

## RIESGO ASOCIADO A MICOTOXINAS EN SUBPRODUCTOS AGROINDUSTRIALES REUTILIZADOS PARA ALIMENTACIÓN HUMANA

### RISK ASSOCIATED WITH MYCOTOXINS IN AGROINDUSTRIAL BY-PRODUCTS REUSED FOR HUMAN FOOD

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**RESUMEN:** Las micotoxinas son metabolitos secundarios tóxicos producidos por hongos filamentosos que contaminan una amplia variedad de alimentos y subproductos agroindustriales. Su elevada estabilidad les permite persistir a lo largo de la cadena de producción, lo que representa un desafío para la seguridad alimentaria, especialmente en países con condiciones agroclimáticas favorables para su proliferación. Es así como la reutilización de subproductos para alimentación humana, en el marco de la economía circular, puede suponer un riesgo para la salud pública cuando estos contienen micotoxinas en niveles superiores a los límites permitidos por organismos internacionales. El objetivo principal es evaluar, los riesgos para la salud humana asociados a la presencia de micotoxinas en subproductos agroindustriales reutilizados para alimentación humana. Se realizó una revisión bibliográfica sistemática siguiendo el protocolo PRISMA, abarcando estudios publicados en bases de datos indexadas (SCOPUS, PubMed, Web of Science y ScienceDirect), donde se seleccionaron artículos que cuantificaban micotoxinas en subproductos agroindustriales y evaluaban su riesgo para el consumo humano. Los hallazgos evidencian que los subproductos analizados mostraron prevalencias de contaminación entre el 40 % y el 100 %, con concentraciones que en varios casos superaron los límites de la Unión Europea. En Ecuador, el maíz y la cáscara de cacao fueron las matrices de mayor preocupación, presentando fumonisinas y aflatoxinas en niveles críticos. La co-contaminación y los efectos sinérgicos entre toxinas fueron frecuentes, incrementando el riesgo sanitario. En conclusión, la elevada prevalencia y niveles de micotoxinas en subproductos agroindustriales, particularmente en Ecuador, representan un riesgo significativo para la salud pública y la competitividad en mercados internacionales. Se requiere el fortalecimiento de los sistemas de control, monitoreo y manejo postcosecha para mitigar este problema.

**Palabras clave:** Micotoxinas, seguridad alimentaria, toxinas, riesgo sanitario, control de calidad

**ABSTRACT:** Mycotoxins are toxic secondary metabolites produced by filamentous fungi that contaminate a wide variety of foods and agro-industrial by-products. Their high stability allows them to persist throughout the production chain, posing a challenge to food safety, especially in countries with agroclimatic conditions favorable to their proliferation. Thus, the reuse of by-products for human consumption, within the framework of the circular economy, can pose a risk to public health when they contain

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mycotoxins at levels above the limits permitted by international organizations. The main objective is to assess the risks to human health associated with the presence of mycotoxins in agro-industrial by-products reused for human consumption. A systematic literature review was conducted following the PRISMA protocol, covering studies published in indexed databases (SCOPUS, PubMed, Web of Science, and ScienceDirect), where articles that quantified mycotoxins in agro-industrial by-products and assessed their risk for human consumption were selected. The findings show that the by-products analyzed had contamination rates ranging from 40% to 100%, with concentrations that in several cases exceeded European Union limits. In Ecuador, corn and cocoa husks were the matrices of greatest concern, with critical levels of fumonisins and aflatoxins. Co-contamination and synergistic effects between toxins were frequent, increasing the health risk. In conclusion, the high prevalence and levels of mycotoxins in agro-industrial by-products, particularly in Ecuador, represent a significant risk to public health and competitiveness in international markets. Strengthening control, monitoring, and post-harvest management systems is required to mitigate this problem.

**Keywords:** Mycotoxins, food safety, toxins, health risk, quality control

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## INTRODUCTION

Mycotoxins are toxic secondary metabolites produced mainly by filamentous fungi of the genera *Aspergillus*, *Fusarium*, *Penicillium*, and *Alternaria* (1). These toxins represent one of the most persistent problems in global food safety due to their high physico-chemical stability, which allows them to resist processes such as drying, milling, cooking, and prolonged storage, favoring their permanence in food products and by-products even under control conditions (2).

In the context of the circular economy, the valorization of agroindustrial by-products such as dried distiller grains with solubles (DDGS), brewers' spent grain, beet pulp, cocoa husk, and grape pomace has been positioned as a strategy that promotes the integral utilization of raw materials, reduces residues, and contributes economic benefits (3). However, the reuse of these materials for human consumption presents a critical challenge: the potential accumulation of mycotoxins at levels that exceed the maximum limits established for primary foods by regulatory organisms such as the European Union (EU) and the Codex Alimentarius.

The mycotoxins of greatest sanitary impact include:

- Aflatoxins (AFs): Group 1 carcinogens according to the IARC, with hepatotoxic and immunosuppressive effects.
- Ochratoxin A (OTA): Associated with nephrotoxicity and possible neurotoxicity.

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- Fumonisin (FBs): Related to hepatorenal alterations, neural tube defects, and neurodevelopmental alterations.
- Zearalenone (ZEN): With estrogenic activity and effects on fertility.
- Trichothecenes such as deoxynivalenol (DON): which provoke immunosuppression and gastrointestinal disturbances (4).

At the world scale, it is estimated that between 60% and 80% of the crops destined to human feeding are contaminated with mycotoxins, and that around 20% surpass the established legal limits. In agroindustrial by-products, the situation is aggravated by the high frequency of contamination, where two or more mycotoxins act jointly, generating additive or synergistic interactions that intensify their toxicity (5).

In Ecuador, the problem takes on special relevance due to the importance of crops such as maize, rice, cocoa, and coffee, which are susceptible to contamination by mycotoxins both in the field and in storage. Recent investigations have documented the presence of aflatoxins, fumonisins, and ochratoxin A in grains and flours destined to internal consumption, as well as in processed products based on cereals (6). Factors such as the elevated environmental humidity in tropical and subtropical regions, the deficiencies in storage infrastructure, and the absence of a continuous monitoring system contribute to the persistence of the problem.

In the Ecuadorian agroindustrial sector, the reuse of by-products is an extended practice, especially in artisanal and semi-industrial production. Brewers' spent grain, wheat and maize bran, as well as cocoa by-products, are incorporated with frequency in foods and supplements, many times without a previous evaluation of the content of mycotoxins (7). This poses risks not only for the health of the consumers, but also for the competitiveness of the country in international markets that impose strict standards of safety. The sanitary implications range from acute episodes (vomiting, diarrhea, fever, and hepatic damage) to chronic effects such as cancer, immunosuppression, endocrine alterations, reproductive problems, and delay of infantile growth (8). Additionally, the chronic exposure to mycotoxins can compromise the national food security and occasion economic losses by the rejection of contaminated exports.

Before this panorama, the management of the risk associated with mycotoxins in agroindustrial by-products requires an integral approach that contemplates the origin of the raw material, the postharvest practices, the storage conditions, the humidity, and the microbial load, as well as the implementation of systems of control and regulation specific for this type of products. For that reason the objective is to evaluate the risks for human health derived from the presence of mycotoxins in agroindustrial by-products reused for human feeding.

## MATERIALS AND METHODS

Research method: A systematic bibliographic review was carried out following the directives of the PRISMA 2020 protocol, integrating quantitative and qualitative data. The search included publications between the years 2000 and 2025, prioritizing studies with methodological rigor and peer review.

Population or sample: The documentary sample was composed of 32 articles reviewed to full text, of which 16 fulfilled with the criteria of inclusion, which were:

- Quantification of mycotoxins in agroindustrial by-products
- Data of prevalence and concentration expressed in standardized units ( $\mu\text{g/kg}$  or  $\text{mg/kg}$ )
- Analysis of the risk associated with human health.

Environment: The study compiled information originating from investigations carried out in America, Europe, Asia, and Africa, covering agroindustrial industries of bioethanol (DDGS), brewing (brewers' spent grain), sugar (beet pulp), wine (grape pomace), and cocoa (cocoa husk). For the Ecuadorian context, data of investigations of the INIAP, national universities, and technical reports of the Ministry of Agriculture and Livestock (MAG) were included, with special attention to the Coast region, where the agroclimatic conditions favor the proliferation of mycotoxigenic fungi.

Measurements: From each study data were extracted about:

- Mean and maximum concentrations of regulated mycotoxins
- Percentage of positive samples by by-product
- Analytical methods utilized

Statistical analysis: Descriptive statistics were applied to summarize prevalences and levels of concentration. The data were normalized for comparability.

## RESULTS

The analysis of the 16 included publications, originating from international databases and from recent Ecuadorian studies, evidenced that the agroindustrial by-products are matrices of high risk regarding contamination by mycotoxins. In the majority of the cases, the detected concentrations surpassed the Maximum Residue Limits (MRLs) established by the European Union (EU) and the Codex Alimentarius, which implies potential risks for human health and the loss of competitiveness in international markets (9), (10).

In Ecuador, the agroclimatic conditions of the Coast region (high relative humidity, temperatures between 24–32 °C, and intense rains) and the lack of adequate infrastructure for drying and storage favor the proliferation of mycotoxigenic fungi (*Aspergillus* spp., *Fusarium* spp., *Penicillium* spp.) (11). This is reflected in the elevated prevalence reported in maize, cocoa, rice, and their by-products.

### Prevalence by type of by-product

**Table 1. Prevalence by type of by-product.**

| Agroindustrial by-product     | Global prevalence (%) | Main mycotoxins    | Average levels                                                                             | Maximum reported levels | Observations in Ecuador                                               |
|-------------------------------|-----------------------|--------------------|--------------------------------------------------------------------------------------------|-------------------------|-----------------------------------------------------------------------|
| Dried distiller grains (DDGS) | 70–100                | FB1, FB2, ZEN, DON | FBs: 1.0–3.0 $\text{mg/kg}$ ; ZEN: 80–167.6 $\mu\text{g/kg}$ ; DON: 1.5–3.0 $\text{mg/kg}$ | FBs: 5.0 $\text{mg/kg}$ | In Ecuador FB1 > 4.5 $\text{mg/kg}$ has been detected in Coast maize; |

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|                            |       |                    |                                   |                                |                                                                                                                                                                                                                     |
|----------------------------|-------|--------------------|-----------------------------------|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                            |       |                    |                                   |                                | frequent use in feed generates risk of cross-contamination.                                                                                                                                                         |
| Brewers' spent grain (BSG) | 60–85 | DON, ZEN, FBs, AFs | DON and ZEN > 50% of the UE limit | DON: 1.2 mg/kg; ZEN: 150 µg/kg | National studies report high fungal load in artisanal breweries that store in jute sacks without humidity control.                                                                                                  |
| Cocoa husk                 | 65–90 | AFB1, AFG1         | 1.0–5.5 µg/kg                     | 8.0 µg/kg                      | In provinces such as Los Ríos and Esmeraldas, post-fermentation humidity > 12% and inadequate drying favor elevated levels; export rejections for surpassing UE limits ( $\geq 5$ µg/kg AFB1) have been documented. |
| Grape pomace               | 60–70 | OTA, ENNs, BEA     | OTA: 2–4 µg/kg                    | 5.0 µg/kg                      | Without ample data in Ecuador; potential risk in emerging wineries in the central Sierra.                                                                                                                           |
| Beet pulp                  | 40–55 | ZEN, DON           | ZEN: 120 µg/kg; DON: 0.8 mg/kg    | 2.0 mg/kg                      | Limited production in the Sierra, but its inclusion in artisanal foods can be an underestimated risk.                                                                                                               |

Source: (12)

Interpretation: Table 1 indicates that the most concerning prevalence in Ecuador is registered in cocoa and maize. The cocoa husk, which represents a by-product of export and of internal use, shows an incidence superior to 60% for aflatoxins, which constitutes a direct risk of hepatocarcinogenesis. In the maize, the fumonisins are predominant, affecting both the raw material and the by-products reused in foods.

### Levels and estimated risk

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The models of food exposure, adjusted with data of consumption and average body weight for the Ecuadorian population (INEN and MSP), show that:

- Fumonisin (FBs): The TDI (2 µg/kg bw/day) is exceeded in 45% of the scenarios that include contaminated maize and DDGS.
- Deoxynivalenol (DON): The TDI (1 µg/kg bw/day) is surpassed in 38% of the simulated diets that contain brewers' spent grain or contaminated maize.
- Aflatoxin B1 (AFB1): Although it does not have TDI for being a genotoxic carcinogen, the MOE calculated for cocoa husk in Ecuador was < 10,000 in all the scenarios, which indicates high risk of hepatic cancer according to EFSA.

**Table 2. Levels and estimated risk.**

| Mycotoxin | TDI (µg/kg bw/day) | % of scenarios that exceed TDI (Ecuador) | Critical products    |
|-----------|--------------------|------------------------------------------|----------------------|
| FBs       | 2.0                | 45                                       | Maize, DDGS          |
| DON       | 1.0                | 38                                       | Brewers' spent grain |
| AFB1      | N/A (carcinogen)   | MOE < 10,000 in 100% of cases            | Cocoa husk           |

Source: (13)

Interpretation: In Table 2, it is evidenced that the habitual consumption of maize and derivatives, summed to the reuse of by-products such as the DDGS and the spent grain, increments the risk of chronic exposure to FBs and DON in Ecuador. The case of the cocoa is particularly grave, since even low concentrations of AFB1 represent an elevated risk by its carcinogenic potency.

### Co-contamination and toxic synergy

The co-contamination was a constant in the analyzed by-products:

- FBs + DON in DDGS and ground maize (prevalence > 70%).
- AFB1 + OTA in cocoa stored in humid warehouses for more than three months.
- ZEN + ENNs in beet pulp and brewers' spent grain.

The Ecuadorian studies indicate that the combinations FB1 + DON and AFB1 + OTA have synergistic effects, affecting the intestinal integrity and provoking immunosuppression, even when the individual concentrations are below their respective limits.

## DISCUSSION

The results obtained in this review show that the presence of mycotoxins in agroindustrial by-products reused for human feeding is a recurrent problem at the global level and, in particular, in Ecuador. The high prevalence found in matrices such as DDGS, brewers' spent grain, cocoa husk, and maize coincides with what is reported by authors such as (14) and (15), who highlight that the storage conditions, the relative humidity, and the environmental temperature are critical factors for the proliferation of mycotoxigenic fungi.

In the Ecuadorian context, the provinces of the Coast especially Los Ríos, Manabí, and Guayas present agroclimatic conditions favorable for *Aspergillus* spp. and *Fusarium* spp., responsible for the production of aflatoxins and fumonisins. National studies of

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the INIAP and local universities have documented that, in maize stored by small producers, the prevalence of FB1 surpasses 80%, with concentrations that in some cases double the maximum limit established by the EU (1.0 mg/kg for FB1 in products of human consumption).

The cocoa husk constitutes a case of special interest. At the international level, the EFSA has warned about the contamination with aflatoxins in cocoa by-products, and in Ecuador export rejections toward the EU have been documented for lots that surpassed the limit of 5 µg/kg for AFB1. This agrees with what is reported by (16) and (17), who signal that the post-fermentation humidity and the deficiency in the drying are the principal determinants of contamination.

Regarding the co-contamination, the simultaneous presence of FBs and DON in DDGS and Ecuadorian maize is consistent with findings in Latin America reported (18), (19), where the interaction of these mycotoxins showed a synergistic effect that amplifies the toxicity on the intestinal epithelium and compromises the immune response.

From a regulatory perspective, Ecuador faces a challenge: while the EU and the Codex Alimentarius establish strict limits and mechanisms of systematic control, the Ecuadorian regulation presents specific voids for by-products reused in human feeding (10). This leaves a margin of risk, especially in artisanal production chains, where the control of humidity and storage is not rigorous.

In terms of public health, the risk estimated in this study particularly for fumonisins and aflatoxin B1 indicates that certain by-products could surpass the Tolerable Daily Intake (TDI) or present a Margin of Exposure (MOE) unacceptably low. This translates into potential chronic effects such as hepatocarcinoma, immunosuppression, reproductive alterations, and delay in infantile growth, risks that have been documented widely in international literature (20), (21), and (22).

Likewise, from the point of view of foreign trade, the non-compliance of the international standards by contamination with mycotoxins implies significant economic losses. In the case of the Ecuadorian cocoa, a single rejected lot can mean the loss of long-term contracts with European buyers, affecting the entire value chain.

In conjunction, the national and international evidence confirms that the problematique of the mycotoxins in agroindustrial by-products cannot be addressed solely from the productive point of view, but rather requires an integral approach that includes systematic monitoring, training to producers, improvement in the infrastructure of drying and storage, and normative updating aligned with international standards.

## CONCLUSIONS

The agroindustrial by-products reused for human feeding, such as the dried distiller grains (DDGS), the brewers' spent grain, the cocoa husk, the grape pomace, and the beet pulp, present a prevalence of mycotoxins that oscillates between 40% and 100%. In several cases, the detected concentrations surpass the maximum limits established by the European Union and the Codex Alimentarius, as in the case of the fumonisins in DDGS (up to 5.0 mg/kg) and the ochratoxin A in grape pomace (up to 5.0 µg/kg), which

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constitutes a real risk for the public health upon exceeding the tolerable daily intakes (TDI) in a significant proportion of the population.

In the Ecuadorian context, the maize and the cocoa husk represent critical matrices by their high prevalence and levels of contamination. The maize produced in the Coast region has shown concentrations of fumonisin B1 superior to 4.5 mg/kg, while in the cocoa husk levels of aflatoxin B1 of up to 8.0 µg/kg have been detected, surpassing the limit of 5.0 µg/kg fixed by the EU. Factors such as post-fermentation humidity superior to 12%, average temperatures of 24–32 °C, and deficient storage favor the proliferation of *Aspergillus* spp. and *Fusarium* spp., occasioning even rejections of exports and affecting the commercial competitiveness of the country.

The models of exposure carried out for the Ecuadorian population estimated that the intake of fumonisins (TDI = 2.0 µg/kg bw/day) is exceeded in 45% of the evaluated scenarios, while the deoxynivalenol (TDI = 1.0 µg/kg bw/day) surpasses the limit in 38% of the simulated diets. The aflatoxin B1, upon not counting with a safe threshold by its carcinogenic character, presented in cocoa husk a margin of exposure (MOE) lesser than 10,000 in 100% of the scenarios, which indicates an elevated risk of hepatic cancer and reinforces the need to implement systems of monitoring, control, and technical training for producers and processors at the national level.

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