, being directly linked to the geometric and operational nature of the processing lines. In the automated cutting and cubing position, the mechanical danger due to trapping and cutting related to direct access to the high-speed blades contains a Risk Level that is classified as Intolerable, deriving it from a deficiency level of 10, a continuous exposure level of 4 and a very serious consequence level being evaluated at 60 points. As in the washing and sorting area, the physical danger due to exposure to wet and slippery surfaces is assessed as a Moderate risk with a high probability of occurrence. In manual packaging and palletizing stations, the ergonomic dangers associated with repetitive movements of the upper extremities with prolonged standing and forced postures are unanimously classified as Moderate risks that have a tendency to evolve into occupational diseases.

*Table 1. Comparative Matrix of Critical Risks by Job Ex-Ante and Ex-Post Intervention.*

| Position<br>Job | Hazard<br>Identified | ND(e<br>x) | NE(e<br>x) | NR(Ex-<br>Ante) | ND(pos<br>t) | NE(pos<br>t) | NR(Ex-<br>Post) | Control of<br>Engineeri<br>ng |
|-----------------|----------------------|------------|------------|-----------------|--------------|--------------|-----------------|-------------------------------|
|-----------------|----------------------|------------|------------|-----------------|--------------|--------------|-----------------|-------------------------------|



| Evaluate                |                                                                   |    |   |             |   |   |           | Applied                                                                      |
|-------------------------|-------------------------------------------------------------------|----|---|-------------|---|---|-----------|------------------------------------------------------------------------------|
| Reception and Selection | Ergonomic: Forced postures and prolonged standing.                | 6  | 3 | Moderate    | 2 | 3 | Tolerable | Ergonomic mats and adjustable resting platforms.                             |
| Washing and Sanitizing  | Physical: Falls to the same level from wet surfaces.              | 6  | 4 | Moderate    | 2 | 4 | Tolerable | Non-slip epoxy coating with high efficiency drain.                           |
| Cutting and Cubing      | Mechanical: Trapping and amputation by high-speed blades.         | 10 | 4 | Intolerable | 2 | 2 | Tolerable | Fixed physical guards and magnetic emergency stop switches.                  |
| Line of Packaging       | Ergonomic: Musculoskeletal disorders due to repetitive movements. | 6  | 4 | Moderate    | 2 | 2 | Trivial   | Redesign of work stations with adjustable height tables and hourly rotation. |
| Cold Rooms / Warehouse  | Physical: Prolonged exposure to low temperatures                  | 6  | 3 | Moderate    | 2 | 2 | Tolerable | Automation of gates and thermal locks of insulation.                         |

### Quantitative Reduction of Workplace Accident Rates

After the twelve-month time horizon of maturation and continuous audit of the industrial safety management system based on the ISO 45001 standard, the key performance indicators (KPI) demonstrated a drastic transformation in the accident rate dynamics of the plant. The total number of accidents that are recorded at work annually contracted from 28 events in the baseline to only 10 events during the post-intervention period, which means a net decrease of 64.2%. When processing these data using the ILO's standardized equations, the accident frequency index (IF) experienced a statistically significant decrease, going from an initial value of 93.33 accidents per million man-hours worked to a rate of 33.33 at the end of the evaluation year. This reduction demonstrates the effectiveness of physical barriers and magnetic switches installed in automatic vegetable processing lines. On the other hand, the economic and operational impact of the system was reflected most strongly in the mitigation of days lost due to



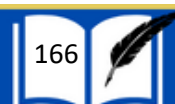
medical incapacity for work. The annual consolidated number of days not worked due to accidents went from 340 days in the ex-ante stage to 95 days in the ex-post stage, representing a reduction of 72.1%. When calculating the Severity Index (GI), the severity of the injuries was observed, which decreased from a value of 1133.33 days lost per million hours worked to 316.67 in the evaluated period. This behavior is directly attributed to the complete elimination of major accidents with severe disabling events such as amputations or complex fractures, with the remaining events being restricted to minor incidents with low severity such as minor contusions or superficial lacerations that required only first aid attention with immediate returns to work.

**Table 2. Monthly Indicators of Accident Rate, Severity and General Absenteeism (Evaluated Period of 12 Months).**

| Months).<br>Period /<br>Month     | Man-Hours<br>Worked<br>(HHT) | Number of<br>Accidents<br>(AT) | Days Lost<br>(DP) | Frequency<br>Index (IF) | Severity<br>Index (IG) | Rate of<br>Percentage<br>Absenteeism |
|-----------------------------------|------------------------------|--------------------------------|-------------------|-------------------------|------------------------|--------------------------------------|
| Baseline (Ex-Ante)                | <b>300,000</b>               | <b>28</b>                      | <b>340</b>        | <b>93.33</b>            | <b>1133.33</b>         | <b>5.8%</b>                          |
| <b>Month 1<br/>(Start)</b>        | 25,000                       | 2                              | 24                | 80.00                   | 960.00                 | 5.2%                                 |
| <b>Month 2</b>                    | 25,000                       | 1                              | 15                | 40.00                   | 600.00                 | 4.7%                                 |
| <b>Month 3</b>                    | 25,000                       | 1                              | 12                | 40.00                   | 480.00                 | 3.9%                                 |
| <b>Month 4</b>                    | 25,000                       | 1                              | 10                | 40.00                   | 400.00                 | 3.1%                                 |
| <b>Month 5</b>                    | 25,000                       | 1                              | 8                 | 40.00                   | 320.00                 | 2.5%                                 |
| <b>Month 6<br/>(Half)</b>         | 25,000                       | 0                              | 0                 | 0.00                    | 0.00                   | 2.1%                                 |
| <b>Month 7</b>                    | 25,000                       | 1                              | 7                 | 40.00                   | 280.00                 | 1.9%                                 |
| <b>Month 8</b>                    | 25,000                       | 0                              | 0                 | 0.00                    | 0.00                   | 1.8%                                 |
| <b>Month 9</b>                    | 25,000                       | 1                              | 5                 | 40.00                   | 200.00                 | 1.6%                                 |
| <b>Month 10</b>                   | 25,000                       | 0                              | 0                 | 0.00                    | 0.00                   | 1.6%                                 |
| <b>Month 11</b>                   | 25,000                       | 1                              | 4                 | 40.00                   | 160.00                 | 1.5%                                 |
| <b>Month 12<br/>(Closing)</b>     | 25,000                       | 1                              | 10                | 40.00                   | 400.00                 | 1.5%                                 |
| <b>Consolidated<br/>(Ex-Post)</b> | 300,000                      | 10                             | 95                | 33.33                   | 316.67                 | 1.5%                                 |

### Impact on Absenteeism Rates and Effectiveness of Ergonomic Controls

The optimization of environmental conditions and the ergonomic redesign of workstations had a direct influence on the availability of operational personnel. The plant's overall absenteeism rate, which averaged 5.8% per month at baseline due to constant medical leave for low back pain, tendinitis, and carpal tunnel syndromes in the packaging area, was steadily reduced until it stabilized at 1.5% at the end of the study period. The ergonomic control evaluation using the REBA (Rapid Entire Body Assessment) method during the automated packaging lines verified that the installation of adjustable rest platforms in conjunction with the scheduled rotation of shifts every two hours reduced the postural load from a critical action level with a score > 8 to a tolerable low risk level with a score < 3. Additionally, the non-slip epoxy treatment that was applied to the floors eradicated slip incidents by 100%. and falls in the vegetable washing area, obtaining a safe work environment that enhanced the performance of each operator.



## Statistical Validation of the Research Hypothesis

To confirm the scientific validity of the findings and rule out that the metric reductions were due to random fluctuations in production, the statistical significance analysis was carried out through SPSS software version 25. The Shapiro-Wilk normality test determined that the monthly data of the Frequency Rates and Severity Rates They followed a normal distribution  $p > 0.05$ . Applying the Student t test for related samples, comparing the monthly means of the ex-ante period versus the ex-post period, a value of  $t = 5.42$  was obtained for the Frequency Index and for the Severity Index a value of  $t = 6.18$ . In both analyzes the bidirectional statistical significance value was  $p = 0.001$ , being markedly lower than the established critical threshold of  $\alpha = 0.05$ . These mathematical results allow for a categorical rejection of the null hypothesis and the formal acceptance of the research hypothesis, which demonstrates with 95% confidence that the implementation of the industrial safety management system that is based on IPERVR matrices and engineering controls significantly reduces the levels of accidents and severity of accidents in the vegetable processing plant.

## DISCUSSION

The quantitative findings derived from this research strongly demonstrate the effectiveness of the implementation of an industrial safety management system based on the ISO 45001 standard and IPERVR matrices to mitigate accidents within the agri-food sector of plant processing. When critically contrasting the 64.2% reduction in the Frequency Rate (FI) of accidents obtained in this study, a clear convergence is observed with the trends reported by contemporary international scientific literature. Various authors maintain that the transition from a reactive security model to one structured under the continuous improvement of the PHVA cycle achieves drastic reductions in mechanical operational incidents, placing the general effectiveness range of these systematic interventions between 50% and 70% in industrial SMEs (9, 16). This validates that the nature of the food sector, despite its high rates of environmental humidity and high-velocity flows, responds positively to the technical standardization of operational controls (2).

A core analytical aspect in this research lies in the drastic contraction of 72.1% in days lost due to medical work disability and the consequent decrease in the Severity Index (GI). This behavior is different from previous research in conventional agro-industrial plants in the region, where it was argued that, although management systems reduced the overall number of incidents, the severity of the remaining mechanical events (such as amputations or entrapments in cutting machinery) tended to remain constant due to the lack of capital investment in hard physical barriers (17). In our case study, the total eradication of major disabling accidents is directly due to the strict prioritization of engineering controls—such as the installation of fixed physical guards and magnetic emergency stop switches in automated dicers—over traditional administrative measures or the mere use of Personal Protective Equipment (10). This methodological approach reinforces the premise that investment in collective engineering barriers is the

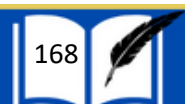


only methodological avenue capable of altering the intrinsic severity of hazards in high-speed manufacturing environments (10, 11).

From an economic perspective, the implementation of the main engineering controls represented an approximate investment of USD 18,500, distributed among the installation of non-slip epoxy coatings, physical guards, magnetic emergency stop sensors and ergonomic adaptations of the workstations. However, the reduction in absenteeism from work from 5.8% to 1.5%, together with the decrease in days lost due to accidents, made it possible to recover an important part of said investment through the increase in hours actually worked, the reduction of costs associated with temporary replacements, medical care and payment of disability subsidies. Additionally, the strengthening of legal compliance reduced the risk of administrative sanctions derived from non-compliance with occupational health and safety regulations, demonstrating that the implementation of the management system constitutes a productive investment with economic and operational benefits for the organization.

On the other hand, the reduction of the general absenteeism rate from 5.8% to 1.5% after the execution of ergonomic redesigns using the REBA method and the application of non-slip epoxy coatings provides crucial empirical evidence on a latent discussion in the sector: that between worker safety and corporate productivity. Some researchers claim that recurring absenteeism on prepared food packaging lines is a structural factor that is difficult to mitigate due to the repetitive and monotonous nature of the position (18). However, the data collected demonstrate that by attenuating the postural load through adjustable platforms and programmed rotations, not only do musculoskeletal disorders decrease, but the continuity of the manufacturing line is stabilized. This corroborates the theoretical postulates that indicate that the costs of implementing a SGSST are absorbed organically by the organization by eliminating the extra costs associated with the temporary replacement of qualified personnel and the penalties for delays in the shipment of fresh products (1, 4).

Finally, it is imperative to recognize the limitations of the present study. Having been developed under a longitudinal quasi-experimental design focused on a single medium-sized agro-industrial company, the correlation coefficients and specific reduction rates of the plant sector cannot be directly generalized to other food branches of high biological complexity, such as the meat or dairy processing industries, where hygienic variables and pathogen risk vectors impose even more severe restrictions on conventional engineering materials (6, 14). The time horizon for post-intervention evaluation is limited to twelve months, which restricts the observation of the sustainability of the operators' preventive culture in the long term. It is suggested that for future lines of research, multicenter studies be carried out that evaluate the automated integration of IPERVR matrices with digital platforms with real-time monitoring, allowing the estimation with predictive statistical models of the probability of occurrence of accidents in the face of seasonal variations in production demand.



## CONCLUSIONS

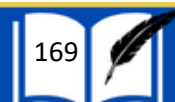
It was diagnosed that the agro-industrial plant was initially operating under a reactive scheme with a legal compliance rate of only 42% in terms of occupational health and safety, with the greatest deficiencies concentrating on the lack of physical guards on automatic cutting machinery and the absence of standardized safe work procedures for humid environments. The Hazard Identification and Risk Evaluation with Results Assessment (IPERVR) matrix applied made it possible to map the critical levels of the jobs, classifying the mechanical dangers of entrapment as intolerable, while the risks of falls at the same level and ergonomic conditions due to repetitive movements in the packaging stations were characterized as moderate.

The design and implementation of the industrial safety management system, structured under the continuous improvement cycle of the ISO 45001 standard, strictly prioritized collective engineering controls over administrative ones. The key technical interventions were constituted with the installation of fixed guards with magnetic emergency stop sensors in the cubing lines, while the non-slip epoxy coating in the vegetable washing areas to nullify the surface humidity factor with the ergonomic redesign through adjustable stations, managed to comprehensively mitigate the severity of the dangers evaluated in the organization's baseline.

The statistical evaluation after twelve months of post-intervention monitoring demonstrated the effectiveness of the management system with a 64.2% reduction in the Accident Frequency Rate and a 72.1% contraction in the Injury Severity Index, which completely eradicates accidents due to major disabling injuries. Likewise, the rate of absenteeism from work decreased from 5.8% to 1.5% due to the control of musculoskeletal disorders. The parametric Student's t tests validated the research hypothesis with a high level of statistical significance of  $p = 0.001$ , demonstrating with scientific rigor that the proactive management of industrial safety drastically reduces accidents and absenteeism in the food company.

## REFERENCES

1. Organización Internacional del Trabajo. Seguridad y salud en el centro del futuro del trabajo: Aprovechar 100 años de experiencia. Ginebra: OIT; 2019.
2. Alvareda M, Santos J. Gestión de riesgos laborales en la industria agroalimentaria contemporánea. *Rev Ciencias Trabajo*. 2021;23(68):112-120.
3. Ramírez G, Torres L. Análisis de accidentes de trabajo mecánicos y ergonómicos en plantas de procesamiento de vegetales. *Avances Investigación Agroind*. 2022;16(2):45-58.
4. Asfahl CR, Rieske DW. Seguridad industrial y salud en el trabajo. 7a ed. México: Pearson Educación; 2019.
5. González R, Martínez S, Pérez J. Desafíos de la normativa de salud ocupacional en las pequeñas y medianas empresas de América Latina. *Rev Salud Pública Global*. 2020;14(3):201-215.
6. Smith T, Jones M. The intersection between food safety systems (HACCP) and occupational health and safety. *J Food Protect*. 2022;85(4):612-624.



7. López H, Castro M. Sinergia operativa entre ISO 22000 e ISO 45001 en la manufactura de alimentos preparados. *Rev Calidad Agroalimentaria*. 2023;29(1):78-92.
8. Ortega F. Impacto de los accidentes laborales en la contaminación cruzada biológica de líneas de producción agroindustrial. *Food Security Safety Int*. 2021;9(2):144-156.
9. International Organization for Standardization. Occupational health and safety management systems — Requirements with guidance for use (ISO Standard No. 45001:2018). Ginebra: ISO; 2018.
10. Heinrich HW, Petersen D, Roos NE. Industrial accident prevention: a safety management approach. 5a ed. Nueva York: McGraw-Hill; 1980.
11. Instituto Colombiano de Normas Técnicas y Certificación. Guía para la identificación de los peligros y la valoración de los riesgos en seguridad y salud ocupacional (GTC 45). Bogotá: ICONTEC; 2012.
12. Merino A, Silva J. Evaluación cualicuantitativa de riesgos industriales a través de matrices IPERVIR en la agroindustria de alimentos frescos. *Res Safety Sci*. 2020;44(3):310-325.
13. Castillo V, Paredes E. Cultura de seguridad, liderazgo organizacional y su impacto en la reducción de la siniestralidad. *Rev Latinoamericana Psicología Trabajo*. 2022;11(2):89-102.
14. Baker P, Downing C. Engineering controls versus personal protective equipment in wet environments of food processing facilities. *Int J Occup Saf Ergonom*. 2023;29(1):15-27.
15. Hernández-Sampieri R, Mendoza CP. Metodología de la investigación: las rutas cuantitativa, cualitativa y mixta. México: McGraw-Hill; 2018.
16. Neumann WP, Dul J. Integrating human factors into production system design: A de facto standard approach. *Human Factors Ergonom Manuf*. 2020;30(4):243-257.
17. Vargas M, Gutiérrez R. Análisis longitudinal de la gravedad de accidentes en la industria de manufactura con maquinaria automatizada. *Rev Prevención Riesgos*. 2021;18(4):214-228.
18. Choobineh A, Tabatabaei SH, Tozihian M. Musculoskeletal problems and ergonomic assessment of posture in vegetable processing workers. *Int J Ind Ergonom*. 2022;88(2):103-115.
19. Montgomery DC. Introduction to statistical quality control. 8a ed. Nueva York: John Wiley & Sons; 2019.
20. Chang FR, Wang YL. Occupational accident frequency and severity rate trends: A multicenter study in agro-industrial packaging lines. *Safety Science J*. 2024;170(1):106-118.



## ELABORACIÓN DE MERMELADA PREBIÓTICA CON DIFERENTES NIVELES DE PULPA DE COPOAZÚ

### PREPARATION OF PREBIOTIC JAM WITH DIFFERENT LEVELS OF COPOAZÚ PULP

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**RESUMEN:** La presente investigación tuvo como objetivo elaborar una mermelada prebiótica utilizando diferentes niveles de pulpa de copoazú (*Theobroma grandiflorum*), con la finalidad de obtener un producto funcional con características fisicoquímicas, sensoriales y económicas adecuadas para el consumo humano. Se aplicó un Diseño Completamente al Azar con tres tratamientos correspondientes a diferentes porcentajes de pulpa de copoazú: T1 (30 %), T2 (40 %) y T3 (50 %), cada uno con cinco repeticiones de 500 gramos. Las muestras elaboradas fueron sometidas a análisis fisicoquímicos, evaluación sensorial y análisis económico. Entre los parámetros fisicoquímicos evaluados se determinaron humedad, pH, acidez titulable, cenizas, actividad de agua, fibra bruta y sólidos solubles (°Brix). Los resultados mostraron diferencias significativas entre tratamientos para algunas variables, evidenciando que el incremento del porcentaje de pulpa influye en las características finales del producto. En cuanto al mejor tratamiento fue al 40% de adición de pulpa de copoazú (T2), presentó el valor más alto en fibra (1,38%), ceniza (0,24%), menor Aw (0,863%), lo que demuestra el aporte funcional del copoazú como fuente natural de fibra dietética. La evaluación sensorial se llevó a cabo mediante escala hedónica donde no se evidenció diferencias significativas entre tratamientos en ninguno de los atributos evaluados. Asimismo, el análisis económico permitió determinar la viabilidad del proceso mediante el cálculo de costos de producción y relación beneficio-coste. Se concluye que la incorporación de pulpa de copoazú permitió obtener una mermelada con características de calidad adecuadas, potencial prebiótico asociado al contenido de fibra y aceptación sensorial favorable, constituyéndose en una alternativa innovadora para el aprovechamiento agroindustrial de esta fruta amazónica.

**Palabras clave:** Copoazú, mermelada prebiótica, fibra dietética, alimento funcional, innovación alimentaria

**ABSTRACT:** The present research aimed to develop prebiotic jam using different levels of copoazu pulp (*Theobroma grandiflorum*) to obtain a functional product with

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physicochemical, sensory, and economic characteristics suitable for human consumption. A completely randomized design was applied with three treatments corresponding to different percentages of copoazu pulp: T1 (30%), T2 (40%), and T3 (50%), each with five replicates of 500 grams. The samples were subjected to physicochemical analyses, sensory evaluation, and economic analysis. Among the physicochemical parameters evaluated were moisture content, pH, titratable acidity, ash content, water activity, crude fiber, and soluble solids ( $^{\circ}$ Brix). The results showed significant differences among treatments for some variables, indicating that increasing the pulp percentage influences the final characteristics of the product. Regarding the best-performing treatment, the 40% copoazu pulp formulation (T2) showed the highest fiber content (1.38%), the highest ash content (0.24%), and the lowest water activity (0.863%), which highlights the functional contribution of copazu as a natural source of dietary fiber. Sensory evaluation was carried out using a hedonic scale, and no significant differences were found among treatments for any of the attributes assessed. Likewise, the economic analysis made it possible to determine the feasibility of the process through the calculation of production costs and the benefit-cost ratio. It is concluded that the incorporation of copoazu pulp yielded a jam with suitable quality characteristics, prebiotic potential linked to its fiber content, and favorable sensory acceptance, positioning it as an innovative alternative for the agro-industrial utilization of this Amazonian fruit.

**Keywords:** *Copoazú, prebiotic jam, dietary fiber, functional food, food innovation*

## INTRODUCTION

Interest in functional foods has grown significantly in recent years, as consumers look for options that not only provide basic nutrients but also contribute to health and prevent diseases. Within this, prebiotic foods stand out because they help maintain the balance of the intestinal microbiota, they also strengthen the immune system and provide benefits against chronic non-communicable problems. This is an approach that opens the door to the development of new products or the improvement of traditional products such as jam, products that, although their formulation cannot be completely changed, can be made to be somewhat more beneficial than the products that are normally consumed and have a health benefit (1).

Jams are classified as frequently consumed products in homes, they are accepted by a large part of the population of Ecuador and the world (2); This means that prebiotics can be incorporated in a practical way, and thus have the possibility of transforming a food into a functional food that provides health benefits, allowing innovation to expand in agribusiness and being within current trends in the food consumption market.

Under this concept, the idea of making a jam was created using the fiber of Copoazú (*Theobroma grandiflorum*), an Amazonian fruit that is similar to cocoa, with pleasant aromatic properties that are slightly acidic and with an exotic flavor that makes it a spectacular candidate for developing new foods. This without mentioning all the benefits that it would bring to Amazonian communities by promoting the valorization of native species and generating an impact on the communities that depend on their

cultivation and commercialization, according to (3) mentions that this fruit can become a useful ingredient in the manufacture of rich and healthy foods.

This process favors the production of metabolites with positive effects on intestinal health. The proposal of a prebiotic jam based on cupoazú becomes an innovative idea that combines flavor, aroma, color and texture with an additional physiological value. Prebiotic ingredients (such as fruit pectin or inulin) have been added to this fruit jam, which is healthy for the consumer.

This work aims to:

1. Evaluate the physicochemical properties of jam made with different levels of copoazú pulp (30, 40 and 50% fruit pulp).
2. Establish organoleptic characteristics through sensory tests.
3. Establish production costs and their profitability using the benefit-cost indicator.

## MATERIALS AND METHODS

### Location and duration of the experiment

The research was carried out in the Food Laboratory of the Faculty of Livestock Sciences of the Higher Polytechnic School of Chimborazo (ESPOCH), located at km 1½ of the Panamericana Sur. Laboratory analyzes were carried out in the Food and Bromatology Laboratory of the same faculty. The experimental phase had a total duration of 360 hours.

### Experimental units

Each experimental unit was composed of three treatments which had in their mixture 30%, 40% and 50% of cupoazú pulp and other components used as ingredients for jam, which in turn were distributed into five repetitions per treatment; each composed of 500g of product, giving a total of 2500g per treatment.

### Treatment and experimental design

In this experimental work, the effect of different levels of copoazú pulp (30, 40 and 50% addition) in the production of jam was evaluated, using 5 repetitions, resulting in a total of 2500 ml for each treatment, under a completely randomized design (DCA) in a combinatorial arrangement using an additive linear model.

The results of the physical tests were analyzed using:

- Analysis of variance (ADEVA) with  $P < 0.05$ .
- Multiple comparisons between the means, using the Tukey test ( $P < 0.05$ ).
- The results of the sensory analysis were obtained according to the Kruskal wallis test

- INFOSTAT statistical software was used for data tabulation.

**Table 1. Scheme of the experiment.**

| Niveles de pulpa añadida | Repeticiones | TUE* | Total/g |
|--------------------------|--------------|------|---------|
| 30%                      | 5            | 500  | 2500    |
| 40%                      | 5            | 500  | 2500    |
| 50%                      | 5            | 500  | 2500    |
| <b>Total</b>             |              |      | 7500    |

*Prepared by: Parra, J., 2026*

### Statistical analysis and significance tests

The data obtained were subjected to an Analysis of Variance (ANOVA) corresponding to the completely randomized design (DCA), with the objective of determining if there are significant differences between treatments in the variables evaluated; If significant differences are detected ( $p < 0.05$ ), the Tukey test is applied to compare the means of the treatments and establish the optimal level of copoazú pulp in the jam formulation

**Table 2. Scheme of the analysis of variance (ADEVA).**

| Fuente de variación | Grados de libertad (gl) | Suma de cuadrados (SC) | Cuadrado medio (CM) | F calculado            |
|---------------------|-------------------------|------------------------|---------------------|------------------------|
| Tratamientos        | $t - 1$                 | SCT                    | $SCT/(t - 1)$       | $CM_{trat}/CM_{error}$ |
| Error               | $N - t$                 | SCE                    | $SCE/(N - t)$       |                        |
| Total               | $N - 1$                 | SCTotal                |                     |                        |

*Prepared by: Parra, J., 2026*

### Experimental procedure

Ripe and undamaged copoazú fruits were selected, washed with drinking water, the pulp was extracted by opening the fruit and manually removing it from the seeds. The base formulation was made and the different percentages of copoazú (30,40 and 50%) were added.

Once the formulation was made, the pulp was placed in a stainless steel kettle and sugar and part of the water was added, then pectin dissolved in warm water was added to avoid lumps and cooking continued until reaching 65-68°Brix.

Glass jars and lids were sterilized (hot water at 100 °C) and filled with hot jam (85-90°C), then allowed to cool and stored in a cool, dry place.

The physicochemical parameters evaluated were pH, soluble solids (°Brix), titratable acidity, water activity ( $A_w$ ), humidity, ash, crude fiber.

The sensory evaluation was carried out with 50 untrained panelists using a structured five-point hedonic scale, considering the attributes of color, smell, flavor, texture and appearance. Finally, an economic analysis was carried out using the benefit/cost indicator to determine the viability of the evaluated formulations.

## RESULTS

### Humidity

Averages of 36.17 were obtained for treatment 1 (T1); 35.61 for treatment 2 (T2) and 34.82 for treatment 3 (T3); means that did not show significant differences between the samples, which is a clear indicator that the level of water that was added is not different from the level of water that the fruit pulp brings once extracted, it could be inferred that the water content in the fruit within its natural composition is very high, (4) mentions that it also has to do with microbiological stability, according to the analyzes carried out the humidity is below 40%, an indicator that other components such as sugar are in higher concentration and may have a favorable effect on conservation indirectly.

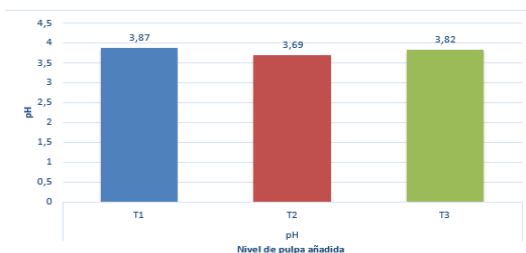
### Hydrogen potential (pH)

The pH known as hydrogen potential is fundamental in the physical-chemical evaluation of foods; it is a determining factor in its conservation, palatability and microbiological stability (5). In the results obtained, significant differences were observed between treatments, where T2 presented the lowest pH value (3.69), while T1 and T3 recorded values of 3.87 and 3.82, respectively, without statistical differences between them. It can also be said that the pH obtained contributes positively to the microbiological stability of the jam. According to what (6) mentions, foods with a pH lower than 4.5 present a lower risk of microorganism growth.

This behavior can be directly associated with the proportion of cupoazú pulp and the interaction of the organic acids naturally present in the fruit with the citric acid incorporated in the formulation, in addition to influencing unmeasured parameters but that are quality characteristics such as the level of pectin gelation and consequently influencing the texture.

Although T3 presented a higher pulp content (50%), the considerable reduction in added water could generate a buffer effect due to the concentration of solids and structural compounds of the fruit. (7) point out that food systems rich in

polysaccharides, sugars and minerals can modify the activity of free protons, causing variations between pH and total acidity.



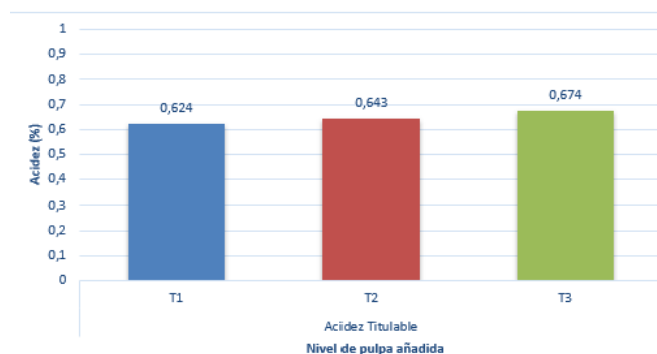
**Figure 1. Behavior of pH between the three treatments.**

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### Titrateable Acidity

The behavior of the pH is closely related to the titrateable acidity obtained in the treatments, although both parameters are associated, the pH measures the concentration of free hydrogen ions, while the titrateable acidity quantifies the total acids present in the food (8). This explains why T3 presented the highest titrateable acidity, but not the lowest pH value. The presence of fiber, soluble solids and minerals from the pulp can exert a buffer effect on the system, partially stabilizing the pH value.

From a technological point of view, the values obtained were suitable for the production of jams with high methoxylation pectin, used in the experimental formulation. This type of pectin requires an approximate pH range between 2.8 and 3.8 to form stable gels, because acidity reduces the electrostatic repulsion between pectin chains and favors the formation of the gelled network. (9) mentions that higher pH values decrease the gelling capacity and affect the final texture of the product.



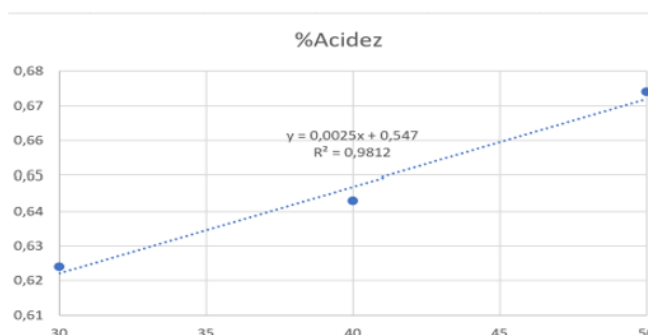
**Figure 2. Behavior of titrateable acidity between the three treatments.**

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Although the analysis of variance showed significant differences between treatments for pH, the linear regression presented a low  $R^2$  (0.0724), indicating that these differences do not follow a linear behavior with the increase in the percentage of

cupoazú pulp. Consequently, the effect of pulp percentage on pH cannot be adequately explained by a simple linear model.

Linear regression ( $y = 0.0025x + 0.547$ ;  $R^2 = 0.98$ ) shows a very strong positive linear relationship between the percentage of cupoazú pulp and acidity. As pulp increases, acidity also increases, and the model explains 99% of the observed variation.



**Figure 3. Linear correlation of acidity between the three treatments.**

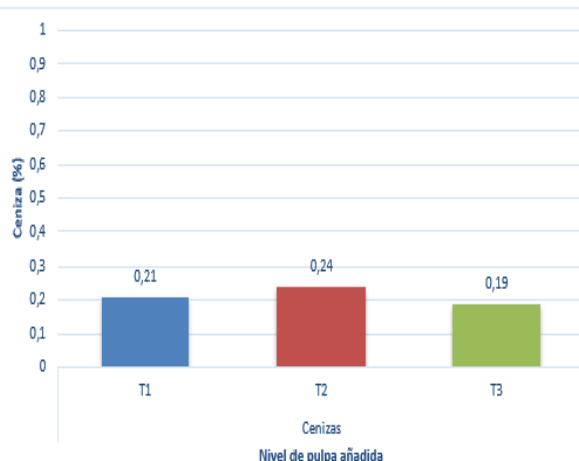
*Prepared by: Parra, J. 2026*

## Ashes

The ash content presented significant statistical differences between treatments, with T2 being the one that registered the highest value (0.24%), followed by T1 (0.21%) and T3 (0.19%); The parameter studied represents the total content of minerals present in the product.

The increase observed in T2 can be attributed to a greater availability of minerals from the cupoazú pulp, especially potassium, calcium and phosphorus, which remain relatively stable during cooking, but in T3, despite containing a higher percentage of pulp, the decrease in ash could be related to structural dilution phenomena and possible mineral losses during prolonged heat treatment. According to (10), it is mentioned that thermal concentration processes can modify the mineral distribution in fruit products due to interactions with peptic compounds and salt precipitation.

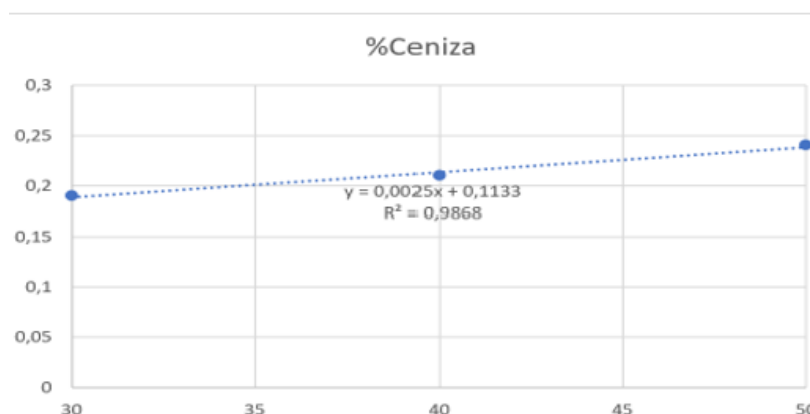
Furthermore, the behavior of the ashes is related to the solids content and the physicochemical composition of the treatment.



**Figure 4. Ash behavior between the three treatments.**

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The linear regression ( $y = -0.0025x + 0.1133$ ;  $R^2 = 0.9868$ ) indicates a very strong negative linear relationship between the percentage of copoazú pulp and the ash content. As the pulp increases, the ash content decreases slightly, the model explaining 98.68% of the observed variation



**Figure 5. Linear correlation of ash between the three treatments.**

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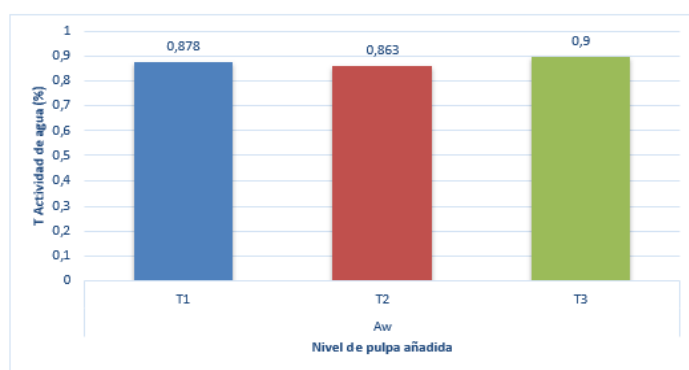
### Water activity ( $A_w$ )

Water activity ( $A_w$ ) presented significant statistical differences between treatments, where T2 presented the lowest value (0.863), while T3 reached the highest value (0.900). This behavior is directly related to the proportion of pulp, the content of added water and the concentration of soluble solids present in each formulation.

The smaller value of  $A_w$  in T2 indicates a greater retention of bound water within the final product, which was inferred to have been favored by an adequate balance

between sugar, pectin and structural compounds of the pulp. In jam-type systems, sugars reduce the availability of free water through osmotic effects, thus limiting water mobility and contributing to product stability. According to (11), the decrease in  $A_w$  in concentrated foods is one of the main conservation mechanisms, since it restricts microbial development and reduces the speed of chemical deterioration.

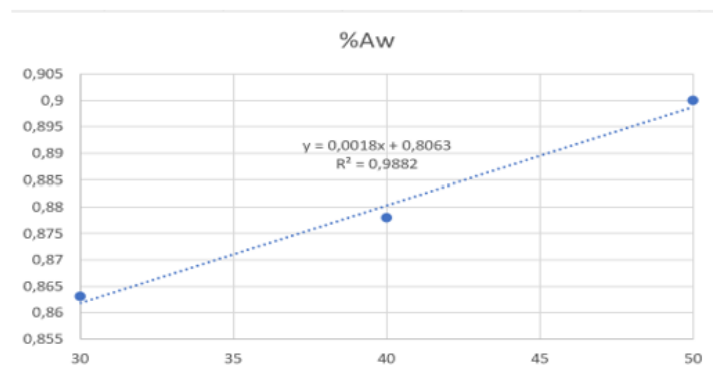
In treatment 3, on the other hand, it can be associated with the higher content of cupoazú pulp, which provides intracellular water and hydrophilic compounds capable of retaining moisture within the system. Although this treatment had a lower added water content, the fruit contributed significantly to the total available water. Furthermore, the reduction of soluble solids observed in T3 decreased the depressing effect of sugar on water activity, favoring higher  $A_w$  values.



**Figure 6. Behavior of water activity ( $A_w$ ) between the three treatments.**

*Prepared by: Parra J. 2026*

The  $A_w$  also showed an inverse relationship with the soluble solids obtained in the treatments. T1 presented a higher °Brix and a lower  $A_w$  than T3, confirming what was said by (12) that the increase in sugars favors the immobilization of free water. This behavior coincides with what was reported by (13), who points out that foods with a high concentration of soluble solids present lower water activity due to the formation of bonds between water molecules and solutes.



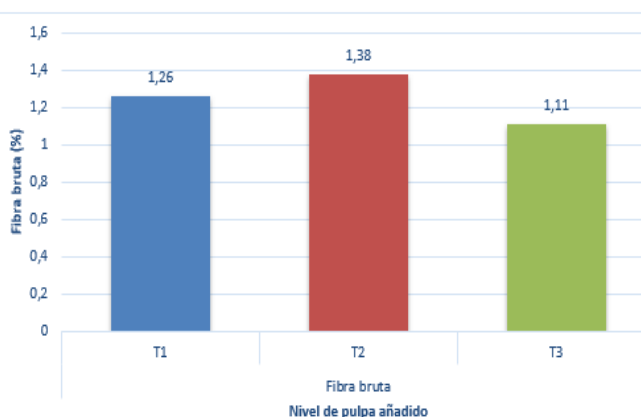
**Figure 7. Linear correlation of  $A_w$  between the three treatments.**

*Prepared by: Parra J.2026*

The regression equation showed a positive linear relationship and a high coefficient of determination ( $R^2=0.9882$ ), indicating that the percentage of pulp significantly influenced this parameter. This behavior can be attributed to the contribution of moisture from the copoazú pulp.

### Gross fiber

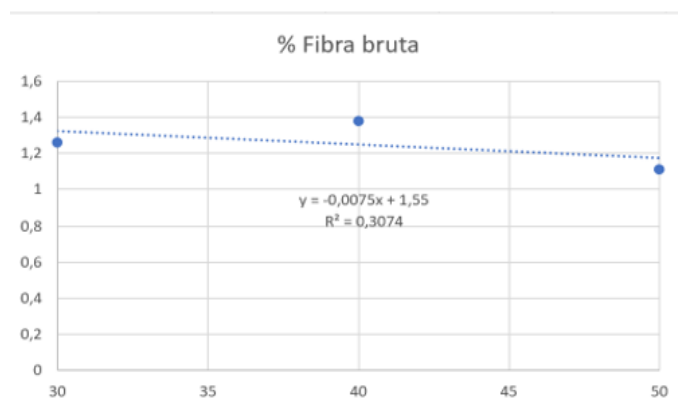
The crude fiber presented significant statistical differences between treatments, obtaining the highest value in T2 (1.38%), followed by T1 (1.26%) and T3 (1.11%), the behavior is assured to be directly influenced by the proportion of cupoazú pulp and by the effect of thermal processing on the structural components of the fruit.. The increase observed in T2 can be attributed to an adequate concentration of plant tissue in the formulation, allowing the preservation of a greater amount of structural polysaccharides such as cellulose, hemicellulose and insoluble pectins.. Although, in T3, despite containing a higher percentage of pulp, a decrease in fiber was evident, possibly associated with thermal degradation.. According to (14), cellulose, hemicellulose and lignin are part of this fruit and during cooking and concentration of the product they can degrade since the temperature in the burner could have varied at a critical moment.. The behavior of the fiber is related to the consistency and water retention of the product since dietary fibers have the capacity for hydration and formation of structural networks, influencing parameters such as viscosity and water activity.. (15) menciona que, en productos derivados de frutas, la estabilidad de la fibra depende tanto de la intensidad térmica como del equilibrio entre sólidos solubles y contenido de humedad.



**Figure 8. Behavior of crude fiber between the three treatments.**

*Prepared by: Parra, J. 2026.*

Although the treatment with 40% pulp had the highest crude fiber content, a strong linear relationship was not observed between the percentage of pulp and the fiber content, due to the low coefficient of determination ( $R^2=0.3074$ ). This indicates that other factors, such as thermal processing or experimental variability, could have influenced the results.



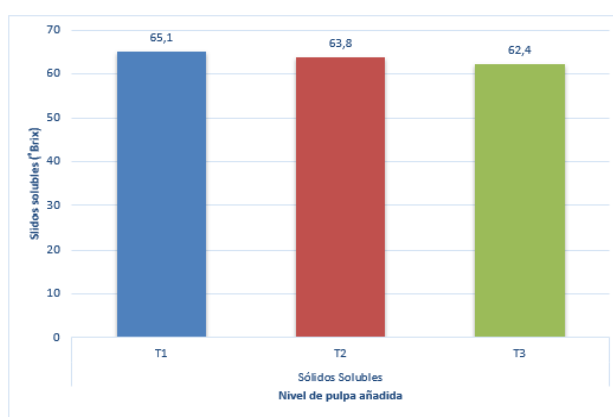
**Figure 9. Linear correlation of crude fiber between the three treatments.**

*Prepared by: Parra, J. 2026.*

### Soluble solids (°Brix)

Soluble solids presented significant statistical differences between treatments, with the highest value recorded in T1 (65.1 °Brix) and the lowest in T3 (62.4 °Brix). Behavior was influenced by the increase in the content of copoazú pulp and the relative decrease in soluble solids available in the formulation, and as the proportion of fruit increased, greater quantities of intrinsic water and insoluble compounds were incorporated, generating a dilution effect on the final concentration of sugars. and dissolved solids.

From a regulatory point of view, T1 was the only treatment that met the minimum established for jams, which indicate minimum values close to 65 °Brix to guarantee stability, consistency and conservation of the product. In T2 and T3, lower values could affect the conservation capacity due to lower osmotic pressure and greater availability of water for microbial development, but at the pH level used in all treatments this situation can be faced and counteracted.



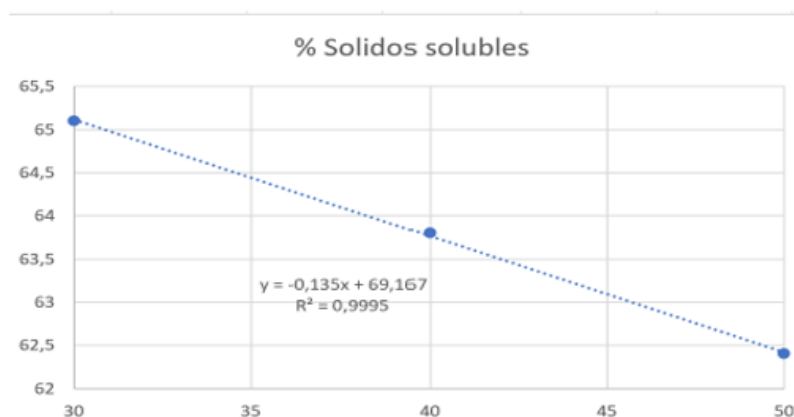
**Figure 10. Behavior of soluble solids between the three treatments.**

*Prepared by: Parra, J. 2026*

The progressive decrease in soluble solids by increasing the concentration of copoazú pulp. The behavior presented a very strong negative linear correlation ( $R^2=0.9995$ ),

indicating that the increase in pulp reduces the concentration of soluble sugars in the formulation.

(16) points out that insufficient concentrations of solids can reduce the firmness and stability of jam-type products.



**Figure 11. Behavior of soluble solids between the three treatments.**

*Prepared by: Parra, J. 2026*

### Sensory evaluation

An acceptability test was performed on 50 untrained panelists where they were presented with the attributes odor, flavor, texture, color and general appearance. A 5-point hedonic scale was imposed on them, where they were asked to give a value based on this range to describe the sensory qualities of the product in question. Each sample was coded with three random numbers without repeating any. The rules were not to communicate with each other, avoid turning and being very honest in their perception of the importance of the study. Table 3 shows the average results obtained for each experimental treatment

**Table 3. Average results of the Sensory evaluation of jam made with different levels of copoazú pulp.**

| Tratamiento | Color | Olor | Sabor | Textura | Apariencia | Promedio general |
|-------------|-------|------|-------|---------|------------|------------------|
| T1 (30%)    | 4.18  | 4.04 | 4.06  | 3.8     | 3.98       | 4.01             |
| T2 (40%)    | 4.28  | 3.98 | 3.98  | 4.1     | 3.94       | 4.06             |
| T3 (50%)    | 4.02  | 4.02 | 3.9   | 4.08    | 3.86       | 3.98             |

*Prepared by: Parra, J. 2026*

The sensory analysis of the prebiotic copoazú jam, evaluated using a five-point hedonic scale and analyzed with the non-parametric Kruskal-Wallis test ( $p > 0.05$ ), showed that there were no significant differences between the treatments for the attributes of color, smell, flavor, texture and appearance. The averages obtained ranged between 3.80 and 4.28, which indicates favorable acceptance by the panelists. Although the treatment with 40% pulp presented the highest overall average of acceptability (4.06), followed by the treatment with 30% (4.01) and 50% (3.98), these differences were not statistically significant. These results suggest that the increase in the content of copoazú pulp did not perceptibly modify the sensory characteristics of the product, maintaining an adequate organoleptic quality and demonstrating that it is possible to increase the pulp content without affecting consumer acceptance, as mentioned (17), the thermal treatment given to the jam favors a certain loss of compounds, partially homogenizing the characteristics between the treatments, likewise its smell was quite characteristic, according to (18) the fruit of the copoazú has a high content of compounds. aromatics.

### Economic Analysis

The economic analysis was carried out with the purpose of determining the economic viability of making jam using different levels of cupoazú pulp. For this, the costs of raw materials, inputs, packaging, labor, energy, cleaning and depreciation were considered; all these aspects are described in table 4.

**Table 4. Production costs of jam with different levels of cupoazú pulp.**

| Elemento                | Costo total    | Costo/frasco (500 g) |
|-------------------------|----------------|----------------------|
| Materia prima           | 30.00          | 2.5                  |
| Insumos                 | 8.7            | 0.7                  |
| Envase                  | 10             | 0.8                  |
| Mano de obra            | 10             | 0.8                  |
| Energía                 | 3              | 0.2                  |
| Limpieza                | 1.5            | 0.13                 |
| Depreciación de equipos | 2              | 0.17                 |
| <b>Total</b>            | <b>\$ 65.2</b> | <b>\$ 5.3</b>        |

*Prepared by: Parra, J. 2026.*

The costs incurred for the production of copoazú jam allowed us to determine a total production cost of 65.20 USD, equivalent to an approximate cost of 5.30 USD per 500 g jar and with a cost-benefit index of \$1.49.

The raw material represented the highest percentage of the total production cost, mainly due to the price of cupoazú and the low yield of pulp obtained during processing; This fruit has a high proportion of peel and seeds, which increases shrinkage and reduces industrial yield. According to (19), products made from non-traditional tropical fruits usually have higher costs due to the limited availability of raw materials and the difficulty of standardizing production processes, which was explained previously.

Labor also presented a significant value, which is related to the artisanal nature of production and the value of the basic salary, according to (20) mentions that in developing countries the availability of this is affected by the lack of industry that demands and sees viability.

The benefit/cost ratio was favorable for all the treatments evaluated since an established market sale price of \$6.50 and the production price of \$65.25 were taken, the total benefit was \$97.5 and giving us a final profitable value of \$1.49.

## DISCUSSION

The results obtained showed that the percentage of cupoazú pulp mainly influenced the pH, titratable acidity, ash, water activity, crude fiber and soluble solids, while humidity did not present significant differences. Treatment T2 (40% pulp) presented the best general performance, standing out for its highest crude fiber content (1.38%), ash (0.24%) and lower water activity (0.863). This behavior demonstrates that the formulation and processing conditions influence the final characteristics of the jam, as also pointed out by (4) for products made from fruits.

The pH presented significant differences, with the lowest value in T2 (3.69), while T1 and T3 registered 3.87 and 3.82, respectively. The values obtained correspond to an acidic food and favor the stability of the product. (5) point out that pH is an important parameter in the physicochemical stability of fruit products. On the other hand, the titratable acidity increased as the amount of pulp increased, presenting a strong linear relationship ( $R^2 = 0.98$ ). This difference between pH and acidity can be explained because pH represents free hydrogen ions, while titratable acidity reflects the total amount of acids present in the food.

The ash content was higher in T2 (0.24%) and lower in T3 (0.19%), which demonstrates that a higher percentage of pulp does not necessarily proportionally increase the mineral content. (10) mentions that thermal processes can modify the distribution of minerals in foods. Regarding water activity, T2 presented the lowest value (0.863), while T3 reached 0.900. This behavior can be related to the concentration of sugar, pectin and soluble solids. (11) point out that the reduction of water activity contributes to improving the stability of foods, while (13) indicate that a higher concentration of soluble solids favors the decrease in available water.

Crude fiber presented its highest value in T2 (1.38%), followed by T1 (1.26%) and T3 (1.11%). Although a progressive increase was expected with a greater amount of pulp, treatment T3 presented a decrease, possibly related to the effect of thermal processing. (14) points out the importance of the structural components of plant cell walls, while (15) indicates that processing can modify the stability of the fiber. Soluble solids, for their part, decreased from 65.1 °Brix in T1 to 62.4 °Brix in T3, presenting a very strong negative linear relationship ( $R^2 = 0.9995$ ). This can be attributed to the greater contribution of water and insoluble components of the pulp as their proportion increases.

In the sensory evaluation, no significant differences were found between treatments for color, smell, flavor, texture and appearance, with favorable averages between 3.80 and 4.28 points. T2 obtained the highest general acceptance (4.06), although the differences were not significant. These results indicate that the increase in pulp did not negatively affect the acceptance of the product. (17) relate heat treatment to the homogenization of certain characteristics of fruit products, while (18) highlight the characteristic aromatic compounds of copoazú.

Finally, the economic analysis showed a total production cost of 65.20 USD, an approximate cost of 5.30 USD per 500 g jar and a benefit/cost ratio of 1.49, indicating economic viability under the experimental conditions. (19) points out that products made with non-traditional tropical fruits may have high costs due to the availability and performance of the raw material. Overall, T2 was the treatment with the best physicochemical and sensory balance. Although the product contains dietary fiber, the content obtained does not allow it to be considered strictly as a prebiotic. However, the use of copoazú represents a value-added alternative for the development of innovative agroindustrial products.

## CONCLUSIONS

Among the treatments evaluated, treatment T2, corresponding to 40% of cupoazú pulp, presented the best balance, standing out for registering the highest crude fiber content (1.38%), highest ash content (0.24%), and lowest water activity (0.863%). These results allow it to be considered the most suitable formulation for making jam. Furthermore, although the jam obtained cannot be strictly considered a prebiotic product because it has a moderate fiber content, it can be classified as a product with a significant contribution of dietary fiber, which gives it nutritional value and functional potential for the consumer.

Regarding the sensory evaluation, it was carried out using the same hedonic scale that did not show significant differences ( $p > 0.05$ ) between treatments, in any of the attributes evaluated, which indicates that the variation in pulp content does not generate perceptible changes in consumer acceptance, maintaining a homogeneous and pleasant sensory profile for the consumer, since on average the results were favorable.

The economic analysis determined a total production cost of 65.20 USD and a unit cost of 5.30 USD per 500 g jar, evidencing that the cost structure is mainly determined by the raw material, packaging and labor, the high cost responds to structural factors such as the limited availability of copoazú in the study area since it was worked in the mountains of Ecuador and the product is grown in the Amazon area, therefore, the product was brought to order, therefore the logistical supply costs and the experimental scale of production increased the cost, which prevents the application of economies of scale, but the results demonstrate the technical viability of the product and its potential for agro-industrial scaling, especially in market niches of natural and value-added products, or as

an exclusive product due to its great sensory profile. Likewise, the product was profitable by achieving a 1.49 in the benefit-cost index.

## REFERENCES

1. Ballesteros, Gonzales. Role of prebiotics and probiotics in the functionality of the microbiota in the patients receiving enteral nutrition. 2020. DOI: <https://dx.doi.org/10.20960/nh.1956>.
2. Montecel N. Plan de negocio para la producción y comercialización de mermelada y té de cacao con stevia en la ciudad de Guayaquil [tesis]. Universidad Agraria del Ecuador; 2021. Disponible en: <https://cia.uagraria.edu.ec/Archivos/MONTECEL%20GOMEZ%20MELISSA%20NAYBI.pdf>.
3. Salazar J. Agroindustrial Residues as Sources of Nutrients and Phenolic Compounds. *Epistemus*. 2023;17(34). DOI: <https://doi.org/10.36790/epistemus.v17i34.265>.
4. Guevara-García M, et al. Energetic value and sensorial characteristics of jam formulated with Cucurbita ficifolia B. - Citrus sinensis L. and pectin sweetened with stevia. *Revista de Invest. Agropecuaria Science and Biotechnology*. 2025;5(4):1-11. DOI: <http://doi.org/10.25127/riagrop.20254.1127>.
5. Castillo K, et al. Bromatological and physicochemical characterization of an acai jam (Euterpe Oleracea Mart.) sweetened with cocoa mucilage. *Reincisol*. 2024;3(6):929-952. DOI: [https://doi.org/10.59282/reincisol.V3\(6\)929-952](https://doi.org/10.59282/reincisol.V3(6)929-952).
6. FAO. Bases técnicas para el aprovechamiento agroindustrial de especies nativas de la amazonia. 2025. Disponible en: <https://www.fao.org/fileadmin/templates/inpho/documents/ad418s00.pdf>.
7. Shahida A, et al. An overview of fermentation in the food industry - looking back from a new perspective. *Bioresour Bioprocess*. 2023;10. DOI:10.1186/s40643-023-00702-y.
8. Geraldine M. Acidez Titulable y pH en Alimentos. 2025. Disponible en: <https://es.scribd.com/document/526676883/ACIDEZ-TITUABLE-Y-PH>.
9. García E. Desarrollo y Caracterización de Mermelada producida a partir del fruto de mate Crescentia cujete L. [tesis]. Universidad Técnica de Ambato; 2019. Disponible en: <https://repositorio.uta.edu.ec/server/api/core/bitstreams/e2c6160a-76d6-40ea-a53e-18724b6effd9/content>.
10. Jacqueline B. Mineral in Food. 2020. En: ScienceDirect Topics. Disponible en: <https://www.sciencedirect.com/topics/food-science/mineral-in-food>.
11. Campo R, et al. Degradación de los componentes químicos presentes en los alimentos por influencia de la temperatura. *Pol. Con*. 2023;8(85). DOI:10.23857/pc.v8i8.
12. Febles J, et al. Análisis preliminar del efecto de la actividad de agua sobre la viabilidad y estabilidad en formulaciones de probióticos. 2016. Disponible en: [http://scielo.sld.cu/scielo.php?script=sci\\_arttext&pid=S2223-48612016000100009](http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2223-48612016000100009).
13. Yadav A, et al. Deshidratación osmótica de frutas y verduras. 2012. DOI:10.1007/s13197-012-0659-2.

14. Fujimori S. Humans have intestinal bacteria that degrade the plant cell walls in herbivores. World J Gastroenterol. 2021;27(45):7784. DOI:10.3748/wjg.v27.i45.7784.
15. Pak N. Fibra dietética en frutas cultivadas en Chile. Arch Latinoam Nutr. 2013;53(4). Disponible en: [https://ve.scielo.org/scielo.php?script=sci\\_arttext&pid=S0004-06222003000400013](https://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0004-06222003000400013).
16. López C, et al. Fourier transform infrared spectroscopy (FTIR) application chemical characterization of enamel, dentin and bone. 2025. DOI:10.1080/05704928.2018.1431923.
17. Zelanda C, et al. Efecto de la temperatura de pasteurización y proporción de mezclas binarias de pulpa de carambola y mango sobre su capacidad antioxidante lipofílica. 2013. Disponible en: <https://www.redalyc.org/pdf/3374/337430545009.pdf>.
18. Quispe R, et al. Análisis de la actividad antioxidante durante el proceso de producción del néctar de copoazú. Revista Alfa. 2025;9(26). DOI: <https://doi.org/10.33996/revistaalfa.v9i26.357>.
19. Monar A. Relación entre la manufactura de frutas tropicales y la cadena de valor de bebidas no alcohólicas en Manabí-Ecuador. ECA Sinergia. 2019;10(3). DOI: [https://doi.org/10.33936/eca\\_sinergia.v10i3.1815](https://doi.org/10.33936/eca_sinergia.v10i3.1815).
20. Revilla, Guerrero. Desarrollo de mermelada de flor de jamaica (*Hibiscus sabdariffa*) en diferentes estados (natural y deshidratada). Pontificia Universidad Católica del Ecuador; 2025. Disponible en: <https://repositorio.puce.edu.ec/items/fa790407-15e1-4907-952c-63c1e262e37d>.

# EFFECTO DE LA SUSTITUCIÓN PARCIAL DE CARNE POR HARINA DE SOYA SOBRE LAS PROPIEDADES FISICOQUÍMICAS, SENSORIALES Y MICROBIOLÓGICAS DE HAMBURGUESAS

## EFFECT OF PARTIAL MEAT REPLACEMENT WITH SOY FLOUR ON PHYSICOCHEMICAL, SENSORY AND MICROBIOLOGICAL PROPERTIES OF BEEF BURGERS

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**RESUMEN:** En la actualidad el beneficio de cambiar la composición de productos cárnicos sin eliminar su matriz tradicional es reemplazar parcialmente la carne por ingredientes vegetales. Este estudio se propuso determinar el impacto que tiene la adición de harina de soya (*Glycine max*) en hamburguesas de res a través de análisis microbiológicos, fisicoquímicos y sensoriales. Se formularon cuatro tratamientos: uno de control sin harina de soya (C1S1B) y tres con 5% (C2S2B), 10% (C3S3B) y 15% (C4S4B). Cada uno fue examinado en tres ocasiones. Se establecieron los niveles de pH, grasa, proteína, fibra, cenizas y humedad; para procesar la información se emplearon la prueba de Tukey con  $\alpha=0,05$  y el análisis de varianza. Se llevó a cabo la valoración sensorial con 20 catadores y una escala hedónica de cinco grados para el color, el aroma, el gusto y la apariencia. El aumento de harina de soya generó diferencias importantes en las variables fisicoquímicas. El tratamiento con 15% mostró el aporte composicional más alto, con 3,31% de cenizas, 19,02% de grasa, 2,41% de fibra y 26,71% de proteína. No obstante, el tratamiento con un 10% fue el que tuvo la mayor aceptación sensorial, con una media total de 4.45/5. Este tratamiento mostró  $8 \times 10^6$  UFC/g de aerobios mesófilos,  $3 \times 10^2$  UFC/g de *Escherichia coli*,  $8 \times 10^3$  UFC/g de *Staphylococcus aureus* y no hubo *Salmonella* en 25 g. En el análisis se consideraron estos valores como acordes con la NTE INEN 1338. Se concluye que la harina de soya altera en gran medida la composición de las hamburguesas y que el 10% es el porcentaje óptimo entre mejoramiento composicional y aceptabilidad.

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**Palabras clave:** *hamburguesa; harina de soya; sustitución parcial; análisis proximal; evaluación sensorial*

**ABSTRACT:** Partial replacement of meat with plant-based ingredients is an alternative for modifying the composition of meat products without eliminating their traditional matrix. This study aimed to evaluate the effect of incorporating soy flour (Glycine max) into beef burgers through physicochemical, sensory and microbiological analyses. Four formulations were prepared: a control without soy flour (C1S1B) and treatments containing 5% (C2S2B), 10% (C3S3B) and 15% (C4S4B), analyzed in triplicate. Moisture, ash, fat, fiber, protein and pH were determined, and the data were processed by analysis of variance and Tukey's test at  $\alpha=0.05$ . Sensory evaluation was performed by 20 panelists using a five-point hedonic scale for color, odor, flavor and appearance. Increasing soy flour caused significant differences in the physicochemical variables. The 15% treatment contained 3.31% ash, 19.02% fat, 2.41% fiber and 26.71% protein, showing the greatest compositional contribution and the lowest fat content among treatments. However, the highest sensory acceptance was observed for the 10% treatment, with an overall mean score of 4.45/5. This treatment showed  $8 \times 10^6$  CFU/g of mesophilic aerobes,  $3 \times 10^2$  CFU/g of *Escherichia coli*, and  $8 \times 10^3$  CFU/g of *Staphylococcus aureus*, with an absence of *Salmonella* in 25 g values interpreted in the study as compliant with NTE INEN 1338. It is concluded that soy flour significantly modifies the composition of the hamburger and that the 10% level offers the best balance between compositional improvements and acceptability.

**Keywords:** *beef burger; soy flour; partial replacement; proximate analysis; sensory evaluation*

## INTRODUCTION

Processed meat products constitute a technological matrix susceptible to reformulation through the incorporation of plant ingredients that act as extenders and modify their composition. In the case of minced meat used to make hamburgers, it can be combined with permitted ingredients and seasonings, as long as the product meets the composition and safety requirements established for its category. The incorporation of soy is of interest due to its protein, lipid, carbohydrate and fiber content, in addition to the diversity of technological applications described for this legume and its derivatives (1-3).

Soy (Glycine max) is characterized by having a high protein content in addition to providing lipid fractions and carbohydrates that can influence the properties of the food in which it is incorporated. The use of soy flour as a partial meat substitute has been previously evaluated in different meat products. Odiase et al. (2013) studied the incorporation of whole soy flour at levels of 10, 15, 20 and 25% in meatballs made with beef, showing that intermediate levels of inclusion, particularly 10 and 15%, presented greater sensory acceptance. Similarly, Cho et al. (2017) evaluated the incorporation of 5% defatted soy flour with different particle sizes in hamburgers, analyzing its physicochemical and sensory properties; Their results demonstrated that the use of superfine flour allowed maintaining a general acceptability comparable to the control

treatment and reducing cooking losses. These antecedents show the technological potential of soy flour in meat products and support the need to continue studying levels of substitution that allow maintaining the acceptance of the product. In this sense, it is pertinent to evaluate the use of non-textured soy flour at intermediate levels of beef substitution through a comprehensive approach that jointly considers the physicochemical composition, sensory acceptance and microbiological quality of the product. In this context, the nutritional characteristics of soy flour justify its evaluation as a partial substitute for meat, particularly due to its contribution of protein and fiber and its potential influence on the final composition of the product. The literature compiled in the research also describes soy as an ingredient used in the production of foods with a high protein content and in various agro-industrial applications (19,20).

The use of protein sources of plant origin in meat products has been studied with different raw materials. García evaluated pigeon pea flour in low-fat hamburgers and reported modifications in the composition and technological properties of the product (4). Solórzano studied the substitution of beef for textured soy vegetable protein in a meat system, finding that a substitution of up to 9% could improve nutritional quality and maintain adequate sensory acceptance (5). In hamburgers, Beltrán analyzed the partial substitution of beef for soy meat and observed that a 40% substitution affects the acceptance of attributes such as flavor, smell and color (6). Soy by-products, such as okara, have also been evaluated in sausages, with favorable results from a nutritional and sensory point of view (7).

Consumer acceptance is a critical component in these types of reformulations. A compositional improvement does not necessarily translate into greater preference, because the incorporation of vegetable proteins can alter color, aroma, flavor, texture or appearance. Studies with preparations based on soy and other plant ingredients show that the sensory response depends on the formulation and the level of incorporation (8). Similarly, Lema and Majin evaluated hamburgers enriched with vegetable proteins and showed that the composition of the product changes according to the percentage of substitution (9). For this reason, the selection of a treatment must simultaneously consider physicochemical outcomes and acceptability.

In addition to the composition and sensory response, microbiological safety is an essential requirement. The NTE INEN 1338 establishes criteria applicable to raw meat products and was used in the original study as a reference to interpret the quality of the product (10). The microbiological evaluation of the sensorially preferred treatment included mesophilic aerobes, *Escherichia coli*, *Staphylococcus aureus* and *Salmonella* (23), with the purpose of verifying that the selected formulation remained within the limits considered in the research.

From this framework, the central problem is to determine what level of substitution with soy flour allows obtaining a hamburger with a favorable physicochemical profile and adequate sensory acceptance. The established experimental hypothesis was that partial substitution with soy flour influences the physicochemical properties of the hamburgers. Consequently, the objective of this article was to synthesize and analyze the effect of three levels of soy flour substitution (5%, 10% and 15%), compared to a

control treatment without substitution (0%), on humidity, ash, fat, fiber, protein and pH; compare the acceptability of treatments by color, odor, taste and appearance; and present the microbiological condition of the treatment with greater sensory acceptance. This integration allows us to identify both the treatment with the best nutritional composition and the formulation with the greatest sensory acceptance, two criteria that do not necessarily coincide and that are relevant for the development of a reformulated meat product.

## MATERIALS AND METHODS

An experimental investigation was developed with four beef burger formulations. The C1S1B treatment corresponded to the control without soy flour; C2S2B added 5%; C3S3B, 10%; and C4S4B, 15%. In all formulations, 4.98% of seasonings remained constant, distributed in 2.37% onion powder, 0.47% parsley, 0.23% pepper and 1.90% salt. The proportion of meat was 95.01%, 90.26%, 85.02% and 80.02%, respectively. Physicochemical analyzes were performed in triplicate.

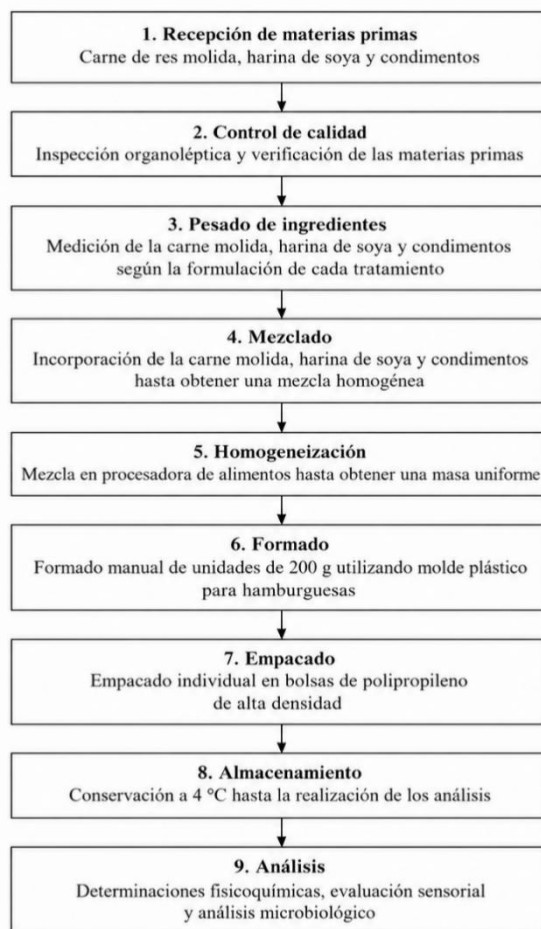
For each formulation, 200 g hamburgers were made, obtained by homogeneously mixing ground beef, soy flour and seasonings; They were subsequently packed in polypropylene bags and stored at 4 °C until analysis. Physicochemical determinations of humidity, ash, fat, fiber, protein and pH were carried out in triplicate (n = 3) in each treatment. The sensory evaluation was carried out with 20 panelists using a five-point hedonic scale for color, smell, flavor and appearance. The microbiological analysis was applied only to the treatment with greater sensory acceptance.

**Table 1. Hamburger formulations with partial substitution of soy flour.**

| Ingredient       | C1S1B<br>Control | C2S2B<br>5% | C3S3B<br>10% | C4S4B<br>15% |
|------------------|------------------|-------------|--------------|--------------|
| Beef (%)         | 95,01            | 90,26       | 85,02        | 80,02        |
| Soy flour (%)    | 0,00             | 5,00        | 10,00        | 15,00        |
| Onion powder (%) | 2,37             | 2,37        | 2,37         | 2,37         |
| Parsley (%)      | 0,47             | 0,47        | 0,47         | 0,47         |
| Pepper (%)       | 0,23             | 0,23        | 0,23         | 0,23         |
| Salt (%)         | 1,90             | 1,90        | 1,90         | 1,90         |

*Source: synthesis of the reported formulations.*

The beef was purchased previously ground and, along with soy flour and seasonings, was subjected to reception and quality control. The ingredients were weighed on a ME204 digital scale and mixed in a food processor until a uniform mass was obtained. Subsequently, 200 g portions were manually formed using a plastic hamburger mold, packed in high-density polypropylene bags, and stored at 4 °C until analysis. The original study did not report the particle size of the meat or specific values of time and temperature during mixing, so these parameters could not be specified



**Figure 1. Flow diagram for making hamburgers with soy flour.**

For the physicochemical analyzes the following were included: humidity, ash, fat, protein, crude fiber and pH. Humidity was determined by mass loss due to oven heating, using the NTE INEN 0777 method and the analytical procedure described by AOAC (11). The ashes obtained at  $550 \pm 10$  °C until constant weight, according to NTE INEN 786; The fat was determined by extraction with hexane and evaporation of the solvent, following the NTE INEN 778 regulations; The protein was estimated by nitrogen determination, acid digestion, alkalinization, distillation and titration, according to NTE INEN 781; crude fiber instead using the MAL-50/Pearson method; and the pH in accordance with NTE INEN 783. and all of this for the meat product was taken as a reference by NTE INEN 1338 (10), in this way all analyzes are carried out based on current and regularized regulations and procedures.

The sensory evaluation was carried out with a semi-trained panel of 20 Agroindustrial Engineering students, who had previously participated in sensory evaluations. Each treatment was rated on color, smell, taste, and appearance using a five-point hedonic scale: 1, "I really dislike it"; 2, "I dislike it"; 3, "I neither like nor dislike"; 4, "I like it"; and 5, "I like it a lot." The results were tabulated and represented using a radial graph, and the overall mean of the four attributes was used only as a descriptive measure of acceptance. It was carried out by randomizing the samples with control and balancing

of the order of presentation. It should be noted that no inferential statistical analysis was applied to the sensory data.

This evaluation was not intended to microbiologically compare the treatments, but rather to verify the microbiological quality of the selected formulation, which is why it was applied only to the treatment with the best sensory evaluation where mesophilic aerobes were analyzed using NTE INEN 1529-5 (13), *Escherichia coli* using AOAC 991.14 with the use of Petrifilm type plates (14), *Staphylococcus aureus* using NTE INEN 1529-14 (15) and *Salmonella* through NTE INEN 1529-15 (16). The work reported the use of Nissui Compact Dry Discs plates. Microsoft Excel 2019 and InfoStat version 6.2 were used for the statistical analysis of the physicochemical variables. The data were analyzed using analysis of variance (ANOVA) and Tukey's multiple comparison test, with a significance level of  $\alpha = 0.05$ .

Regarding storage, once prepared, the burgers were individually packaged in high-density polypropylene bags and kept refrigerated at 4 °C until analysis. The physicochemical and sensory determinations were carried out within 24 hours after preparation, keeping the samples under refrigeration during this period.

## RESULTS

The results showed a consistent response of the composition of the hamburgers to the increase in the percentage of soy flour. In all the physicochemical variables evaluated, significant differences between treatments were reported. For humidity, fiber, fat, protein and pH, the analysis of variance presented values of  $p < 0.0001$ ; for ashes  $p = 0.0002$  was obtained. Consequently, the study rejected the null hypothesis and accepted that partial substitution with soybean flour significantly influences the physicochemical properties of the product.

The values obtained in the proximal analyzes carried out on the ground beef that was used as raw material in the preparation of the hamburger, presented averages of 58.15% humidity, compared to the humidity presented in the soy flour which was 4.38%, an expected result because soy flour is a dehydrated product, which favors its conservation and incorporation in the formulation, with regard to The ash values obtained 2.22% of the mineral fraction in the soy flour, higher than the 0.43% obtained in the meat raw material, indicating that the soybeans contribute a greater amount of minerals to the formulation.

Regarding the protein values, the meat material presented 21.80% and 1.83% fiber while the soy flour presented 27.01% protein and 2.15% fiber, in this way it can contribute with an important protein content and improve the fiber value in the final product, increasing its nutritional value.

Regarding the fat percentage of the ground beef, it was 19.10%, while the soy reached 19.10%, although the value is lower than that of beef, it does constitute a relevant source of fat from a nutritional point of view, since using it as a replacement ingredient will maintain a considerable contribution of fat in the final product. With regard to the pH values, there is no major difference since the pH of the meat matrix was 6.57. and

for soy flour it was 6.73%, indicating that both ingredients have similar acidity conditions.

**Table 2. Physicochemical means reported in Tukey tests by treatment.**

| Process   | Moisture % | Ash % | Fiber % | Fat % | Protein % | pH   |
|-----------|------------|-------|---------|-------|-----------|------|
| C1S1B 0%  | 64,36      | 2,53  | 1,83    | 27,70 | 21,80     | 6,60 |
| C2S2B 5%  | 60,04      | 3,09  | 2,04    | 23,54 | 23,41     | 6,68 |
| C3S3B 10% | 56,98      | 3,22  | 2,27    | 19,83 | 25,27     | 7,04 |
| C4S4B 15% | 55,24      | 3,31  | 2,41    | 19,02 | 26,71     | 7,07 |

ANOVA: moisture, fiber, fat, protein and pH,  $p < 0.0001$ ; ashes,  $p = 0.0002$ . Means taken from Tukey tables from the original study.

Moisture showed a decrease as the percentage of substitution in the formulations increased, observing a reduction in the value of the parameter between the control sample and the 15% substitution by 9.12 percentage points. This behavior was one of the most notable changes in the product and may be related to the lower water content that soy flour has compared to meat matter.

Regarding the ash content, it was observed that this parameter increases gradually as the percentage of substitution was increased, showing a difference of 0.78 percentage points between the control and 15%. In this case, the Tukey test separated the four levels, showing a gradual and significant increase. The result of the fiber analysis shows that the value increased, because soy flour has a higher fiber content, with 0.58 percentage points being the difference between the control and the 15% formulation.

The fat content values indicated a decrease of 8.68 percentage points between the control treatment and the 15% treatment; this result may be related to the lower fat content of the soy flour compared to the meat mixture. Protein is one of the parameters of greatest interest and relevance since it contributes to the nutritional value of the product and also participates in technological characteristics such as water retention and structure formation during processing, so going from 21.80% in the control sample to 26.71% in the 15% substitution represents approximately a 22.5% relative increase with respect to the initial value.

Considering the physicochemical variables together, C4S4B presented 3.31% ash, 19.02% fat, 2.41% fiber and 26.71% protein. Due to these characteristics, the original study identified it as the best treatment from the point of view of nutritional and compositional contribution. However, the sensory response showed a different pattern. The control obtained average ratings of 4.0 for color, 4.2 for odor, 4.2 for flavor, and 4.0 for appearance, with an overall descriptive mean of 4.10/5. C2S2B achieved 3.6 for color, 4.4 for smell, 4.8 for flavor and 4.2 for appearance, equivalent to 4.25/5. C3S3B obtained 4.2 in color, 4.8 in smell, 4.6 in flavor and 4.2 in appearance, reaching the highest overall average, 4.45/5. C4S4B presented 3.8 in color, 4.0 in smell, 4.0 in flavor and 3.8 in appearance, with an average of 3.90/5.

**Table 3. Descriptive sensory evaluation of the four formulations.**

| Treat.    | Color | Odor | Taste | Appearance | Medium |
|-----------|-------|------|-------|------------|--------|
| C1S1B 0%  | 4,0   | 4,2  | 4,2   | 4,0        | 4,10   |
| C2S2B 5%  | 3,6   | 4,4  | 4,8   | 4,2        | 4,25   |
| C3S3B 10% | 4,2   | 4,8  | 4,6   | 4,2        | 4,45   |
| C4S4B 15% | 3,8   | 4,0  | 4,0   | 3,8        | 3,90   |

*Note. Hedonic scale from 1 to 5. The global average was calculated from the four attributes as a descriptive synthesis.*

These data show that the maximum incorporation of soy did not coincide with the maximum sensory acceptance. Although C4S4B was higher in protein and fiber and recorded the lowest fat, its sensory evaluation was lower than that of C2S2B and C3S3B, and even slightly lower than that of the control. The 10% formulation achieved the best combined ratings, especially in smell, with 4.8/5, and flavor, with 4.6/5. In the interpretation of the work, this result made C3S3B the sensory preferred treatment.

The microbiological analysis was carried out exclusively in C3S3B as it is the most widely accepted treatment.  $8 \times 10^6$  CFU/g of mesophilic aerobes,  $3 \times 10^2$  CFU/g of *Escherichia coli* and  $8 \times 10^3$  CFU/g of *Staphylococcus aureus* were reported; *Salmonella* was absent in 25 g. The study compared these values with the intervals used to interpret NTE INEN 1338 and concluded that the treatment was within the permitted limits. Therefore, the sensorially selected formulation also presented a microbiological condition considered acceptable within the framework of the research.

**Table 4. Microbiological results of the C3S3B treatment (10% soybean flour).**

| Analysis                     | Unit    | Minimum reported  | Maximum reported  | Result          |
|------------------------------|---------|-------------------|-------------------|-----------------|
| Mesophilic aerobes           | CFU/g   | $1.0 \times 10^6$ | $1.0 \times 10^7$ | $8 \times 10^6$ |
| <i>Escherichia coli</i>      | CFU/g   | $1.0 \times 10^2$ | $1.0 \times 10^3$ | $3 \times 10^2$ |
| <i>Staphylococcus aureus</i> | CFU/g   | $1.0 \times 10^3$ | $1.0 \times 10^4$ | $8 \times 10^3$ |
| <i>Salmonella</i>            | in 25 g | Absence           | Absence           | Absence         |

*Note: interpretation of results as in accordance with NTE INEN 1338.*

The integration of results allows two selection criteria to be differentiated. If the objective focuses on maximizing protein and fiber and reducing fat, the C4S4B treatment, with 15% soy flour, showed the most favorable response. If sensory acceptance is simultaneously considered, C3S3B, with 10%, presented a better balance: its protein was 25.27%, its fiber 2.27% and its fat 19.83%, clearly improved values compared to the control, while its global sensory average was the highest. This difference between compositional performance and sensory preference is the central finding of the study and supports the need to value both components when selecting the level of substitution.

## DISCUSSION

The results obtained provide relevant evidence on the potential of soy flour as a partial substitute for beef in hamburgers, particularly by identifying a favorable trend of acceptance for the formulation with 10%. However, the sensory evaluation was analyzed descriptively, so the observed differences represent preference trends and not a statistically demonstrated superiority. Likewise, the microbiological analysis was carried out only on the most widely accepted formulation with the purpose of verifying its hygienic-sanitary condition. Although this approach does not allow establishing microbiological comparisons between treatments, it allowed us to complement the evaluation of the selected formulation and provide preliminary evidence for subsequent validation studies.

It is clear that the main differences between studies are based on parameters such as matrices, raw materials and substitution percentages; However, the evidence supports that the incorporation of plant ingredients positively modifies the composition of meat products.

The changes in the composition of the hamburgers show the effect of soy flour on the meat matrix. The increase in protein and fiber can be attributed to the composition of this legume and coincides with what was pointed out by Gallegos, Ridner and Riaz about its nutritional contribution and potential as an ingredient in foods (1,2,18). In turn, the decrease in fat and humidity suggests that the partial substitution of meat modified the balance of the components of the formulation, a behavior similar to that described in meat products made with vegetable extenders (4,9). Together, these results support the potential of soy flour as an ingredient for the reformulation of meat products, although its incorporation must be balanced with the sensory characteristics of the product.

Solórzano denotes that an intermediate level of textured vegetable protein provides a favorable sensory response to higher or lower formulations of the percentages treated (5). Taken together, the data indicate the existence of a balance point between two important aspects: the improvement in the composition and the intensity with which the sensory characteristics are seen once the soy is added.

The microbiological result of C3S3B was interpreted in the investigation as in accordance with NTE INEN 1338 (10). The absence of Salmonella and the reported counts for mesophilic aerobes, *Escherichia coli* and *Staphylococcus aureus* supported the selection of the treatment from a safety perspective. However, the microbiological evaluation was carried out only in the sensorially preferred treatment, so the data do not allow us to compare the effect of the percentage of soy flour on the microbial load of the four formulations.

It is necessary to consider that the sensory evaluation is descriptive, that is, through the use of averages and radial graphs, the data obtained is shown, where an inferential test of significant acceptance differences is not reported. This limitation was not an obstacle to the observed preference for C3S3B, but it does restrict the scope of the conclusion at the sensory level. Likewise, the study focused on proximal composition, pH, acceptance and microbiology of the selected treatment; Instrumental measurements of texture,

cooking performance or storage stability of the product were not included. In future evaluations, these variables would allow the technological feasibility of the formulation to be characterized in greater depth.

Taken together, the results show a clear relationship between the level of substitution and the compositional properties of the hamburgers, accompanied by a favorable sensory response at intermediate levels. While a greater incorporation of soy flour favored physicochemical changes, the intermediate treatment showed the best balance between nutritional contribution and sensory acceptance. These findings support its potential as a viable formulation for future validation and development studies.

## CONCLUSIONS

The partial replacement of beef with soy flour significantly modified the physicochemical properties of the burgers. By increasing the incorporation from 0 to 15%, moisture decreased from 64.36% to 55.24% and fat from 27.70% to 19.02%, while fiber increased from 1.83% to 2.41% and protein from 21.80% to 26.71%. The C4S4B treatment, with 15% soy flour, presented the highest compositional contribution according to the criteria considered in the research.

The sensory response showed that a greater substitution of meat for soy flour did not necessarily imply greater acceptance. The treatment with 10% substitution presented the best overall rating (4.45/5), with a favorable response in color, smell, flavor and appearance, which allowed it to be identified as the formulation with the best sensory balance. Likewise, this treatment was subjected to microbiological evaluation and its results were interpreted in accordance with the criteria established in NTE INEN 1338, highlighting the absence of Salmonella in 25 g of sample.

Altogether, the results show that the incorporation of soy flour constitutes a viable alternative for the partial replacement of beef in hamburgers. The treatment with 10% presented the best balance between composition and sensory acceptance, while 15% showed the greatest compositional contribution. These findings support the technological potential of soy flour in the reformulation of meat products. Future studies may expand these results through sensory inferential analysis, texture evaluation, cooking performance, storage stability and microbiological characterization of all formulations.

## REFERENCES

1. Ridner E. Soja: propiedades nutricionales y su impacto en la salud. Buenos Aires: Grupo QSA; 2006. Disponible en: <http://www.sanutricion.org.ar/files/upload/files/soja.pdf>
2. Riaz MN. Soy Applications in Food. Boca Ratón: CRC Taylor & Francis Group; 2006.
3. Bairy EM, Tosh SM, Corredig M, Poysa V, Woodrow L. Varietal differences of carbohydrates in defatted soybean flour and soy protein isolate byproducts. Carbohydrate Polymers. 2008;72:664-672.

4. García O. Evaluación físico-química de carnes para hamburguesas bajas en grasas con inclusión de harina de quinchoncho (*Cajanus cajan*) como extensor. UCLA; 2012. <https://www.redalyc.org/pdf/959/95925106002.pdf>
5. Solórzano W. Sustitución de la carne de bovino por proteína vegetal texturizada de soya en un sistema cárnico tipo pastel mexicano (trabajo de titulación). ESPOCH; 2016.
6. Beltrán C. Evaluación sensorial de hamburguesa, utilizando carne de soya como sustituto parcial de carne de res (trabajo de titulación). UTM; 2014. <http://repositorio.utmachala.edu.ec/bitstream/48000/1600/7/CD00011-TESES.pdf>
7. Carillo M. Utilización de okara de soya en un embutido cárnico de pollo (tesis de grado). USFQ; 2012. Disponible en: <http://repositorio.usfq.edu.ec/bitstream/23000/2195/1/104378.pdf>
8. Criollo F. Utilización de soja y quinua en la elaboración de preparaciones gourmet 2010 (proyecto de titulación). ESPOCH; 2010. <http://dspace.esPOCH.edu.ec/bitstream/123456789/2320/1/84T00071.pdf>
9. Lema C, Majin M. Elaboración de tortas de carne para hamburguesa enriquecidas con diferentes porcentajes de proteínas vegetales: soya texturizada, quinua y amaranto; conservadas a diferentes temperaturas (tesis). Universidad Estatal de Bolívar; 2010. <http://dspace.ueB.edu.ec/bitstream/123456789/905/1/044.pdf>
10. Instituto Ecuatoriano de Normalización. NTE INEN 1338. 2012. <https://archive.org/details/ec.nte.1338.2012>
11. AOAC. Métodos de análisis. 1977. <http://www.usc.es/caa/MetAnalisisStgo1/derivados%20de%20cereales.pdf>
12. Instituto Ecuatoriano de Normalización. NTE INEN 1217. 2006. <https://archive.org/stream/ec.nte.1217.2006#mode/2up>
13. Instituto Ecuatoriano de Normalización. NTE INEN 1529-5. 2006. <https://archive.org/stream/ec.nte.1529.5.2006#page/n1/mode/2up>
14. 3M. Placas Petrifilm para el recuento de *E. coli*/coliformes. 2006. <https://multimedia.3m.com/mws/media/4449500/3m-petrifilm-e-coli-coliform-count-plate-interpretation-guide-spanish.pdf>
15. Instituto Ecuatoriano de Normalización. NTE INEN 1529-14. 1998. <https://archive.org/details/ec.nte.1529.14.1998/page/n1/mode/2up>
16. Instituto Ecuatoriano de Normalización. NTE INEN 1529-15. 1994.
17. Valdiviezo V. Estudio del efecto de diferentes niveles de carragenato en la jugosidad de la hamburguesa de carne de res (trabajo de titulación). ESPOCH; 2010. <http://dspace.esPOCH.edu.ec/bitstream/123456789/1683/1/84T00048.pdf>
18. Gallegos R. Determinación proximal de los principales componentes de seis leguminosas (disertación). PUCE; 2013. <http://repositorio.puce.edu.ec/bitstream/handle/22000/7111/4.7.001037.pdf>
19. Pérez S. Estudio monográfico sobre bebidas con alto contenido proteico a base de soya (tesis de maestría). FUNIBER; 2015. Disponible en: <https://www.slideshare.net/funiber/funiber-sergio-enrique-prez-estudio-monogrfrico-sobre-bebidas-con-alto-contenido-proteico-a-base-de-soya>
20. Guzmán E. Obtención de una bebida proteica a base de soya (*Glycine max*) y naranjilla (*Solanum quitoense*) (proyecto de titulación). Escuela Politécnica

- Nacional; 2018. <https://bibdigital.epn.edu.ec/bitstream/15000/19333/1/CD-8705.pdf>
21. Ludeña B. Isoflavonas en soja, contenido de daidzeína y genisteína y su importancia biológica. 2007. <https://www.redalyc.org/pdf/651/65111118009.pdf>
22. González N. Isoflavonas de soja y evidencias sobre la protección cardiovascular. 2013. [http://scielo.isciii.es/scielo.php?script=sci\\_arttext&pid=S0212-16112014000600007](http://scielo.isciii.es/scielo.php?script=sci_arttext&pid=S0212-16112014000600007)
23. Ayabaca E. Análisis proximal del agregado de soja en polvo (glycine max) a carne molida para la elaboración de hamburguesas. 2020. <http://dspace.unach.edu.ec/handle/51000/7249>

# LA MEDIACIÓN COMO MEDIO ALTERNATIVO EN LA

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## SOLUCIÓN DE CONFLICTOS

### MEDIATION AS AN ALTERNATIVE MEANS OF CONFLICT RESOLUTION

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**RESUMEN:** El sistema de justicia ordinario ecuatoriano, con una alta carga procesal y presupuestal para el Estado, se ha convertido en un sistema anacrónico e ineficiente a la hora de ofrecer respuestas oportunas a sus ciudadanos ante sus demandas de justicia. Frente a esta problemática, la mediación, con procesos más simples, se presenta como una urgente y necesaria respuesta para el acceso, desde la voluntad y aprobación de los conflictuados, a la solución pronta y oportuna de sus controversias. El objetivo de esta investigación persigue precisamente, determinar la influencia de la mediación como procedimiento eficaz en la solución de conflictos en el sistema de justicia ecuatoriano y su repercusión sobre su carga procesal. La metodología aplicada tuvo un enfoque mixto, documental, descriptivo, cualitativo no experimental y cuantitativo analítico, sustentado en la recopilación y revisión de normas jurídicas (Constitución, Ley de Arbitraje y Mediación, COGEP, entre otras), artículos científicos, libros, tesis y estadísticas secundarias del Consejo de la Judicatura. Los resultados de la presente investigación muestran que la mediación como método alternativo en la solución de conflictos está amparada en el ordenamiento jurídico ecuatoriano por la Constitución y la ley y se puede aplicar en diferentes materias y asuntos transigibles. No obstante, la normativa no delimita expresamente los ámbitos de procedencia de la mediación, por lo que se requiere trabajar en su delimitación con una data dinámica unificada y actualizada en tiempo real. Se recomienda promover y fortalecer los mecanismos de mediación mediante políticas públicas, difusión institucional y capacitación especializada para consolidar su utilización como vía preferente de solución de conflictos.

**Palabras clave:** *Mediación, métodos alternativos de solución de conflictos, acceso a la justicia, carga procesal, justicia ecuatoriana*

**ABSTRACT:** The Ecuadorian ordinary justice system, burdened by a high procedural and budgetary load for the State, has become an anachronistic and inefficient system

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in providing timely responses to citizens' demands for justice. Faced with this problem, mediation, with its simpler processes, emerges as an urgent and necessary solution, enabling access to prompt and timely resolution of disputes based on the will and approval of the parties involved. The objective of this research is precisely to determine the influence of mediation as an effective conflict resolution procedure within the Ecuadorian justice system and its impact on its procedural workload. The methodology employed a mixed-methods approach, combining documentary, descriptive, non-experimental qualitative, and analytical quantitative methods. This approach was based on the compilation and review of legal norms (Constitution, Arbitration and Mediation Law, COGEP, among others), scientific articles, books, theses, and secondary statistics from the Council of the Judiciary. The results of this research show that mediation as an alternative dispute resolution method is protected under Ecuadorian law by the Constitution and other legislation and can be applied to various matters and issues subject to negotiation. However, the regulations do not explicitly define the scope of mediation, thus requiring further work to delimit it using unified, dynamic, and real-time updated data. It is recommended that mediation mechanisms be promoted and strengthened through public policies, institutional outreach, and specialized training to consolidate its use as the preferred method for conflict resolution.

**Keywords:** *Mediation, alternative dispute resolution, access to justice, procedural burden, the Ecuadorian justice system*

## INTRODUCTION

Humanity needs to coexist in harmony in the different activities we carry out; However, we are constantly in disputes and conflicts, many of which, in order to find justice, undergo complex and economically, socially and psychologically exhausting legal processes, in the midst of an anachronistic, collapsed, ineffective system, with a high procedural burden and a high budget burden for the State. Faced with this problem, mediation, with shorter, direct and simpler processes, is presented as an urgent and necessary response for access, based on the will and approval of the conflicted parties, to the prompt and timely solution of their disputes, with rapid access to justice and the effective protection of their rights, with agreements that constitute enforceable sentences with the force of *res judicata*.

When addressing mediation and reviewing its origins, we see that this legal institution is not new, we have found it since ancient times, so in Greece it was known by the name "*mesiteuontes*". The publication *The Pioneers of Mediation* takes us to ancient Rome, mentioning that mediation was also used there, and at this time they already had "*judices pacis*" (justices of the peace) in their legal system. In Ecuador, through Supreme Decree No. 735 published in the Official Registry No. 90 of October 28, 1963, the Commercial Arbitration Law was promulgated, which became the first Special Law for the resolution of conflicts between merchants of the time. During the government of Fabián Alarcón, the Arbitration and Mediation Law, currently in force, was published in the Official Registry No. 145 of September 4, 1997, and which incorporates mediation

into Ecuadorian regulations as a conflict resolution procedure, recognizing a neutral third party as a mediator, who seeks voluntary agreements on transmissible matters, of an extrajudicial nature and which puts an end to a conflict, as established in its Art. 43 "Mediation is a procedure of conflict resolution by which the parties, assisted by a neutral third party called a mediator, seek a voluntary agreement, which deals with transmissible matters, of an extrajudicial and definitive nature, that puts an end to the conflict. In the Official Registry No. 417 of December 14, 2006, Codification 014 of the Arbitration and Mediation Law is issued, which repeals the Commercial Arbitration Law issued in 1963, its application regulations were promulgated in the government of Guillermo Lasso through Executive Decree No. 165 published in the Official Registry No. 524 of August 26, 2021, First Supplement.(1) (2) (3) (4)

With this brief historical review, this research, in its first objective, analyzes the current regulations on mediation in Ecuador; and thus we have that, from the Constitution of the Republic, it is recognized as a peaceful and consensual way to resolve disputes, its Art. 190 states "Arbitration, mediation and other alternative procedures for the resolution of conflicts are recognized. These procedures will be applied subject to the law, in matters in which due to their nature they can be compromised...", Likewise, the Arbitration and Mediation Law in its articles 44 and 45 establish the requirements, subjects of mediation and the entities before which must be appealed by requesting the establishment of hearings, recognizing mediation centers and authorized independent mediators, with the capacity to mediate as neutral third parties in transmissible matters. The Regulations to the Law in its Art. 1 shield the Arbitration and Mediation Centers with the principles of independence and autonomy, stating that they are not subject to a provision or authority that seeks to undermine their powers, exercise control or interfere in their functions; Therefore, the parties in conflict enjoy the freedom to compromise and reach agreements with their sole voluntary acceptance of everything that the law authorizes them to do.

For its part, the Organic Code of the Judicial Function recognizes in its article 17 Arbitration and Mediation as a form of public service of administration of justice and within the jurisdictional powers established in its Art. 130 grants judges in its number 11, the possibility that the parties can conciliate and agree on everything that the law allows them, therefore, if actor and defendant If they consider it pertinent, the judge, at the appropriate procedural moment, will refer the case to a Mediation Center recognized by the Judicial Council, whose effect after signing the mediation record is the solution of the conflict in dispute and the motivation for the resolution of the definitive file of the case. In matters of childhood and adolescence, Ecuadorian regulations allow mediation, respecting the inalienable rights of the child or adolescent as established in articles 294 and 295 of the Code of Children and Adolescence.

In its second specific objective, to determine the impact of mediation in the ordinary justice system, quantitative analyzes were carried out based on information contained and reflected by the Judiciary Council on its informative web pages.

## MATERIALS AND METHODS

### Research methodology

This research was carried out under a mixed modality methodology, which combines non-experimental qualitative documentary analysis with secondary quantitative-statistical analysis. Based on non-experimental qualitative documentary analysis, an analysis of the current regulatory framework applicable to mediation is examined and carried out with a brief historical synthesis of this institution. From the quantitative approach, the research has an analytical nature supported by the description and interpretation of secondary statistical data published by the Judicial Council of Ecuador, which made it possible to evaluate the impact of mediation in reducing the procedural burden of the ordinary justice system in the period between 2019 and 2025. The articulation between both approaches made it possible not only to describe and analyze the regulatory and institutional framework of mediation; but also, contrast its application with empirical evidence from official sources.

### Population and sample

The population under study constituted current legal norms regarding mediation, academic literature (articles, magazines, theses and books with a scientific basis) and statistical and institutional records of the Judicial Council of Ecuador. The sample was selected through intentional non-probabilistic sampling, prioritizing those sources directly linked to the object of study, updated and with verifiable academic and institutional rigor, specialized in mediation as an alternative method of conflict resolution.

### Research environment

The research was developed in a documentary and bibliographic environment using secondary sources of a legal nature. The main data sources and tools used are summarized in the following:

- . Specialized academic databases such as Scielo, Google Scholar.
- . Current regulations applicable to the institution of mediation.
- . Management reports, statistics portals and information pages published by the Judicial Council of Ecuador, which served as the basis for the preparation of descriptive tables and statistical graphs.
- . University institutional repositories.

The selection of these sources was based on the following criteria:

- . Linkage, timeliness and relevance in the approach of the institution of mediation as an alternative means of conflict resolution.
- . Verifiable academic and institutional support and rigor.
- . Reliability and specialization.

These sources allowed access to reliable and updated information about the institution of mediation as an alternative method of conflict resolution in Ecuador.

### Collection of information

The collection of information was structured in two complementary levels:

First, the current and applicable regulatory framework was examined, made up of the Constitution of the Republic of Ecuador, the Arbitration and Mediation Law of 1997 and its Codification of 2006, its subsequent reforms, Code Organic of the Judicial Function and the Code of Children and Adolescents.

Secondly, indexed academic and documentary sources were used, including scientific articles published in specialized journals, degree theses available in university institutional repositories. Additionally, sources of a statistical and institutional nature were incorporated, such as management reports, statistics portals and information pages published by the Judicial Council of Ecuador, corresponding to the different centers and mediation matters.

## RESULTS

Once the regulatory framework that supports mediation has been analyzed, regarding its application, it indicates that it proceeds in transmissible matters, without specifying them; However, the National Mediation Center of the Judicial Function in Ecuador, on its website, refers to the matters on which a compromise must be made; and based on which in this article, the following table has been prepared that details the subjects and their transmissible issues, as well as the type of procedure to be applied in each topic. (See Table 1.)

**Table 1. Transmissible subjects.**

| SUBJECT | SUBJECT                                                                                                                                                                                                                                                                                                                                                                                                  | No. SUBJECTS | PROCEDURE |
|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|-----------|
| FAMILY  | <ul style="list-style-type: none"> <li>Food</li> <li>Visitation regime</li> <li>Tenancy for divorce by mutual consent without opposition</li> <li>Food for older people</li> <li>Food for pregnant women</li> <li>Consistent and/or necessary foods</li> <li>Voluntary division of inheritance assets by mutual agreement</li> <li>Liquidation of the marital partnership by mutual agreement</li> </ul> | 8            | SD        |
|         | <ul style="list-style-type: none"> <li>Liquidation of the marital partnership with opposition</li> </ul>                                                                                                                                                                                                                                                                                                 | 3            | DJ        |

|                                           |                                                                                                                                                                                                                                                                                                                                                                                                |    |    |
|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|----|
|                                           | <ul style="list-style-type: none"> <li>• Tenure with opposition</li> <li>• Voluntary division of inheritance assets with opposition</li> </ul>                                                                                                                                                                                                                                                 |    |    |
| <b>TENANCY</b>                            | <ul style="list-style-type: none"> <li>• Vacancy of property</li> <li>• Return of guarantee</li> <li>• Breach of contract</li> <li>• Payment of rental fees</li> </ul>                                                                                                                                                                                                                         | 4  | SD |
| <b>LABOR</b>                              | <ul style="list-style-type: none"> <li>• Payroll settlement</li> <li>• Employer retirements</li> <li>• Form of late salary payments</li> <li>• Partial or hourly remuneration</li> <li>• Overtime or supplementary hours</li> <li>• Bonuses and profits</li> <li>• Compensation</li> </ul>                                                                                                     | 7  | SD |
| <b>TRANSIT</b>                            | <ul style="list-style-type: none"> <li>• Traffic referrals regarding violations without the result of death or serious injury that causes permanent disability, loss or disablement of any organ.</li> </ul>                                                                                                                                                                                   | 1  | SD |
| <b>CIVIL</b>                              | <ul style="list-style-type: none"> <li>• Demarcation of boundaries</li> <li>• Easements</li> <li>• Replacement of Boundaries</li> <li>• Accountability</li> <li>• Partition and allocation of civil society assets</li> <li>• Inventory</li> <li>• Bankruptcy</li> <li>• Breach of contract</li> <li>• Debt collection</li> <li>• Compensation for damages</li> </ul>                          | 10 | SD |
|                                           | <ul style="list-style-type: none"> <li>• Vindictory action,</li> <li>• Possessory protection</li> <li>• Acquisitive prescription of ownership</li> <li>• Moral Damage</li> <li>• Execution of judgment of mediation record</li> <li>• Execution of judgment of transactional record</li> <li>• Execution of judgment of arbitration award</li> <li>• Execution of mortgage judgment</li> </ul> | 8  | DJ |
| <b>SOCIAL OR NEIGHBORHOOD COEXISTENCE</b> | <ul style="list-style-type: none"> <li>• Small amounts of damages</li> <li>• Formula for payment of arrears rates</li> <li>• Respect for rules of community coexistence and/or use of communal areas</li> </ul>                                                                                                                                                                                | 4  | SD |

|                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |   |    |
|----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|----|
|                                              | <ul style="list-style-type: none"> <li>Damage caused to private property by animals domestic or breeding.</li> </ul>                                                                                                                                                                                                                                                                                                                                                      |   |    |
| <b>ADOLESCENTS IN CONFLICTS WITH THE LAW</b> | Comply with the provisions of articles 345 and 348-c of the Organic Code of Children and Adolescence. Adolescent offenders                                                                                                                                                                                                                                                                                                                                                | 1 | DJ |
| <b>CONSUMERS AND USERS</b>                   | <ul style="list-style-type: none"> <li>Payment for basic services</li> <li>Claims about quality of goods</li> <li>Claims for misleading advertising</li> <li>Claims for poor quality of services</li> </ul>                                                                                                                                                                                                                                                               | 4 | SD |
| <b>PUBLIC PROCUREMENT</b>                    | <ul style="list-style-type: none"> <li>Breach of contract</li> <li>Fines</li> <li>Declaration of early termination of contract</li> </ul>                                                                                                                                                                                                                                                                                                                                 | 3 | SD |
| <b>TAX</b>                                   | Comply with the requirements stipulated in articles 56.6 and 56.7 of the Law Organic for Economic Development and Fiscal Sustainability after the Covid-19 Pandemic, in accordance with article 119 of the Organic Tax Code; as well as, with the provisions of paragraphs 1, 2, 3 and 4 of article 25 of the Regulations to the Organic Law for Economic Development and Fiscal Sustainability after the Covid-19 Pandemic, and other related current legal regulations. |   |    |

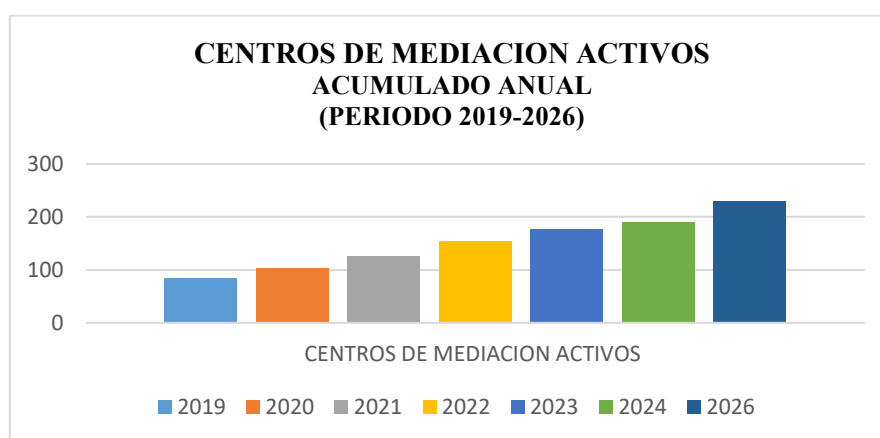
**Source: National Mediation Center of the Judicial Function (10 – 19)**

**Note: SD = Direct request; DJ = Judicial Derivation**

Of the matters transmissible in mediation and indicated in the table above and considering also that each matter contains one or more matters susceptible to mediation (except for tax matters in which the National Mediation Center does not specify matters and procedure); We have that, of the 53 topics subject to mediation contained in the different transmissible matters, 41 of them, that is, 77.36%, can be requested directly by the parties or one of them; while 12, representing 22.64%, are due to judicial referral DJ.

It is important to highlight that in civil matters of 18 matters susceptible to mediation, 10 of these can be carried out with the direct request procedure SD and 8 with judicial referral DJ; In family matters, of 11 transmissible matters, 8 proceed with a direct request SD and 3 with judicial referral DJ; Considering that, adding civil and family matters, these concentrate 54.71% of the matters that, being transmissible, can be resolved through mediation.

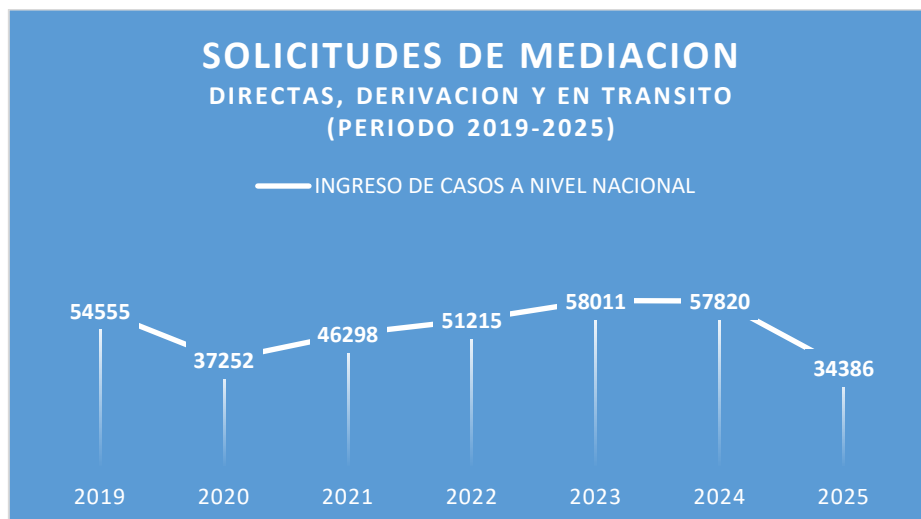
The Ecuadorian justice system to meet the demand for solutions to conflicts transmissible through mediation, has at the national level with 229 mediation centers approved by the Plenary and the General Directorate of the Council of the Judiciary, according to the information published by this public entity as of April 24, 2026, which are distributed in different provinces; and, some of them, such as the case of the mediation center of the Judicial Function, maintains 141 offices open in most of the cities of the country according to the information published by the Council of the Judiciary through its website as of August 11, 2025. These mediation centers in Ecuador have been experiencing sustained growth over time and that for the period between 2019 and 2024 has meant an increase in 126%; and if we consider that, according to the information published by the Judiciary Council as of April 24, 2026, it registers 229 approved mediation centers nationwide, we would then have an increase of 172% for the last seven years taking into account the same base year 2019. (See Figure 1.)



**Figure 1. Annual accumulation of active mediation centers**

**Sources:** *Judicial Council of Ecuador, National Directorate of Access to Justice Services (20); Council of the Judiciary of Ecuador. Judicial Council (21 – 22).*

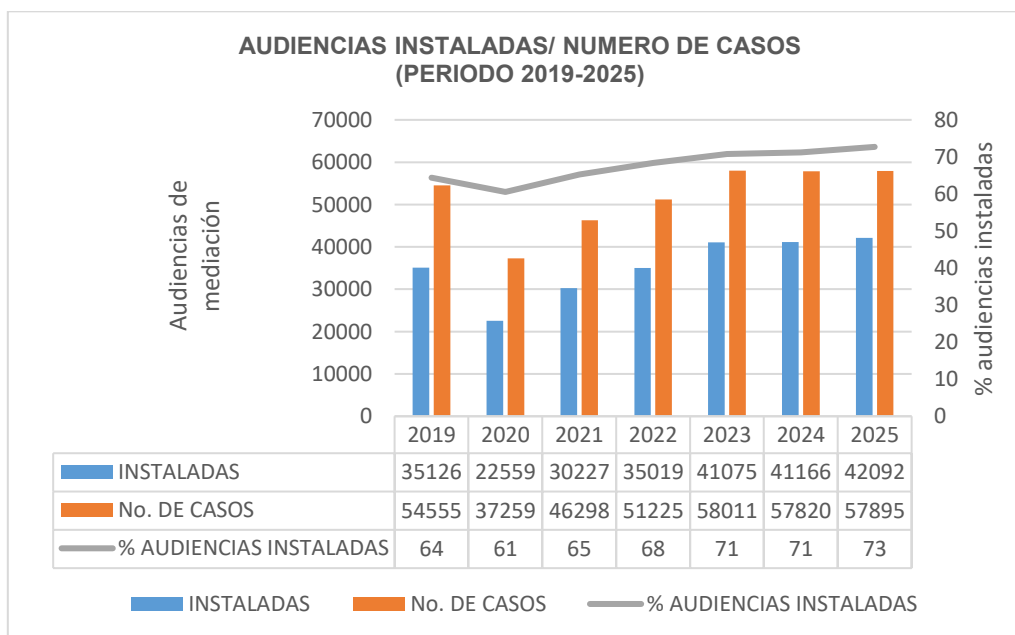
Regarding the requests entered at the national level for the provision of the mediation service, the information provided by the Judicial Council through its website and which contain direct requests, judicial referrals and referrals in transit; We have that, for the period between the years 2019-2024, these have experienced a growing curve with the exception of the year 2020 where we have a decrease of 31.72%, a trend that is reversed between the years 2021 to 2023 where there is an average growth of 15.97%; between 2023 and 2024 there is a slight decrease of 0.3%. For the year 2025, mediation requests total 34,386 with the consideration that these correspond to information published until July 2025. These trends demonstrate the degree of incidence of the institution of mediation within the justice system of Ecuador, directly impacting the decongestion of its procedural load. (See Figure 2.)



**Figure 2. Mediation requests**

**Source: Judicial Council of Ecuador, National Mediation Center of the Judicial Function (23)**

Regarding the hearings installed in relation to the cases presented for mediation in the period 2019-2025, We have a growing trend with the exception of 2020; Thus, we have that, for the year 2021, the percentage of installed audiences is 65%, 2022 68%, 2023 and 2024 71% and 2025 73% with an annual average of installed audiences between the years 2021-2025 of 69.6%. (See Figure 3.)

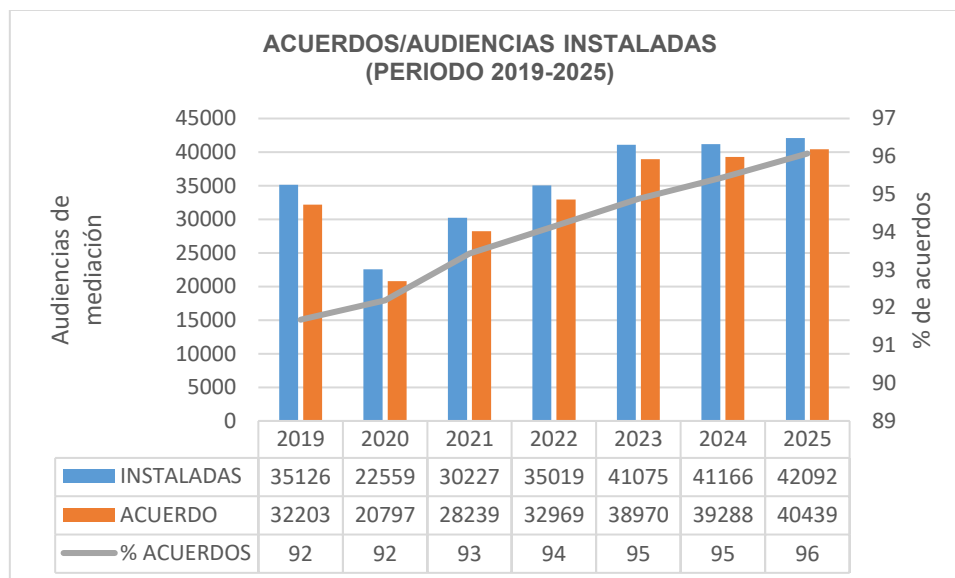


**Figure 3. Hearings installed/number of cases**

**Source: Judicial Council of Ecuador. Judicial Statistics Portal (24)**

From the agreements reached in mediation in relation to the installed hearings, we have that for the period 2019-2025 there is a growing trend in all these years; Thus, in the years 2019 and 2020 the percentage of agreements reached in relation to the number

of installed audiences is 92%, for 2021 93%, 2022 94%, 2023 95%, 2024 95% and 2025 96%, with an annual average of agreements reached in this period of 93.86%; and that involves the solution to conflicts that may have added to the procedural burden of the ordinary justice system, but were resolved through mediation in a faster and more efficient manner. (See Figure 4.)



**Figure 4. Agreements reached through mediation/installed hearings**

*Source: Judicial Council of Ecuador. Judicial Statistics Portal (24)*

## DISCUSSION

In this research work, the results obtained show that mediation as an alternative method in conflict resolution is protected in the Ecuadorian legal system by the Constitution and the law and can be applied in different subjects and transmissible matters.

Its endorsement in article 190, together with its development in the Arbitration and Mediation Law, shows that it is not an accessory route, but rather a legal institution fully incorporated into the system of administration of justice. In that sense, mediation responds to the principles of speed, procedural economy and effective access to justice. Patricia Balbuena, author of the article (Justice does not have a woman's face), finds two meanings of the concept of access to justice, pointing it out as "The right of every person to go to the justice system (formal and alternative) and obtain an adequate response"; and, "The duty of the State to provide a public service that complies with the guiding principles of continuity, adaptability of the service, equality, speed, and free of charge." (5)

Mediation has legal force but its essence lies in voluntariness; And then a question arises: What makes an individual or community oppose solving their conflicts through peace and harmony? Dragging them into complex legal conflict in the search for justice

and satisfaction of their interests and demands; The answers could have different meanings, but probably all have the same common denominator, which lies in the lack of cultural persuasion regarding the benefits of applying mediation. According to Francisco Javier Gorjón Gómez “persuasion identifies and highlights people's needs and desires and focuses on achieving trust.” It is imperative, therefore, socially to move towards the culturalization of peaceful alternative methods of conflict resolution through the identification of reliable responses to constantly evolving individual and social needs and desires. (6)

From a functional perspective, the findings show that mediation contributes to judicial decongestion by allowing early resolution of disputes without the need to exhaust an ordinary process. This is particularly important in a context of high procedural burden, in which self-composition mechanisms represent ideal responses to optimize public resources, reduce processing times and strengthen effective access to justice. Consequently, mediation not only resolves specific conflicts, but also produces a favorable institutional impact on the public justice service.

Likewise, the voluntary, extrajudicial and definitive nature of the mediation record reinforces its legal effectiveness. The possibility of judicially demanding compliance in the event of non-compliance confirms that the agreement reached does not constitute a simple informal understanding, but rather an act endowed with binding force and executive capacity. This feature strengthens legal security and explains why mediation can be considered an ideal mechanism for the protection of rights in disputes that can be settled.

On the other hand, the legal delimitation of the matters in which mediation proceeds demonstrates that the Ecuadorian legislator has sought to balance the autonomy of the will with the protection of unavailable rights. The specific regulation in areas such as family, childhood and adolescence, labor, tenancy, civil and transit shows that the origin of the mechanism responds to precise legal criteria and not to an indiscriminate liberalization of conflict. To this extent, the research confirms that mediation is not only compatible with the Ecuadorian regulatory framework, but also represents a necessary tool for more agile, accessible justice oriented toward social pacification.

## CONCLUSIONS

The institution of mediation in the Ecuadorian legal system constitutes an alternative conflict resolution mechanism fully recognized by the Constitution of the Republic of Ecuador, the Arbitration and Mediation Law, the Organic Code of the Judicial Function and other applicable regulations, which is why its legal nature is duly consolidated within the system of administration of justice, responding to the principles of voluntariness, speed, procedural economy, impartiality and self-composition and allowing the parties, assisted by a third party neutral, reach valid, effective and definitive agreements on transmissible matters without the need to submit the controversy to an ordinary judicial process; However, it must be considered that the regulations as such do not expressly

and specifically delimit the areas in which mediation proceeds; Therefore, it is necessary to work on its delimitation and with unified dynamic data updated in real time.

The analysis based on the statistics presented allows us to affirm that mediation has a positive impact on decongesting the procedural load of the Ecuadorian judicial system, as it avoids the judicialization of certain conflicts and contributes to a more agile, efficient and timely administration of justice, for the benefit of the mediators and the State.

Mediation stands as an ideal legal institution for the peaceful resolution of disputes, to the extent that it not only preserves the autonomy of the will of the parties, but also strengthens the culture of peace, access to justice and the effectiveness of the Ecuadorian jurisdictional system. It is imperative to continue promoting and strengthening mediation mechanisms through public policies, institutional dissemination and specialized training, in order to consolidate their use as a preferred means of conflict resolution and a means of optimizing the public justice service.

## REFERENCES

1. Medina J. Noticias Jurídicas. [Online].; 2024 [cited 2026 Apr 13]. Available from: <https://noticias.juridicas.com/conocimiento/tribunas/18960--mediacion-pasado-y-presente/>.
2. Medina JCC. Escuela Internacional de Mediación. [Online].; 2024 [cited 2026 Apr 14]. Available from: <https://eimediacion.edu.es/ser-mediador/historia-de-la-mediacion/>.
3. Encalada GMC. Métodos alternativos de solución de conflictos en el Ecuador: sus alcances y limitaciones. Tesis de grado. Cuenca: Universidad de Cuenca, Carrera de Derecho; 2021.
4. Congreso del Ecuador. Área de Libre Comercio de las Américas. [Online].: Registro Oficial No. 145; 1997 [cited 2026 Jul 16]. Available from: [https://www.newyorkconvention.org/media/uploads/pdf/5/4/548\\_law-on-arbitration-and-mediation-ley-no-000-ro-145-of-4-september-1997-ley-de-arbitraje-y-mediacion-de-4-de-septiembre-de-1997.pdf](https://www.newyorkconvention.org/media/uploads/pdf/5/4/548_law-on-arbitration-and-mediation-ley-no-000-ro-145-of-4-september-1997-ley-de-arbitraje-y-mediacion-de-4-de-septiembre-de-1997.pdf).
5. Balbuena P. La justicia no tiene rostro de mujer. Obstáculos para el acceso a la justicia de las mujeres. *El Otro Derecho*. 2006 Dec;35(35):237-246.
6. Gorjón Gómez FJ. Mediación su valor intangible y efectos operativos “Una visión integradora de los métodos alternos de solución de conflictos”. Ciudad de México: Tirant Lo Blanch; 2017.
7. Noticias Jurídicas. Mediación: pasado y presente. [Online].; 2024. Available from: <https://noticias.juridicas.com/conocimiento/tribunas/18960--mediacion-pasado-y-presente/>.
8. Escuela Internacional de Mediación. Historia de la mediación. [Online].; 2024. Available from: <https://eimediacion.edu.es/ser-mediador/historia-de-la-mediacion/>.
9. Encalada Carrera M. [Online].; 2021. Available from: <https://rest-dspace.ucuenca.edu.ec/server/api/core/bitstreams/6662ee78-7c7b-4501-be1f-2b66fbf4d773/content>.

10. Área de Libre Comercio de las Américas. Ley de Arbitraje y Mediación. [Online].; 2014. Available from: [https://www.newyorkconvention.org/media/uploads/pdf/5/4/548\\_law-on-arbitration-and-mediation-ley-no-000-ro-145-of-4-september-1997-ley-de-arbitraje-y-mediacion-de-4-de-septiembre-de-1997.pdf](https://www.newyorkconvention.org/media/uploads/pdf/5/4/548_law-on-arbitration-and-mediation-ley-no-000-ro-145-of-4-september-1997-ley-de-arbitraje-y-mediacion-de-4-de-septiembre-de-1997.pdf).
11. Congreso Nacional del Ecuador. Codificación de la Ley de Arbitraje y Mediación, No. 2006-014. Codificación de la Ley de Arbitraje y Mediación. Quito: Congreso Nacional del Ecuador; 2006.
12. Congreso Nacional Electoral. Ley Orgánica Reformatoria del Código Orgánico de la Función Judicial. Quito: Congreso Nacional Electoral; 2020.
13. Presidencia de la República del Ecuador. Reglamento a la Ley de Arbitraje y Mediación. Decreto Presidencial. Quito: Presidencia de la República del Ecuador; 2021.
14. Centro Nacional de Mediación de la Función Judicial. Mediación Función Judicial. [Online].; 2026 [cited 2026 Apr 30]. Available from: <https://mediacion.funcionjudicial.gob.ec/familia/>.
15. Centro Nacional de Mediación de la Función Judicial. Mediación Función Judicial. [Online].; 2026 [cited 2026 May 1]. Available from: <https://mediacion.funcionjudicial.gob.ec/inquilinato/>.
16. Centro Nacional de Mediación de la Función Judicial. Mediación Función Judicial. [Online].; 2026 [cited 2026 May 1]. Available from: <https://mediacion.funcionjudicial.gob.ec/tributario/>.
17. Centro Nacional de Mediación de la Función Judicial. Mediación Función Judicial. [Online].; 2026 [cited 2026 May 1]. Available from: <https://mediacion.funcionjudicial.gob.ec/civil/>.
18. Centro Nacional de Mediación de la Función Judicial. Mediación Función Judicial. [Online].; 2026 [cited 2026 May 1]. Available from: <https://mediacion.funcionjudicial.gob.ec/convivencia-social-o-vecinal/>.
19. Centro Nacional de Mediación de la Función Judicial. Mediación Función Judicial. [Online].; 2026 [cited 2026 May 1]. Available from: <http://mediacion.funcionjudicial.gob.ec/transito/>.
20. Centro Nacional de Mediación de la Función Judicial. Mediación Función Judicial. [Online].; 2026 [cited 2026 May 2]. Available from: <https://mediacion.funcionjudicial.gob.ec/adolescentes-infractores/>.
21. Centro Nacional de Mediación de la Función Judicial. Mediación Función Judicial. [Online].; 2026 [cited 2026 May 2]. Available from: <https://mediacion.funcionjudicial.gob.ec/laboral/>.
22. Centro Nacional de Mediación de la Función Judicial. Mediación Función Judicial. [Online].; 2026 [cited 2026 May 2]. Available from: <https://mediacion.funcionjudicial.gob.ec/consumidores-y-usuarios/>.
23. Centro Nacional de Mediación de la Función Judicial. Mediación Función Judicial. [Online].; 2026 [cited 2026 May 3]. Available from: <https://mediacion.funcionjudicial.gob.ec/contratacion-publica/>.
24. Consejo de la Judicatura del Ecuador, Dirección Nacional de Acceso a los Servicios de Justicia. Boletín de Mediación No. 1: Estadísticas de Mediación a Nivel Nacional. Quito: Consejo de la Judicatura del Ecuador; 2025.

25. Consejo de la Judicatura del Ecuador. Consejo de la Judicatura. [Online].; 2025 [cited 2026 May 6]. Available from: <https://www.funcionjudicial.gob.ec/centros-mediacion-aprobados/oficinas-del-centro-de-mediacion-de-la-funcion-judicial/>.
26. Consejo de la Judicatura del Ecuador. Consejo de la Judicatura. [Online].; 2026 [cited 2026 May 7]. Available from: <https://www.funcionjudicial.gob.ec/centros-mediacion-aprobados/>.
27. Consejo de la Judicatura del Ecuador, Centro Nacional de Mediación de la Función Judicial. Informe de Gestión: Enero 2014 a Julio 2025. Informe de gestión. Quito: Consejo de la Judicatura; 2025.
28. Consejo de la Judicatura del Ecuador. Portal de Estadística Judicial. [Online].; 2026 [cited 2026 May 16]. Available from: <https://fsweb.funcionjudicial.gob.ec/estadisticas/datoscj/centrosmediacionfj.html>

# ANÁLISIS JURÍDICO DEL USO DE LA EVIDENCIA DIGITAL EN LOS PROCESOS PENALES Y SU IMPACTO EN LA GARANTÍA DEL DEBIDO PROCESO

## LEGAL ANALYSIS OF THE USE OF DIGITAL EVIDENCE IN CRIMINAL PROCEEDINGS AND ITS IMPACT ON THE GUARANTEE OF DUE PROCESS

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**RESUMEN:** El uso de la evidencia digital en los procesos penales constituye uno de los fenómenos jurídicos más relevantes derivados de la transformación tecnológica de las últimas dos décadas, en la medida en que los sistemas de justicia penal de América Latina, y particularmente de Ecuador, enfrentan el reto de incorporar mensajes de datos, metadatos, imágenes, videos, registros de geolocalización y demás elementos electrónicos como medios de prueba válidos, sin comprometer las garantías del debido proceso. Este trabajo examinó, mediante una revisión sistemática de la literatura especializada siguiendo los parámetros PRISMA, el abordaje procesal de la evidencia digital en las causas penales y cómo esta repercute en las garantías del debido proceso. Se empleó una metodología documental de carácter cualitativo y con un alcance descriptivo-analítico; para lograrlo, se llevó a cabo una búsqueda estructurada en bases de datos indexadas aplicando criterios definidos de inclusión y exclusión, lo que permitió seleccionar un grupo final de artículos académicos publicados entre 2021 y 2026. Los hallazgos revelan que, aunque la normativa ecuatoriana y de la región admite el valor probatorio de los componentes informáticos, aún existen vacíos legales y operativos al resguardar la cadena de custodia, sumado a la ausencia de protocolos forenses uniformes, la limitada formación de los servidores judiciales y la falta de criterio único al momento de evaluar su autenticidad e integridad. Estas falencias perjudican de forma directa el derecho a la defensa, la contradicción de las pruebas y la imparcialidad en las resoluciones de los jueces. En consecuencia, asegurar una verdadera protección judicial frente a las pruebas tecnológicas exige adecuar las leyes locales a los parámetros internacionales, formalizar guías para las pericias y capacitar de forma permanente a los profesionales del sistema de justicia. Únicamente de esta manera se

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podrá consolidar un juzgamiento penal transparente, riguroso y en apego estricto a los derechos constitucionales en el entorno digital.

**Palabras clave:** *prueba electrónica, cadena de custodia, informática forense, garantías judiciales, ciberdelincuencia*

**ABSTRACT:** The use of digital evidence in criminal proceedings is one of the most significant legal developments resulting from the technological transformation of the past two decades, as criminal justice systems in Latin America—and particularly in Ecuador—face the challenge of incorporating data messages, metadata, images, videos, geolocation records, and other electronic elements as valid forms of evidence without compromising due process guarantees. This study examined, through a systematic review of the specialized literature following the PRISMA guidelines, the procedural approach to digital evidence in criminal cases and how it impacts due process guarantees. A qualitative, descriptive-analytical documentary methodology was employed; to achieve this, a structured search was conducted in indexed databases using defined inclusion and exclusion criteria, which allowed for the selection of a final set of academic articles published between 2021 and 2026. The findings reveal that, although Ecuadorian and regional regulations recognize the evidentiary value of digital evidence, there are still legal and operational gaps in safeguarding the chain of custody, compounded by the absence of uniform forensic protocols, limited training for judicial officials, and the lack of a single standard for evaluating the authenticity and integrity of such evidence. These shortcomings directly undermine the right to a defense, the right to challenge evidence, and the impartiality of judicial rulings. Consequently, ensuring genuine judicial protection against digital evidence requires aligning local laws with international standards, formalizing guidelines for forensic analysis, and providing ongoing training to professionals in the justice system. Only in this way can a transparent and rigorous criminal justice process be established, one that strictly adheres to constitutional rights in the digital environment.

**Keywords:** *electronic evidence, chain of custody, computer forensics, judicial safeguards, cybercrime*

## INTRODUCTION

Contemporary society is going through a process of digital transformation that has substantially modified the way in which criminal acts are committed, investigated and prosecuted. The massive use of mobile devices, social networks, messaging systems, cloud storage platforms and Internet of Things devices has generated a growing volume of information that can become a source of evidence in criminal proceedings (1). This phenomenon has given rise to the legal category of digital evidence, understood as any data or information stored or transmitted in binary format that can be used as an element of conviction within a judicial process (15). Unlike traditional evidence, digital evidence is characterized by its volatility, its easy alterability and the need for specialized technical knowledge for its identification, collection, preservation and analysis, as

evidenced by recent studies on the forensic analysis of volatile memory applied to common crimes with a technological component in the Ecuadorian context (3), which requires the development of rigorous forensic protocols that guarantee its authenticity and integrity throughout the entire chain of custody (4).

On an international level, organizations such as the Council of Europe have promoted the Convention on Cybercrime since 2001, known as the Budapest Convention, as the first binding instrument aimed at harmonizing the criminal prosecution of computer crimes and establishing common criteria for obtaining electronic evidence between States (17). In parallel, the International Organization for Standardization developed the family of standards ISO/IEC 27037 and ISO/IEC 27042, which establish technical guidelines for the identification, collection, acquisition, preservation, analysis and interpretation of digital evidence, becoming references for good forensic practices adopted by police laboratories and computer experts from different countries (15,16).

In Latin America, the exponential growth of computer crimes has, in many cases, exceeded the regulatory and institutional response capacity of criminal justice systems. According to the regional diagnosis prepared by the Organization of American States, the countries of the region face significant gaps in forensic infrastructure, training of justice operators and international cooperation to obtain cross-border digital evidence, which has a direct impact on the effectiveness of criminal prosecution and the protection of the rights of those prosecuted (2). Comparative studies carried out in countries such as Spain, Colombia, Chile and Peru also show tensions between the need to incorporate technology into criminal investigation and respect for guarantees such as privacy, the inviolability of communications and the right to defense (5).

In the particular case of Ecuador, the Comprehensive Organic Criminal Code expressly recognizes data messages, computer records, emails and other digital documents as valid means of proof within the criminal process, and regulates, although in a general way, the chain of custody and the actions of accredited experts (8). Without prejudice to this regulatory recognition, various investigations carried out in the country have identified relevant deficiencies in its practical application: absence of unified technical protocols, insufficient specialized forensic infrastructure, shortage of accredited computer experts and disparity in judicial criteria to assess the authenticity and integrity of digital evidence (5,6,7). These deficiencies acquire special constitutional relevance, to the extent that article 76 of the Constitution of the Republic of Ecuador enshrines due process as a set of basic guarantees applicable to any procedure in which rights and obligations are determined, among them the presumption of innocence, the right to defense, the contradiction of evidence and the motivation of judicial resolutions (9).

Due process, in addition to its internal constitutional consecration, finds foundation in Article 8 of the American Convention on Human Rights, which recognizes the right of every person to be heard with due guarantees by a competent, independent and impartial judge or tribunal (10). The Inter-American Court of Human Rights has developed consolidated jurisprudence on the components of criminal due process, including the right of defense, access to criminal evidence and the effective possibility of challenging it, standards that are fully applicable to the treatment of digital evidence (11). When the chain of custody of a digital element is broken, when there are no

verifiable collection protocols or when the computer expert lacks technical accreditation, the possibility opens up that the evidence is questioned due to manipulation, affecting guarantees such as contradiction and equality of procedural arms.

From a criminological perspective, the growth of crimes that leave a digital trace, computer fraud, identity theft, extortion through social networks, online child pornography and digital gender violence, among others, has made digital evidence the central evidentiary element of a growing number of criminal cases, even in crimes traditionally investigated through physical evidence, such as homicide or robbery, in which geolocation records, video surveillance cameras and Metadata from mobile devices have been incorporated as key pieces of research (1,2). This marked relevance of computer evidence intensifies the legal impact of any failure in its expert handling: a modification in the chain of custody or obtaining it outside the law not only invalidates an isolated piece of information, but also annuls the entire trial. This opens the door both for various crimes to go unpunished and for innocent people to be unfairly punished based on altered or defective information (3,4).

Faced with this panorama, it is necessary to systematize the scientific knowledge available on the legal treatment of digital evidence in criminal proceedings and its relationship with the guarantees of due process, identifying the main regulatory, technical and jurisprudential gaps documented in the specialized literature of recent years. In this sense, the general objective of the present study was to analyze, through a systematic review of the scientific literature, the legal treatment of digital evidence in criminal proceedings and its impact on the guarantee of due process, with emphasis on the Ecuadorian and Latin American context.

The research problem addressed in this study is located at the intersection between criminal procedural law, constitutional law and computer forensics, three disciplinary fields that, according to the literature reviewed, do not always dialogue in an articulate manner in judicial practice. While the legislator has made progress in the formal recognition of digital evidence as a means of proof, the development of expert technical capabilities and institutional action protocols has not followed the same pace, generating an asymmetry that transfers to judges the burden of resolving, case by case and without uniform criteria, eminently technical issues related to the authenticity, integrity and traceability of electronic evidence (6,7).

Despite the regulatory recognition of digital evidence as a valid means of proof in the Ecuadorian criminal process and in most Latin American legal systems, a gap remains between said formal recognition and the technical and institutional conditions necessary to guarantee its authenticity, integrity and evidentiary reliability (5,6). This gap translates into heterogeneous evidence collection and preservation practices, absence of standardized national protocols, insufficient accreditation of forensic computer experts, and disparate judicial criteria for admitting or excluding digital evidence, which generates legal uncertainty for both the Prosecutor's Office and the technical defense (12,13). The problem becomes especially serious when it is noted that the violation of the digital chain of custody not only compromises the effectiveness of criminal prosecution, but can lead to the violation of the fundamental rights of the

accused, by admitting as evidence of prosecution elements whose traceability cannot be fully verified (14). Consequently, the following research question is posed: What is the legal treatment that scientific literature has documented regarding the use of digital evidence in criminal proceedings in Ecuador and Latin America, and in what way does said treatment affect the guarantee of due process?

This research analyzed, through a systematic review of academic literature applying the PRISMA approach, the legal regulation of digital evidence within the criminal system and its impact on the guarantees of due process. The study examined with special emphasis the panorama of Ecuador and Latin America, compiling the scientific production disseminated between 2021 and 2026.

## MATERIALS AND METHODS

This study uses a documentary design, prepared from a qualitative perspective and with a descriptive-analytical level. Its development was carried out through a systematic examination of specialized literature, aligned with the guidelines of the PRISMA 2020 declaration. This methodological scheme ensures a clear and rigorous process in the stages of location, selection, evaluation of evidentiary quality and incorporation of the texts that constitute the final analysis sample, significantly reducing the bias inherent in usual theoretical reviews.

Information collection was carried out between June and August 2026 in specialized databases such as Scopus, Dialnet, Redalyc, SciELO, Latindex and Google Academic, reinforced with access to university digital libraries in the region and legal repositories oriented to technology and procedural law. The search formulas combined descriptors such as "digital evidence", "digital evidence", "criminal process", "due process", "chain of custody" and "cybercrime" using Boolean operators AND and OR, also adding their equivalents in English ("digital evidence", "criminal proceedings", "due process") to extend the bibliographic coverage.

The selection process gave priority to indexed articles with peer evaluation, postgraduate theses, institutional reports and book chapters published between 2021 and 2026, written in Spanish or English, with access to full text and focused on the use of computer evidence in criminal justice. Non-refereed publications, duplicate records, non-scientific content and technical works lacking normative-procedural analysis were discarded.

The initial crawl identified 138 records. After eliminating 22 duplicates, 116 were analyzed by title and abstract, discarding 61 for not adjusting to the object of study. Of the 55 full-text works reviewed, 24 were purged for failing to meet the rigor criteria (12 purely computer science, 7 without formal arbitration and 5 redundant), consolidating a final sample of 31 academic publications processed using synthetic analysis matrices.

**Table 1. Phases of the selection process according to the PRISMA method.**

| Phase | No. of records | Observation |
|-------|----------------|-------------|
|-------|----------------|-------------|

|                            |     |                                               |
|----------------------------|-----|-----------------------------------------------|
| Identification             | 138 | Search in indexed databases and repositories  |
| Duplicates eliminated      | 22  | Bibliographic manager and manual review       |
| Screening (title/abstract) | 116 | 61 excluded due to lack of thematic relevance |
| Eligibility (full text)    | 55  | 24 excluded due to quality/relevance criteria |
| Included in the synthesis  | 31  | Final sample analyzed                         |

The 31 selected documents were cataloged in a bibliographic template that recorded authorship, year of publication, country, type of study, methodology and main findings. On this basis, a qualitative content analysis was carried out aimed at identifying recurring patterns, structured in four thematic axes: (a) regulatory framework of digital evidence; (b) procedural guarantees and technical requirements; (c) evidentiary assessment of the computer material; and (d) protection of due process. Given the qualitative-documentary approach of the work, no inferential statistical models were used, restricting the data treatment to the basic descriptive calculation (frequencies and percentages) to characterize the body of literature examined.

## RESULTS

The results of this systematic review are organized following the four thematic axes derived from the content analysis of the documentary sample, preceded by a general characterization of the included studies. This organization allows us to offer a comprehensive reading of the state of the art on digital evidence in criminal proceedings, from its regulatory recognition to its specific impact on the guarantees of due process, passing through the technical-forensic and judicial assessment aspects that constitute the core of the debate identified in the specialized literature.

Of a total of 31 inquiries analyzed in this research, 58% (n=18) derive from publications distributed in Ecuadorian scientific journals indexed in Latindex, Dialnet and various regional repertoires. Likewise, 23% (n=7) finds its origin in comparative studies from other Ibero-American nations, while the remaining 19% (n=6) is made up of regulatory frameworks, technical opinions and inter-American jurisprudence. Regarding the date of issue, 74% of the bibliographic inputs are between 2023 and 2026, which reflects increasing academic attention to the convergence between digital evidence and due process guarantees.

**Table 2. Distribution of the documentary sample according to thematic axis.**

| Thematic axis                             | n  | %    | Main source                              |
|-------------------------------------------|----|------|------------------------------------------|
| Regulatory framework for digital evidence | 9  | 29 % | COIP, COGEP, LOPD                        |
| Chain of custody and technical standards  | 11 | 35 % | ISO/IEC 27037, ISO/IEC 27042             |
| Judicial assessment of digital evidence   | 6  | 20 % | Jurisprudence and procedural doctrine    |
| Due process guarantees                    | 5  | 16 % | Constitution, ACHR, Inter-American Court |

## Regulatory framework for digital evidence

The documentary analysis shows that the Comprehensive Organic Criminal Code expressly recognizes electronic documents, data messages and computer records as means of proof, referring in a complementary manner to the Law on Electronic Commerce, Electronic Signatures and Data Messages for the purposes of their evidentiary assessment (8). However, the studies agree that said regulation is insufficient in the face of the technical complexity of contemporary digital evidence, as it does not establish specific and unified collection protocols for mobile devices, cloud systems or institutional servers, leaving said standardization to be left to specific technical proposals rather than to a consolidated public policy (1,6). In the comparative field, the laws of Spain, Colombia, Chile and Peru present an uneven regulatory development: while Spain has specific regulation on technological research proceedings, Ecuador and other countries in the region still lack an autonomous legal framework for electronic evidence, relying on general provisions of the criminal procedure code (5,20).

## Chain of custody and technical standards

The thematic axis with the highest frequency of documentation was that related to the digital chain of custody, present in 35% of the sample. The studies reviewed repeatedly identify the absence of unified technical protocols at the national level in Ecuador for the identification, collection, packaging, transportation and storage of electronic devices, which increases the risk of contamination or alteration of the evidence before its expert analysis (12,22). The limited formal adoption of international standards such as the ISO/IEC 27037 standard is also documented, which establishes the principles of auditability, repeatability, reproducibility and justifiability as minimum conditions to guarantee the reliability of digital evidence (15,16). Judicial cases analyzed in the literature illustrate how the lack of coincidence between the hash values recorded at the time of seizure and those verified in the expert phase has led to the declaration of nullity or exclusion of the evidence due to breaking the chain of custody (14).

Likewise, a significant lack of accredited computer forensic experts and specialized laboratories equipped with bit-by-bit forensic duplication tools is identified in the region, which forces in many cases to resort to external experts or international cooperation organizations, generating procedural delays and making access to justice more expensive (6,24). The Organization of American States has indicated that this limitation of technical capabilities constitutes one of the main obstacles to the effective prosecution of cybercrime in the region (2).

## Judicial assessment of digital evidence

Regarding judicial assessment, the studies reviewed show disparate criteria among justice operators regarding the admissibility of screenshots, instant messaging conversations and publications on social networks as evidence of prosecution, in the absence of technical expertise that certifies their authenticity (13,25). A growing jurisprudential trend is documented to require technical verification of metadata and complete traceability of the chain of custody as a condition of admissibility, although this requirement is not applied uniformly in all judiciaries in the country (28,29). On the

other hand, some studies warn about the risk of an excessively formal judicial assessment, which could discard substantially relevant digital evidence due to minor procedural defects, to the detriment of the search for material truth (21,23).

### **Due process guarantees**

Documents that directly address the relationship between digital evidence and due process highlight three main tensions. Firstly, the possible impact on the right to privacy and the inviolability of communications during the obtaining of digital evidence without proper judicial authorizations, as well as the risk that said evidence will be used selectively or at convenience by the procedural parties (30). Secondly, the limitations on the right of defense when the prosecuted party does not have timely access or the technical capacity to dispute the digital evidence of the charge, which compromises the principle of equality of arms (11,31). Thirdly, the requirement of judicial motivation is reinforced when the conviction is based predominantly on digital evidence, by virtue of the standards set by the Inter-American Court of Human Rights in matters of judicial guarantees (10,11). These findings converge in pointing out that the technical validity of digital evidence constitutes a necessary, although not sufficient, condition to guarantee comprehensive respect for due process, which also requires conditions of contradiction, procedural equality and sufficient judicial motivation.

### **Comparative jurisprudence and illustrative cases**

The documentary analysis identified several illustrative cases cited repeatedly in the reviewed literature, which allow us to observe the practical application of the principles described above. In one case analyzed within the sample, the acquittal of the defendants was based, among other elements, on the finding that the hash values of the seized computer material did not coincide with those recorded in the police report at the time of the intervention, which led the court to declare the evidence contaminated, invalid and unreliable, due to the lack of certainty about its preservation and authenticity (14). This type of precedent reinforces the practical and not merely theoretical importance of the technical standards for the preservation of digital evidence, to the extent that non-compliance can directly determine the meaning of the ruling. In the Ecuadorian sphere, the National Court of Justice has had the opportunity to rule on the assessment of electronic evidence in processes for computer crimes, reiterating that the mere existence of digital data is not enough to prove its authenticity if the technical process of obtaining it is not documented (22).

On a comparative level, the studies reviewed on Colombia document a jurisprudential development aimed at requiring the intervention of accredited experts and the application of standardized forensic protocols as a condition for the admissibility of digital evidence in judicial processes, in line with the principles of the ISO/IEC 27037 standard (15,23). In Chile, the Public Ministry has developed specific institutional guidelines on the integrity and authenticity of technological evidence, aimed at unifying the action criteria of prosecutors at the national level, an institutional development that, according to the documents analyzed, is still in an incipient stage in the Ecuadorian case (5). These comparative findings suggest that institutional strengthening rather than

exclusively normative constitutes a determining factor for the effective guarantee of due process in the face of digital evidence.

## DISCUSSION

The results obtained confirm, in general terms, the findings reported by Avemañay Lema et al. (5), who identified a gap between the regulatory recognition of digital evidence in Ecuador and its practical application, marked by the absence of technical protocols and limitations in the chain of custody. This coincidence suggests that this gap does not constitute an isolated finding, but rather a sustained trend in recent Ecuadorian literature, also documented by Navas-Abad and Vázquez-Martínez (6) and by Morante Mendoza et al. (12), who attribute the problem to the absence of specific regulation on electronic evidence, in contrast to the Model Law on Electronic Evidence promoted for the Latin American region by international cooperation organizations.

In relation to the chain of custody, the findings of this study reinforce what was pointed out by Ordoñez Ordoñez et al. (14), who documented specific cases of impunity derived from the breaking of the chain of custody by security agencies, as well as what was exposed by Quichimbo Román et al. (13) regarding the insufficient regulation of digital evidence in the General Organic Code of Processes. These results are consistent with the international literature: Casey (3) and Kerr (4) have maintained for more than a decade that the volatility of digital evidence requires more rigorous forensic protocols than those applicable to traditional physical evidence, while the ISO/IEC 27037 and ISO/IEC 27042 standards constitute, at a comparative level, the most accepted technical reference for its collection and analysis (15,16), a coincidence that supports the recommendation, supported by multiple studies of the sample, to adopt formally said standards in the Ecuadorian expert protocols.

However, the results of this study partially qualify the conclusions of López (20) and López Morales (21), who, in the comparative Latin American context, maintain that the legal validity of digital evidence has been consolidated more clearly in those countries that have developed specific jurisprudence on its admissibility. Unlike this scenario, the evidence collected in the present study indicates that Ecuador continues to rely on general procedural provisions, without an equivalent autonomous regulatory development, which could explain the greater disparity in judicial criteria identified in the evaluation of Ecuadorian digital evidence compared to that observed in the compared systems (28).

Regarding the guarantees of due process, the findings coincide with the jurisprudence of the Inter-American Court of Human Rights in the case of Suárez Rosero vs. Ecuador, in that they reaffirm that the right of defense requires timely and effective access to the evidence that supports the accusation (11). This convergence reinforces the thesis, also supported by Mendoza (25) and by San Martín Andrade et al. (26), that the technical validity of digital evidence is insufficient if procedural conditions of contradiction and equality of arms are not guaranteed. However, unlike more deterministic positions that attribute the violation of due process exclusively to technological factors, the results of this study suggest that the main causes identified in the literature are institutional and

organizational in nature, lack of protocols, insufficient training, shortage of accredited experts rather than strictly technological, which reorients public policy recommendations towards institutional strengthening rather than solely updating regulations.

An additional aspect that deserves discussion is the practical effectiveness of international cooperation instruments regarding cross-border digital evidence. Although the Budapest Convention constitutes the most cited framework in the literature for obtaining electronic evidence hosted on servers located outside national jurisdiction (17), Ecuador is not part of said instrument as a full subscriber State, which, according to the studies reviewed, hinders the processes of mutual judicial assistance and expeditious conservation of computer data before providers of international messaging and social networking services (2,7). This limitation coincides with what was indicated by the Organization of American States in its regional diagnosis, which identifies international cooperation as one of the most lagging components of the state response to cybercrime in Latin America (2), and suggests that internal regulatory reforms, by themselves, are insufficient if they are not accompanied by an active foreign policy on digital judicial cooperation.

Finally, it is worth noting as a limitation of the present study the eminently documentary nature of the review, which did not incorporate a primary empirical component through interviews or surveys with justice operators, unlike mixed studies such as that of Avemañay Lema et al. (5). It is recommended that future research complement this systematic review with field studies that allow the documentary findings to be contrasted with daily judicial practice in the different judiciaries of the country.

## CONCLUSIONS

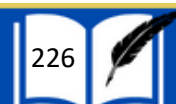
The systematic review of the literature shows that, although the Ecuadorian legal system and the majority of Latin American criminal systems normatively recognize the validity of digital evidence as a means of proof, said formal recognition is not accompanied by sufficient technical-procedural development, which generates a structural gap between the norm and its practical application in the criminal process.

Strengthening the digital chain of custody, through the adoption of internationally recognized technical standards such as the ISO/IEC 27037 standard and the formal accreditation of computer forensic experts, constitutes an essential condition to guarantee the authenticity and integrity of digital evidence and, therefore, to prevent its exclusion or nullity due to procedural defects.

The impact of digital evidence on the guarantee of due process does not depend exclusively on technological factors, but mainly on institutional conditions related to the specialized training of judges, prosecutors, defenders and experts, as well as the existence of clear protocols that ensure the right of defense, contradiction and reinforced judicial motivation in those criminal processes supported predominantly by electronic evidence, thus responding to the general objective set out in the present study.

## REFERENCES

1. De la Torre Muñoz FM, Puertas Realpe AX, Burbano Peña CE. Manejo de la evidencia digital con visión en normas internacionales aplicables por los primeros interventores y peritos forenses en Ecuador. *ISUPOL Rev Investig Segur Ciudadana Orden Público*. 2024;(9):43-57.
2. Organización de los Estados Americanos. Ciberdelito en América Latina y el Caribe: diagnóstico regional 2022. Washington DC: Secretaría de Seguridad Multidimensional, OEA; 2022.
3. Vaca H. El análisis forense de memoria RAM como evidencia digital en delitos comunes: simulación de peculado en Ecuador. *Rev Dig Cienc Forense*. 2026;5(1).
4. Kerr OS. *Computer Crime Law*. 5th ed. St. Paul: West Academic Publishing; 2022.
5. Avemañay Lema SA, Avemañay Lema AJ, Duarte Correa MA. La prueba digital en el proceso penal ecuatoriano, desafíos constitucionales, técnicos y comparados frente a los estándares iberoamericanos de evidencia tecnológica. *Cienc Lat Rev Cient Multidiscip*. 2025;9(5):17880-900. doi:10.37811/cl\_rcm.v9i6.21212
6. Navas-Abad CE, Vázquez-Martínez DS. La importancia de la prueba digital en los procedimientos penales en Ecuador. *Polo Conoc*. 2025;10(1):1742-75. doi:10.23857/pc.v10i1.8778
7. Herrera Zapata SM. El papel de la prueba digital en los procedimientos penales en Ecuador: marco legal, desafíos y necesidad de modernización [tesis de maestría]. Quito: Universidad Andina Simón Bolívar; 2025.
8. Asamblea Nacional del Ecuador. Código Orgánico Integral Penal. Registro Oficial Suplemento 180, 10 de febrero de 2014 (actualización 2023).
9. Constitución de la República del Ecuador. Registro Oficial 449, 20 de octubre de 2008.
10. Convención Americana sobre Derechos Humanos. Art. 8, Garantías Judiciales. San José: Organización de los Estados Americanos; 1969.
11. Corte Interamericana de Derechos Humanos. Caso Suárez Rosero Vs. Ecuador. Sentencia de fondo, 12 de noviembre de 1997.
12. Morante Mendoza LE, Safadi Mendoza JA, Gómez Rivera GP. Delitos informáticos y prueba digital en el COIP: validez, cadena de custodia y pericia forense en el Ecuador. *Tesla Rev Cient*. 2025;5(2):e542. doi:10.55204/trc.v5i2.e542
13. Quichimbo Román MA, Mereci Balcázar LS, Ramón Merchán ME. La admisibilidad de la prueba digital en los procesos judiciales incorporados en el Código Orgánico General de Procesos. *Domin Cienc*. 2024;10(3):1126-42. doi:10.23857/dc.v10i3.3972
14. Ordoñez Ordoñez LA, Vázquez Olaya AY, Campoverde Nivicela LJ. La impunidad por violentarse la cadena de custodia por parte de la Policía Nacional. *Cienc Lat Rev Cient Multidiscip*. 2024;8(2):1742-75. doi:10.37811/cl\_rcm.v8i2.11208
15. International Organization for Standardization. ISO/IEC 27037:2012. Information technology — Security techniques — Guidelines for identification, collection, acquisition and preservation of digital evidence. Geneva: ISO; 2012.
16. International Organization for Standardization. ISO/IEC 27042:2015. Guidelines for the analysis and interpretation of digital evidence. Geneva: ISO; 2015.



17. Consejo de Europa. Convenio sobre la Ciberdelincuencia (Convenio de Budapest). Budapest: Consejo de Europa; 2001.
18. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. Declaración PRISMA 2020: una guía actualizada para la publicación de revisiones sistemáticas. *Rev Esp Cardiol*. 2021;74(9):790-9.
19. González Reyes M. Naturaleza y valoración de la evidencia digital. Salamanca: Universidad de Salamanca; 2021.
20. López JA. Evidencia digital y su admisibilidad en los procesos penales latinoamericanos. *Rev Iberoam Derecho Penal Proces*. 2023;10(2):55-74.
21. López Morales ZA. Validez jurídica de la prueba digital en Guatemala. *Rev Cienc Multidiscip CUNORI*. 2023;7(2).
22. Porras MA. La cadena de custodia digital en el proceso penal ecuatoriano. *Rev Ecuat Cienc Juríd*. 2023;12(3):87-105.
23. Yepes J, Cárdenas S, Gómez D. La evidencia digital en los procesos judiciales colombianos: un análisis forense comparado. *Rev Derecho Proces Comp*. 2022;8(1):33-49.
24. Espinoza EE. Análisis de técnicas y herramientas forenses para la investigación de delitos informáticos en Ecuador. *Rev Cient*. 2024;8(2):101-15.
25. Mendoza M. Interpretación y desafíos de la evidencia digital en la investigación criminal. *Código Cient Rev Investig*. 2024;5(3):480-98. doi:10.55813/gaea/ccri/v5/nE3/328
26. San Martín Andrade MA, Bravo Moreno SR, Garza Lomas CD. Desafíos de la evidencia digital en la protección de datos personales: la cadena de custodia. *Rev Lechuzas*. 2026;2(4):1-14.
27. Espinales J. Análisis del derecho procesal y los entornos jurídicos. *Rev Cient Arbit Investig Comun Mark Empresa REICOMUNICAR*. 2023;6(12):89-97.
28. Riofrío García IA, Ruiz K, Lema P. La prueba electrónica en los procesos penales en Ecuador en concordancia con celeridad y economía procesal. *Serie Cient UCI*. 2025;18(2):49-62.
29. Imaicela Revilla JA, Alvarado Ajila LA. La incorporación de la prueba digital en el derecho procesal ecuatoriano. *Rev Lex*. 2024;7(27):1338-50. doi:10.33996/revistalex.v7i27.247
30. Valdés R. La excepcional limitación al derecho fundamental a la intimidad: una reflexión sobre la prueba ilícita y su uso a conveniencia. *Rev Derecho Debates Pers*. 2023.
31. Jiménez Guartán FA. La prueba digital y su valoración en el proceso penal ecuatoriano frente a las garantías constitucionales. *Polo Conoc*. 2026;11(1):1-18.

# APLICACIÓN DE *Saccharomyces cerevisiae* Y EXTRACTOS FRUTALES EN LA POSCOSECHA DEL CACAO (*Theobroma Cacao* L.) COMO ESTRATEGIA PARA MEJORAR LA CALIDAD DEL GRANO Y EL PERFIL SENSORIAL DE LA PASTA DE CACAO

## APPLICATION OF *Saccharomyces cerevisiae* AND FRUIT EXTRACTS IN THE POST-HARVEST OF COCOA (*Theobroma Cacao* L.) AS A STRATEGY TO IMPROVE BEAN QUALITY AND THE SENSORY PROFILE OF COCOA PASTE

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**RESUMEN:** La fermentación constituye una etapa determinante para el desarrollo de la calidad del cacao, por lo que el empleo de cultivos iniciadores y matrices frutales representa una alternativa para mejorar el control del proceso postcosecha. El objetivo de esta investigación fue evaluar el efecto de *Saccharomyces cerevisiae* y extractos frutales durante la fermentación del cacao (*Theobroma cacao* L.) sobre la calidad fisicoquímica, fermentativa y sensorial del grano y de la pasta obtenida. Se evaluaron nueve tratamientos resultantes de la combinación de tres niveles de *S. cerevisiae* (0, 0,05 y 1 %) y tres conficiones de extracto (sin extracto, papaya y guanabana). La fermentación se desarrolló durante cinco días en cajas de microfermentación tipo Rohan, con seguimiento de temperatura, pH y sólidos solubles. Posteriormente, se determinaron las características físicas y la calidad fermentativo y de calidad. La combinación de una cantidad del 1 % de *S. cerevisiae* combinado con el extracto de papaya alcanzó un valor de 92 % de granos fermentados; 7 % de granos violetas y 6,13 % de humedad, lo cual favoreció el comportamiento tecnológico más correcto entre los tratamientos propuestos. Asimismo, el tipo de extracto ejerció un efecto significativo sobre el pH, acidez, humedad y cenizas de la pasta, y la modalidad de los tratamientos generó diferentes perfiles sensoriales como resultado de los mismos. Por tanto, se llega a la conclusión de que *S. cerevisiae* y los extractos de fruta pueden ser usados para modular la fermentación y las características de calidad del cacao, destacando el extracto de papaya como el más

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interesante debido a su capacidad para regular las fermentaciones y las condiciones postcosecha.

**Palabras clave:** *Saccharomyces cerevisiae*; *Theobroma cacao*; fermentación; extractos frutales; calidad postcosecha; análisis sensorial.

**ABSTRACT:** Fermentation is a critical stage in the development of cocoa quality; therefore, the use of starter cultures and fruit-based matrices represents an alternative approach to improve the control of postharvest processing. This study aimed to evaluate the effect of *Saccharomyces cerevisiae* and fruit extracts during cocoa (*Theobroma cacao* L.) fermentation on the physicochemical, fermentative, and sensory quality of the beans and the resulting cocoa paste. Nine treatments were evaluated, resulting from the combination of three levels of *S. cerevisiae* (0, 0.5, and 1%) and three extract conditions (no extract, papaya, and soursop). Fermentation was conducted for five days in Rohan-type microfermentation boxes, with temperature, pH, and total soluble solids monitored throughout the process. Subsequently, the physical characteristics and fermentative quality of the beans, the physicochemical properties of the cocoa paste, and its sensory profile were evaluated. The combination of 1% *S. cerevisiae* mixed with papaya extract resulted in 92% fermented grains, 7% violet grains, and 6.13% moisture content, which yielded the best technological performance among the proposed treatments. Likewise, the type of extract had a significant effect on the paste's pH, acidity, moisture content, and ash content, and the treatment conditions resulted in different sensory profiles. Therefore, it is concluded that *S. cerevisiae* and fruit extracts can be used to modulate fermentation and the quality characteristics of cocoa, with papaya extract standing out as the most promising due to its ability to regulate fermentation and post-harvest conditions.

**Keywords:** *Saccharomyces cerevisiae*; *Theobroma cacao*; fermentation; fruit extracts; postharvest quality; sensory analysis

## INTRODUCTION

Cocoa (*Theobroma cacao* L.) constitutes one of the tropical crops of greatest economic, social and environmental importance worldwide, because it represents the livelihood of millions of small producers and supplies a chocolate industry whose demand continues to increase, especially in the segment of fine and original chocolates. In this context, the quality of cocoa has acquired strategic relevance, since it determines the competitiveness of the product in specialized markets and the added value of the agroindustrial chain. Various studies agree that the final quality of cocoa does not depend only on the genetic material or cultivation conditions, but also on the proper management of post-harvest operations, with fermentation being the process with the greatest influence on the development of the physicochemical, biochemical and sensory characteristics of the grain. During this stage, the main precursors of the aroma and flavor are generated, which are subsequently developed during roasting through Maillard reactions, determining attributes such as the aroma, flavor, color and quality of the chocolate.(1)(2)(3)(4)

Cocoa fermentation corresponds to a highly dynamic microbiological ecosystem in which yeasts, lactic acid bacteria and acetic acid bacteria participate sequentially. During the first 24 to 48 hours, yeasts predominate due to the high availability of sugars present in the mucilage and the initial conditions of low oxygen availability. Subsequently, the production of ethanol and the increase in aeration favor the establishment of acetic acid bacteria, responsible for the oxidation of ethanol to acetic acid and the increase in the temperature of the fermentative mass to values close to 45–50 °C. These changes lead to the death of the embryo and provoke a series of enzymatic reactions that favor the hydrolysis of proteins, carbohydrates and polyphenols into free amino acids, peptides and reducing sugars that are the main precursors of the aromatic profile of chocolate.(5)(6)(7)

However, in most producing countries, fermentation continues to be carried out using traditional and spontaneous methods, the efficiency of which depends on the native microbiota, environmental conditions and the management applied by producers. This high variability generates significant differences in the fermentation dynamics and in the physicochemical and sensory quality of the almonds, limiting the standardization of the process and the obtaining of grains with homogeneous characteristics. In response to this problem, in recent years directed fermentation using starter cultures has acquired growing interest as a biotechnological strategy to control microbial succession, optimize the formation of aromatic compounds and improve the quality of fermented cocoa.(8)(9)(10)(11)

In response to the need to increase the reproducibility of fermentation and improve the quality of cocoa, the use of starter cultures has acquired a relevant role within the biotechnological strategies applied to postharvest. Among the microorganisms evaluated, *Saccharomyces cerevisiae* has demonstrated high potential due to its rapid adaptation to mucilage conditions, its efficient sugar metabolism and its ability to produce ethanol, higher alcohols, esters and other volatile compounds that directly participate in the formation of the aromatic profile of cocoa. In addition to promoting alcoholic fermentation, this yeast presents pectinolytic activity that contributes to the degradation of mucilage, facilitating the aeration of the fermentative mass and promoting the establishment of acetic acid bacteria, responsible for the production of acetic acid and the increase in the temperature necessary to induce the internal biochemical transformations of the almond.(12)(13)(14)

Simultaneously, the search for sustainable alternatives to improve fermentation has led to the study of plant matrices that have a high content of nutrients with properties that are capable of stimulating microbial metabolism. In this context, tropical fruit extracts represent a promising alternative due to their content of fermentable sugars, vitamins, minerals, organic acids and bioactive compounds, which could favor the growth of beneficial microorganisms and modify the physicochemical conditions of the fermentation process. Among these fruits, papaya (*Carica papaya* L.) stands out for its high glucose, fructose and sucrose content, in addition to the presence of papain, a proteolytic enzyme widely recognized for its ability to hydrolyze proteins and generate peptides and amino acids that can potentially increase the availability of aromatic precursors during cocoa processing. On the other hand, soursop (*Annona muricata* L.)

contains carbohydrates, vitamin C, organic acids and phenolic compounds with antioxidant activity, characteristics that could contribute to maintaining a favorable environment for the development of the fermentative microbiota and favor the stability of the process.(4)(12)(15)(16)

Despite the growing interest in the directed fermentation of cocoa, most of the research has focused on the selection and evaluation of starter cultures, particularly yeasts and lactic acid or acetic acid bacteria, while the incorporation of fruit extracts as natural sources of nutrients during fermentation has been barely studied. Since the review of the recent scientific literature, no work has been carried out that has evaluated the combined effect of *Saccharomyces cerevisiae* with papaya and soursop extracts in the post-harvest fermentation of cocoa, which reveals a gap in knowledge and the development of innovative biotechnologies that seek to improve the physicochemical quality and sensory profile of cocoa and its derivatives.(5)(12)

The development of biotechnological strategies aimed at optimizing cocoa fermentation represents an opportunity to increase the quality of the bean and strengthen the competitiveness of the agro-industrial chain, especially in producing countries where traditional post-harvest systems predominate. The application of starter cultures in combination with natural sources of nutrients constitutes an innovative approach that could favor the microbiological stability of the process, promote a more uniform fermentation and improve the formation of aroma precursor compounds. Likewise, the use of tropical fruits such as papaya and soursop is framed within the principles of the bioeconomy and the circular economy, by encouraging the sustainable use of locally available plant resources with the potential to generate added value in cocoa production.(17)(18)(19)

From a scientific point of view, the combination of *Saccharomyces cerevisiae* with extracts of papaya (*Carica papaya* L.) and soursop (*Annona muricata* L.) poses a novel strategy based on the possible synergistic interaction between a highly efficient starter culture and natural matrices rich in fermentable sugars, vitamins, minerals and bioactive compounds. It is proposed that these extracts could favor the establishment and metabolic activity of yeast during the initial stages of fermentation, promoting greater ethanol production, facilitating the subsequent activity of acetic acid bacteria and favoring the biochemical transformations responsible for the formation of amino acids, peptides and reducing sugars, considered the main precursors of the aroma and flavor of chocolate. However, the existing scientific evidence on this combination remains scarce, so it makes sense to generate experimental information that allows establishing its effect on the physicochemical, fermentative and sensory quality of cocoa.(20)

The research presented below was carried out in order to offer scientific evidence on a new biotechnological strategy for improving cocoa postharvest, which has contributed, in this way, to advances in the improvement of fermentation processes that are more efficient, sustainable and reproducible. The results obtained may serve as a basis for future research aimed at optimizing fermentation through the use of starter cultures and natural resources, as well as for the design of technologies applicable to the cocoa industry and producers seeking to increase the quality and added value of their products. Consequently, the present study aimed to evaluate the effect of the

application of *Saccharomyces cerevisiae* and fruit extracts during the postharvest fermentation of cocoa (*Theobroma cacao* L.) on the physicochemical, fermentative and sensory quality of the bean, as well as on the sensory profile of the cocoa paste obtained.

## MATERIALS AND METHODS

### Location

The cocoa pods (*Theobroma cacao* L.) used in the present investigation, as well as the fruits intended for the preparation of the extracts, corresponding to papaya (*Carica papaya* L.) and soursop (*Annona muricata* L.), were collected in the El Naranjo facility, Bajo Perdido sector, Mocache canton, province from Los Ríos, Ecuador (1°11'30.7" S; 79°35'43.6" W). Both the ears and the fruits were selected in an optimal state of physiological maturity, free of mechanical damage, diseases, insect attacks and other alterations that could affect the quality of the raw material or the development of the experimental process.

The post-harvest fermentation of the cocoa kernels was carried out according to the established experimental design, while the production of the cocoa paste was carried out at the Agroindustry Bromatology Plant of the Technical University of Babahoyo (UTB). Subsequently, the physicochemical determinations of the fermented almonds and cocoa paste, including pH, titratable acidity (%), humidity (%) and ash (%), were carried out in the Agroindustry Laboratory of the Technical University of Babahoyo, using standardized analytical methodologies for the analysis of products derived from cocoa.

### Experimental design

The research was carried out using an experimental approach aimed at determining the effect of the incorporation of *Saccharomyces cerevisiae* and fruit extracts on the postharvest fermentation of cocoa (*Theobroma cacao* L.). The study contemplated the controlled manipulation of the independent variables with the purpose of establishing their influence on the fermentative dynamics, the physicochemical and fermentative properties of the almonds, and the quality of the cocoa paste obtained at the end of the process of the cocoa paste obtained.

The experimental trials were carried out under controlled conditions at the Agroindustry Bromatology Plant, where the working conditions were standardized to ensure the uniformity of the experimental process, favor the reproducibility of the results and minimize the influence of external factors. As raw material, fresh cocoa kernels were used, obtained from pods harvested in an optimal state of physiological maturity, free of mechanical damage, diseases, insect attacks and other defects that could compromise the normal development of fermentation.

The experiment was established using a completely randomized design (DCA) with a 3 × 3 factorial arrangement. The first factor corresponded to the concentration of *Saccharomyces cerevisiae* applied during fermentation (0, 0.5% "5 g" and 1.0% "10 g"),

while the second factor was represented by the type of fruit extract (without extract, papaya extract (*Carica papaya* L.) and soursop extract (*Annona muricata* L.). The combination of both factors gave rise to nine experimental treatments, each with three repetitions, making up a total of 27 experimental units. The assignment of the treatments was carried out completely randomly, as seen in Table 1.

During the fermentation, the main variables of the process were continuously monitored, including the internal temperature of the fermentative mass, the pH and the total soluble solids. (°Brix), using previously calibrated equipment. Fermentation took place under the environmental conditions of the study area, with temperatures between 25 and 30 °C and relative humidity characteristic of the humid tropical climate.

Data collection was carried out longitudinally throughout the fermentation process, through periodic monitoring of the physicochemical and fermentative variables. Once the fermentation was completed and the product was prepared, a cross-sectional evaluation was carried out to determine the degree of fermentation of the almonds and the sensory characteristics of the cocoa paste, allowing the response of the different experimental treatments to be compared.

**Table 1. Scheme of Study Factors.**

| Factor A                             | Factor B                              |
|--------------------------------------|---------------------------------------|
| <i>Saccharomyces cerevisiae</i> (gr) | (Fruit extract)                       |
| 0%                                   | Without fruit extract                 |
| 0.5%                                 | Papaya ( <i>Carica papaya</i> L.)     |
| 1%                                   | Soursop ( <i>Annona muricata</i> L.). |

## ANOVA

In table number 2 you can find the ANOVA, where the treatments, the measured factors and the interactions are found, which offers a statistical basis to interpret the main effects and the combined effects of the experimental model.

**Table 2. Analysis of variance (ANOVA) diagram.**

| Source variation (VS)       |        | Degrees of freedom (DOF) |
|-----------------------------|--------|--------------------------|
| Treatment                   | axb-1  | 8 <sup>#</sup>           |
| Repetitions                 | r-1    | 2                        |
| Factor <i>Saccharomyces</i> | (LE-1) | 2                        |
| <i>cerevisiae</i>           |        |                          |

|                        |                 |    |
|------------------------|-----------------|----|
| Factor Extract         | (Ex-1)          | 2  |
| Yeast x Extract Factor | (LE-1)(EX-1)    | 4  |
| Experimental Error     | (LE x EX) (r-1) | 18 |
| Total                  | LE x EX r-1     | 27 |

### Treatment arrangement

Table 3 presents the organization of the 9 treatments established in the experimental design, each one identified by a specified code according to the factors considered in the study. This nomenclature allowed us to clearly differentiate the combinations evaluated, maintain adequate control of the samples during fermentation and simplify the recording of information. Likewise, it contributed to reliably relating each experimental unit with the data generated, favoring the subsequent interpretation and comparison of the results.

**Table 3. Treatment codes and study variables.**

| No. | Code   | <i>Saccharomyces cerevisiae</i> | Fruit Extract         |
|-----|--------|---------------------------------|-----------------------|
| 1   | Sc0Ex0 | 0                               | Without fruit extract |
| 2   | Sc0Ex1 | 0                               | Papaya                |
| 3   | Sc0Ex2 | 0                               | Soursop               |
| 4   | Sc1Ex0 | 0.5                             | Without fruit extract |
| 5   | Sc1Ex1 | 0.5                             | Papaya                |
| 6   | Sc1Ex2 | 0.5                             | Soursop               |
| 7   | Sc2Ex0 | 1                               | Without fruit extract |
| 8   | Sc2Ex1 | 1                               | Papaya                |
| 9   | Sc2Ex2 | 1                               | Soursop               |

### Fermentation process

Fermentation was carried out in Rohan-type wooden microfermentation boxes (100 x 100 x 15 cm) that were assigned to carry out the experimental study factors; Each box had 27 compartments (1 kg per unit), which were used as experimental units. Cocoa beans, before fermentation, were inoculated with *Saccharomyces cerevisiae* and then fruit extracts were added inside low-density polypropylene covers for 24 hours. The casings were then removed and fermentation was carried out under aerobic conditions for five days. Manual turning was carried out daily to ensure homogenization of the dough and its oxygenation. The control physicochemical parameters (temperature, pH and soluble solids) were monitored daily. In total, 27 kg of fresh cocoa beans were processed. The amount of perishable grains was similar for both varieties.(21)(22)

### Inocula (*Saccharomyces cerevisiae*)

Cocoa fermentation was carried out by applying active dry yeast of *Saccharomyces cerevisiae* as a starter culture. Three application levels were evaluated: (Control treatment) 0%, 0.5% (5 g) and 1% (10 g) per experimental unit, corresponding to 1000 g of fresh cocoa beans, in accordance with the established experimental design.(12)

Prior to inoculation, the active dry yeast was rehydrated in 50 mL of sterile distilled water, previously conditioned at a temperature of 35 – 38 °C, for 10 minutes. Subsequently, the suspension obtained was incorporated uniformly into the fresh cocoa mass and mixed manually until a homogeneous distribution of the inoculum was achieved throughout the fermentation mass.(17)

### Preparation of diluted fruit extracts

The diluted extracts of papaya (*Carica papaya* L.) and soursop (*Annona muricata* L.) were prepared following the experimental procedure described in the corresponding flow chart (Figure 1), with modifications adapted to the characteristics of each fruit. To guarantee the uniformity of the treatments, fruits were used in an optimal state of physiological maturity, free of mechanical damage, rot, microbiological contamination and visible alterations that could affect the composition of the extract or the development of fermentation.

Prior to obtaining the extracts, the fruits were washed with drinking water to eliminate surface impurities and subsequently disinfected by immersion in a sodium hypochlorite solution at 100 mg L<sup>-1</sup> for 2 min. They were then rinsed with sterile distilled water and allowed to drain at room temperature.

In the case of papaya (*Carica papaya* L.), the peel and seeds were manually removed, obtaining only the edible pulp. Subsequently, 150 g of fresh pulp was weighed and mixed with 200 mL of sterile distilled water. The mixture was homogenized for 2 min using a laboratory blender until obtaining a uniform extract.(11)

For soursop (*Annona muricata* L.), the peel and seeds were removed, keeping only the pulp. Similarly, 150 g of fresh pulp were weighed, which were mixed with 200 mL of sterile distilled water and homogenized for 2 min using a laboratory blender, obtaining a homogeneous extract.

The extracts of both fruits had an approximate final mass of 350 g, corresponding to a fruit concentration of 42.86% (w/w), calculated using the following equation:

$$\% \text{ de fruta} = \frac{\text{Pulpa (g)}}{\text{Pulpa (g)} + \text{Agua (mL)}} \times 100$$

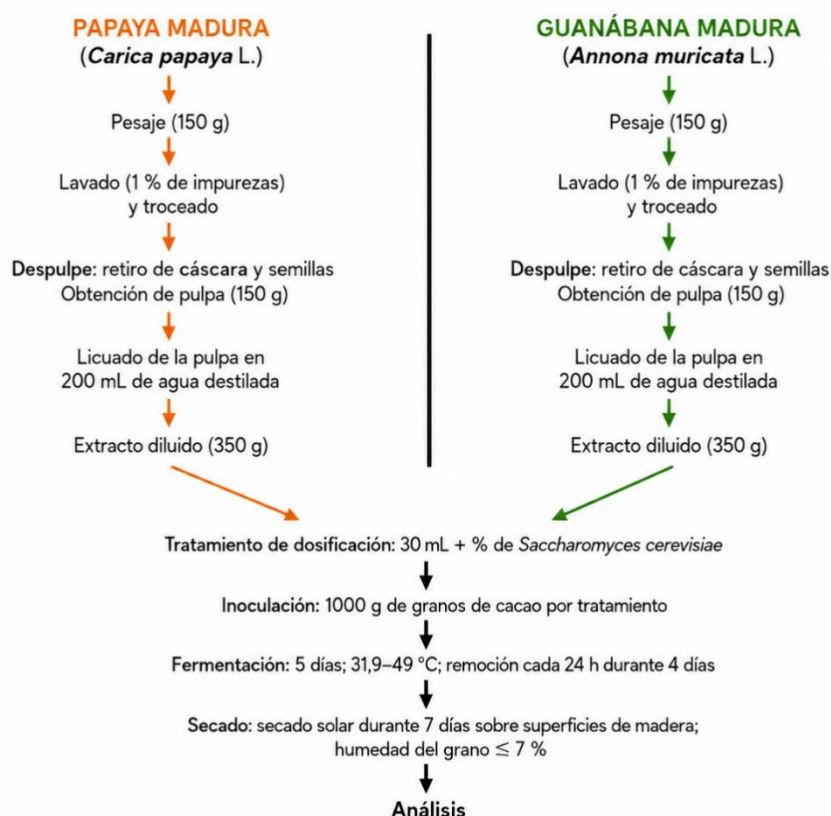


Figure 1. Diagram of the process for obtaining diluted fruit extracts.

## Physicochemical variables of fermented and dried cocoa beans

### pH analysis

The determination of pH was carried out using a standardized protocol. 10 g of finally ground cocoa beans were weighed, which were homogenized with 10 mL of distilled water previously heated to 40 °C. The mixture was prepared in glass containers and allowed to stabilize before measurement. The pH was determined with a digital meter (Thermo Orion Waterproof, USA), with buffer solutions of pH 4.0 and 7.0, according to the manufacturer's instructions. The determination was carried out in duplicate for each treatment.(11)

### Determination of total soluble solids (°Brix)

The content of total soluble solids (°Brix) was determined by digital reflectometry. To do this, 10 g of cocoa beans were randomly selected, which were finally ground and homogenized with 10 mL of distilled water previously heated to warm temperature. Subsequently, the suspension was filtered to obtain a particle-free extract, which was used for analysis. Determinations were carried out using a digital refractometer (OPTI + 38-A2, Brix 0-95; Bellingham and Stanley, United Kingdom). It was previously calibrated for distilled water (0.00 °Brix) following the manufacturer's guidelines before each measurement. 1-3 drops of extract were placed on the surface of the prism for each sample, and readings were performed in triplicate.(23)

### Temperature determination

The temperature of the fermentative mass was recorded throughout the process using a previously calibrated digital thermometer. The continuous monitoring of this variable made it possible to evaluate the evolution of fermentation and verify that the values achieved were within the range of 45-50 °C, considered appropriate to favor the activity of fermentative microorganisms. Temperatures above this range can accelerate the process and affect the quality of the almonds, while lower values can decrease microbial activity and delay the development of fermentation.(4)

### Drying of cocoa beans

At the end of the fermentation process, the cocoa beans were dried by direct exposure to solar radiation on wooden platforms, avoiding contact with surfaces that could generate contamination. Drying constitutes a critical stage of the postharvest benefit, since it allows humidity to be reduced, residual microbial activity to be stopped and the biochemical transformations associated with the development of the sensory profile of cocoa to be consolidated. The process was carried out during the approximate period of 7 to 8 days, until reaching a moisture content between 6 and 7%, a recommended value to guarantee the conservation and technological quality of the product.(24)

### Storage of cocoa beans

After finishing drying, the cocoa beans were stored in paper bags, a material that facilitates air exchange and reduces the risk of moisture condensation during the storage period. These conditions allowed preserving the quality of the samples and maintaining the physicochemical and sensory characteristics acquired during the fermentation and drying process until the execution of the experimental analyses.(25)

### Physicochemical variables of cocoa beans

#### Pod index

This variable corresponds to the number of fruits required to obtain 1 kg of dry cocoa (20 pods). The calculation was obtained from the equation that relates the weight of the pods to the dry cocoa yield with which we can estimate the effectiveness of the production process and the quality of the cocoa from the treatments applied. This parameter is key to determining the productivity of the farms and the sustainability of the crop.(12)

#### Equation 1. Pod index

$$IM = \frac{\text{Numero de mazorcas}}{\text{peso en gramos de las almendras secas}} * 1000$$

#### Seed indices

Before the cutting test, the seed index (SI) was determined by weighing 100 previously fermented and dried cocoa beans using a high precision analytical balance (Mx Analytical Balance, Mettler Toledo, USA) calculating the average weight per grain using the formula .(12)

### Equation 2. Seed index

$$IS = \frac{\text{Peso en gramos de 100 almendras de cacao fermentadas y secas}}{100}$$

### Testa and cotyledon test

The proportions of shell and cotyledon were determined using a 30 g sample of fermented and dried cocoa beans, weighed on a precision analytical balance and calculated according to the formula.(12)

$$\text{Equation 3. \% of testa and cotyledon} \% \text{ de testa} = \frac{(\text{Peso de la testa})}{\text{Peso de 30 gramos de cacao}} * 100$$

The cutting test was carried out on 100 randomly selected cocoa beans to evaluate the quality of fermentation. Beans were sorted longitudinally using a stylus and classified as well-fermented, moderately fermented, purple, slate, or moldy, following standard guidelines.

### Determination of the number of cocoa beans in 100 g

The number of poop beans per 100 g was determined by randomly selecting a representative sample and counting the number of beans needed to complete 100 g.(12)

### Humidity

The humidity of the cocoa beans was determined after fermentation and drying. This variable is decisive for storage and commercial quality, being within the optimal range of 6 to 7%. No lower percentage of this parameter, which is considered optimal, is economical for the cocoa industry, as it influences the price and processing properties. The measurement was carried out with a moisture meter (AQUA BOY III, United Kingdom), specific for grains, placing the sample on top of the sensor of the device and taking the reading.(26)

### Processing to obtain 100% cocoa paste

Figure 2 is a flow diagram that represents the procedure for obtaining 100% cocoa paste. The particularities of each of the phases are described below.



**Figure 2. Diagram of the process for obtaining 100% cocoa paste.**

*Selection and classification:* The cocoa raw material was classified through an exhaustive manual inspection, eliminating any contaminants or foreign bodies attached to the beans. This process guarantees the purity of the grains used.

*Roasting:* The beans underwent a roasting process with the help of a clay pot under controlled conditions at an average temperature of 120°C for 18 to 25 minutes, ensuring uniform heat distribution to prevent burns and facilitate the removal of residual moisture.

*Hulling:* A manual process of hulling the beans was carried out, which made it possible to separate the hulls from the cotyledons. The hulled beans were preserved in paper to avoid contamination and alteration.

*Grinding:* The grinding of the cotyledons was carried out with a traditional manual mill. Through this phase, the intended particle size was reached to facilitate subsequent refining and ensure a homogeneous texture of the cocoa paste.

*Refining:* The refining process was carried out using a melanger type cocoa refiner (Spectra 11 Stone Melanger, Spectra, Coimbatore, India) for a particle size less than 40  $\mu\text{m}$ , thus guaranteeing a homogeneous texture without the existence of granules that could extend on the surfaces of the palate. This phase is key to optimize the organoleptic characteristics of the product to be obtained.

*Conching of the cocoa mass:* The refined cocoa mass was introduced into a 5 kg conching machine, during which the sample was slowly introduced into the machine in such a way

*that the machine collected all the raw material adhered to its walls, thus achieving a uniform emulsion of the cocoa mass. The temperature control and stirring notably strengthened the emulsion and its homogeneity of the cocoa mass. This process was extended for 48 h for each of the treatments and the cocoa mass produced had a development that marked an outstanding sensory profile.*

*Tempering: Once the refining process was finished, the cocoa paste was subjected to the tempering process where, after heating it, its temperature must be lowered little by little. Subsequently, the cocoa paste was extracted from the previously sterilized molds and allowed to rest until it acquired the desired consistency.*

*Packaging and storage: Subsequently, the cocoa paste was packaged in aluminum-type paper with unique codes for traceability, in addition to being stored at 4 °C, which reduces the risk of cross contamination and also maintains its physicochemical or organoleptic properties.*

## Physicochemical analysis of cocoa paste

### Determination of the pH of cocoa paste

The pH of cocoa paste was determined through standardized processing. A previously homogenized cocoa sample (approximately 10 g) was dispersed in 10 mL of analytical grade distilled water to obtain a uniform suspension suitable for semisolid matrices. The mixture was allowed to equilibrate before measurement. The pH was measured in duplicate using a digital potentiometer (pH meter) equipped with a glass electrode (Thermo Orion, Waterproof, Beverly, USA), previously calibrated with standard buffer solutions (pH 4.0 and 7.0; Merck, Darmstadt, Germany) according to the manufacturer's instructions.(12)

### Determination of titratable acidity and total acidity in cocoa paste.

Titratable acidity was determined by acid-base titration using a previously homogenized cocoa paste sample. Approximately 10 g of sample was weighed and transferred to a 250 mL Erlenmeyer flask, adding 250 mL of distilled water (analytical grade, Merck, Darmstadt, Germany). The mixture was subjected to constant stirring using a magnetic stirrer to ensure complete dispersion. Subsequently, it was titrated with a 0.1 N sodium hydroxide (NaOH) solution, added gradually until reaching a final pH of 8.3, considered the titration end point for this type of matrix. The volume of NaOH consumed was recorded and the titratable acidity was calculated using formula (4), expressing the results as percentages of acidity.(22)

$$\text{Equation 4. Titratable acidity and total acidity. \% Acidez} = \frac{V1 \times N1 \times M \times 100}{V2}$$

Where:

V1= Volume of NaOH used in the titration (mL);

N1= Normality of the NaOH solution;

M= Molecular weight of the acid considered as reference (g mol<sup>-1</sup>);  
V2= Volume of the sample taken for analysis (mL).

### Determination of moisture in cocoa paste

The samples were presented in porcelain crucibles in an oven for about 30 min and then cooled to room temperature, and their weight was recorded with a precision analytical balance. Next, 2 g of previously homogenized cocoa paste were taken from the crucibles and dried in an oven at 130 °C for 2 hours. After two hours, the crucibles were placed in a desiccator and allowed to cool for about 30 min, and their weight was determined. Finally, the humidity of the cocoa paste was determined using formula 5.(22)

$$\% Humedad = \frac{M2 - M3}{M2 - M1} \times 100$$

Where:

M1= Mass of the empty crucible (g);  
M2= Mass of the crucible plus the sample (g);  
M3= Mass of the crucible with ashes (g)

### Determination of ashes in cocoa paste

Approximately 2 g of homogeneous cocoa paste were taken from pretreated porcelain crucibles (as described in the section "Determination of moisture in cocoa paste" and heated in a muffle oven at 600 ± 20 °C for 3 hours. The weight of the crucible was determined before and after heating, as described in the previous section. From the weights obtained, the ash content was determined by applying the formula.(22)

$$\% Cenizas = \frac{M3 - M1}{M2 - M1} \times 100$$

Where:

M1= Mass of the empty crucible (g);  
M2= Mass of the crucible plus the sample (g);  
M3= Mass of the crucible with ashes (g).

### Sensory analysis

In the sensory analysis we carried out a semi-trained tasting panel which was made up of 30 tasters, who determined: Flavor, Smell, Texture, Bitterness, Floral, Almond. The sensory analysis was carried out through a structured descriptive evaluation of the cocoa liquor obtained from the experimental treatments. To this end, a sensory sheet with an ordinal hedonic scale from 1 to 5 was used, where each of the values referred to some predefined category for each of the attributes. Five parameters of main interest were taken into consideration: Color, Appearance, Aroma, Flavor and Aftertaste, each subject to a specific descriptor.(22)

The scale used for each of the parameters was the following:

**Color: Caramel coffee, 2= Brown, 3= Walnut, 4: Carob, 5= Black coffee.**

**Appearance: 1= Very shiny, 2= shiny, 3= satin, 4= opaque, 5= very opaque.**

**Aroma: 1= Tropical fruits, 2= cocoa, 3= citrus fruit, 4= toasted, 5= nutty.**

**Flavor: 1= fruity, 2= roasted cocoa, 3= dry fruity, 4= bitter, 5= very bitter.**

**Aftertaste: 1= Smooth persistence, 2= bitter, 3= citrus not prolonged, 4= astringent, 5= spotty sensation.**

The samples were subjected to sampling, identifying them with codes (T1-T9) and in this way maintaining a blind tasting to avoid perceptual biases. The tasting session was carried out under neutral lighting conditions, in a temperature-controlled room of  $20 \pm 2$  °C and without visual or olfactory interference. Each sample was served in coded containers and was evaluated individually and independently.

The data obtained were organized for subsequent statistical analysis according to the experimental design.

## RESULTS

### Temperature dynamics during cocoa fermentation

The temperature of the cocoa mass was progressively increasing during the fermentation time as can be seen in Table 4. On day 0 of temperature measurement, the values were homogeneous between the treatments and ranged between 27.45 and 27.56 °C. At this stage, no significant effects of *Saccharomyces Cerevisiae* ( $p = 0.8530$ ), the type of fruit extract ( $p = 0.4623$ ) or the interaction between both factors ( $p = 0.9990$ ) were observed.

From day 1, a differentiation in the thermal response was evident. Both *S. cerevisiae* and the type of fruit extract exerted significant effects on temperature ( $p < 0.0001$ ), a behavior that was maintained until day 4. During this period, temperature increased from an interval of 31.48-34.07 °C on day 1 to 43.20-47.01 °C at the end of the evaluation. Among the experimental combinations, the treatment with 1% *S. cerevisiae* and papaya extract consistently recorded the numerically highest values from day 1, with temperatures of 34.07; 40.64; 44.92 and 47.01 °C on days 1, 2, 3 and 4, respectively. However, the treatment without *S. cerevisiae* and without extract presented the lowest records during the same period, with 31.48; 36.70; 40.77 and 43.20 °C.

Despite the differences observed for the main effects, the *S. cerevisiae* x extract interaction was not significant on any of the days evaluated ( $p = 0.9990$ ; 0.6319; 0.1536 and 0.2853 for days 0, 1, 2, 3 and 4). This behavior indicates that, under the experimental conditions evaluated, no statistical evidence was detected that the effect of *S. cerevisiae* on temperature depended on the type of extract incorporated, or vice versa. Altogether, the results show an ascending thermal evolution of the cocoa mass during fermentation and evidence significant effects of the factors *S. cerevisiae* and fruit extract type from day 1, without evidence of significant interaction between both factors.

**Table 4. Effect of *Saccharomyces cerevisiae* and fruit extracts on temperature dynamics during cocoa fermentation.**

| Factor                   |                          | Variable   |                     |                     |                     |                     |
|--------------------------|--------------------------|------------|---------------------|---------------------|---------------------|---------------------|
| Saccharomyces Cerevisiae | Fruit Extract            | Temp-day 0 | Temp-day 1          | Temp-day 2          | Temp-day 3          | Temp-day 4          |
|                          | Without fruit extract    | 27,47      | 31,48               | 36,70               | 40,77               | 43,20               |
|                          | 0 Papaya                 | 27,50      | 32,13               | 37,39               | 41,57               | 44,12               |
|                          | 0 Soursop                | 27,45      | 31,94               | 37,17               | 41,27               | 43,87               |
|                          | Without fruit extract    | 27,50      | 32,77               | 38,58               | 42,97               | 45,18               |
|                          | 0,5 Papaya               | 27,56      | 33,32               | 39,48               | 43,97               | 46,16               |
|                          | 0,5 Soursop              | 27,47      | 33,17               | 39,24               | 43,72               | 45,92               |
|                          | Without fruit extract    | 27,47      | 33,65               | 39,92               | 44,32               | 46,35               |
|                          | 1 Papaya                 | 27,55      | 34,07               | 40,64               | 44,92               | 47,01               |
|                          | 1 Soursop                | 27,45      | 33,98               | 40,51               | 44,82               | 46,89               |
| EEM ±                    |                          | 0,08       | 0,07                | 0,08                | 0,08                | 0,07                |
| CV                       |                          | 0,49       | 0,38                | 0,36                | 0,31                | 0,28                |
| Probability              | Saccharomyces Cerevisiae | 0,8530     | n <0,000 *<br>s 1 * | n <0,000 *<br>s 1 * | n <0,000 *<br>s 1 * | n <0,000 *<br>s 1 * |
|                          | Extract                  | 0,4623     | n <0,000 *<br>s 1 * | n <0,000 *<br>s 1 * | n <0,000 *<br>s 1 * | n <0,000 *<br>s 1 * |
|                          | S.Cerevisiae x Extract   | 0,9990     | n 0,6364<br>s s     | n 0,6319<br>s s     | n 0,1536<br>s s     | n 0,2853<br>s s     |
|                          |                          |            |                     |                     |                     |                     |
|                          |                          |            |                     |                     |                     |                     |

#### Dynamics of total soluble solids during cocoa fermentation

Soluble solids were those with the greatest progressive decrease during cocoa fermentation, as seen in Table 5. On day 0, the values ranged between 20.56 and 20.66 °Brix, with no difference attributable to *Saccharomyces cerevisiae* ( $p = 0.9664$ ), the type of fruit extract ( $p = 0.8011$ ) or the interaction between both factors ( $p = 0.8815$ ), which shows homogeneous initial conditions between the treatments.

From day 1 onwards, a general reduction in soluble solids was observed, accompanied by a significant effect of *S. cerevisiae* ( $p < 0.0001$ ). At this time, the values were between 18.15 and 19.40 °Brix, while the effect of the fruit extract was not significant ( $p = 0.5641$ ). On day 2, soluble solids decreased to a range of 14.39 to 16.81 °Brix, with significant effects of both *S. cerevisiae* ( $p < 0.0001$ ) and the type of extract ( $p = 0.0004$ ) being recorded. This behavior was maintained during days 3 and 4, in which both factors presented completely significant effects ( $p < 0.0001$ ).

At the end of the evaluation, the values ranged between 7.93 and 11.78 °Brix. The treatment with 1% *S. cerevisiae* and papaya extract presented the lowest numerical

value on day 4 (7.93 °Brix), followed by the treatments with 1% *S. cerevisiae* without extract (8.64 °Brix). However, the treatment without *S. cerevisiae* and without extract retained the highest content of soluble solids at the end of the process (11.78 °Brix).

The *S. cerevisiae* x extract interaction was not significant on any of the days evaluated ( $p = 0.8815$ ;  $0.0717$ ;  $0.1257$ ;  $0.3926$  and  $0.3668$  for days 0, 2, 3 and 4). Therefore, the results show a sustained reduction in soluble solids during fermentation, with a significant effect of *S. cerevisiae* during day 1 and the type of fruit extract from day 2 onwards, with no evidence of significant interaction between both factors.

**Table 5. Effect of *Saccharomyces cerevisiae* and fruit extracts on the dynamics of total soluble solids (°Brix) during cocoa fermentation.**

| Factor                   |                          | Variable   |                |                |                |                |
|--------------------------|--------------------------|------------|----------------|----------------|----------------|----------------|
| Saccharomyces Cerevisiae | Fruit Extract            | Brix-day 0 | Brix-day 1     | Brix-day 2     | Brix-day 3     | Brix-day 4     |
| 0                        | Without fruit extract    | 20,60      | 19,24          | 16,81          | 13,92          | 11,78          |
|                          | Papaya                   | 20,66      | 19,40          | 16,74          | 13,55          | 11,34          |
|                          | Soursop                  | 20,56      | 19,22          | 16,79          | 13,84          | 11,53          |
| 0,5                      | Without fruit extract    | 20,63      | 18,76          | 15,69          | 12,39          | 9,84           |
|                          | Papaya                   | 20,60      | 18,61          | 15,27          | 11,91          | 9,33           |
|                          | Soursop                  | 20,63      | 18,75          | 15,49          | 12,16          | 9,54           |
| 1                        | Without fruit extract    | 20,57      | 18,34          | 14,84          | 11,33          | 8,64           |
|                          | Papaya                   | 20,64      | 18,15          | 14,39          | 10,74          | 7,93           |
|                          | Soursop                  | 20,61      | 18,29          | 14,56          | 10,95          | 8,15           |
| EEM ±                    |                          | 0,07       | 0,07           | 0,08           | 0,08           | 0,07           |
| CV                       |                          | 0,58       | 0,63           | 0,85           | 1,06           | 1,29           |
| Probability              | Saccharomyces Cerevisiae | 0,9664     | n <0,000 s 1 * | n <0,000 s 1 * | n <0,000 s 1 * | n <0,000 s 1 * |
|                          | Extract                  | 0,8011     | n 0,5641 s     | n 0,0004 s     | n <0,000 s 1 * | n <0,000 s 1 * |
|                          | S.Cerevisiae x Extract   | 0,8815     | n 0,0717 s     | n 0,1257 s     | n 0,3926 s     | n 0,3668 s     |
|                          |                          |            |                |                |                |                |
|                          |                          |            |                |                |                |                |

### pH dynamics during cocoa fermentation

The pH of the cocoa mass showed a gradual increase during the fermentation period, shown in Table 6. On day 0, the values ranged between 3.64 and 3.73. At this time, *Saccharomyces cerevisiae* did not show a significant effect on pH ( $p = 0.7209$ ), while the type of fruit extract presented a highly significant effect ( $p < 0.0001$ ). The *S. cerevisiae* x extract interaction was also not significant ( $p = 0.9131$ ).

From day 1 onwards, pH increased in all treatments and a significant effect of *S. cerevisiae* was observed ( $p = 0.0008$ ), while the effect of fruit extract remained highly

significant ( $p < 0.0001$ ). The values recorded on this day were between 3.70 and 3.83. The upward trend continued during days 2 and 3, when the pH reached ranges of 3.82 – 4.02 and 3.97 – 4.26, respectively. At both times, both *S. cerevisiae* and the type of extract presented highly significant effects ( $p < 0.0001$ ).

At the end of the evaluation, the pH reached values between 4.14 and 4.49. Among the experimental combinations, treatment with 1% *S. cerevisiae* and papaya extract recorded the highest numerical value (4.49), followed by 1% *S. cerevisiae* with soursop extract (4.42) and 0.5% *S. cerevisiae* with papaya extract (4.40). On the contrary, the treatments without *S. cerevisiae* and without extract, and without *S. cerevisiae* with soursop extract, presented the lowest numerical values on day 4 (4.14 in both cases). At this last moment, both *S. cerevisiae* and the type of extract maintained highly significant effects on pH ( $p < 0.0001$ ).

The *S. cerevisiae* x extract interaction was not significant on any of the days evaluated ( $p = 0.9131$ ; 0.8731; 0.8829; 0.6970 and 0.4729 for days 0, 1, 2, 3 and 4). Therefore, under the experimental conditions evaluated, no statistical evidence of interaction between both factors on pH was found. Altogether, the results show an upward evolution of pH during fermentation, with a significant effect of the type of fruit extract from day 1 and of *S. cerevisiae* from day 1.

**Table 6. Effect of *Saccharomyces cerevisiae* and fruit extracts on the pH dynamics during cocoa fermentation.**

| Factor                   |                          | Variable |            |          |          |          |
|--------------------------|--------------------------|----------|------------|----------|----------|----------|
| Saccharomyces Cerevisiae | Fruit Extract            | pH-day 0 | pH-day 1   | pH-day 2 | pH-day 3 | pH-day 4 |
|                          | Without fruit extract    |          |            |          |          |          |
| 0                        |                          | 3,70     | 3,76       | 3,87     | 4,00     | 4,14     |
| 0                        | Papaya                   | 3,73     | 3,80       | 3,92     | 4,08     | 4,23     |
| 0                        | Soursop                  | 3,64     | 3,70       | 3,82     | 3,97     | 4,14     |
|                          | Without fruit extract    |          |            |          |          |          |
| 0,5                      |                          | 3,70     | 3,78       | 3,92     | 4,11     | 4,29     |
| 0,5                      | Papaya                   | 3,73     | 3,82       | 3,99     | 4,20     | 4,40     |
| 0,5                      | Soursop                  | 3,65     | 3,73       | 3,89     | 4,09     | 4,31     |
|                          | Without fruit extract    |          |            |          |          |          |
| 1                        |                          | 3,69     | 3,79       | 3,96     | 4,17     | 4,38     |
| 1                        | Papaya                   | 3,72     | 3,83       | 4,02     | 4,26     | 4,49     |
| 1                        | Soursop                  | 3,64     | 3,74       | 3,93     | 4,17     | 4,42     |
|                          | EEM ±                    | 0,01     | 0,01       | 0,01     | 0,01     | 0,01     |
|                          | CV                       | 0,41     | 0,40       | 0,50     | 0,50     | 0,48     |
| Probability              | Saccharomyces Cerevisiae | 0,7209   | n s 0,0008 | <0,001   | <0,001   | <0,001   |
|                          | Extract                  | <0,001   | <0,001     | <0,001   | <0,001   | <0,001   |

|                       |       |   |        |   |       |   |       |   |       |   |
|-----------------------|-------|---|--------|---|-------|---|-------|---|-------|---|
| <b>S.Cerevisiae x</b> | 0,913 | n |        | n | 0,882 | n | 0,697 | n | 0,472 | n |
| <b>Extract</b>        | 1     | s | 0,8731 | s | 9     | s | 0     | s | 9     | s |

### Physical and fermentative quality of cocoa beans

The physical and fermentation quality of cocoa beans was mainly influenced by the individual effects of *Saccharomyces cerevisiae* and fruit extract (Table 7). The analysis of variance revealed a highly significant effect of *S. cerevisiae* on dry weight, percentage of cotyledons, seed index, fermented, violet and slate-colored grains, as well as on moisture content ( $p < 0.0001$ ). The pod index was the only variable that did not show significant differences with respect to this factor ( $p = 0.5264$ ).

The type of fruit extract also significantly influenced most of the variables. Differences were observed in dry weight ( $p = 0.0012$ ) and highly significant effects on percentage of cotyledons, seed index, fermented grains, purple grains and moisture content ( $p < 0.0001$ ). Similarly, the percentage of slate gray kernels showed significant differences ( $p = 0.0004$ ), while the cob index was not affected by the extract ( $p = 0.3540$ ).

Among the treatments evaluated, the incorporation of 1% of *Saccharomyces cerevisiae* resulted in the highest percentages of fermented grains, with values of 85.00%, 92.00% and 90.00% for the treatments without extract, with papaya and with soursop, respectively. This response was accompanied by a reduction in the percentage of purple beans, which decreased to 13.00%, 7.00% and 8.33%, respectively. A similar trend was observed for slate gray grains, which reached 2.00%, 1.00%, and 1.67% under the same conditions. In particular, treatment with 1% *Saccharomyces cerevisiae* gave the best results. The treatment that combined *Saccharomyces cerevisiae* and papaya extract presented the most favorable technological profile, with the highest percentages of fermented grains (92.00%), cotyledons (88.97%) and seed index (1.71), as well as the lowest percentages of purple (7.00%) and slate gray (1.00%) grains. Furthermore, this treatment had a water content of 6.13%, lower than the 6.90% recorded for the treatment without *Saccharomyces cerevisiae* or extract.

In contrast, the treatment without *Saccharomyces cerevisiae* or extract showed the lowest percentage of fermented grains (68.33%) and the highest proportions of purple (26.00%) and slate gray (5.67%) grains. In general, by increasing the concentration of *Saccharomyces cerevisiae*, better performance was observed. The presence of *Saccharomyces cerevisiae* was associated with a progressive increase in the percentage of fermented grains and a decrease in purple and slate gray grains.

Despite these differences between treatments, no significant interaction was observed between *Saccharomyces cerevisiae* and the fruit extract for any of the variables studied ( $p > 0.05$ ). Interaction probability values were 0.9072 for dry weight, 0.4435 for cotyledons, 0.9674 for seed index, 0.3412 for fermented kernels, 0.1157 for purple kernels, 0.6674 for slate gray kernels, 0.7640 for ear index, and 0.3054 for moisture. For all these reasons, the observed difference was mainly attributed to the individual effects of the factors tested with the absence of statistical evidence of interactions between them. The variation coefficients showed a low behavior in the vast majority of the

variables, obtaining 0.66% in the dry weight, 0.30% in the cotyledons, 0.92% in the seed index, 1.58% in the fermented grains, 0.69% in the spike index and 0.64% in humidity, the highest being those that belonged to the purple (6.07%) and slate gray grains. (14.34%).

***Table 7. Effect of *Saccaromyces cerevisiae* and fruit extracts on the physical characteristics and fermentative quality of cocoa beans (*Theobroma cacao* L.)***

| Factor                   |                          | Variable       |               |            |               |             |            |           |              |
|--------------------------|--------------------------|----------------|---------------|------------|---------------|-------------|------------|-----------|--------------|
| Saccharomyces Cerevisiae | Fruit Extract            | Dry Weight (g) | Cotyledon (%) | Seed index | Fermented (%) | Violets (%) | Slates (%) | Pod index | Moisture (%) |
| 0                        | Without fruit            |                |               |            |               |             |            |           |              |
|                          | extract                  | 552,47         | 85,72         | 1,62       | 68,33         | 26,00       | 5,67       | 24,99     | 6,90         |
|                          | Papaya                   | 546,53         | 86,45         | 1,66       | 72,33         | 23,00       | 4,67       | 24,99     | 6,72         |
|                          | Soursop                  | 551,12         | 86,07         | 1,65       | 71,00         | 24,33       | 4,67       | 52,20     | 6,69         |
|                          | Without fruit            |                |               |            |               |             |            |           |              |
|                          | extract                  | 549,40         | 86,98         | 1,65       | 77,33         | 19,67       | 3,00       | 25,00     | 6,60         |
|                          | Papaya                   | 539,95         | 88,19         | 1,69       | 82,33         | 15,67       | 2,00       | 24,91     | 6,40         |
|                          | Soursop                  | 544,71         | 87,58         | 1,67       | 81,00         | 16,67       | 2,33       | 24,99     | 6,44         |
|                          | Without fruit            |                |               |            |               |             |            |           |              |
| 1                        | extract                  | 542,88         | 87,81         | 1,66       | 85,00         | 13,00       | 2,00       | 25,06     | 6,31         |
|                          | Papaya                   | 535,67         | 88,97         | 1,71       | 92,00         | 7,00        | 1,00       | 24,94     | 6,13         |
|                          | Soursop                  | 539,32         | 88,61         | 1,69       | 90,00         | 8,33        | 1,67       | 25,02     | 6,18         |
| EEM ±                    |                          | 2,08           | 0,15          | 0,01       | 0,73          | 0,60        | 0,25       | 0,10      | 0,02         |
| CV                       |                          | 0,66           | 0,30          | 0,92       | 1,58          | 6,07        | 14,34      | 0,69      | 0,64         |
| Probability              | Saccharomyces Cerevisiae | <0,0001        | *             | <0,0001    | *             | <0,0001     | *          | <0,0001   | *            |
|                          | Extract                  | 0,0012         | *             | <0,0001    | *             | <0,0001     | *          | 0,0004    | *            |
|                          | S.Cerevisiae x Extract   | 0,9072         | n             | 0,4435     | n             | 0,9674      | n          | 0,6674    | n            |
|                          |                          |                | s             |            | s             |             | s          |           | s            |

### Physicochemical characteristics of cocoa paste

Physicochemical characteristics of cocoa paste presented variations associated with the factors evaluated as It is seen in Table 8. The type of fruit extract had a highly significant effect on the pH, acidity, humidity and ash content ( $p < 0.0001$ ). On the other hand, *Saccharomyces cerevisiae* did not show significant effects on pH ( $p = 0.2657$ ), acidity ( $p = 0.4258$ ) or ash ( $p = 0.7568$ ), although it did present a significant effect on humidity ( $p = 0.0353$ ).

The pH of the paste was between 5.87 and 6.47. The numerically highest values corresponded to the treatments with papaya extracts, with a record of 6.44; 6.46 and 6.47 for 0.5 or 1% *S. cerevisiae*, respectively. On the contrary, the pastas from the treatments without extract presented values between 5.87 and 5.88. The acidity ranged between 0.57 and 0.88%, with the lowest numerical value observed in the treatment with 1% *S. cerevisiae* and papaya extract (0.57%) while the treatments without extracts recorded the highest values, between 0.87 and 0.88%.

Humidity presented values between 3.36 and 4.02%. The lowest numerical record turned out to be 1% of *S. cerevisiae*. The assembly of *S. cerevisiae* and papaya extract (3.36%), and the treatments of 0.5 and 0% of *S. cerevisiae* linked in isolation with papaya (3.38 and 3.42% respectively) presented a balanced development between these interactions. However, treatments without extract showed values between 3.99 and 4.02%. The statistical analysis confirmed significant effects of both *S. cerevisiae* ( $p = 0.0353$ ) and the type of fruit extract ( $p < 0.0001$ ) on this variable.

The ash content showed a narrower variation, with values between 2.99 and 3.14%. The highest numerical records were observed in the pastas from the treatments with soursop extract (3.12 - 3.14%), while the combinations with papaya extract presented the lowest values (2.99 - 3.01%). For this variable, the type of extract exerted a highly significant effect ( $p < 0.0001$ ), while *S. cerevisiae* did not show a significant effect ( $p = 0.7568$ ).

No significant interaction was detected between *S. cerevisiae* and the type of extract for any of the physicochemical properties analyzed: pH ( $p = 0.8336$ ), acidity ( $p = 0.7878$ ), humidity ( $p = 0.9940$ ) and ash ( $p = 0.9784$ ). Together, these results show that the type of fruit extract had a significant effect on the four physicochemical characteristics evaluated in the cocoa paste, while the effect of *S. cerevisiae* was statistically limited to humidity. The absence of significant interaction indicates that, under the conditions of the study, no statistical dependence was detected between both factors for the variables analyzed.

**Table 8. Effect of *Saccharomyces cerevisiae* and fruit extracts on the physicochemical characteristics of cocoa paste.**

| Factor                          |                                 | Variable                   |                       |                       |                       |
|---------------------------------|---------------------------------|----------------------------|-----------------------|-----------------------|-----------------------|
| <i>Saccharomyces Cerevisiae</i> | Fruit Extract                   | pH                         | Acidity (%)           | Moisture (%)          | Ash (%)               |
|                                 | Without fruit                   |                            |                       |                       |                       |
| 0                               | extract                         | 5,87                       | 0,88                  | 4,02                  | 3,02                  |
| 0                               | Papaya                          | 6,44                       | 0,59                  | 3,42                  | 2,99                  |
| 0                               | Soursop                         | 6,30                       | 0,64                  | 3,47                  | 3,12                  |
|                                 | Without fruit                   |                            |                       |                       |                       |
| 0,5                             | extract                         | 5,88                       | 0,87                  | 4,00                  | 3,01                  |
| 0,5                             | Papaya                          | 6,46                       | 0,58                  | 3,38                  | 3,00                  |
| 0,5                             | Soursop                         | 6,32                       | 0,63                  | 3,43                  | 3,13                  |
|                                 | Without fruit                   |                            |                       |                       |                       |
| 1                               | extract                         | 5,87                       | 0,88                  | 3,99                  | 3,02                  |
| 1                               | Papaya                          | 6,47                       | 0,57                  | 3,36                  | 3,01                  |
| 1                               | Soursop                         | 6,33                       | 0,62                  | 3,41                  | 3,14                  |
|                                 | EEM ±                           | 0,02                       | 0,01                  | 0,02                  | 0,02                  |
|                                 | CV                              | 0,47                       | 2,97                  | 1,00                  | 1,03                  |
| Probability                     | <i>Saccharomyces Cerevisiae</i> | n<br>0,2657<br>s<br><0,000 | n<br>0,4258<br>s<br>* | n<br>0,0353<br>s<br>* | n<br>0,7568<br>s<br>* |
|                                 | Excerpt                         | 1<br>*                     | <0,0001<br>*          | <0,0001<br>*          | 1<br>*                |
|                                 | <i>S.Cerevisiae</i> x           | n                          | n                     | n                     | n                     |
|                                 | Extract                         | 0,8336<br>s                | 0,7878<br>s           | 0,9940<br>s           | 0,9784<br>s           |
|                                 |                                 |                            |                       |                       |                       |

### Sensory profile of the cocoa paste

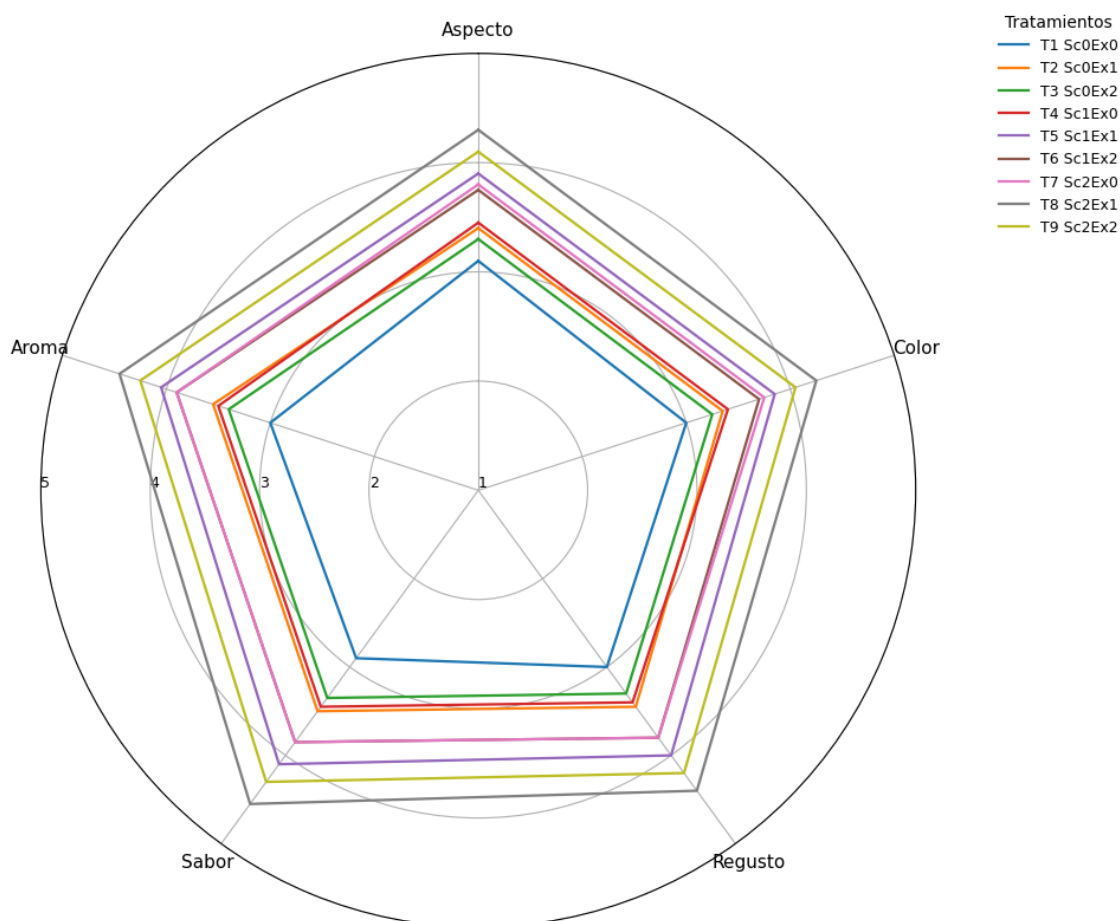
The sensory analysis allowed us to characterize the descriptive profile of the cocoa paste corresponding to the nine experimental treatments as evidenced in Figure 3. The joint representation of the attributes color, appearance, aroma, flavor and aftertaste showed variations in the configuration of the profiles between the different combinations of *Saccharomyces cerevisiae* and fruit extracts.

In the representation obtained, a progressive differentiation was observed between the treatments, particularly in those corresponding to the highest level of application of *S. cerevisiae*. Treatments T8 (Sc2Ex1: 1% *S. cerevisiae* + papaya extract) and T9 (Sc2Ex2: 1% *S. cerevisiae* + soursop extract) presented more external profiles for the set of attributes represented, while T7 (Sc2Ex0: 1% *S. cerevisiae* without extract) showed an intermediate configuration. Similarly. Within the 0.5% yeast level, differences were observed between T4, T5 and T6, reflecting descriptive variations associated with the different experimental combinations.

On the other hand, T1 (Sc0Ex0: without *S. cerevisiae* and fruit extract) presented a comparatively more internal and homogeneous profile. However, the relative position of the treatments. The scores represent descriptive sensory categories and not

increasing levels of acceptability; Therefore, a greater extension of the polygon does not necessarily imply better quality or sensory preferences. For example, increasing scores in flavor approach the descriptor “very bitter,” while in appearance they correspond progressively to greater opacity.

Altogether, the radar diagram allows us to visualize the differentiation of the sensory profile of the cocoa paste between the nine experimental combinations and facilitates the identification of simultaneous changes in the evaluated attributes.



**Figure 3.** Sensory profile of cocoa paste obtained using different combinations of *Saccharomyces cerevisiae* and fruit extracts.

## DISCUSSION

The observed evolution is consistent with the microbial succession typical of cocoa fermentation. During the early stages, *Saccharomyces cerevisiae* actively participates in the consumption of sugars from mucilage and in the production of ethanol. Subsequently, greater aeration favors acetic acid bacteria, whose oxidations of ethanol generate heat and lead to an increase in the temperature of the dough. This behavior has been described by De Vuyst and Leroy et al. point out that this metabolic transition normally leads from initial conditions close to ambient temperature to values typical of an active fermentation, where the oxidation of ethanol and subsequent overoxidation of organic acid contribute decisively to the generation of heat.(13)

The observed influence of *S. cerevisiae* on the thermal behavior from the first active stages of fermentation finds support in studies that show that the temperature level is closely related to the performance of this yeast, the influence of this yeast observed from the first day also coincides with Kouamé et al. , using a predictive model developed specifically for the alcoholic fermentation of cocoa, precisely identified the initial concentration of the inoculum and the thermal evaluation as determining variables of the growth of *S. cerevisiae*. This relationship allows us to interpret that a greater initial presence of yeast can favor a faster colonization of the mucilage and a more efficient transformation of the available carbohydrates, generating favorable metabolic conditions for the continuity of microbial succession. However, one should avoid attributing the thermal increase exclusively to *S. cerevisiae*, because the more pronounced increase in temperature is subsequently associated with oxidative metabolism of acetic acid bacteria.(27)

Comparable results were reported by Streule et al. in Ecuadorian cocoa fermentations, where an adequate temperature progression was associated with more complete fermentation processes. Similarly, Gutiérrez et al. indicate that the aerobic stage can raise the temperature of the dough to approximately 40-52 °C, a range related to the activity of acetic acid bacteria and the internal biochemical transformations of the cotyledon.(28)(29)

The lack of significant interactions between *S. cerevisiae* and extracts suggests that *S. cerevisiae* and papaya acted independently on temperature, avoiding demonstrating a synergistic effect not confirmed statistically. Diaz et al. They also showed that the effect of a starter culture depends on its implantation capacity and the particular conditions of the process, so the fermentative response does not always result from additive interactions between the evaluated components.(30)

Overall, the thermal response obtained is compatible with active fermentation and functional microbial succession. The role of *S. cerevisiae* seems to be mainly related to the initial stages, while the subsequent increase in temperature is associated with the oxidative metabolism of acetic acid bacteria.

Concordantly, Plua et al. observed that the directed fermentation of Nacional and CCN-51 cocoa with *Weissella confusa* and *Lactiplantibacillus plantarum* was accompanied by

a progressive increase in temperature, associated with the metabolic activity developed during the process. The authors highlight that thermal evolution constitutes a relevant indicator of fermentative progress, due to its relationship with the transformation of mucilage substrates and the succession of microbial groups. This evidence supports the importance of microbiological control of fermentation and suggests that the use of selected cultures can contribute to more uniform dynamics; However, the magnitude of the response also depends on the fermentation system and the conditions under which the process takes place.(20)

The progressive reduction of soluble solids is consistent with the use of mucilage carbohydrates as a substrate for microbial metabolism. Viesser et al. demonstrated that glucose and fructose constitute the main fermentable sugars of cocoa pulp, observing a preferential consumption of glucose during the first 48-72 hours. This behavior allows the loss of soluble solids to be related to the advancement of the fermentation phase and the transformation of available sugars.(31)

The participation of *S. cerevisiae* is particularly important in this dynamic. What is indicated by Muñoz and De Vuyst et al. It agrees with the functioning of yeasts that used as starter cultures affect the utilization of carbohydrates in the pulp, as well as the production of ethanol and compounds involved in aroma. Consequently, a more intense reduction of soluble solids in inoculated fermentations may reflect greater metabolic activity on the available substrates.(32)

This interpretation also coincides with recent research on controlled fermentation. A 2025 study with different strains of *S. cerevisiae* showed a progressive decrease in °Brix during cocoa fermentation and a higher residual concentration of soluble solids in natural fermentation compared to inoculated treatments. This supports the use of °Brix as a complementary indicator of the use of substrates during fermentation.

On the other hand, the incorporation of fruit matrices can modify the composition of the fermentation medium. Vizcaino et al. By replacing cocoa mucilage with fruit pulps in unconventional fermentations, they verified important transformations in sugars and organic acids as the process progressed. This suggests that fruit extracts can alter the availability of substrates for the microbiota; However, its specific contribution must be confirmed by the individual quantification of glucose, fructose, sucrose, ethanol, organic acid, given that °Brix represents the set of soluble solids or exclusively sugars.(33)

The ascending evaluation of pH can be related to the transformations of the organic acids present in the mucilage and to the microbial succession during fermentation. Diaz et al. point out that the consumption of citrate, mainly associated with the activity of lactic acid bacteria, progressively reduces the initial acidity of the pulp and modifies the conditions for the establishment of the microorganisms that participate in later stages.(18)

This trend has also been observed experimentally. In controlled cocoa fermentations, initial values close to pH 3.5 and final values around 4.0 – 4.3 have been reported, attributed to the microbial transformation of citrate and carbohydrates present in the

pulp. Likewise, recent research with *S. cerevisiae* as a starter culture shows that the pH can fluctuate during the process and subsequently increase, confirming its behavior depends on the metabolic activity and the fermentation stage.(34)(35)

The effect of fruit extracts may be associated with differences in their composition of sugars and organic acids. Vizcaino et al. , by replacing cocoa mucilage with fruit pulps, verified changes in pH, titratable acidity and concentrations of citric, lactic and acetic acid during fermentation. These antecedents support that the incorporation of fruit matrices can modify the chemical environment of the fermentative mass; However, the specific mechanism will depend on the composition of each extract.(36)

The physical quality of the grain is closely related to the efficiency of fermentation, particularly with internal transformations of the cotyledon and the reduction of defects associated with incomplete fermentation. Ecuadorian National cocoa, Falconí et al. demonstrated that the use of a native microbial cocktail as a starter culture favored the development of the fermentative process compared to conventional fermentation. This background supports the use of selected microorganisms as a strategy to improve the uniformity and quality of cocoa processing.(10)

The participation of *Saccharomyces cerevisiae* is particularly relevant due to its ability to establish during the first stages of fermentation and transform the available substrates into mucilage. Diaz et al. verified that fermentations inoculated with *S. cerevisiae* led to a more advanced process than those inoculated with *Hanseniaspora opuntiae*, in addition to generating richer and more reproducible aromatic profiles. This supports the potential of *S. cerevisiae* as a starter culture to promote a more consistent transformation of the grain.(30)

The decrease in violet grains takes on special importance, because their presence is associated with an incomplete transformation of the cotyledon. Vizcaino et al. , in unconventional fermentations of CCN-51 cocoa with replacement of mucilage by fruit pulps, obtained more than 81% of fermented beans and less than 18.4% of violet beans after five to six days. The methodological proximity of this study is particularly relevant, since it demonstrates that the modification of the fermentative matrix using fruit pulps can be accompanied by favorable changes in the quality determined by cutting test.(37)

The absence of interaction between *S. cerevisiae* and fruit extracts indicates that there is no statistical evidence to suggest a synergistic effect between both factors. Their contributions on physical characteristics and fermentative quality must be interpreted independently. In applied terms, the available evidence supports the use of starter cultures to promote a more uniform fermentation, while the use of fruit matrices constitutes a promising alternative to modulate the process and deserves a more in-depth microbiological and metabolic characterization.

The physicochemical variations of cocoa paste reflect that the changes induced during fermentation and drying are subsequently maintained in the processed product. In this sense, pH and acidity are particularly sensitive to the accumulation and diffusion of organic acids during fermentation. Various studies have shown that the acidification of

the cotyledon depends mainly on the penetration of acetic and lactic acid, which subsequently affects the cocoa liquor or paste and can modify its sensory quality.(38)

The influence of the type of extract on pH and acidity can be related to the composition of each plant matrix. Fruit extracts add sugars and organic acids which would modify the conditions of the mucilage and therefore the metabolic trajectories during fermentation, while this adjusts to what was found in previous works where the addition or substitution of matrices rich in carbohydrates modified the metabolism of sugars and organic acids in the fermentation of cocoa, later finding differences in the chemical nature of the product. However, establishing which compounds were responsible for these variations would require individually quantifying citric, lactic and acetic acid.

Humidity constitutes another parameter of technological interest, since it is related to the stability of the raw material and subsequent transformation operations. In studies carried out with fermented cocoa, the moisture content showed variations attributable to both the fermentation process and drying, while reduced contents favored greater stability during storage. Similarly, recent research with induced fermentations has highlighted that post-harvest handling determines water retention and the final composition of processed cocoa.(39)

For its part, the differences in ash can be linked mainly to the mineral composition of the raw material and the added matrices. Unlike pH or acidity, this variable does not directly depend on the fermentative activity, because it represents the residual inorganic fraction of the product. Studies on fermentation dynamics have shown that ash content can vary between processing conditions and cocoa materials, although these changes are usually less pronounced than those observed in humidity or acidity.(11)

The absence of interaction between *Saccharomyces cerevisiae* and the fruit extracts indicates that there is no evidence of a synergistic effect on the physicochemical properties of the paste. Therefore, the influence of both factors must be interpreted independently. Overall, the literature supports that the physicochemical composition of cocoa paste constitutes the cumulative result of fermentation, drying and the nature of the raw material, with the balance between pH and acidity being particularly important due to its subsequent relationship with the technological and sensory quality of cocoa.

The differences observed between the sensory profiles confirm that fermentation conditions can modify the perceptible characteristics of the cocoa paste. The activity of yeast plays an important role in this process, due to its participation in the formation of alcohols, esters and other metabolites that subsequently contribute to aroma and flavor. In this sense, Díaz et al. demonstrated that the use of *Saccharomyces cerevisiae* as a starter culture produced richer and more reproducible aromatic profiles of cocoa and chocolate liquor than other fermentative conditions, associated with differences in the composition of the volatile organic compound.(30)

The influence of yeasts on the sensory profile also depends on their metabolic capacity. Chagas et al. , when evaluating indigenous yeasts from cocoa fermentations, identified

sensory differences linked to the production of compounds such as ethyl acetate, isoamyl acetate and 2-phenylethyl acetate, related to fruity and floral notes. This shows that the selection of the starter microorganism can qualitatively modify the aromatic profile developed during fermentation.(40)

In Ecuadorian National cocoa Streule et al. They also verified the fermentation and drying conditions have a direct impact on the sensory profile of the liquor. Insufficient fermentations were associated with bitter, astringent, woody and earthy attributes, confirming that postharvest handling conditions the sensory expression of the final product.(28)

## CONCLUSIONS

The application of *Saccharomyces cerevisiae* and extract of papaya (*Carica papaya* L.) and soursop (*Annona muricata* L.) allowed modifying the conditions of the postharvest fermentation of cocoa, showing variations in temperature, pH and soluble solids. The results obtained presented a greater guarantee of fermentative development given the more transformative character that the almonds showed and demonstrated the potential of directed fermentation as an alternative to have a more controlled and uniform postharvest process.

The treatments influenced the fermentative quality of the grain and the physicochemical characteristics of the cocoa paste. Among the combinations evaluated, the treatment consisting of 1% of *S. cerevisiae* and papaya extract presented the most favorable technological behavior, with 92% of fermented grains, 7% of violet grains and 1% of slate grains, in addition to a paste characterized by lower acidity and humidity. These results allow us to consider this combination as the one with the greatest potential to optimize postharvest quality within the experimental conditions studied.

The different fermentation conditions generated variations in the sensory attributes of the cocoa paste, confirming that fermentative management has an impact on the perceptible characteristics of the final product. However, the absence of a statistically significant interaction between *S. cerevisiae* and fruit extracts indicates that a synergistic effect between both factors was not proven, so their effects must be interpreted mainly independently.

The results support the potential of *S. cerevisiae* and, particularly, papaya extract as a tool to guide biotechnological strategies aimed at improving the fermentation and quality of cocoa.

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## DECLARATION OF INTEREST (OPTIONAL)

The authors declare that they have no personal or conflicts of interest that could have influenced the development, analysis, interpretation or publication of the results of this research.

## AUTHOR CONTRIBUTIONS (OPTIONAL)

Luis Humberto Vásquez Cortez and Sanyi Lorena Rodríguez Cevallos: conceptualization, research design, methodology, experimental development, conceptualization, research design, methodology, experimental development of treatments, data collection and processing, statistical analysis, interpretation of results, completed research, generation of figures, tables, writing of the original draft, review and editing of the manuscript. José Francisco Falconi Novillo: methodology, supervision, critical review and approval of the final version of the manuscript. All authors read and approved the final version of the article.

## REFERENCES

1. Vásquez V, Rosales T. El origen de la domesticación de *Theobroma cacao* "cacao": la evidencia de la Amazonía-Revisión. *Revista ARCHAEOBIOS* No [Internet]. 2025 [cited 2026 May 16];2(20):39–50. Available from: <https://dialnet.unirioja.es/servlet/articulo?codigo=10513204>
2. Subroto E, Djali M, Indiarto R, Lembong E, Baiti N. Microbiological activity affects post-harvest quality of cocoa (*Theobroma cacao* L.) beans. *Horticulturae*. 2023;9(7):1–25. doi:10.3390/horticulturae9070805
3. Santander M, Vaillant F, Sinuco D, Rodríguez J, Escobar S. Enhancement of fine flavour cocoa attributes under a controlled postharvest process. *Food Research International*. 2021 May;143(110236). doi:10.1016/j.foodres.2021.110236
4. Vásquez. Luis, Rodríguez S, Cadena L, Plua J. Aroma, Ciencia y Tradición: Nuevas fronteras en la fermentación del cacao [Internet]. 1st ed. Rodríguez S, editor. Manabí: GESICAP; 2025 [cited 2026 May 13]. 1–126 p. Available from: <https://edicionesgesicap.com/index.php/gesicap/catalog/book/47>
5. Campos S, Martínez W, Anacleto G, Ocán D, dos Santos G, Rosas F, et al. The Role of microbial Dynamics, Sensorial compounds, and producing regions in cocoa fermentation. *Microbiology Research*. 2025. p. 1–34. doi:10.3390/microbiolres16040075
6. Vizcaino C, Guajardo D, Caroca R, Serna SO, Briones M, Lazo M. Non-conventional fermentation at laboratory scale of cocoa beans: Using probiotic microorganisms and substitution of mucilage by fruit pulps. *Int J Food Sci Technol*. 2022;57(7):4307–15. doi:10.1111/ijfs.15757
7. Balcázar C, Fernández E, Lopes A, Ferreira N, Chagas G, Yoplac I, et al. Amino acid profile behavior during the fermentation of Criollo cocoa beans. *Food Chem X*. 2024 Jun;22(101486). doi:10.1016/j.fochx.2024.101486

8. Quintana L, García A, Rodríguez A, Hoyos N, Alvis A. Impact of spontaneous fermentation on the physicochemical and sensory qualities of Cacao. Fermentation. 2025;11(7):1–9. doi:10.3390/fermentation11070377
9. Vásquez L, Montoya E, Cadenas Morales LI, Plua J, Camacho C, Cobos F, et al. Physical, chemical and sensory evaluation of cocoa (*Theobroma cacao* L.) CCN51 fermented with *Saccharomyces cerevisiae* and fruit extract (Manila mango) at different stages of ripeness. Nutricion Clinica y Dietetica Hospitalaria. 2025 Aug;45(3):117–28. doi:10.12873/453vasquez
10. Falconí C, Yáñez V, Haro R, Claudio D. Inoculum of a Native Microbial Starter Cocktail to Optimize Fine-Aroma Cocoa (*Theobroma cacao*) Bean Fermentation. Agronomy. 2023;13(10):1–16. doi:10.3390/agronomy13102572
11. Vásquez L, Rodríguez S, Clavijo S, Carrillo M, Maddela N, Radice M, et al. Impact of Microbial Inoculants and Fruit Extracts on Cadmium Reduction and Quality Parameters in Cocoa (*Theobroma cacao* L.): From Beans to Cocoa Paste. Processes. 2026;14(9):1–26. doi:10.3390/pr14091348
12. Vásquez L, Vásquez K, Intriago F, Chang J, Maddela N, Prasad R. Banana and apple extracts with efficient microorganisms and their effect on cadmium reduction in cocoa beans (*Theobroma cacao* L.). Discover Food. 2024;4(163):1–13. doi:10.1007/s44187-024-00205-5
13. De Vuyst L, Leroy F. Functional role of yeasts, lactic acid bacteria and acetic acid bacteria in cocoa fermentation processes. FEMS Microbiol Rev. 2020;44(4):432–53. doi:10.1093/femsre/fuaa014
14. Vásquez L, Cevallos C, Uvidia M, Segobia S, Plua J. Evaluation of fermentation methods for Nacional and CCN51 cacao introducing microorganisms in jute, rohan boxes for organoleptic improvement. Revista Luna Azul. 2025;(60):168–81. doi:10.17151/luaz.2025.60.10
15. Ayodipupo B, Ifeolu A, Otunba A, Ebenezer G, Babalola O, Nwufo C. Therapeutic benefits of *Carica papaya*: A review on its pharmacological activities and characterization of papain. Arabian Journal of Chemistry. 2024;17(1):105369. doi:10.1016/j.arabjc.2023.105369
16. Ibrahim N, Hidayat C, Utami T, Yanti R, Witasari L. Flavor precursor and volatile compounds formation of unfermented cocoa beans hydrolyzed by papain. Food Science and Technology. 2024;44:1–7. doi:10.5327/fst.00224%20
17. Intriago F, Cedeño J, Parraga C, Alvarado K, Vásquez L, Revilla K, et al. Induction of effective microorganisms (EM) in the fermenting mass of cocoa (*Theobroma cacao* L.) and their impact on physicochemical and antioxidant characteristics. Biotecnica. 2024;26:1–8. doi:10.18633/biotecnica.v26.2422
18. Díaz C, Vuyst L. Functional yeast starter cultures for cocoa fermentation. J Appl Microbiol. 2022 Jul;133(1):39–66. doi:10.1111/jam.15312
19. Morales W, Morante J, Herrera R, Ayuso M, Bernalte M. Effect of addition of yeasts and enzymes during fermentation on physicochemical quality of fine aroma cocoa beans. J Agric Food Res. 2024;16:1–11. doi:10.1016/j.jafr.2024.101126
20. Plua J, Vásquez L, Valenzuela J, Barragan R, Pérez S, Maddela N, et al. Effect of Lactic Acid Bacteria (*Weissella confusa* and *Lactiplantibacillus plantarum*) and Fermentation Type on the Quality of Nacional and CCN-51 Cocoa (*Theobroma cacao* L.). Appl Microbiol. 2026;6(8):97. doi:10.3390/applmicrobiol6080097

21. Vera J, Vásquez L, Alvarado K, Intriago F, Raju M, Radice M. Physical and Organoleptic Evaluation of 12 Cocoa Clones (*Theobroma Cacao* L.) of National Type, in Cocoa Liquor—a Study from Ecuador. In: Salgado J, Vega H, García G, Robles V, editors. Systems, Smart Technologies and Innovation for Society. Guayaquil: Springer Cham; 2024. p. 199–211. doi:10.1007/978-3-031-51982-6\_18
22. Vásquez L, Clavijo S, Carrillo M, Díaz E, Tacle P, Arias D. Effect of efficient microorganisms and fruit extracts on the organoleptic and chemical profile of CCN-51 cacao liquor during postharvest processing. *Nutricion Clinica y Dietetica Hospitalaria*. 2025;45(4):343–53. doi:10.12873/454vasquez-2
23. Vásquez L, Cevallos C, Uvidia M, Segobia S, Plua J. Evaluación de métodos fermentativos de cacao Nacional y CCN51 induciendo microorganismos en yute y cajas Rohan para mejora organoléptico. *Luna Azul*. 2025;(60):168–81. doi:10.17151/luaz.2025.60.10
24. Dzelagha B, Ngwa N, Nde D. A Review of Cocoa Drying Technologies and the Effect on Bean Quality Parameters. *Int J Food Sci*. 2020;2020:1–11. doi:10.1155/2020/8830127
25. Barreiro J, Sandoval A. Kinetics of moisture adsorption during simulated storage of whole dry cocoa beans at various relative humidities. *J Food Eng*. 2020;273:109869. doi:10.1016/j.jfoodeng.2019.109869
26. Streule S, Freimüller S, Chatelain K, Miescher S. Effect of pod storage and drying temperature on fermentation dynamics and final bean quality of cacao Nacional in Ecuador. *Foods*. 2024;13(10):1536. doi:10.3390/foods13101536
27. Kouamé C, Loiseau G, Grabulos J, Boulanger R, Mestres C. Development of a model for the alcoholic fermentation of cocoa beans by a *Saccharomyces cerevisiae* strain. *Int J Food Microbiol*. 2021;337:108917. doi:10.1016/j.ijfoodmicro.2020.108917
28. Streule S, Freimüller S, Galler M, Motzer D, Poulouse M, Miescher S. Variations in Ecuadorian cocoa fermentation and drying at two locations: Implications for quality and sensory. *Foods*. 2024;13(1):1–22. doi:10.3390/foods13010137
29. Gutiérrez H, Suárez M, Hernández Z, Castellanos O, Alonso R, Rayas P, et al. Yeasts as producers of flavor precursors during cocoa bean fermentation and their relevance as starter cultures: A review. *Fermentation*. 2022;8(7):1–18. doi:10.3390/fermentation8070331
30. Díaz C, Van D, Tuentner E, Lemarcq V, Van D, Soares J, et al. An in-depth multiphasic analysis of the chocolate production chain, from bean to bar, demonstrates the superiority of *Saccharomyces cerevisiae* over *Hanseniaspora opuntiae* as functional starter culture during cocoa fermentation. *Food Microbiol*. 2023 Feb;109:1–24. doi:10.1016/j.fm.2022.104115
31. Viesser J, de Melo G, de Carvalho D, Rogez H, Góes A, Azevedo V, et al. Co-culturing fructophilic lactic acid bacteria and yeast enhanced sugar metabolism and aroma formation during cocoa beans fermentation. *Int J Food Microbiol*. 2021;339:109015. doi:10.1016/j.ijfoodmicro.2020.109015
32. Díaz C, De Vuyst L. Functional yeast starter cultures for cocoa fermentation. *J Appl Microbiol*. 2022;133(1):39–66. doi:10.1111/jam.15312
33. Vizcaino C, Guajardo D, Caroca R, Serna S, Briones M, Lazo M. Non-conventional fermentation at laboratory scale of cocoa beans: Using probiotic microorganisms

- and substitution of mucilage by fruit pulps. *Int J Food Sci Technol.* 2022;57(7):4307–15. doi:10.1111/ijfs.15757
34. Settapramote N, Phungam N, Hunsakul K, Chuensun T, Yatale T, Kawee-ai A. Optimization of Cocoa Nibs Fermentation Using *Saccharomyces cerevisiae* Starter Cultures: Impact on Physicochemical Properties and Aroma Profile. *Trends in Sciences.* 2025;22(8):10201. doi:10.48048/tis.2025.10201
  35. Rojas K, Hernández C, Mencía A. Transformaciones bioquímicas del cacao (*Theobroma cacao* L.) durante un proceso de fermentación controlada [Internet]. Vol. 45. 2021;45(1):53–65. doi:10.15517/rac.v45i1.45694
  36. Vizcaino C, Guajardo D, Caroca R, Serna S, Briones M, Lazo M. Non-conventional fermentation at laboratory scale of cocoa beans: Using probiotic microorganisms and substitution of mucilage by fruit pulps. *Int J Food Sci Technol.* 2022;57(7):4307–15. doi:10.1111/ijfs.15757
  37. Vizcaino C, Guajardo D, Caroca R, Serna S, Briones M, Lazo M. Non-conventional fermentation at laboratory scale of cocoa beans: Using probiotic microorganisms and substitution of mucilage by fruit pulps. *Int J Food Sci Technol.* 2022;57(7):4307–15. doi:10.1111/ijfs.15757
  38. Ruiz F, Márquez F, García P, Carrera A, Ramírez C, Ocaranza E, et al. Physicochemical and biochemical changes in cocoa during the fermentation step. *Fermentation.* 2024 Aug;10(8):1–14. doi:10.3390/fermentation10080405
  39. Ramírez A, Gutiérrez G, Polonía P, López L, Suárez J. Fermentation and its effect on the physicochemical and sensory attributes of cocoa beans in the Colombian Amazon. *PLoS One.* 2024 Oct 1;19(10 October). doi:10.1371/journal.pone.0306680
  40. Mendoza M, Martínez O, Ardila M, Lizarazo P. Bioprospecting of indigenous yeasts involved in cocoa fermentation using sensory and chemical strategies for selecting a starter inoculum. *Food Microbiol.* 2022;101:103896. doi:10.1016/j.fm.2021.103896

# LA CONTABILIDAD SOCIAL COMO HERRAMIENTA ESTRATÉGICA PARA LA SOSTENIBILIDAD EN LAS EMPRESAS PESQUERAS DE MANTA, MANABÍ, ECUADOR

## SOCIAL ACCOUNTING AS A STRATEGIC TOOL FOR SUSTAINABILITY IN FISHING COMPANIES IN MANTA, MANABÍ, ECUADOR

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**RESUMEN:** La sostenibilidad empresarial constituye un imperativo para sectores de alto impacto ambiental como la pesca industrial, y en Manta, Manabí, Ecuador, esta actividad enfrenta tensiones constantes entre el crecimiento productivo y sus externalidades socioambientales. Este artículo tiene como objetivo analizar críticamente la relación entre la contabilidad social y la sostenibilidad empresarial en el clúster pesquero de Manta, bajo la hipótesis de que la contabilidad social incide positivamente en dicha sostenibilidad al integrar la información financiera con los impactos no financieros de las operaciones. Mediante una revisión sistemática de literatura reciente (2021-2026) y la propuesta de un diseño metodológico cuantitativo, no experimental, de corte transversal y alcance descriptivo-correlacional, se sintetizó la evidencia disponible sobre contabilidad social y ambiental en contextos pesqueros e industriales de Ecuador y la región. Los resultados de la revisión muestran que, si bien las empresas pesqueras de Manta cumplen mayoritariamente con normativas ambientales básicas, la integración de esta información en los sistemas contables formales continúa siendo parcial, y que la Teoría de los Stakeholders y la Teoría de la Legitimidad ofrecen un marco explicativo convergente para esta relación. La discusión evidencia que la contabilidad social funciona, sobre todo, como herramienta de legitimación y gestión de riesgos, condicionada por la capacitación técnica y la voluntad gerencial. Se concluye que la contabilidad social posee potencial estratégico para fortalecer la competitividad y la permanencia de las empresas pesqueras de Manta, y se propone un instrumento validado para contrastar empíricamente esta relación en estudios posteriores.

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**Palabras clave:** *contabilidad social; sostenibilidad empresarial; sector pesquero; gestión ambiental; teoría de los stakeholders; teoría de la legitimidad*

**ABSTRACT:** Corporate sustainability is an imperative for high environmental-impact sectors such as industrial fishing, and in Manta, Manabí, Ecuador, this activity faces constant tension between productive growth and its socio-environmental externalities. This article critically analyzes the relationship between social accounting and corporate sustainability in the Manta fishing cluster, under the hypothesis that social accounting positively affects such sustainability by integrating financial information with the non-financial impacts of operations. Through a systematic review of recent literature (2021-2026) and the proposal of a quantitative, non-experimental, cross-sectional, descriptive-correlational methodological design, the available evidence on social and environmental accounting in fishing and industrial contexts in Ecuador and the region was synthesized. The review results show that, although fishing companies in Manta largely comply with basic environmental regulations, the integration of this information into formal accounting systems remains partial, and that Stakeholder Theory and Legitimacy Theory offer a convergent explanatory framework for this relationship. The discussion shows that social accounting works, above all, as a legitimation and risk-management tool, conditioned by technical training and managerial commitment. It is concluded that social accounting has strategic potential to strengthen the competitiveness and permanence of fishing companies in Manta, and a validated instrument is proposed to empirically test this relationship in future studies.

**Keywords:** *social accounting; corporate sustainability; fishing industry; environmental management; stakeholder theory; legitimacy theory*

## INTRODUCTION

Business sustainability has become an imperative for productive sectors with high environmental impact, including industrial fishing. In Manta, province of Manabí, Ecuador, this activity constitutes one of the main pillars of the local economy and a strategic export hub for the country; However, it faces constant tensions between productive growth and the socio-environmental externalities it generates, including the intensive consumption of water resources, the generation of waste and the pressure on coastal ecosystems. Against this backdrop, social accounting, understood as the process of communicating the social and environmental effects of the economic activity of organizations to their stakeholders and society as a whole (1), emerges as a strategic tool capable of closing the gap between traditional financial performance and the non-financial impacts of the fishing operation.

The need for this tool is not merely theoretical. The evidence available for the Manta fishing sector documents that the companies in the Los Esteros cluster orient their practices mainly towards regulatory and operational compliance in environmental matters, without these practices being systematically integrated into the accounting systems that support strategic decision-making (2). This disconnection between operational environmental management and its formal accounting record limits the

ability of companies to verifiably communicate their socio-environmental performance to their stakeholders, workers, coastal communities, clients and regulatory bodies, and therefore restricts their margin of social legitimation and competitive differentiation in an export market that is increasingly sensitive to sustainability criteria. Previous studies similarly document the contribution of environmental accounting to corporate social responsibility in other Latin American contexts (3), as well as research that explicitly links environmental sustainability with corporate social responsibility as complementary axes of contemporary business management (4). This gap is explained, in part, by the design of the Ecuadorian accounting and tax framework. The accounting regulations applicable to the majority of fishing companies in Manta, the IFRS for SMEs, whose application regulates the Superintendence of Companies, Securities and Insurance, does not require the recognition or differentiated disclosure of costs, liabilities or investments of an environmental or social nature; These, when they exist, are diluted within generic operating items. At the tax level, the Organic Law of the Internal Tax Regime also does not contemplate specific deductibility criteria for voluntary environmental management expenses, which reduces the tax incentive for companies to account for them separately and traceable. Added to this is that the international sustainability disclosure standards, IFRS S1 and S2, are not yet mandatory for SMEs in Ecuador, so that the communication of socio-environmental impacts is, in practice, left to managerial will and without a formal regulatory framework that requires or standardizes it.

This article maintains that social accounting has a positive impact on the sustainability of fishing companies in Manta, to the extent that it allows financial information to be integrated with the social and environmental impacts of their operations. This hypothesis is supported by previous evidence that documents a still partial integration of environmental practices in the sector's accounting systems (2), as well as comparative studies in other industrial and geographic contexts that confirm similar patterns of fragmented adoption of socio-environmental accounting. The general objective of the article is to critically analyze the relationship between social accounting and business sustainability in the Manta fishing cluster, based on a systematic review of recent literature and the proposal of a methodological design that allows, in a subsequent empirical study, to contrast said relationship. Specifically, it seeks to: (i) synthesize the state of knowledge on social and environmental accounting in comparable fishing and industrial contexts; (ii) identify the theoretical frameworks that explain the relationship between social accounting and sustainability; and (iii) propose a validated and adaptable methodological instrument for future application in the sector.

The justification for this work lies in the need to improve the traceability of socio-environmental costs in a sector that constitutes a strategic export hub for Ecuador, and whose social legitimacy depends, to a large extent, on its ability to demonstrate, in a verifiable manner, that its productive growth is compatible with the environmental and social sustainability of its environment. Achieving this balance allows fishing companies to comply with growing regulatory demands and strengthens their competitive position in international markets and consumers who are increasingly attentive to the social and environmental responsibility criteria of their suppliers. This article is organized into four additional sections: first, the proposed methodological design is described to empirically test the proposed hypothesis; Secondly, the results of the systematic literature review

are presented, organized around the theoretical frameworks and the available empirical evidence; Third, the implications and limits of this evidence are discussed; and finally, the conclusions and lines of future research derived from this analysis are presented.

## MATERIALS AND METHODS

The proposed research adopts a quantitative, non-experimental, cross-sectional approach and descriptive-correlational scope. This approach is pertinent because it allows analyzing the relationship between social accounting and sustainability through numerical measurement and statistical analysis, without manipulating the study variables. The choice is based on previous research carried out in the same sectoral context: an equivalent design applied in fishing companies in Los Esteros, Manta, obtained statistically significant results on the relationship between accounting practices and environmental commitment (2).

The proposed instrument is a structured five-level Likert-type questionnaire, aimed at the accounting and administrative managers of the Manta fishing companies, organized around the economic, social and environmental dimensions of social accounting and its relationship with sustainability indicators. A previous study validated, for the same productive sector, a 22-item instrument with high levels of reliability (Cronbach's alpha greater than 0.79) to measure sustainability practices in the Ecuadorian fishing sector (2), which supports the suitability of this type of instrument for the present study; The adapted instrument is available upon request from the authors. The data will be primary, collected directly from the study subjects.

The population is made up of fishing companies formally registered in Manta that are active and have personnel linked to accounting or administrative management. To select the sample, non-probabilistic sampling of an intentional or convenience type will be used, considering inclusion criteria such as formal registration, operation during the study period and the availability of basic accounting information. This method has been used in similar research on the fishing sector of Manta (2), which supports its methodological relevance in a context where accessibility to the units of analysis constitutes a determining factor.

Data processing will be carried out using descriptive statistics, measures of central tendency and dispersion, calculated in Microsoft Excel given the small size of the planned sample, to identify patterns in the analyzed variables, complemented with correlational analysis to evaluate the relationship between social accounting and business sustainability. This procedure is consistent with that used in previous studies in the same sector, which used exploratory and confirmatory factor analysis to show significant relationships between the financial and non-financial dimensions of accounting in fishing companies in Manta (2).

The operationalization of the variables is carried out based on three dimensions. The independent variable, social accounting, is decomposed into an economic dimension (environmental costs and benefits incorporated into accounting, investment in environmental management), a social dimension (relationship with workers, coastal communities and regulatory bodies) and an environmental dimension (waste

management, water consumption, regulatory compliance). The dependent variable, business sustainability, is operationalized through financial, reputational and market performance indicators, following the criteria used for the same productive sector (2). Regarding validity and reliability, it is planned to adapt the aforementioned 22-item instrument to the particularities of the Manabi fishing cluster, previously subjecting it to a pilot test and to the judgment of experts in accounting and auditing. The ethical safeguards inherent to research with business actors are also considered: informed consent, confidentiality of sensitive accounting information and anonymization of responses at the company level. As a methodological limitation, non-probabilistic convenience sampling restricts the possibility of statistically generalizing the results to the entire universe of fishing companies in Ecuador, so the conclusions of an eventual empirical study should be interpreted as representative evidence of the Manta cluster and not as a national pattern.

## RESULTS

Social accounting expands the traditional boundaries of financial measurement to incorporate the social and environmental dimensions of business activity. It is defined as the process of communicating the social and environmental effects of the economic activity of organizations to their stakeholders and society as a whole (1), which implies expanding corporate responsibility beyond shareholders. A particularly relevant subfield is environmental management accounting, described as an interdisciplinary area that combines the measurement tools of management accounting with the biocentric perspective of environmental accounting, thus integrating financial results with their impact on the environment (5). Added to this description are recent findings according to which environmental accounting faces specific technical challenges, but also opens up real opportunities for companies and society (6); In fact, its effective implementation has resulted in measurable improvements in business sustainability in comparable Latin American contexts (7). Other studies expand this panorama by showing that social accounting is not limited to environmental measurement, but directly affects the business model, extending accountability beyond the strictly financial sphere (8).

Within this discipline three paradigms can be distinguished: the functionalist or market paradigm, based on neoclassical economic theory; the interpretive or social, which recognizes multiple interest groups beyond the investor; and the radical one, which proposes transforming the accounting function to account for social relations in a broader way (1). The interpretive paradigm is the most relevant for the Manta fishing sector, as it justifies the disclosure of information to both shareholders and employees, coastal communities and regulatory bodies.

The Manta fishing sector faces problems of high environmental impact associated with the consumption of water resources, the generation of waste and environmental management systems that are still incipient. The evidence available for the fishing companies of Los Esteros, in Manta, shows practices aimed at environmental compliance, particularly in waste management and control of hazardous waste, although these practices are concentrated in the operational and regulatory sphere, without being systematically integrated into the accounting systems that support strategic decision making (2). This gap between operational environmental

management and its accounting integration constitutes the central problem of this research.

Recent literature confirms that this tension is not exclusive to the Ecuadorian context. A systematic review of thirteen studies indexed in Scopus and Web of Science finds that environmental management accounting continues to be treated as an emerging topic, with a still superficial conceptual use that reveals a utilitarian tendency rather than a structural understanding of the phenomenon (9). A study on industrial companies documents, for its part, that socio-environmental accounting is implemented through heterogeneous approaches, without a single consolidated model (10). Water accounting in sustainable companies in Mexico offers relevant data in the opposite direction: the incorporation of sustainable accounting principles can have positive and measurable effects on the valuation of companies (11). These findings support the idea that social accounting is not an additional cost, but rather a source of value.

The relationship between social accounting (independent variable) and business sustainability (dependent variable) is, according to the available evidence, positive and multidimensional. For Manta fishing companies, a positive and significant covariance is reported between financial and non-financial practices ( $r = 0.681$ ;  $p = 0.001$ ), which suggests that advancing the accounting integration of social and environmental information directly contributes to sustainable performance (2). A study on the integration of environmental accounting in business practices reaches a similar result: it identifies implementation barriers, mainly technical training and organizational culture, but concludes that the benefits justify its adoption and recommends closer collaboration between academia, industry and regulators (12). Research that directly links business sustainability with the measurement of shared value through accounting points in the same direction (13).

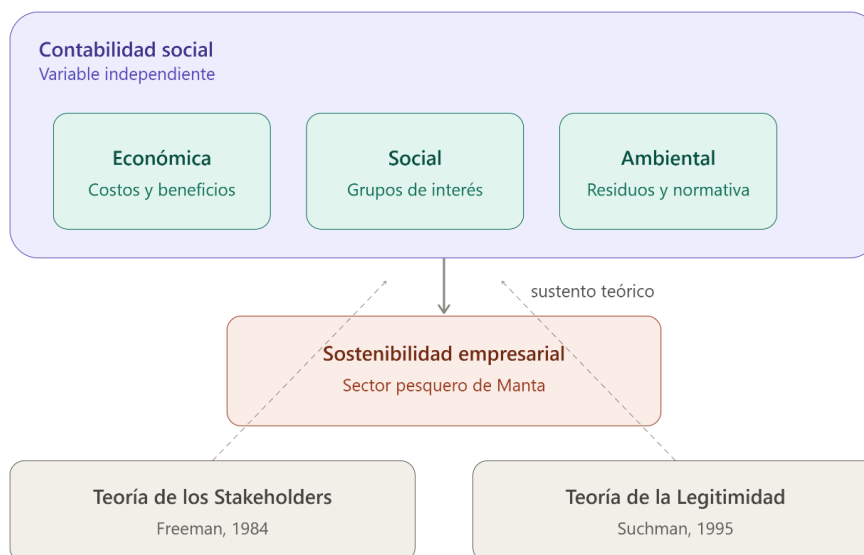
Two theoretical frameworks support this relationship. The Stakeholder Theory posits that organizations have responsibilities to all groups affected by their activities, beyond their shareholders (1), which underpins the need for Manta fishing companies to generate and disseminate social and environmental information as an accountability mechanism. Legitimacy Theory, for its part, maintains that organizations must operate within the limits that society considers appropriate to legitimize themselves in their environment (2); In a sector with high environmental visibility such as the fishing industry, social accounting becomes the instrument through which companies communicate their commitment to sustainability. Both frameworks converge on one point: social accounting is not an additional cost, but a strategic tool that strengthens the competitive position of the company and ensures its permanence in the long term.

Despite the conceptual advance of environmental and three-dimensional accounting, traditional financial accounting continues to be the main tool for decision making in most organizations. A study carried out in commercial companies in Cuenca, Ecuador, found a high familiarity with innovative approaches to financial accounting, highlighting transparency and technological integration as the aspects most valued by accounting managers, although challenges persist related to the costs of this technological integration and the need to adapt current accounting regulations (14). For the Manta fishing sector, this evidence highlights the need to integrate physical consumption

metrics, volume of water extracted, energy used in the cold chain, directly into the financial statements, instead of treating them as complementary information and unrelated to formal accounting.

A relevant complement to social accounting is the circular economy approach, defined as a restorative system by design that replaces the linear logic of extraction, use and disposal with cycles of recovery and revaluation of resources (15). For the fishing sector, this approach is particularly relevant: the by-products of industrial processing, viscera, heads, scales and tailwater, which are traditionally managed as waste, could be transformed into inputs for fishmeal, biofertilizers or biogas, generating additional income and reducing the environmental burden on the coastal environment. The adoption of circular supplies and the recovery of resources from one's own waste constitute a concrete way through which social accounting can be translated into verifiable economic value (15), and not only into regulatory compliance.

The empirical solidity of the Three-Dimensional Theory of Accounting is not limited to the fishing sector. Evidence obtained in small and medium-sized tourism companies in the province of Manabí itself confirms that the integration of the economic, social and environmental dimensions of accounting is consistently associated with better performance in sustainability, which suggests that the theoretical model applied to the fishing companies of Manta is generalizable, at least partially, to other productive sectors in the same region (16). Figure 1 synthesizes this conceptual model, showing how the three dimensions of social accounting are articulated, through the Stakeholder Theory and the Legitimacy Theory, with the business sustainability of the Manta fishing sector.



**Figure 1. Conceptual model of social accounting and business sustainability.**  
**Source: own elaboration.**

Added to this pair of theoretical frameworks, at the operational level, is the triple bottom line approach (9), which proposes evaluating organizational performance

simultaneously in its economic, social and environmental dimensions, instead of reducing it to financial profit. This tripartite logic is what, in practice, is adopted by the most internationally used sustainability reporting standards, and coincides with the structure of dimensions, economic, social and environmental, that is used in the methodological instrument proposed in the previous section. The convergence between Stakeholder Theory, Legitimacy Theory and the triple bottom line approach suggests that social accounting should not be understood as three parallel agendas, but as the same information system with three interdependent dimensions.

The Legitimacy Theory, applied to the Manta fishing sector, highlights the need to reduce the gap between the real performance of the organization and the expectations of its social and institutional environment (2): pragmatic legitimacy, based on the direct exchange of benefits with the closest interest groups, workers, coastal communities, clients, and moral and cognitive legitimacy, based on the broader social perception that the extractive activity is carried out appropriately. While the Stakeholder Theory explains to whom the fishing company must be accountable, the Legitimacy Theory explains why it is convenient to do so in a visible and verifiable way: the disclosure of social and environmental information works as a signaling mechanism that reduces the distance between the real performance of the organization and the expectations of its environment. Table 1 summarizes the main findings from the empirical literature reviewed, organized by author, context, and main finding, that support the relationships described in this section.

**Table 1. Synthesis of the empirical literature reviewed (2021-2026).**

| Author(s) [ref.]                           | Context                          | Main finding                                                                                                                                                                               |
|--------------------------------------------|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Alegre Brítez (13)                         | Paraguay                         | Relates sustainability and accounting to the measurement of shared value.                                                                                                                  |
| Arias Suárez and Cano Mejía (5)            | Conceptual, Latin America        | They define environmental management accounting as an interdisciplinary subfield that integrates financial measurement and a biocentric perspective.                                       |
| Camargo Estrella (6)                       | Conceptual                       | Identifies challenges and opportunities of environmental accounting for companies and society.                                                                                             |
| Carrillo González and Pomar Fernández (15) | Business models                  | The circular economy makes it possible to revalue waste and recover resources as a source of competitive advantage.                                                                        |
| Chamorro-Quiñónez (7)                      | Companies, Latin America         | Environmental accounting has a measurable impact on business sustainability.                                                                                                               |
| Díaz-Domínguez and Silva-López (17)        | Industrial fishing company, Cuba | They propose an accounting procedure to integrate the environmental dimension into the financial information system; They show that environmental elements are not usually integrated into |

|                                         |                                             |                                                                                                                                                                                            |
|-----------------------------------------|---------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                         |                                             | the formal accounting of fishing companies.                                                                                                                                                |
| Díaz Gil (8)                            | Corporate business model                    | Social accounting affects the business model, expanding accountability beyond the financial.                                                                                               |
| Maestre Macías and Loo Alcívar (2)      | Fishing companies of Los Esteros, Manta     | Positive and significant covariance between financial and non-financial practices ( $r = 0.681$ ; $p = 0.001$ ); They validate a 22-item instrument.                                       |
| Moscoso Córdova et al. (9)              | Systematic review (Scopus / Web of Science) | Environmental management accounting is an emerging topic, with still superficial conceptual use and a utilitarian approach.                                                                |
| Párraga Franco et al. (16)              | Tourism SMEs, Manabí                        | They confirm the empirical validity of the Three-Dimensional Theory of Accounting in another productive sector in the same region.                                                         |
| Pérez and Ritacca (1)                   | South America                               | They trace the retrospective evolution of social and environmental accounting in the region and confirm its current validity.                                                              |
| Sánchez-Caguana et al. (12)             | Business practices                          | They identify technical training and organizational culture barriers, but conclude that the benefits justify their adoption.                                                               |
| Sinforoso Martínez et al. (11)          | Sustainable companies, Mexico               | The incorporation of sustainable accounting principles related to water generates positive and measurable effects on the valuation of companies.                                           |
| Vargas González et al. (10)             | Industrial companies                        | Socio-environmental accounting is implemented through heterogeneous approaches, without a single consolidated model.                                                                       |
| Vásquez-Sánchez and Reyes-Cárdenas (14) | Commercial companies, Cuenca-Ecuador        | High familiarity with innovative financial accounting approaches; Transparency and technological integration are the most valued aspects, although cost and regulatory challenges persist. |

*Source: own elaboration based on the references cited in the table.*

## DISCUSSION

The results of the literature review support the proposed hypothesis: that social accounting has a positive impact on the sustainability of fishing companies in Manta. This reading is supported by empirical evidence accumulated in the local and regional context, which consistently shows a gap between existing environmental practices and their integration into formal accounting systems (2,17). The systematic review of thirteen indexed studies confirms that this pattern is not exclusive to Manta or Ecuador: in the set of studies analyzed, sustainable accounting continues to be applied in a fragmented way, without delving into its potential as a comprehensive information system (9).

When triangulating these sources, a relevant convergence is observed: both in the Manta fishing sector and in industries in other countries, social accounting seems to work better as a legitimation and risk management tool than as an exhaustive measurement system. The available evidence on water accounting and on socio-environmental accounting in industrial companies documents, in different contexts, that the incorporation of sustainable accounting principles generates tangible value, improvements in market valuation, greater transparency before investors (10,11), which supports the Legitimacy Theory as an explanatory framework also applicable to the Manabi fishing sector: the greater the social and environmental visibility of an extractive activity, the greater the company's incentive to adopt social accounting mechanisms that legitimize its operation. Table 2 summarizes this convergence between the theoretical frameworks reviewed and the empirical evidence that supports it.

**Table 2. Convergence between theoretical framework and empirical evidence reviewed.**

| Dimension / hypothesis                                     | Supporting evidence                                                       | Theoretical framework           | Implication for the Manta fishing sector                                                             |
|------------------------------------------------------------|---------------------------------------------------------------------------|---------------------------------|------------------------------------------------------------------------------------------------------|
| Social accounting → sustainability (positive relationship) | Master and Loor (2); $r = 0.681$                                          | Stakeholder Theory              | Legitimizes accountability to interest groups                                                        |
| Environmental visibility → adoption of social accounting   | Sinforoso Martínez et al. (11); Vargas González et al. (10)               | Legitimacy Theory               | Greater incentive to disclose environmental performance                                              |
| Implementation barriers                                    | Sánchez-Caguana et al. (12)                                               | —                               | Training and organizational culture as an enabling condition                                         |
| Power regimes and social criticism                         | Arias Suárez and Cano Mejía (18); Cabrera-Narváez and Quinche-Martín (19) | Critical / Foucauldian approach | Questions the technical neutrality of accounting; counter-accounts push towards greater transparency |

**Source: own elaboration.**

A critical reading of this evidence forces us to qualify the purely instrumental narrative of social accounting. Part of the recent literature warns that traditional cost systems can function as control and power devices that make socio-environmental impacts invisible under euphemisms such as “savings” or “efficiency” (18), which questions the technical neutrality that is usually attributed to accounting information. In this same sense, the so-called counter-accounts, alternative reports prepared by social movements and affected communities, have been consolidated as an exercise of criticism that makes visible the socio-environmental conflicts that the official accounting of companies tends to omit (19). For the Manta fishing cluster, this perspective is relevant: pressure from coastal communities and environmental organizations could function, in practice, as an external mechanism of demanding transparency as important as the legitimation incentives themselves described by the Legitimacy Theory.

This discussion can also be situated in relation to the literature on emerging organizational models. The evidence on start-ups and young companies in trans-complex contexts shows that these organizations, by operating with more flexible structures and supported by digital technologies, tend to more quickly adopt innovative

business models that integrate sustainability criteria (20). Although the Manta fishing sector is mainly composed of consolidated companies and not start-ups, this evidence suggests that the speed of adoption of social accounting could also be related to the organizational size and structural flexibility of each company, a variable that the proposed methodological instrument does not explicitly consider and that future research could incorporate.

The optimism of this reading, however, must be qualified. The evidence on the effective implementation of environmental accounting points to specific obstacles: lack of technical training of accounting personnel, absence of clear internal policies and cultural resistance to change (12). These obstacles are also plausible in the Manta fishing sector, where accounting management is usually subordinated to tax requirements and basic regulatory compliance, rather than to a strategic vision of sustainability. Closing the identified gap, therefore, does not depend solely on the existence of a solid theoretical framework, which does exist, but on concrete organizational conditions: training, managerial will and pressure from interest groups.

This tension ultimately refers to a broader conceptual debate: the one that proposes reconceptualizing accounting not as a system oriented exclusively to satisfying the financial interest of capital, but as a discipline capable of responding to human needs and the preservation of the biospheric environment (21). Adopting this perspective does not diminish the relevance of the strategic and competitive argument developed in this article, but it does qualify its scope: social accounting in the Manta fishing sector should be understood both as a tool for business legitimation and as a mechanism for accountability to the communities and ecosystems on which the extractive activity depends.

If this relationship is confirmed in a subsequent empirical study, the systematic implementation of social accounting would allow Manta fishing companies to improve their environmental risk management, strengthen their relationship with coastal communities and workers, and move towards business models aligned with the Sustainable Development Goals. Social accounting would thus be consolidated not as a compliance cost, but as a strategic tool for creating value and social legitimacy.

It is important to specify the scope of this analysis. As this is a systematic review and a methodological proposal, and not a study with primary data, the relationships discussed here have the character of hypotheses based on indirect and comparative evidence, not their own statistical findings; Its value lies in offering a theoretical map and an instrument already validated in an analogous context, rather than in a definitive causal conclusion. From a public policy perspective, the results suggest an active role for Manta's fisheries and environmental control agencies: encouraging, through recognition mechanisms or regulatory simplification, the voluntary adoption of social accounting systems could accelerate a transition that, left only to the logic of minimum compliance documented in the reviewed literature, would advance more slowly (12). For the companies themselves, the practical implication is that the investment in specialized accounting training, identified as the main barrier, must be understood as an enabling condition, and not as an additional cost unrelated to the strategy.

## CONCLUSIONS

The literature review confirms that social accounting constitutes a tool with strategic potential for the Manta fishing sector, as it allows the translation of the environmental and social impacts of extractive activity into manageable and communicable information. The available local evidence (2) and comparative evidence from other industrial contexts (9,10,11), together with studies that explicitly link environmental sustainability with corporate social responsibility (4), converge in pointing out that, although companies usually comply with basic environmental regulations, the integration of this information in formal accounting systems remains incomplete. This gap, more organizational and cultural than theoretical, is the main challenge facing the business sustainability of the sector.

The theoretical foundations reviewed, the Stakeholder Theory and the Legitimacy Theory, consistently support the hypothesis that social accounting strengthens the competitive position of companies and their long-term permanence, beyond regulatory compliance. However, the evidence also invites us to qualify any optimistic conclusion: effective implementation depends on organizational conditions, technical training, managerial will and pressure from interest groups, which are not guaranteed by the mere existence of a favorable theoretical framework.

It is recommended that future research apply the proposed methodological instrument to a representative sample of fishing companies in Manta, in order to empirically contrast the relationship projected in this article, and explore the role of specialized accounting training as a moderating variable between the existence of an environmental regulatory framework and its effective translation into social accounting systems, also expanding the comparative analysis with other fishing clusters in the Latin American region. Altogether, this article provides an integrated theoretical framework, which articulates the Stakeholder Theory, the Legitimacy Theory and the triple bottom line approach, and a replicable methodological route, ready to be applied in the empirical study that this research proposes as the next step.

Finally, the incorporation of the circular economy approach, through the revaluation of by-products of fish processing, and a broader vision of accounting, oriented to human needs beyond business profit (21), expand the strategic scope of social accounting beyond regulatory compliance (15), opening a second line of applied research for the Manta fishing cluster.

## DECLARATION OF INTEREST

The authors declare that they have no conflict of interest related to this article.

## REFERENCES

1. Pérez VG, Ritacca MI. Contabilidad social y ambiental. Referencia retrospectiva y su actualidad en Sudamérica. *Ejes de Economía y Sociedad*. 2022;6(11):257-73. doi: 10.33255/25914669/61030

2. Maestre Macías IB, Loor Alcívar MI. La contabilidad tridimensional para evaluar el compromiso ambiental en el sector pesquero de Los Esteros, Manta. *Horizon Nexus Journal*. 2026;4(2):76-89. doi: 10.70881/hnj/v4/n2/130
3. Murrieta Martínez N, López Castro EM, Báez Hernández D. La contabilidad ambiental y su relación con la responsabilidad social empresarial. *Ciencia Administrativa*. 2023;(2):1-14. ISSN: 1870-9427
4. Loor Quijije LA, Zambrano Alcívar KG. La sostenibilidad ambiental y la responsabilidad social empresarial. *Desafío Organizacional*. 2025;3(1):1-8. doi: 10.51260/desafio\_organizacional.v3i1.531
5. Arias Suárez JD, Cano Mejía V. Contabilidad de Gestión Ambiental: avances conceptuales para construir una contabilidad para la sustentabilidad. *Apuntes Contables*. 2024;(35):25-47. doi: 10.18601/16577175.n35.03
6. Camargo Estrella JA. Contabilidad ambiental: desafíos y oportunidades para empresas y sociedad en el cuidado del medio ambiente. *Revista de Investigación Académica Sin Frontera*. 2024;(41). doi: 10.46589/riasf.vi41.686
7. Chamorro-Quiñónez JG. Impacto de la contabilidad ambiental en la sostenibilidad empresarial. *Revista Científica Ciencia y Método*. 2025;3(1):15-29. doi: 10.55813/gaea/rcym/v3/n1/33
8. Díaz Gil ND. La contabilidad social y su efecto en el modelo de negocio empresarial. *Aibi Revista de Investigación, Administración e Ingeniería*. 2024;12(2):182-95. doi: 10.15649/2346030X.3224
9. Moscoso Córdova JL, Chango Galarza MC, Pinda Guanolema BR, Urbina Poveda MA. La contabilidad y su relación con la gestión sostenible de los recursos naturales: una revisión sistemática de enfoques. *Pacha. Revista de Estudios Contemporáneos del Sur Global*. 2025;6(19):e250462. doi: 10.46652/pacha.v6i19.462
10. Vargas González V, Gallego GG, Hernández AC. Contabilidad socio-ambiental en empresas industriales: diversos enfoques para su implementación. *Revista Venezolana de Gerencia*. 2024;29(Especial 11):793-810. doi: 10.52080/rvgluz.29.e11.47
11. Sinforoso Martínez S, Álvarez Velázquez E, Salas Benítez L. Contabilidad ambiental del agua en empresas sustentables establecidas en México. *Revista Venezolana de Gerencia*. 2021;26(Especial 5):614-31. doi: 10.52080/rvgluz.26.e5.39
12. Sánchez-Caguana DF, Landázuri-Álvarez MB, Ramírez-Martínez SL, Acosta-Muñoz MM. Desarrollo Sostenible y Contabilidad: Integrando la Contabilidad Ambiental en Prácticas Empresariales. *Journal of Economic and Social Science Research*. 2024;4(2):157-77. doi: 10.55813/gaea/jessr/v4/n2/105
13. Alegre Brítez M. Relación entre sostenibilidad y contabilidad para la medición del valor compartido. *Revista de la Sociedad Científica del Paraguay*. 2025;30(2):75-86. doi: 10.32480/rscp.2025.30.2.7586
14. Vásquez-Sánchez MV, Reyes-Cárdenas NA. Contabilidad financiera 2.0: estrategias innovadoras para empresas comerciales. *Revista Metropolitana de Ciencias Aplicadas*. 2024;7(S2):146-56. doi: 10.62452/c6as5b16
15. Carrillo González G, Pomar Fernández S. La economía circular en los nuevos modelos de negocio. *Entreciencias: Diálogos en la Sociedad del Conocimiento*. 2021;9(23):1-16. doi: 10.22201/enesl.20078064e.2021.23.79933

16. Párraga Franco SM, Moreira Largacha JM, Loor Alcívar M, Zambrano Loor RM. Teoría tridimensional de contabilidad en las pymes turísticas de Manabí: enfoque hacia la sostenibilidad empresarial. *Revista Internacional de Gestión, Innovación y Sostenibilidad Turística (RIGISTUR)*. 2025;5(1):26-35. doi: 10.51260/rigistur.v5i1.552
17. Díaz-Domínguez D, Silva-López CA. Procedimiento para información financiera medioambiental en la Empresa Pesquera Industrial de Cienfuegos. *Ciencias Holguín*. 2021;27(3):66-77. ISSN: 1027-2127
18. Arias Suárez JD, Cano Mejía V. Contabilidad de gestión y regímenes de poder: revisión de la literatura y reflexión crítica sobre los eufemismos de los sistemas de costos en las organizaciones. *Innovar*. 2021;31(82):45-64. doi: 10.15446/innovar.v31n82.98427
19. Cabrera-Narváez A, Quinche-Martín FL. Movimientos sociales y contabilidad social y ambiental: el rol de las contracuentas como ejercicio de la crítica. *Innovar*. 2021;31(82):125-44. doi: 10.15446/innovar.v31n82.98428
20. Arévalo Molina DE, Fuenmayor Ramírez NA, Abreu Fuentes JR, Marín Gómez CM. Start-ups: modelo de negocios emergentes para dinamizar y revitalizar los mercados desde la transcomplejidad. *Revista Venezolana de Gerencia*. 2021;26(Especial 5):444-58. doi: 10.52080/rvgluz.26.e5.29
21. Rojas-Rojas W, Ospina-Zapata CM, Cardona JD, Ocampo-Salazar CA, García D. Perspectivas para la reconceptualización de la contabilidad en el marco de las necesidades humanas. *Innovar*. 2021;31(82):223-44. doi: 10.15446/innovar.v31n82.98424

# APLICACIÓN DE MODELOS MATEMÁTICOS PARA FORTALECER LA SOSTENIBILIDAD Y COMPETITIVIDAD DE LOS EMPRENDIMIENTOS EMPRESARIALES EN ECUADOR

## APPLICATION OF MATHEMATICAL MODELS TO STRENGTHEN THE SUSTAINABILITY AND COMPETITIVENESS OF BUSINESS VENTURES IN ECUADOR

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**RESUMEN:** Los emprendimientos y las micro, pequeñas y medianas empresas (MiPyMEs) son motores fundamentales de la economía ecuatoriana; sin embargo, su supervivencia es frágil debido a la falta de planificación estratégica y herramientas de gestión adecuadas a los requerimientos administrativos, principalmente en lo que se refiere a la implementación de modelos matemáticos financieros de utilidad práctica en el día a día. Por esto, el objetivo principal de esta investigación es analizar la importancia de los modelos matemáticos en la eficiencia de la gestión empresarial de los emprendimientos en Ecuador, y así determinar su utilidad en la reducción de la incertidumbre, la metodología empleada es de enfoque cualitativo, de alcance descriptivo, en el que se emplea un diseño no experimental y de corte transversal, en la que se implementa como técnica de recolección de datos la revisión sistemática de bibliografía de publicaciones comprendidas entre los años 2022 y 2026, empleando el método prisma. Los hallazgos obtenidos al analizar investigaciones científicas de otros autores, revelan una marcada tendencia hacia la gestión empírica e intuitiva de los emprendedores en Ecuador y otros países de América Latina, identificando la existencia de una distancia significativa entre la teoría financiera y su ejecución práctica, herramientas como la programación lineal y el análisis predictivo incrementa significativamente la eficiencia y la rentabilidad, siendo los recursos tecnológicos intangibles el factor de mayor impacto en el rendimiento organizativo. Se concluye que la sostenibilidad de los emprendimientos depende de la transición hacia una planificación basada en datos y modelos cuantitativos que permitan identificar puntos de equilibrio y optimizar recursos, por lo cual, resulta imperativo fortalecer la formación técnica de los gestores para mitigar riesgos y asegurar la competitividad en mercados volátiles.

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**Palabras clave:** *Modelos matemáticos, emprendimiento, gestión administrativa, toma de decisiones, sostenibilidad financiera*

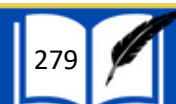
**ABSTRACT:** Entrepreneurship and micro, small, and medium-sized enterprises (MSMEs) are fundamental drivers of the Ecuadorian economy; however, their survival is fragile due to a lack of strategic planning and management tools suited to administrative requirements, particularly regarding the implementation of practical financial mathematical models for daily operations. Therefore, the main objective of this research is to analyze the importance of mathematical models in the efficiency of business management for entrepreneurship in Ecuador, and thus determine their usefulness in reducing uncertainty. The methodology employed is qualitative, descriptive, and uses a non-experimental, cross-sectional design. Data collection is carried out through a systematic literature review of publications from 2022 to 2026, using the PRISMA method. The findings obtained from analyzing scientific research by other authors reveal a marked trend toward empirical and intuitive management by entrepreneurs in Ecuador and other Latin American countries. A significant gap exists between financial theory and its practical application. Tools such as linear programming and predictive analytics significantly increase efficiency and profitability, with intangible technological resources being the factor with the greatest impact on organizational performance. It is concluded that the sustainability of ventures depends on the transition to planning based on data and quantitative models that allow for the identification of break-even points and the optimization of resources. Therefore, it is imperative to strengthen the technical training of managers to mitigate risks and ensure competitiveness in volatile markets.

**Keywords:** *Mathematical models, entrepreneurship, administrative management, decision-making, financial sustainability*

## INTRODUCTION

At the current time, entrepreneurship, micro, small and medium-sized enterprises (MSMEs) have established themselves as important drivers of economic activity and job creation, both in Ecuador and globally, this largely responds to the impact of new technologies and the transition of commercial activities towards the digital era, as well as the need of the population to build independent means of income in the face of the financial uncertainty of recent times both nationally and internationally, contributing to energizing emerging economies (1).

However, its permanence over time is still considered fragile in the Ecuadorian context, despite having one of the highest rates of entrepreneurial activity in Latin America, critical levels of discontinuity and permanence are recorded, this can be attributed to the lack of strategic planning and the implementation of appropriate management tools (8). Despite the indisputable role of MSMEs as drivers of local development, a significant disconnect persists between the abstract rigor of financial mathematics and the daily decision-making of small business owners. This theoretical-practical gap has not been effectively resolved so far, which generates a void in this field of knowledge. Most



traditional management models have been formulated for large companies and corporations with a formal structure, on the other hand, in the pedagogical field.

The teaching of mathematics applied to administration has historically been characterized by rigid, theoretical and decontextualized approaches. This lack of didactic articulation generates a low motivation towards learning and even a marked anxiety in students, as well as a lack of interest in applying them in everyday life situations or commercial processes of particular initiative. In addition, microentrepreneurs who start their businesses empirically usually base their management on intuition or the urgency of daily cash flow. fear or distrust of formal methods, which they may consider complicated or exclusive to banking entities or overestimate their own skills and previous experiences, wrongly assuming that strategic and technical planning is not necessary for the survival of the business (1).

This is why this research seeks to delve into a little explored area and contribute with solid and practical contributions, for the efficient application of the tools that mathematics can provide in a tangible way, analyzing the way in which the application of algebraic limits, linear programming and predictive analysis act as preventive diagnostic tools and providing a contextualized financial literacy framework that translates scientific precision into viable operational decisions for all micro-entrepreneurs.

The competitiveness of any commercial organization is linked to its ability to innovate and adapt to a globalized market in constant transformation. Scientific research in this field has evolved from merely theoretical postulates to models focused on the analysis of determining factors of organizational success and sustainability. In this context, mathematical models are defined as logical structures and simplified representations of reality that use statistical principles to describe, analyze and predict complex behaviors.

"The mathematical model is an effective tool for business management [...] allowing precise quantitative solutions to be obtained, providing a solid basis for making informed and effective decisions in the business context" (19). Their importance lies in the fact that they represent a fundamental link between academic theory and practical execution, facilitating a greater understanding of the causes that encourage business development (1; 16).

Despite its usefulness, there is a significant lack of coherence between the theory of financial mathematics and real business practice in which decisions based on intuition, empirical experience or the urgency of daily cash flow predominate, leaving aside technical analysis on the value of money, interest rates or projected profitability.

Financial mathematics, as a discipline, offers rational tools to evaluate decisions related to the time value of money, interest rates, financing, investment, amortization and profitability (5). Research in this field reveals that entrepreneurs rarely apply structured knowledge in their business management, which increases exposure to unnecessary financial risks and compromises the efficiency of the organization (Chocobar-Reyes, 2023).

The implementation of quantitative tools, such as linear programming, allows companies to optimally allocate resources such as capital, raw materials and labor in order to maximize profits or minimize operating costs (9).

Beyond basic accounting, decision making can be made more technical through calculation. Sánchez (2023) proposes a model where 'the data are managed in a single equation that, when derived mathematically, allows establishing the economic value of a product' (p. 1), which gives the entrepreneur a scientific basis to choose the most profitable segmentation strategy (2).

Likewise, predictive analysis transforms large volumes of data into practical knowledge, allowing organizations to anticipate market demands, detect vulnerabilities and strengthen their operating conditions (17). Currently, the integration of technologies such as artificial intelligence enhances administrative efficiency and resilience in the face of market volatility, however, the effective appropriation of these models faces critical cultural and cognitive barriers (3).

New technologies including artificial intelligence provide important contributions to the management of different mathematical and financial functions, the findings of Colmenero-Fonseca et al (2026) demonstrating that the relationship between formal mathematical modeling and AI not only. It is theoretical, but has strong practical effects. In its simulations, the application of machine learning algorithms to optimize energy and productive resources allowed a "potential increase in economic development of up to 40%" (p. 7930).

In general, entrepreneurs do not know how to implement these tools, and there is a general perception that they are excessively complicated or alien to the reality of small businesses, "intuitive decisions predominate, based on personal experiences, informal advice or the urgency of daily cash flow. This disconnection between theory and practice has caused significant gaps that can compromise the economic efficiency of ventures" (5).

On the other hand, social factors and the lack of contextualized financial training limit the use of technical formulas, reinforcing a business culture based on immediate survival rather than long-term planning (6). The transition from an empirical enterprise to a technical one requires that the manager abandon exclusive dependence on intuition.

The adoption of models based on the theory of expected utility and Bayesian decision allows organizations to "identify scenarios, present probability calculations, anticipate adverse situations, externalities and make decisions to mitigate impacts and take advantage of opportunities" (7). This paradigm shift is vital to transform a subsistence initiative into a sustainable company over time.

This is why the main objective of this research is to analyze the importance of mathematical models in the efficiency of business management of ventures in Ecuador. In order to publicize its usefulness, and the benefits of its implementation through different means and training processes, taking into consideration that the success of this type of business contributes to economic strengthening at the national level.

To guide the development and discussion, the following working hypothesis was proposed:

The systematic adoption of structured quantitative models, such as linear programming, algebraic limits and predictive analysis, supported by an interdisciplinary didactic model and financial literacy will allow overcoming the intuitive and empirical nature of the traditional management carried out by entrepreneurs and small businesses in Ecuador.

## MATERIALS AND METHODS

This research is guided by a qualitative approach with a descriptive and explanatory scope. A non-experimental and cross-sectional design is used, using the systematic review of literature through the prism methodology, as the main information collection technique. It is qualitative and non-experimental given that the phenomena are analyzed and observed in their natural environment without the deliberate manipulation of the study variables, while the cross-sectional section is justified by delimiting the data analysis to a specific time period between the years 2022 to 2026 (1).

Its scope is descriptive because it allows to systematically and orderly characterize the particularities of the current state of financial management and quantitative mathematical models in the efficiency of managerial decision making of ventures. To substantiate this process, an exhaustive exploration and scientific abstraction of written sources and formal records were carried out that provide scientific validity to the theoretical framework of the research. Data collection was structured based on a systematic search of scientific literature in databases of high relevance and academic rigor, such as Scielo, Redalyc, Dialnet and Scopus, as well as official university repositories (2).

The search and documentary selection route was guided by the methodological guidelines of the structured filtering and purification system. The search terms and key descriptors used, both in Spanish and English, were managed using Boolean operators, structuring the following query syntax: “mathematical models” OR “linear programming” OR “algebraic limits”, AND, “entrepreneurship” OR “MiPyMEs”, AND, “decision making” OR “financial sustainability” (1, 2).

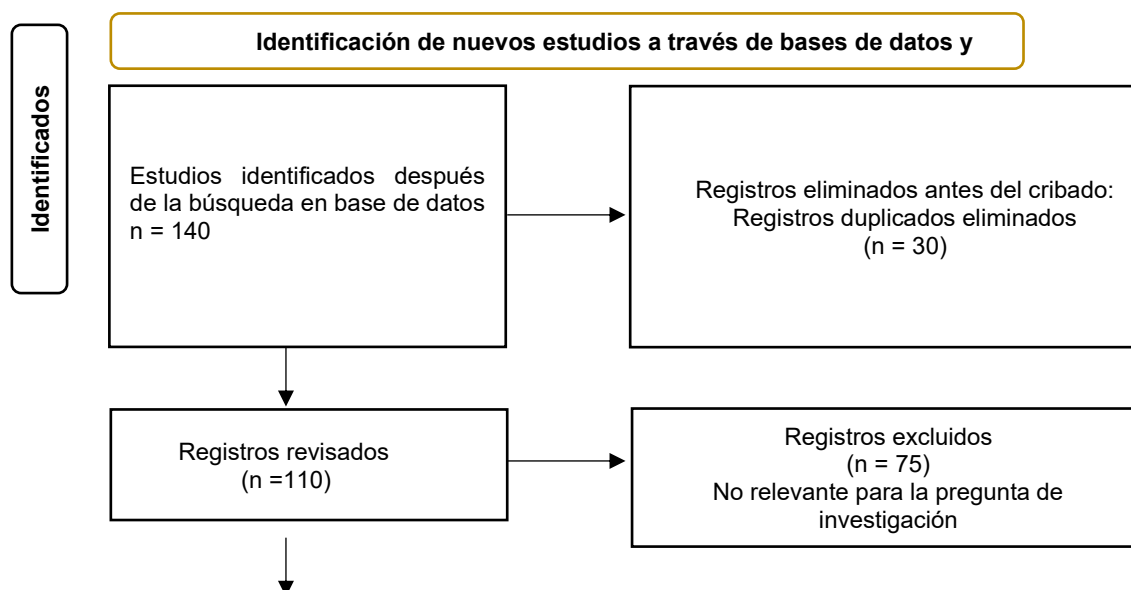
Strict eligibility criteria were established for the purification and elimination of documents, the inclusion criteria considered that they were empirical, experimental or review studies published preferably in a range of no older than five years from 2022 to 2026, prioritizing the most recent scientific literature, research focused directly on the application of quantitative models, predictive analysis or mathematical optimization algorithms in the context of administrative, service or production management of microenterprises and MSMEs in Ecuador and Latin America.

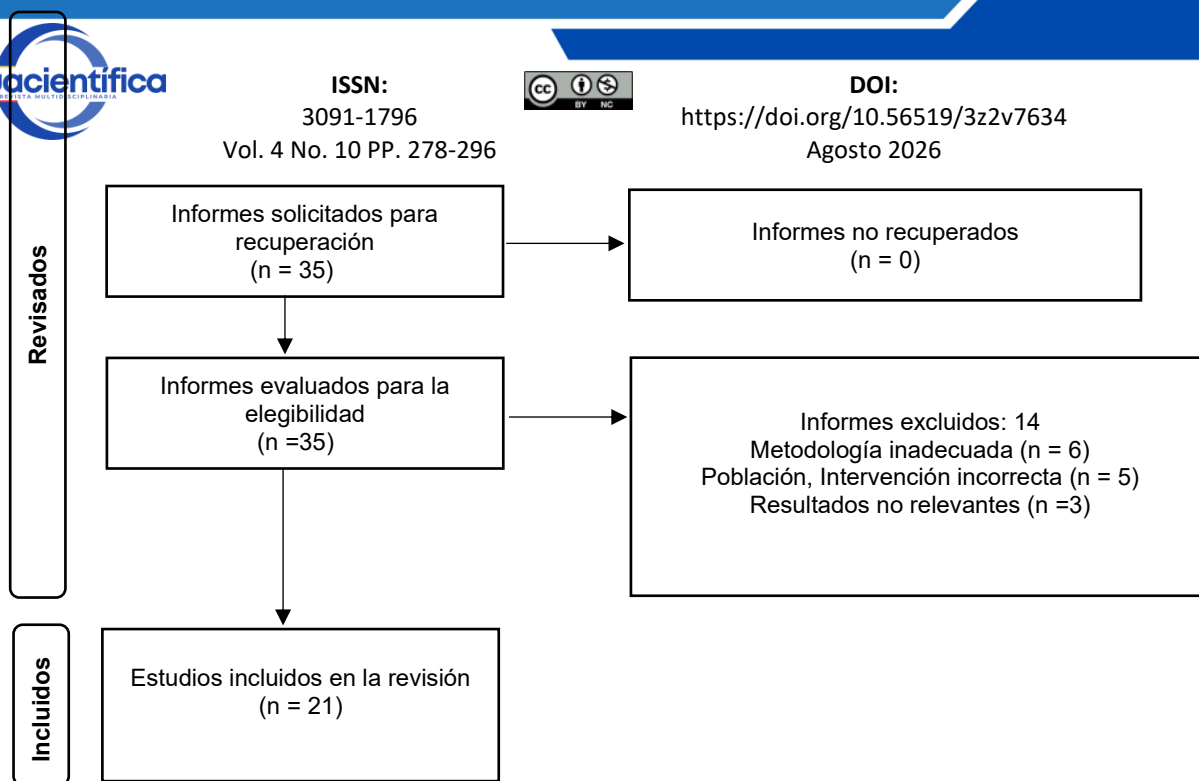
As exclusion criteria, it was considered not to admit abstract mathematical or pure theoretical modeling research that does not present a practical application or direct relationship with business administration or corporate decision making, duplicate

publications in the databases consulted, documents without explicit methodological rigor or those that did not belong to the thematic areas of business, economics or decision sciences.

The information extracted from the selected documents was carefully organized and tabulated in an analysis matrix, which allowed the analyzed research to be classified under three axes of categorization, identification of the source, indicating the author, year of publication, country of origin and database of origin. The applied mathematical dimension, in which the identification of the analyzed model will be indicated, for example, linear programming, multiple regression, algebraic limits or stochastic simulation. The operational variable evaluated, in this case, the documented impact on the dimensions of profitability, cost minimization, resource optimization, production volume or reduction of financial risk, the findings obtained were contrasted and contextualized taking into consideration the cultural, educational and economic dimension of Ecuador compared to the Latin American reality (4).

## RESULTS





**Figure 1. Selection of Research Articles applying the Prism Method.**

The selection and purification process of the scientific literature was structured under the standards of the PRISMA 2020 declaration. The initial search in the PubMed, Scopus and Cochrane databases reported a total of 140 potential records, after eliminating 30 duplicate records, a total of 110 articles were subjected to an initial review of title and abstract, excluding 75 documents for not being directly related to the research question or for lacking a focus. of practical application.

Subsequently, 35 reports were requested for complete recovery, and all of them were recovered. In the eligibility phase, a full-text critical reading of the 35 reports was carried out, excluding 14 articles due to the following specific causes: inadequate methodology (n = 6), incorrect scope of application (n = 5) and results not relevant for the mathematical modeling analysis (n = 3). Finally, 21 empirical and experimental studies rigorously met all the inclusion criteria and were incorporated into the systematic review for subsequent tabulation and analysis

**Table 1. Document Systematization and Analysis Matrix.**

| Source<br>(Vancouver) | Country of Origin /<br>Database                   | Applied Mathematical<br>Dimension                                              | Evaluated<br>Operational<br>Variable                                                                                                       | Finding / Key<br>Contribution of the<br>Modeling                                                                                                                                    |
|-----------------------|---------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sánchez<br>(2023) [2] | Costa Rica National<br>Administration<br>Magazine | Differential Calculus<br>(Market equation based<br>on first-order derivatives) | <ul style="list-style-type: none"> <li>Segmentation strategies</li> <li>Profit maximization</li> <li>Economic value of products</li> </ul> | It allows the profitability of each potential level of segmentation to be scientifically determined through a unique equation that links the unit cost with the market coefficient. |

|                                           |                                           |                                                                                                       |                                                                                                                                                                        |                                                                                                                                                                                                                                      |
|-------------------------------------------|-------------------------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Sarmiento-Tito et al. (2025) [6]</b>   | Ecuador Economy and Politics Magazine     | <b>Multiple Linear Regression (Training with 80% of data and validation with 20%)</b>                 | <ul style="list-style-type: none"> <li>• Organizational performance</li> <li>• Financial profitability</li> <li>• Intangible technological resources</li> </ul>        | It quantifies the impact of management variables in associative ventures in Zone 6, identifying that infrastructure and intangible technological resources are the determinants with the greatest explanatory weight on performance. |
| <b>Moyano &amp; Taborda (2024) [9]</b>    | Colombia Free University                  | <b>Linear Programming and Inventory Models (EOQ and Just In Time Systems - JIT)</b>                   | <ul style="list-style-type: none"> <li>• Minimization of operating costs</li> <li>• Supply chain optimization</li> <li>• Raw material purchasing management</li> </ul> | Demonstrates how mathematical modeling in operations research optimizes resource allocation and physical-operational flow, reducing storage costs and avoiding shortages.                                                            |
| <b>Reinoso-Salazar et al. (2024) [11]</b> | Ecuador Knowledge Pole                    | <b>Algebraic Limits (Analytical modeling through temporal trend lines)</b>                            | <ul style="list-style-type: none"> <li>• Monthly net profitability</li> <li>• Financial break-even point</li> <li>• Income and sales projections</li> </ul>            | Using mathematical limits as a function of time, it projects the viability and monthly net profit of a local food enterprise ("Empanadas Express"), scientifically determining its equilibrium point and optimal profitability.      |
| <b>Muñiz Arana (2026) [14]</b>            | Ecuador International Strategic Knowledge | <b>Mathematical Programming and Multivariate Analysis (Linear regressions and K-means clustering)</b> | <ul style="list-style-type: none"> <li>• Financial risk management</li> <li>• Corporate leverage</li> <li>• Liquidity analysis</li> </ul>                              | Establishes with statistical precision the critical impact of financial leverage on corporate risk ( $\beta = 0.48$ ) and the inverse correlation between available liquidity and instability.                                       |
| <b>Salgado (2024) [18]</b>                | Argentina Revista Unión                   | <b>Algebraic-Functional Modeling (Matrix operations and multivariable functions)</b>                  | <ul style="list-style-type: none"> <li>• Structuring of production costs</li> <li>• Projections under inflation (CPI)</li> <li>• Analysis of marginal costs</li> </ul> | Develops a dynamic total cost model ( $\$C = CF + CV\$$ ) that integrates matrices of threads per amigurumi and adjusts the future values of raw materials by indexing                                                               |

|                                                          |                                                     |                                                                                                                         |                                                                                                                                                                 |                                                                                                                                                                                                                         |
|----------------------------------------------------------|-----------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                          |                                                     |                                                                                                                         |                                                                                                                                                                 | them to the Consumer Price Index.                                                                                                                                                                                       |
| <b>Farinango-Salazar &amp; Porres-Reques (2024) [19]</b> | Ecuador RILCO / Dialnet                             | <b>Linear Programming (Graphic method, definition of feasible region and objective function optimization)</b>           | <ul style="list-style-type: none"> <li>• Profit maximization</li> <li>• Optimization of raw materials</li> <li>• Planning production of clothing</li> </ul>     | Exactly determines the optimal production mix (pillows for furniture vs. bedroom) for the microenterprise "Confecciones Gloria", maximizing economic returns under a budget of \$1160.                                  |
| <b>Romero-Peña &amp; Escudero-Ramírez (2024) [20]</b>    | Mexico Strategies, Models and Trends                | <b>Algebraic Breakeven Point (Linear models of costs and income)</b>                                                    | <ul style="list-style-type: none"> <li>• Setting sales prices</li> <li>• Required sales volume</li> <li>• Projection of profits for 5 years</li> </ul>          | Develops a practical simulation for the commercial and financial structuring of a food business, calculating the exact number of units to sell to cover fixed and variable costs.                                       |
| <b>Neri-Guzmán (2024) [1]</b>                            | Mexico Development Problems / Syntectics            | <b>Structural Equation Modeling (SEM) (Validation of the theoretical model of planned behavior using AMOS software)</b> | <ul style="list-style-type: none"> <li>• Intention entrepreneurial</li> <li>• Support infrastructure</li> <li>• Attitude and behavioral control</li> </ul>      | Quantify through a structural model that the intention to undertake has a direct and strong relationship with the academic and institutional support infrastructure (0.576), surpassing subjective family norms (0.35). |
| <b>Cuellar-Chaves (2025) [7]</b>                         | Colombia European Public & Social Innovation Review | <b>Organizational Decision Theories (Scenario simulation, expected utility and Bayesian decision)</b>                   | <ul style="list-style-type: none"> <li>• Risk mitigation</li> <li>• Decision making strategic</li> <li>• Planning under uncertainty</li> </ul>                  | Develops risk models to outline proactive decisions in uncertain environments, integrating Bayesian decision theory with new market evidence to optimize profitability and resilience.                                  |
| <b>Coronado-Guaita (2025) [8]</b>                        | Ecuador KIRIA: Scientific Journal                   | <b>Quantitative Correlational Analysis (Pearson correlation coefficient and rubric quality metrics)</b>                 | <ul style="list-style-type: none"> <li>• Business plan design</li> <li>• Financial plan viability</li> <li>• Entrepreneurial skills in the classroom</li> </ul> | Identifies a significant correlation ( $r = 0.64$ ; $p < 0.01$ ) between active teaching methodologies and the quality of the business plan in BGU students, revealing that the financial                               |

|                                                          |                                                               |                                                                                                                 |                                                                                                                                                              |                                                                                                                                                                                                                                      |
|----------------------------------------------------------|---------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                          |                                                               |                                                                                                                 |                                                                                                                                                              | area represents the lowest performance (2.8).                                                                                                                                                                                        |
| <b>Jiménez-García et al. (2024) [16]</b>                 | Colombia<br>Fundamentals and perspectives of entrepreneurship | <b>Process Modeling by Regulation (MPR) (Modeling of information flows and strategic management indicators)</b> | <ul style="list-style-type: none"> <li>• Sustainability and scalability</li> <li>• Cost structuring</li> <li>• Operational articulation</li> </ul>           | It proposes a standard knowledge management model that complements the traditional components of the business model, serving as a bridge for the planning of the value proposition to move effectively towards sustainability.       |
| <b>Calderón-López &amp; Rodríguez-Romano (2025) [21]</b> | Mexico Studies and Perspectives                               | <b>Descriptive-Psychometric Modeling (Statistical analysis of frequencies and crossing of variables)</b>        | <ul style="list-style-type: none"> <li>• Stability emotional/Self-control</li> <li>• Decision-making capacity</li> <li>• Tolerance to uncertainty</li> </ul> | Verifies the strong connection between emotional intelligence and entrepreneurship, determining that 73.5% of leaders base their decisions on this capacity, with determining factors such as vision (84.1%) and creativity (67.3%). |

## DISCUSSION

From the information collected in the applied instruments, the initial findings show a marked trend towards the operation of business processes empirically, the data show that a significant percentage of owners support decision making in the company intuitively and based on their experience (1) The review of the scientific literature, which has analyzed statistical data of the operational variables, shows that organizations that incorporate structured quantitative tools achieve higher levels of efficiency in their operational processes, Particularly, the application of linear programming is directly associated with a more efficient allocation of critical inputs, raw materials and labor (5, 6).

Businesses that configure their production margins under these scientific-mathematical principles achieve a significant reduction in their operating costs and, simultaneously, maximize their profits compared to those that operate under a strictly empirical model. Likewise, the results suggest that the use of preliminary predictive analyses, aimed at anticipating fluctuations in market demand, contributes to reducing exposure to financial risk and provides a solid basis to mitigate the fragility of emerging economies.

Sánchez (2023) highlights the importance of the use of derivatives for market segmentation, as the author points out, "the data are managed in a single equation that,

when mathematically derived, allows establishing the economic value of a product or service in a certain market condition" (p. 1), which reflects the practical usefulness of numerical calculations for any type of business (2).

Rivero-Fernández et al (2025), in a research titled "Analysis of financial decision-making in small businesses: gaps between financial mathematics theory and business practice, the authors identified three factors that influence the identified problems, among which are mentioned the lack of understanding of basic technical concepts such as projected cash flow or amortization, the difficulty of trained entrepreneurs to integrate technical knowledge into daily management, and the generalized belief that mathematical models are exclusive tools. of large companies or banking institutions, which are not applicable to small-scale businesses (5).

The research concludes that to ensure the sustainability of these businesses, it is urgent to move from a culture of survival towards strategic planning supported by financial literacy programs contextualized to the reality of microentrepreneurs, which also allows predicting situations that may affect the stability of the business, "predictive models are a powerful tool that can provide valuable information and make accurate predictions in a variety of applications and scenarios" (Viada González et al., 2025, p. 8).

Other important contributions to support the importance of the implementation of mathematical models and strategic planning in ventures are presented by the research of Sarmiento Tito et al. (2025), titled "Predictive Model of the Performance of Associative Enterprises in Zone 6", whose results allow us to quantify the success factors in these management models in the Ecuadorian context (6).

The findings of Rivero-Fernández et al. (2025) show that although a high percentage of entrepreneurs make decisions that commit their capital, only a minority of approximately 20% resorts to the technical calculation of profitability (5). This lack of implementation of mathematical models in small businesses and the results of customer perceptions that are evident through different interviews and surveys, allow us to identify that the application of financial mathematics is usually perceived as overly complex processes or an exclusive tool for large corporations. Microentrepreneurs tend to carry out management based on intuition and empirical processes that focus mainly on the urgency of daily cash flow, drastically increasing the risk of errors in administrative processes.

The weakness in financial planning observed in the studies analyzed coincides with the regional panorama described by Bullón-Solís et al. (2024), who point out that "in Latin America there is low participation in entrepreneurship research" (p. 53). This lack of high-impact technical literature explains why a gap persists between theory and practice, preventing the local ecosystem from being consolidated as an axis that is truly linked to innovation (12).

Without the support of research that validates optimization and linear programming models, startups in South America will continue to face high mortality rates due to the lack of tools that document and expand proven successful strategies (12).

When contrasting these data with the results of Sarmiento-Tito et al. (2025), it is observed that not taking technical analysis into consideration can have a high opportunity cost; the authors, using a linear regression model, 'identified variables with a high impact on performance, such as intangible technological resources, infrastructure, networks, financial profitability and the disposal of solid waste.' These results validate the importance of intangible assets and financial planning over the mere accumulation of traditional physical assets" (6).

The fact that intangible technological resources present the highest impact coefficient on organizational performance validates the premise that modern competitiveness does not depend only on physical assets, but on the ability to process information for decision making. This aligns with Schumpeter's vision of "creative destruction", where disruptive innovation and the use of predictive models allow new companies to overcome resistance to change and gain ground in volatile markets (Leite et al., 2023).

On the other hand, the application of algebraic limits proposed by Reinoso-Salazar et al. (2024) demonstrates that mathematical modeling is not a merely theoretical exercise, but rather a preventive diagnostic tool, which also provides important tools in administrative processes (11). Cedeño-Ortega (2026) presents significant findings on the possible causes of these difficulties in addressing mathematical processes in businessmen and entrepreneurs who have not had professional training in the administrative or business area. These discoveries are mainly linked to the educational training of students. Accordingly, he points out that teachers in the area do not have sufficient tools to encourage the development of these skills (15).

Identifying that the break-even point is reached after 10 months and one week allows the entrepreneur to move from a culture of survival, which generates uncertainty and does not contemplate adequate responses for strategic planning. As Romero Peña and Escudero Ramírez (2024) point out, the equilibrium point is fundamental because "it represents the price at which the quantity of goods that producers are willing to offer coincides exactly with the quantity that consumers wish to acquire" (p. 121). Without this calculation, the entrepreneur is exposed to setting prices that do not cover their operating costs or that distance them from the real market (20).

Finally, it is considered imperative to address the root of the problem from academic training (18), the study by Coronado-Guaita et al. (2025) reveals that, although high school students in Ecuador excel in identifying social problems, their performance in preparing financial plans is notably low, which represents a basic problem that can significantly affect the perception in relation to the complexity that exists regarding the use of mathematical functions in administrative processes (8).

Through the findings obtained in this research, it was possible to identify the importance and strategic potential of quantitative tools and their effective application in ventures, the findings of authors such as Rivero-Fernández et al. (2025) show that although a high percentage of entrepreneurs make decisions that commit their capital, only a minority of approximately 20% resorts to the technical calculation of profitability (1).

This lack of implementation of mathematical models in small businesses and the results of customer perceptions that are evidenced through different interviews and surveys, allow us to identify that the application of financial mathematics is usually perceived as too complex processes or an exclusive tool for large corporations. Microentrepreneurs tend to carry out management based on intuition and empirical processes that focus mainly on the urgency of daily cash flow, drastically increasing the risk of errors in administrative processes. (1).

In this context, the design of efficient value propositions appropriate to the context of the entrepreneurship system is of fundamental importance (2). On the other hand, the application of algebraic limits proposed by Reinoso-Salazar et al. (2024) demonstrates that mathematical modeling is not a merely theoretical exercise, but rather a preventive diagnostic tool, which also provides important tools in administrative processes (3).

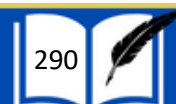
Cedeño-Ortega (2026), presents significant findings on the possible causes of these difficulties in addressing mathematical processes in businessmen and entrepreneurs who have not had professional training in the administrative or business area. These discoveries are mainly linked to the educational training of students, according to this, he points out that teachers in the area do not have sufficient tools to encourage the development of these skills (4).

From the information collected in the applied instruments, the initial findings show a marked tendency towards the operation of business processes empirically, the data show that a significant percentage of owners support decision making in the company intuitively and based on their experience (1). The review of the scientific literature, which has analyzed statistical data of the operational variables, shows that organizations that incorporate structured quantitative tools achieve higher levels of efficiency in their operational processes, particularly, the application of linear programming is directly associated with a more efficient allocation of critical inputs, raw materials and labor (5,6).

In Ecuador, this problem is reflected very markedly in the data from higher education admission exams, where the national average in the logical-mathematical area stood at just 655 points out of 1000. This figure corroborates that traditional pedagogical approaches, based on the rote repetition of abstract processes without a practical or contextualized application, cause a quantitative structural weakness that students carry from secondary education (4).

As direct evidence of this training gap, it has been documented that in the Unified General Baccalaureate (BGU), students achieve outstanding performance when identifying problems in their social environment, with an average of 4.2 out of 5, but they systematically fail when structuring the financial component of their proposals, registering an average of just 2.8 out of 5 (7).

Finally, from a cultural perspective it is observed that there is a tendency to take financial risks, promoting the internalization of personal effort and merit, overestimating intuitive abilities over systematic planning (8). This explains why 73.3% of microentrepreneurs base complex debt or pricing decisions purely on intuition or



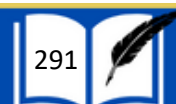
informal advice from family members (1), ignoring that success depends mostly on variables of infrastructure, technology and organizational social capital (9).

Finally, scientific discussion should not be limited to the rigor of numerical data. As Calderón-López and Rodríguez-Romano maintain, entrepreneurship is a dual process where technical stability requires humanistic support. Making effective financial decisions is strongly influenced by emotional intelligence, since factors such as vision (84.1%), creativity (67.3%) and determination (60.2%) are the catalysts that allow the microentrepreneur to face unforeseen situations and overcome the cognitive inertia of fear of risk, allowing mathematical precision to be effectively executed in organizational practice (10).

The scientific literature shows that the intention to undertake a business has a direct and strong relationship with the academic infrastructure and institutional support with a weight of 0.576, which exceeds the influence of subjective family norms located at 0.35 (11). Given this panorama, the development of structured risk models that allow schematizing proactive decisions in uncertain environments becomes a priority, integrating Bayesian decision theory and expected utility as mechanisms to optimize the profitability and adaptive capacity of local entrepreneurship (12).

Given this panorama, the development of structured risk models that allow for schematizing proactive decisions in uncertain environments becomes a priority, integrating Bayesian decision theory and useful mathematical models as mechanisms to optimize the profitability and adaptive capacity of local entrepreneurship. Fear and distrust towards formal methods, mistakenly perceived as exclusive to large corporations or banks, gains more strength in the face of scenarios of social upheaval and economic crises characteristic of the Ecuadorian reality in which formal structuring and the use of more rigorous methods seem distant and inapplicable in the face of the immediacy of daily survival

The existence of weakness in the technical processes linked to financial administration, combined with the factors already mentioned generate a cognitive perception in merchants that financial strategies based on mathematical models are not applicable to small businesses and ventures. The financial sustainability of any business, including those just starting out, depends directly on its ability to identify the break-even point using quantitative tools, such as algebraic limits and linear regression), as this allows strategic management to anticipate risk scenarios, optimize the allocation of technological resources and reduce vulnerability to economic volatility.



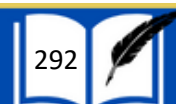
Therefore, it is considered that in order to strengthen business competitiveness, a reform in the teaching-learning processes that integrates mathematical models with the development of soft skills and the entrepreneurial spirit is important and urgent; as well as, incorporating contextualized financial education and the use of business simulations that could transform business management, moving from reactive planning to one based on scientific evidence and real data, as well as the development of both aptitude and attitudinal skills that together allow students to have comprehensive training for their future activities.

## CONCLUSIONS

The incorporation of structured quantitative models is a strategic factor of fundamental importance to mitigate the marked tendency towards empirical and intuitive management that characterizes the microbusiness ecosystem in Ecuador, which fully validates the general research hypothesis. The data obtained from scientific studies carried out on this topic reflect that owners make complex financial decisions regarding debt or pricing intuitively, based on subjective experience or informal advice from family members. Mathematical models based on linear regression, linear programming and predictive analysis offer support that facilitates technical analysis and significantly increases operational efficiency and reduces uncertainty in highly volatile markets. The analysis of economic variables corroborates that the real performance of organizations depends on assessments of specific management determinants, in which intangible technological resources represent the quantitative factor with the greatest explanatory weight on business competitiveness, followed by physical infrastructure and financial profitability.

It is concluded that the practical application of algebraic limits and linear programming responds in a scientific and efficient manner to the objectives of resource optimization, minimization of operating costs and maximum generation of profits in small-scale enterprises. Temporal modeling using algebraic limits acts as an ideal diagnostic and predictive instrument to project viability and determine the financial equilibrium point before the start of physical operations. Which allows us to rigorously anticipate that the monthly net profits will safely exceed the initial accumulated investment estimated at \$1,486.90, starting after 10 months and one week of operation. On the other hand, linear programming demonstrates that, under strict working capital budget constraints, weekly profit maximization is achieved through an optimal distribution of raw materials and labor, evidencing that concentrating production capacity on a high turnover item significantly exceeds the economic returns of traditional empirical diversification.

Furthermore, the urgent need to implement an interdisciplinary teaching model and active learning methodologies in the education system at all levels is confirmed, in order to overcome the severe technical weaknesses that future entrepreneurs have in the field of financial planning. The findings found in the research process confirm the existence of a basic structural weakness due to the predominance of rote and abstract approaches decontextualized from productive reality. Problem-based learning (PBL) and project-based learning (PBL) are pedagogical strategies that can effectively contribute to integrating mathematical knowledge with real business practice, enhancing both hard



quantitative competencies and soft skills essential for the development of a competitive professional profile.

## REFERENCES

1. Neri-Guzmán JC. Universidades públicas en México: análisis del emprendimiento. *Problemas del Desarrollo*. 2024;55(216):141-168. DOI: <https://doi.org/10.22201/iiiec.20078951e.2024.216.70026>
2. Sánchez JD. Ecuación de mercado y segmentación por derivación matemática: un modelo gerencial de toma de decisiones empresariales. *Revista Nacional de Administración*. 2023;13(2). DOI: <https://doi.org/10.22458/rna.v13i2.4478>
3. Varela-Guerrero MI, Santiago-Moreno A, et al. Análisis de la capacidad de los estudiantes en la resolución de identidades trigonométricas. En: Bouza Herrera CN, et al., editores. *Desarrollo y aplicación de modelos y métodos matemáticos para gestión decisional*. La Habana: Pitzilein Books; 2025. p. 68-80. URL: <https://novapraaxisrevista.com/index.php/RENOVA/article/view/17>
4. Colmenero-Fonseca F, Cárcel-Carrasco J, Palomino Bernal JF. Modelo Geoespacial-Matemático Integrado para el Desarrollo Económico Regional Mediante Inteligencia Artificial y Energía Sostenible. *Ciencia Latina*. 2026;10(1):7888-7933. DOI: [https://doi.org/10.37811/cl\\_rcm.v10i1.22870](https://doi.org/10.37811/cl_rcm.v10i1.22870)
5. Rivero-Fernández RR, Velazco-Gonzales AR. Análisis de la toma de decisiones financieras en pequeños emprendimientos. *Revista Minerva*. 2025;6(Número Especial):28-32. DOI: <https://doi.org/10.47460/minerva.v6isp.204>
6. Sarmiento-Tito M., Vintimilla-Álvarez P., Peña-González S.. Modelo Predictivo del Rendimiento de Emprendimientos Asociativos en la Zona 6. *Revista Economía y Política*. 2025;(42):100-120. DOI: <https://doi.org/10.25097/rep.n42.2025.06>
7. Cuellar-Chaves M. Postulados de Emprendimiento Basado en Modelos Teóricos para la Toma de Decisión. *European Public & Social Innovation Review*. 2025;10:1-15. DOI: <https://doi.org/10.31637/epsir-2025-1559>
8. Coronado-Guaita L., Parra-Taboada M., Soria-Chicaiza N., Andrade-García M. Estrategias para el diseño del plan de negocios. *KIRIA*. 2025;3(6):85-99. DOI: <https://doi.org/10.53877/q43yqy55>
9. Moyano J., Taborda F. Aplicación de los modelos matemáticos y estadísticos en la cadena de suministro. Bogotá: Universidad Libre; 2024. (Nota: Esta publicación no cuenta con DOI o URL en tus documentos fuente).
10. Arias-González J, Covinos-Gallardo M. Diseño y metodología de la investigación. *Enfoques Consulting EIRL*. 2021;1(1):66-78. URL: [https://gc.scalahed.com/recursos/files/r161r/w26022w/Arias\\_S2.pdf](https://gc.scalahed.com/recursos/files/r161r/w26022w/Arias_S2.pdf)
11. Reinoso-Salazar S., Pinto-Ibarra J., López-Cobo R., Vallejo-Cueva A. Evaluación de rentabilidad por aplicación de límites algebraicos: Caso de estudio empanadas. *Polo del Conocimiento*. 2024;9(6):2958-2982. DOI: <https://doi.org/10.23857/pc.v9i6.7527>
12. Bullón-Solís O, Méndez-Gutiérrez LL, Gutiérrez-Justo K., Valero-Palomino F.. Estudio bibliométrico del emprendimiento empresarial entre el 2011 y 2021 en Scopus. *Revista San Gregorio*. 2024;1(58):46-55. DOI: <http://dx.doi.org/10.36097/rsan.v1i58.2466>

13. Medina-Beltrán V, Gaitán-Angulo M, et al. Competitividad sostenible un elemento esencial para el emprendimiento. En: Bouza Herrera CN, et al., editores. *Desarrollo y aplicación de modelos y métodos matemáticos para gestión decisional*. La Habana: Pitzilein Books; 2025. p. 54-67. (Nota: Esta publicación de libro no cuenta con DOI o URL en tus documentos fuente).
14. Muñiz-Arana, D. Programación Matemática en la Gestión del Riesgo Financiero Empresarial. *Saber Estratégico Internacional*. 2026;4(1):63-83. DOI: <https://doi.org/10.70577/s.e.v4i1.24>
15. Cedeño-Ortega M. Métodos didácticos y desarrollo de habilidades emprendedoras. Análisis de casos prácticos en la enseñanza de matemáticas [Tesis de grado]. Jipijapa: Universidad Estatal del Sur de Manabí; 2026. URL: <https://repositorio.unesum.edu.ec/handle/53000/9249>
16. Jiménez-García D., Montoya-Restrepo I., Castellanos-Domínguez O.. Modelos de negocio y de gestión orientados al emprendimiento. En: Castellanos OF, editor. *Fundamentos y perspectivas del emprendimiento*. Bogotá: Universidad Nacional de Colombia; 2024. p. 41-68. (Nota: Esta publicación de libro no cuenta con DOI o URL en tus documentos fuente).
17. Viada-González C, Bouza-Herrera C., Allende-Alonso S., et al. Revisión de modelos para el análisis predictivo. En: Bouza Herrera CN, et al., editores. *Desarrollo y aplicación de modelos y métodos matemáticos para gestión decisional*. La Habana: Pitzilein Books; 2025. p. 1-9. (Nota: Esta publicación de capítulo de libro no cuenta con DOI o URL en tus documentos fuente).
18. Salgado, D. Enseñanza por investigación en la universidad: modelización matemática entorno a una pregunta relacionada con la economía. *Unión*. 2024;(71):1-24. URL: <https://revistaunion.org/index.php/UNION/article/view/1634>
19. Farinango-Salazar R., Porres-Requenes J. Análisis de maximización de beneficios mediante el uso del modelo de programación lineal en la empresa "Confecciones Gloria". *RILCO*. 2024;6(57):26-40. URL: <https://dialnet.unirioja.es/servlet/articulo?codigo=9786755>
20. Romero-Peña J., Escudero-Ramírez L. Matemáticas para el emprendedor, caso de estudio Hotdog de pavo. En: Castro Lara RJ, et al., editores. *Estrategias, Modelos y Tendencias*. México: Pitzilein Books; 2024. p. 121-128. (Nota: Esta publicación de capítulo de libro no cuenta con DOI o URL en tus documentos fuente).
21. Calderón-López M, Rodríguez-Romano W. Inteligente Emocional y Emprendimiento en los Negocios. *Estudios y Perspectivas*. 2025;5(1):1273-1294. DOI: <https://doi.org/10.61384/r.c.a.v5i1.911>