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ELABORACIÓN Y EVALUACIÓN NUTRICIONAL DE HOJUELAS A BASE DE CÁSCARA DE PLÁTANO ENRIQUECIDAS CON CUSHURO Y CEBADA

DEVELOPMENT AND NUTRITIONAL EVALUATION OF FLAKES MADE FROM PLANTAIN PEEL ENRICHED WITH CUSHURO AND BARLEY

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RESUMEN: El aprovechamiento de residuos agroindustriales de alto valor nutricional constituye una estrategia clave para el desarrollo de alimentos innovadores, sostenibles y funcionales. En este contexto, la cáscara de plátano (*Musa paradisiaca*), generalmente considerada un desecho, presenta un contenido significativo de fibra, carbohidratos y compuestos bioactivos, mientras que el cushuro (*Nostoc sphaericum*) y la cebada (*Hordeum vulgare*) aportan proteínas, minerales y fibra dietética. El objetivo de este estudio fue desarrollar y evaluar hojuelas elaboradas a partir de cáscara de plátano, enriquecidas con cushuro y cebada, como una alternativa alimentaria de mayor valor nutricional y aceptabilidad sensorial. La investigación tuvo un enfoque experimental, en el que se formularon dos mezclas de hojuelas con diferentes concentraciones de cushuro hidratado y deshidratado, harina de cáscara de plátano y harina de cebada, además de un tratamiento testigo. Los tratamientos fueron evaluados mediante análisis bromatológicos para determinar el contenido de proteínas, carbohidratos, grasas, fibra, cenizas y humedad, así como mediante análisis microbiológicos de aerobios mesófilos, mohos, levaduras y *Escherichia coli*, de acuerdo con la normativa vigente de la INEN. Adicionalmente, se realizó una evaluación sensorial con un panel no entrenado para determinar la aceptabilidad del producto. Los resultados evidenciaron que uno de los tratamientos presentó un perfil nutricional superior, destacándose por su mayor contenido de fibra y carbohidratos, la ausencia de microorganismos patógenos y una aceptabilidad sensorial del 87,9 %. Se concluye que la elaboración de hojuelas a base de cáscara de plátano, enriquecidas con cushuro y cebada, constituye una alternativa viable para el aprovechamiento de residuos agroindustriales y el desarrollo de alimentos con valor agregado.

Palabras clave: *residuos agroindustriales, cáscara de plátano, cushuro, cebada, hojuelas*

ABSTRACT: The valorization of agroindustrial residues with high nutritional potential represents a key strategy for the development of innovative, sustainable, and functional foods. In this context, plantain peel (*Musa paradisiaca*), commonly regarded as a waste product, contains substantial amounts of dietary fiber, carbohydrates, and bioactive compounds. At the same time, cushuro (*Nostoc sphaericum*) and barley (*Hordeum vulgare*) contribute proteins, minerals, and dietary fiber. The objective of this study was to develop and evaluate flakes made from plantain peel, enriched with cushuro and

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barley, as an alternative food product with improved nutritional value and acceptable sensory attributes. An experimental approach was used in which two flake formulations were developed, differing in the proportions of hydrated and dehydrated cushuro, plantain peel flour, and barley flour, and a control treatment was included. Bromatological analyses were conducted to determine protein, carbohydrate, fat, fiber, ash, and moisture contents, and microbiological analyses were performed for mesophilic aerobic bacteria, molds, yeasts, and *Escherichia coli*, in accordance with current INEN standards. In addition, a sensory evaluation was conducted using an untrained panel to assess product acceptability. The results showed that one treatment exhibited a superior nutritional profile, characterized by higher fiber and carbohydrate contents, absence of pathogenic microorganisms, and a sensory acceptability of 87.9%. It is concluded that the production of flakes based on plantain peel enriched with cushuro and barley is a viable alternative for the utilization of agroindustrial residues and the development of value-added food products.

Keywords: *agroindustrial residues, plantain peel, cushuro, barley, flakes*

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INTRODUCTION

During food processing operations, various residues and by-products are generated that, in many cases, could be destined for animal or human consumption or for industrial applications, generating additional economic value (1). Nevertheless, their potential as raw materials is often underestimated owing to the lack of research that allows their chemical and nutritional composition to be characterized, as well as to the scarcity of adequate techniques for their efficient processing and utilization (2). In this context, fruit peels present particular physical, chemical, and biological characteristics that must be evaluated in order to determine their viability as functional ingredients in the food industry (3).

One of the principal applications of these agroindustrial residues is the production of flours, which can be incorporated as ingredients in food products with the purpose of increasing their nutritional value and improving the technological and functional properties of processed foods, such as water-holding capacity, texture, and dietary fiber content (4).

Among these residues, plantain peel stands out for its abundance and nutritional composition. It is estimated that worldwide production of plantain peel reaches approximately 36 million tons, which generate unfavorable environmental impacts when discarded without prior treatment (5).

In some cases, these peels are used as organic fertilizer or as animal feed; however, their potential for human food applications remains underexploited (6). In the Ecuadorian context, this problem acquires relevance owing to the high banana production concentrated in the coastal region. Provinces such as Guayas and Los Ríos contribute a

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significant share to national banana production, which implies a considerable generation of residues associated not only with processing but also with consumption of the fruit (7).

Considering that the peel represents between 30 and 40 % of the total weight of the plantain, the volume of this residue reaches magnitudes that, in the absence of valorization strategies, contribute to the accumulation of organic waste, emission of odors, proliferation of vectors, and higher costs (8,9). In this sense, the utilization of plantain peel as a food ingredient constitutes a viable alternative for mitigating its environmental impact and promoting the circular economy at the regional level.

Despite the wide availability of cereals on the market, the majority of these products are manufactured from traditional cereals such as maize, wheat, or oats, with a high carbohydrate content and a limited contribution of dietary fiber and of proteins of natural origin (10). Various investigations address independently the use of plantain peel as a source of fiber, cushuro as a functional ingredient of high nutritional value, and barley for its β-glucan content; however, these approaches have been developed in isolation and in food matrices different from breakfast cereals (11–13).

In this sense, there exists a knowledge gap regarding the joint integration of these three components in a flake-type product that would make it possible not only to elevate an agroindustrial residue but also to incorporate a non-conventional protein source and a functional cereal in a single formulation. Therefore, the aim is, through the development of flakes based on plantain peel enriched with cushuro and barley, to evaluate in an integral manner their nutritional profile, microbiological safety, and sensory acceptability, as an alternative to conventional cereals.

Among the components of plantain peel are found dietary fiber, carbohydrates, amino acids, polyunsaturated fatty acids such as linoleic acid (Omega-6) and α-linolenic acid (Omega-3), and bioactive compounds associated with health and the prevention of chronic diseases (6). These characteristics make it an innovative raw material for the development of food products.

In the search for non-conventional food sources of high nutritional value, algae and cyanobacteria have acquired special interest. The cyanobacterium Nostoc sphaericum, known as cushuro, is a traditional resource of the Andean region that is characterized by its elevated content of proteins, carbohydrates, fatty acids, and essential minerals such as calcium, iron, phosphorus, sodium, and potassium (14).

In addition, it contains all the essential amino acids and the B-complex vitamins, which positions it as an ingredient with high potential for improving the nutritional status of vulnerable populations, especially children under five years of age, and contributes to the prevention of anemia and malnutrition (15).

On the other hand, among cereals, barley (Hordeum vulgare) has aroused growing interest owing to its capacity to improve the nutritional profile of various foods, especially in bakery and extrusion products (16). Barley is rich in soluble fibers and β-glucans, compounds associated with cholesterol reduction and the improvement of cardiovascular health. Likewise, it constitutes an important source of phytochemicals, such as phenolic compounds, flavonoids, and tocopherols, which present antioxidant activity and contribute to the prevention of diseases related to oxidative stress (17).

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Economic development, population growth, and the growing concern for consumer health have driven new trends in the food industry, oriented toward the development of healthier, more sustainable, and easily consumable products (16). These trends are oriented toward the utilization of industrial residues with nutritional value that, in turn, make it possible to improve the environment. In this context, the present study evaluates the combination of plantain peel flour (Musa paradisiaca), cushuro (Nostoc sphaericum), and barley (Hordeum vulgare) in the elaboration of flakes with an elevated nutritional profile, as a viable food alternative for the utilization of agroindustrial residues through conservation and transformation operations.

The continuous interest in formulating products with an excellent nutritional profile and good sensory acceptability led to the development and evaluation of flakes elaborated from plantain peel (Musa paradisiaca) enriched with cushuro (Nostoc sphaericum) and barley (Hordeum vulgare), with the objective that the incorporation of these ingredients would make it possible to obtain a product with greater nutritional value and superior acceptability relative to a conventional cereal, contributing to the utilization of agroindustrial residues and to the development of value-added foods.

MATERIALS AND METHODS

Preparation of raw materials

For the elaboration of the flakes, dehydrated cushuro flour (Nostoc sphaericum), plantain peel flour (Musa paradisiaca), and barley flour (Hordeum vulgare) were employed, selected for their availability, nutritional value, and potential for application in the development of functional foods. All raw materials were subjected to cleaning, disinfection, and conditioning processes in order to guarantee their safety and homogeneity before incorporation into the formulations.

The cushuro was washed with water and subsequently disinfected with a sodium hypochlorite solution. Next, it was subjected to a dehydration process in an oven at 50 °C for five days, with the objective of reducing moisture content and facilitating its conservation and milling. Once dehydrated, the material was ground in a manual mill until a flour of homogeneous particle size was obtained, suitable for incorporation into the flake formulation.

The plantain peels were selected manually, discarding those with physical damage or signs of deterioration. Subsequently, they were washed with potable water and disinfected with a sodium hypochlorite solution. With the purpose of inactivating enzymes that could affect the stability of the final product, the peels were subjected to blanching at 95 °C for 5 minutes. Once blanched, they were dehydrated in a food dehydrator at 57 °C for eight hours, until a dry raw material was obtained, which was ground in a mill until a flour of uniform particle size was obtained.

The barley was previously subjected to a cleaning process to eliminate impurities. Subsequently, the grains were disinfected with a sodium hypochlorite solution and dried in a food dehydrator at 50 °C for 10 hours. Once dry, the grains were ground in a roller mill until a fine flour was obtained, suitable for incorporation into the formulations.

Obtaining hydrated cushuro

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The cushuro used in its hydrated form was previously inspected to verify its quality and physical state. A washing with potable water was performed, followed by a disinfection process with a sodium hypochlorite solution, in order to eliminate possible impurities, residues, or microbiological contaminants. Subsequently, the cushuro was maintained under adequate hydration conditions until its incorporation into the corresponding formulations.

Elaboration of the flakes

Four treatments were formulated with different proportions of hydrated and dehydrated cushuro, plantain peel flour, and barley flour (Table 1). The first formulation included 10 % cushuro, 20 % plantain peel flour, and 8 % refined sugar. The second formulation was composed of 5 % cushuro, 8 % barley flour, and 24 % plantain peel flour. In both formulations, common ingredients were incorporated: 4 % powdered milk, 6 % cocoa, 2 % vegetable colorant, and 42 % water, in order to improve the sensory and technological characteristics of the final product.

All ingredients were mixed in an electric mixer until a homogeneous mass of uniform consistency was obtained. The resulting mass was subjected to rolling with rollers to obtain thin and uniform sheets. Subsequently, the sheets were baked at 160 °C for 10 minutes. After cooking, the flakes were allowed to cool until room temperature was reached, which permitted them to develop a characteristic crispy texture. Finally, the flakes were packaged in plastic bags and stored at a temperature between 18 and 24 °C until analysis (Figure 1).

Figure 1. Flow diagram of the flake elaboration process.

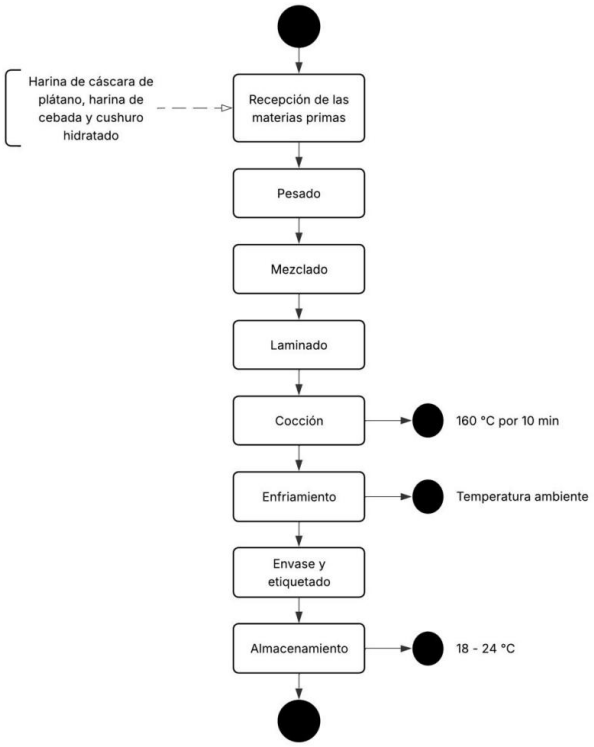

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Table 1. Formulation of the flakes.

Treatment	Cushuro (%)	Plantain peel flour (%)	Barley flour (%)	Sugar (%)	Other ingredients* (%)
T1	10 (dehydrated)	20	–	8	62
T2	5 (dehydrated)	24	8	–	63
T3	10 (hydrated)	20	–	8	62
T4	5 (hydrated)	24	8	–	63

*Other ingredients: powdered milk (4 %), cocoa (6 %), vegetable colorant (2 %), and water (42 %).

Bromatological analyses

The bromatological analyses of the flakes were performed in accordance with Ecuadorian standard INEN 2570:2011. Carbohydrate content was determined by the 3,5-dinitrosalicylic acid (DNS) method; protein content by the Bradford spectrophotometric method; and fat content by extraction and spectrophotometric quantification. Ash content was determined according to standard NTE INEN 520:2012, while crude fiber content was evaluated according to standard NTE INEN 522:2013. All analyses were performed in triplicate.

Microbiological analyses

The microbiological quality of the flakes was evaluated by determination of mesophilic aerobes, molds, yeasts, and Escherichia coli, in accordance with the methods established in standards NTE INEN 1529-5, NTE INEN 1529-10, and NTE INEN 1529-7, respectively, with the objective of verifying the safety of the final product.

Statistical analysis

The present project was evaluated by means of a statistical analysis of the completely randomized design (CRD), and the data were analyzed by analysis of variance (ANOVA) with the Dunn-Bonferroni test, at a significance level of 5 %. The tests were performed with the statistical program JASP.

Sensory analysis

The sensory evaluation of the flakes was performed with an untrained panel of 100 persons, evaluating the parameters of color, flavor, odor, and texture, by means of a five-point hedonic scale, where 1 corresponded to “dislike very much”; 2, “dislike moderately”; 3, “neither like nor dislike”; 4, “like moderately”; and 5, “like very much.”

RESULTS

Results of the bromatological analysis

The bromatological analyses performed on the flakes elaborated from plantain peel, cushuro, and barley evidenced differences in the nutritional profile among the treatments evaluated, associated mainly with the proportion and form of incorporation of cushuro (hydrated and dehydrated) and of the plant flours used (Table 2). In general, all treatments presented nutritional values consistent with those of cereal-type products, standing out for their content of carbohydrates and dietary fiber.

Table 2. Bromatological composition of the elaborated flakes (%).

Treatment	Carbohydrates (%)	Proteins (%)	Fats (%)	Fiber (%)	Ash (%)	Moisture (%)
T1	78.42 ± 0.89a	1.21 ± 0.18ab	0.45 ± 0.09a	13.85 ± 0.42a	0.18 ± 0.04a	2.34 ± 0.07a
T2	74.63 ± 1.12a	1.08 ± 0.21ab	0.48 ± 0.11a	12.46 ± 0.38a	0.22 ± 0.05a	2.91 ± 0.10a
T3	**85.31 ± 11.64a**	**1.94 ± 0.50b**	**0.42 ± 0.10a**	**16.97 ± 0.35b**	**0.13 ± 0.06a**	**1.87 ± 0.06a**

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T4	80.15 ± 1.05a	1.36 ± 0.27a	0.44 ± 0.08a	14.62 ± 0.40a	0.16 ± 0.03a	2.10 ± 0.08a

*Values expressed as mean ± standard deviation (n = 3). Different letters indicate significant difference according to the Dunn-Bonferroni test $p < 0.05$.

Carbohydrate content was the majority component in all formulations analyzed. Treatment T3 presented the highest value, reaching 85.31 ± 11.64 %, which is attributed to the combination of plantain peel flour and barley, ingredients recognized for their high contribution of structural and non-structural polysaccharides. The other treatments showed lower values, although within ranges comparable to those of commercial cereals. No significant differences were observed among treatments ($p > 0.05$).

The results evidenced an increase in protein content in the treatments that incorporated cushuro, especially in its dehydrated form. Treatment T3 presented the most favorable nutritional profile (Table 2), standing out for its higher fiber and carbohydrate content. These values are moderate in comparison with those of fortified cereals; however, they represent a nutritional improvement relative to products elaborated exclusively with conventional flours. Analysis of variance indicated significant differences among T3, T4, and the control treatment ($p < 0.05$).

All treatments presented a low fat content, with values that oscillated between 0.42 ± 0.10 % and 0.48 ± 0.11 %, which is favorable from the nutritional point of view and for product stability. Similarly, ash content was reduced, with values close to 0.13 ± 0.06 %, which indicates that the mineral composition does not exceed the limits established for this type of product. The treatments were significantly similar ($p > 0.05$).

Treatment T3 presented the highest crude fiber content, with a value of 16.97 ± 0.35 %, and was the only one that differed significantly from the others ($p < 0.05$). This result is related directly to the use of plantain peel flour, recognized for its elevated dietary fiber content. Moisture content was minimal in all treatments, with treatment T3 standing out with a value of 1.87 ± 0.06 %, which favored microbiological stability and the shelf life of the product. No significant differences were observed among the treatments evaluated ($p > 0.05$).

Results of the microbiological analysis

The results of the microbiological analysis demonstrated that all flake formulations complied with the requirements of Ecuadorian standard NTE INEN 2570:2011.

Table 3. Microbiological evaluation of the flakes.

Microbiological analysis	Standard applied	Unit	Result	Permitted limit
Mesophilic aerobes	NTE INEN 1529-5	CFU/g	< 10	$\leq 1 \times 10^5$
Molds and yeasts	NTE INEN 1529-10	CFU/g	< 10	$\leq 1 \times 10^3$
Escherichia coli	NTE INEN 1529-7	CFU/g	Absence	Absence

*Source: Own elaboration based on the microbiological reports according to standards NTE INEN 1529-5, NTE INEN 1529-10, and NTE INEN 1529-7.

The presence of mesophilic aerobes, molds, yeasts, or Escherichia coli was not detected in any of the treatments, which confirms the microbiological safety of the final product and the effectiveness of the cleaning, dehydration, and cooking processes applied during its preparation.

Results of the sensory evaluation

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In the sensory evaluation, performed by means of a 5-point hedonic scale, differences were observed among the treatments evaluated. Treatment T3 presented the most consistent performance and the highest global acceptance. When analyzing the attributes individually, color was the best valued in T3, followed by T4, while T1 and T2 registered the lowest means, locating themselves between a neutral perception and moderate acceptance. Regarding odor, T3 again stood out with the highest average score, while the other treatments showed intermediate values, which indicates stable, although less marked, acceptance. Texture was the attribute with the greatest contrast among treatments, since T3 reached the highest score, while T1 and, especially, T2 presented the lowest scores, which suggests that this attribute influenced in an important manner the lower acceptability of those treatments. Finally, in the flavor attribute, T3 obtained the highest mean, followed by T4, while T1 and T2 showed lower ratings, which confirms that the sensory differences, particularly in flavor and texture, influenced the observed global preference.

The results indicate that, by means of the incorporation of cushuro, plantain peel, and barley in adequate proportions, flakes with sensory characteristics acceptable to the consumer can be obtained, comparable to commercial cereals but with a better nutritional profile.

DISCUSSION

The results obtained in the present study confirm the potential of plantain peel, cushuro, and barley as viable raw materials for the development of innovative food products with added nutritional value, as has been reported in previous investigations on the utilization of agroindustrial residues and the development of functional foods (18). The bromatological profile of the elaborated flakes evidenced that the adequate combination of these ingredients makes it possible to obtain a product with characteristics comparable to those of conventional cereals, but with a greater contribution of fiber and of compounds of nutritional interest (19,20).

The elevated carbohydrate content observed in the treatments analyzed, particularly in treatment T3, is in concordance with previous studies that report high levels of polysaccharides in plantain peel and in barley, which contribute to the energy value of the product and to its functionality as a food of everyday consumption (21,22). Investigations carried out by Pilco et al. (2018) and Mohd et al. (2022) have indicated that plantain peel constitutes an important source of structural carbohydrates and of dietary fiber, which supports the results obtained in this study.

Regarding crude fiber content, the highest values recorded in treatment T3 can be attributed mainly to the use of plantain peel flour, an ingredient recognized for its high dietary fiber content. Similar results have been reported in studies in which plantain peel flour has been incorporated into bakery products and cereals, evidencing significant improvements in fiber content and in the functional properties of the final food (23,24). This aspect is relevant from the nutritional point of view, given that adequate consumption of dietary fiber is associated with benefits for gastrointestinal health and the prevention of chronic diseases.

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The protein content observed in the flakes, although moderate, reflects the contribution of cushuro, a cyanobacterium of recognized nutritional value. Various authors have reported elevated protein contents in Nostoc sphaericum, highlighting its potential as an alternative source of protein of non-conventional origin (25,26). Although the protein values obtained in this study are lower than those reported for highly fortified products, their inclusion contributes to diversifying the nutritional profile of the product and to improving its quality relative to cereals elaborated exclusively from refined flours, as has also been evidenced in formulations that incorporate cushuro into food products (27,28).

The low fat content observed in all formulations constitutes a favorable characteristic of the product, since it allows its classification as a food with reduced lipid contribution, in accordance with current consumption trends oriented toward healthier foods. Previous studies have indicated that products elaborated from agroindustrial residues and plant flours tend to present similar fat contents, which coincides with the results obtained in the present investigation (6,29).

From the microbiological point of view, the absence of pathogenic microorganisms in the flakes confirms the efficacy of the cleaning, dehydration, and cooking processes. These results are consistent with investigations in which agroindustrial residues are employed as raw material, demonstrating that, under adequate processing conditions, it is possible to obtain products suitable for human consumption.

The sensory evaluation showed acceptance of the flakes, with treatment T3 standing out as that of greatest preference. This could have been due to the balance reached among the ingredients, which made it possible to obtain adequate sensory characteristics in terms of flavor, texture, and appearance. Results similar to those of the present investigation have been reported in studies that incorporate non-conventional flours into cereal-type products, with formulation and ingredient proportion being determining factors in consumer acceptance (20,28).

The greater sensory acceptance observed in treatment T3 can be explained in function of the concentration and form of incorporation of the ingredients employed. In this treatment, the use of cushuro in its hydrated form and in greater proportion contributed to a more homogeneous matrix, which favored the perception of flavor and texture relative to the treatments with dehydrated cushuro.

Likewise, the balance of plantain peel flour employed in T3 made it possible to increase fiber content without generating negative effects on color or sensory acceptability, in contrast to the formulations with higher proportions of this ingredient. On the other hand, the absence of barley flour in T3 could have favored a lighter and crispier texture, while its inclusion in other treatments was associated with a more compact structure, perceived less favorably by the panelists. Taken together, these results evidence that the trend observed in the sensory data is closely related to the concentration and form of incorporation of each ingredient.

The results of the present study demonstrate the viability of the utilization of residues such as plantain peel, combined with raw materials of high nutritional value such as cushuro and barley, for the development of functional foods, and provide scientific evidence that supports the implementation of the circular economy in the food sector

and open the possibility of carrying out future investigations that seek to optimize the formulations and evaluate their long-term nutritional effect.

CONCLUSIONS

The elaboration of flakes from plantain peel (Musa paradisiaca) enriched with cushuro (Nostoc sphaericum) and barley (Hordeum vulgare) proved to be a viable alternative for the utilization of agroindustrial residues, making it possible to obtain a product with an adequate nutritional profile and characteristics comparable to those of conventional cereals. The incorporation of these ingredients contributed mainly to the increase in fiber and carbohydrate content, as well as to the nutritional diversification of the product, without negatively affecting its safety or sensory properties.

The bromatological analyses demonstrated that the formulation that combined 20 % plantain peel flour and 10 % hydrated cushuro presented a superior nutritional profile, standing out for its higher fiber content and its low fat content, which makes it a healthy food. Likewise, the microbiological results confirmed that all formulations complied with the limits established in current Ecuadorian regulations, which demonstrates that the cleaning, dehydration, and cooking processes proved effective for guaranteeing a final product suitable for consumption.

The sensory evaluation made it possible to establish that the flakes were well received by consumers. This result demonstrates that the use of non-conventional ingredients, such as cushuro and plantain peel, can be integrated effectively into cereal flakes without compromising their acceptance. Taken together, the results of the present study demonstrate the potential of these ingredients for the development of innovative functional foods and orient future investigations aimed at the optimization of products.

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DECLARATION OF INTEREST

The authors declare that there exists no financial, academic, or personal conflict of interest that has influenced the development, the analysis of the results, or the writing of the present scientific article.

AUTHOR CONTRIBUTIONS

The principal author was responsible for the experimental design, for the elaboration of the product, for the execution of the bromatological and microbiological analyses, as well as for the collection and analysis of the data. The academic tutor contributed to the

methodological supervision of the study, to the critical revision of the content, and to the scientific orientation during the development of the research. All authors participated in the writing, the revision, and the final approval of the manuscript.

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