Aflatoxin contents and bromatological quality in two varieties of peanut *(Arachis hypogaea L.)* in different states and storage systems in Ecuador

Juan Alejandro Neira-Mosquera[1,2,3], Sungey Naynee Sánchez-Llaguno[2], **Jhonnatan Placido Aldas-Morejon[4],** Karol Yannela Revilla-Escobar[4,5]*, Mary Carmen Morán-Estrella[2] and Madeleine Josenkha Nogales-Delgado[2]

Juan Alejandro Neira Mosquera[1,2,3], https://orcid.org/0000-0002-7854-832X

Sungey Naynee Sánchez Llaguno[1], https://orcid.org/0000-0003-4247-3386

Jhonnatan Placido Aldas Morejon[4], https://orcid.org/0000-0003-3592-0563

Karol Yannela Revilla Escobar[4,5]*, https://orcid.org/0000-0002-8734-1216

Mary Carmen Morán Estrella[1], https://orcid.org/0000-0001-7130-7892

Madeleine Josenkha Nogales Delgado[1], https://orcid.org/0000-0002-9669-5585

[1]Universidad de las Fuerzas Armadas-ESPE, Departamento de Ciencias de la Vida y la Agricultura. Av. General Rumiñahui s/n Sangolquí, Ecuador

[2]Facultad de Ciencias de la Industria y Producción, Universidad Técnica Estatal de Quevedo, Quevedo, Ecuador

[3]Universidad Pública de Sango Domingo de los Tsachilas - UPSDT, km 28, vía Quevedo, Santo Domingo, Ecuador

[4]Facultad de Ciencias Aplicadas a la Industria, Universidad Nacional de Cuyo, San Rafael, M5600APG, Argentina

[5]Carrera de Agroindustrias, Pontificia Universidad Católica del Ecuador, SEDE Esmeraldas, Esmeraldas, Ecuador

***Correspondence:** jhonnatan.aldas@pg.uleam.edu.ec

Received: 12-Feb-25
Revised: 01-Mar-25
Accepted: 15-Mar-25

ABSTRACT

Aflatoxins produced by fungi such as *Aspergillus flavus* and *Aspergillus parasiticus*, are carcinogenic substances that can contaminate food, posing significant health risks and economic losses. This study aimed to evaluate aflatoxin content and bromatological quality in two peanut varieties (*INIAP-381 Rosita* and *INIAP-382 Caramelo*), considering different sample conditions (fresh, dry, and in pod) and storage systems (bulk and vacuum) using a multifactorial ABC design. The results demonstrate that vacuum storage effectively suppresses

aflatoxin formation. The INIAP-382 Caramelo variety exhibited lower aflatoxin concentrations, ranging from 1.77ppb in fresh samples to 2.22ppb in dry samples. In contrast, the INIAP-381 Rosita variety had aflatoxin concentrations of 2.30ppb and 2.16ppb under the same conditions. Bromatological analysis revealed moisture content ranging from 1.95 to 11.15%, pH between 6.02 and 6.68, an average acidity of 0.02%, ash content from 2.11 to 3.01%, and essential nutrients including protein (7.50-9.75%), fat (21.50-43.00%), and fiber (21.50-32.49%). These findings demonstrated that the combination of peanut variety, sample condition, and storage system significantly influences aflatoxin concentration and overall peanut quality.

Keywords: *Arachis hypogaea L*, contamination, fungus, storage systems.

Introduction

Crops, especially cereals and legumes, serve as an essential source of energy and nutrition in the human diet worldwide. These products are consumed in various forms, whether as whole grains, raw or cooked, or as processed products such as flour, semolina, bread, and biscuits (Bertioli et al., 2019). Beyond their importance in human nutrition, cereals and their by-products play a fundamental role in animal feed, being used as fodder for livestock and poultry. Through this consumption chain, cereals contribute indirectly to the production of dairy products, meat, and eggs, solidifying their relevance in global food security (Pankaj et al., 2018).

However, crop contamination by mycotoxins poses a significant challenge for public health and the sustainability of the agro-industrial sector. According to the Food and Agriculture Organization of the United Nations (FAO), approximately one-quarter of global crop production is contaminated with mycotoxins (Mahato et al., 2019). Over the past few decades, cases of human mycotoxicosis have increased significantly, primarily due to the consumption of food contaminated with one or more mycotoxins. This situation has led to negative consequences for both consumer health and the profitability of agro-industries, affecting production, marketing, and the export of agricultural products (KamLe et al., 2022; KamLe et al., 2022). The acute toxicity and carcinogenic effects of mycotoxins have made cereal contamination a pressing concern for global food safety, while also causing significant economic losses across the agri-food chain.

Among these concerns, the cultivation of *Arachis hypogaea*, commonly known as peanuts, has garnered special attention. Peanuts, also referred to as groundnuts or monkey nuts, are highly valued for their rich nutritional content and are recognized as a "longevity food" due to their numerous health benefits. Peanuts provide an important source of proteins, essential fatty acids, vitamin, and minerals, making them a staple in the diet of many regions worldwide (Sultana et al., 2024). However, peanut production faces multiple challenges, one of the most pressing being fungal contamination and mycotoxin accumulation (KamLe et al., 2022).

Peanut crops are particularly susceptible to infestation by pathogenic fungi, which can negatively impact yield from sowing through to storage. The primary fungal agents associated with peanut contamination include *Aspergillus flavus*, *Aspergillus niger*, *Macrophomina phaseolina*, *Rhizoctonia solani*, *Fusarium oxysporum*, and *Fusarium solani*. These fungi colonize seeds, progressively degrading them and compromising their quality and viability (Pandey et al., 2019). Beyond reducing productivity, these fungi generate mycotoxins that pose severe health risks. Among these, aflatoxins represent the greatest threat to food security (Leyva et al., 2017).

Aflatoxins (AF) are highly toxic and carcinogenic compounds that proliferate in warm, humid environments typical of tropical and subtropical regions (Medina et al., 2017). Due to their high thermal stability, aflatoxins cannot be entirely eliminated by conventional food processing methods, making them persistent contaminants in agricultural products and their derivatives. Aflatoxins have been detected in various food products, including peanuts, maize, wheat, rice, sesame seeds, spices, cocoa, and commercial products such as peanut butter and vegetable oils. Their presence in the food chain represents a significant risk to human and animal health, even at low concentrations, due to their cumulative toxic effects (Mahato et al., 2019).

Multiple factors influence aflatoxin contamination in peanuts, including crop variety, environmental conditions during growth, post-harvest management practices, and storage strategies (Liu et al., 2018). Some peanut varieties exhibit greater resistance to fungal infestation, making them less susceptible to toxin accumulation. Additionally, factors such as temperature, humidity, and precipitation significantly affect fungal proliferation, with warm and humid climates posing the highest risk of contamination (Bertioli et al., 2019).

Storage plays a crucial role in preventing aflatoxin contamination. Traditional methods, such as storing peanuts in open sacks or poorly ventilated environments, create conditions conducive

to fungal growth. In contrast, modern techniques such as controlled-atmosphere storage, hermetic sealing, and the use of antifungal agents have proven to be more effective in reducing aflatoxin presence and ensuring peanut quality (Shabeer et al., 2022). However, the effectiveness of these strategies depends on meticulous control of temperature, humidity, and ventilation (Marr et al., 2021).

To mitigate aflatoxin contamination in peanuts, various control strategies have been developed. One promising approach involves the use of atoxigenic *Aspergillus* strains, which compete with toxin-producing strains and thereby reduce aflatoxin accumulation (Leyva et al., 2017). Additionally, chemical treatments with antifungal agents and detoxification techniques have been implemented to minimize risks. Another strategy under investigation is the genetic improvement of peanut varieties with enhanced resistance to fungal colonization, which could significantly reduce contamination from the cultivation stage (Liu et al., 2018). Furthermore, proper drying practices are essential to prevent the buildup of aflatoxins (Bertioli et al., 2019).

Aflatoxin contamination is not only a serious public health issue but also has considerable economic repercussions. Countries that fail to comply with international food safety standards face trade restrictions, limiting the export of peanuts and other agricultural products (Marr et al., 2021). This problem disproportionately affects small-scale farmers, who often lack the financial resources to implement effective aflatoxin control measures. Investments in research, the development of new storage technologies, and farmer training are crucial to mitigating these negative effects and ensuring the long-term sustainability of the agricultural sector (Medina et al., 2017).

In light of these challenges, the present study aims to evaluate aflatoxin content and bromatological quality in two peanut varieties at different developmental stages and under various storage systems in Ecuador. Understanding the factors influencing aflatoxin contamination and implementing effective control strategies is essential for improving food safety, protecting consumer health, and supporting the economic viability of peanut producers. Future research should focus on integrating biological, chemical, and technological solutions to minimize mycotoxin contamination, ensuring that peanut production remains both safe and sustainable.

Materials and Methods

Plant Material

Peanut varieties were obtained from the province of Santo Domingo de los Tsáchilas, in the Santo Domingo canton, located at latitude -0.25305 and longitude -79.17536. The biochemical and bromatological analyses were conducted in the laboratories of the Armed Forces University ESPE, Santo Domingo Extension (Fig. 1).

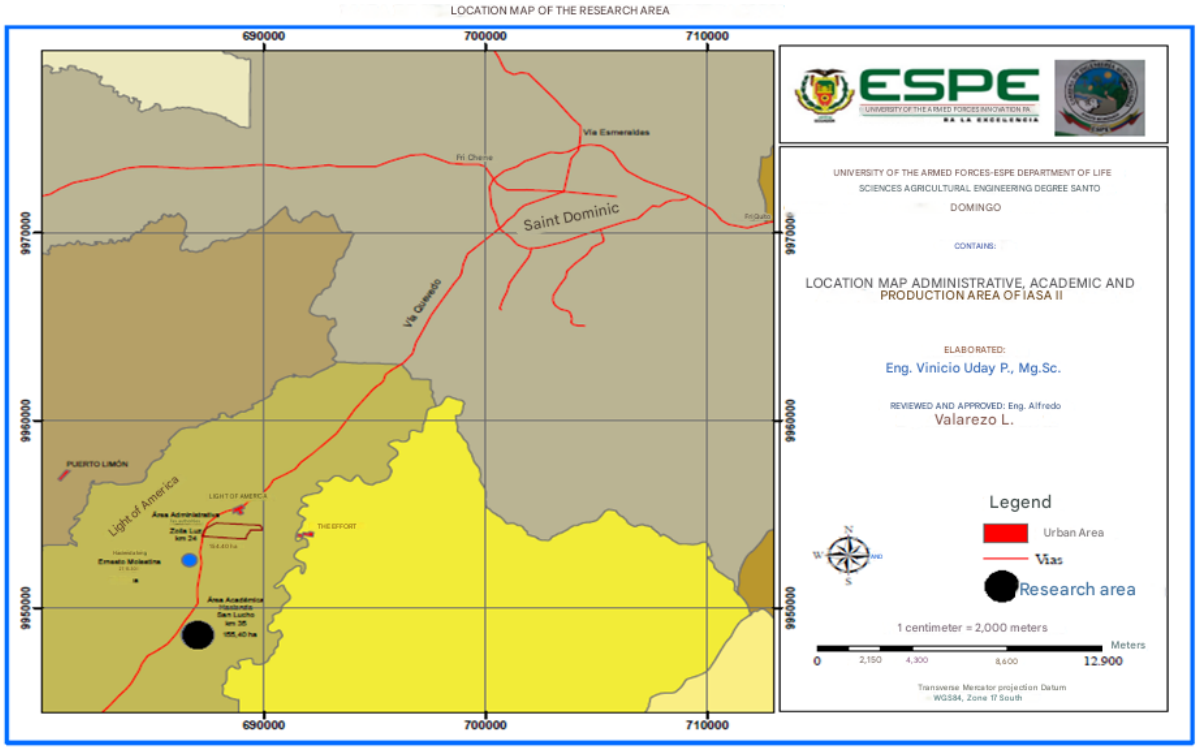

Fig. 1. Geographic location where the research was carried out

Experimental Design

A multifactorial design A*B*C was applied, where each factor consists of two or three levels: Factor A = Peanut varieties (*INIAP – 381 Rosita* and *INIAP – 382 Caramelo*); Factor B = Sample condition (Fresh, Dry, and In Pod) y Factor C = Storage systems (Bulk and Vacuum-sealed). These factors and levels are presented in Table 1. To determine differences between treatment means, a Tukey multiple range test ($P<0.05$) was used. Additionally, for bromatological characteristics, multivariate statistical analysis was applied using principal component analysis (PCA).

Table 1. Factors and levels tested in the bromatological study of two peanut varieties (*Arachis hypogaea* L.).

Factors	Levels
Peanut Varieties (V)	V1= INIAP – 381 Rosita V2= INIAP – 382 Caramelo

Sample Condition (E)	E1= Fresh E2= Dry
Storage Systems (S)	S1= In pod S2= Bulk S3= Vacuum-sealed

Determination of Total Aflatoxins

The VERATOX quantitative test for aflatoxins was used.

Sample Preparation and Extraction

A 70% methyl alcohol solution was prepared by mixing 7 parts of ACS-grade methanol with 3 parts of distilled water for each sample. A representative sample of the material was taken and ground until at least 75% of the material passed through a #20 sieve. Then, 25g of the ground sample was mixed with 125mL of the 70% methyl alcohol solution using a high-speed mixer for 2min. The resulting extract was filtered through a Whatman #1 filter, pouring between 5-15mL to obtain the final filtrate as a sample (Ismail et al., 2024).

Test Procedure

To begin, one red-marked well was selected for each sample tested, along with four red-marked wells designated for controls, which were placed in the corresponding well holder. The same number of wells covered with antibodies was used. Each reagent was mixed before use by gently swirling the containers. Then, 100µL of conjugate from a blue-labeled vial was added to each red-marked mixing well. A new pipette tip was used for each transfer, and 100µL of controls and samples were transferred to the red-marked mixing wells using a 12-channel pipette, mixing the liquid three times up and down.

Next, 100µL was transferred to the antibody-coated wells and mixed by moving the microplate holder in both directions on a flat surface for 10 to 20s, avoiding splashing of the reagents. The plate was then incubated for twomin at room temperature (18–30°C). The red-marked mixing wells were discarded, and each antibody well was filled and emptied under a stream of distilled water, repeating this step five times. The wells were then inverted onto a paper towel and tapped gently to remove any remaining water.

The necessary volume of substrate (green-labeled) was pipetted, and 100µL was added to each well in the reagent tray, mixing in both directions on a flat surface for 10 to 20s. The plate was incubated for 3min, and the remaining substrate was discarded by rinsing the reagent tray with water. Finally, the red stop solution was pipetted into the reagent tray labeled red. Using the same pipette tips as for the substrate, 100µL of red stop reagent was added to each well and mixed by moving in both directions on a flat surface. The bottom of the microwells was cleaned with a cloth or towel, and the reading was performed on a microplate reader using a 650nm filter. The results were obtained with the help of the ELISA equipment (Ismail et al., 2024).

Bromatological Quality

Moisture Determination

Humidity was determined following the methodology established in the Ecuadorian Technical Standard NTE INEN 1464, which specifies the procedures for measuring moisture loss due to heating in cereals. The value obtained was calculated from the difference in weight between dry matter and fresh weight, the results are expressed as a percentage.

pH Determination

The pH was determined following the Ecuadorian Technical Standard NTE INEN 389, which establishes the procedure for determining hydrogen ion concentration (pH) in canned vegetables. A 10g sample was placed in a beaker, and 100cm³ of distilled water was added. The mixture was homogenized through blending until a uniform particle suspension was achieved. Finally, the pH was determined through direct reading by inserting the potentiometer electrodes into the beaker containing the sample.

Acidity Determination

Acidity determination followed the methodology established in the Ecuadorian Technical Standard NTE INEN 2152. A 25cm³ sample was placed in a 250cm³ volumetric flask and diluted to volume with previously boiled and cooled distilled water. The solution was thoroughly mixed, and the electrodes were immersed in the sample. A 0.1N sodium hydroxide solution (10–50cm³) was then added, stirring until a pH of 6 was reached, determined with a potentiometer. The 0.1N sodium hydroxide solution was slowly added until pH 7 was achieved, then added dropwise (four drops at a time), recording the volume and pH after each addition

until reaching approximately pH 8.3. The exact volume of 0.1N sodium hydroxide solution corresponding to pH 8.1 was determined by interpolation, and calculations were performed using Equation 1.

$$A = \frac{(V_1\ N_1 M)_* 10}{V_2} \text{ Eq 1}$$

Where:

A = grams of acid per 1,000cm³ of product

V_1 = cm³ of NaOH used for titration

N_1 = normality of NaOH solution

M = molecular weight of the reference acid

V_2 = volume of aliquot taken for analysis

Ash Determination

Ash content was determined following the methodology established in the Ecuadorian Technical Standard NTE INEN 520. A 2g sample was placed in an oven (Memmert) at 100°C for 24 hours. After cooling for 10min, each crucible was weighed. The crucibles were then placed in a muffle furnace at 600°C for 4 hours. Finally, the ash percentage was calculated using Equation 2.

$$\%\ Ash = \frac{C3 - C1}{C2 - C1}\ x\ 100 \text{ Eq 2}$$

Where:

C_1 = Mass of the empty crucible (g)

C_2 = Mass of the crucible with the sample (g)

C_3 = Mass of the crucible with ashes (g)

Fiber Determination

Two grams of sample per crucible were used. Each crucible was placed in the fiber analysis equipment, and 100mL of sulfuric acid and 10 drops of octanol were added, allowing it to boil for 30min. The liquid was then drained and washed with 200mL of distilled water in each crucible. Next, 100mL of sodium hydroxide solution and 10 drops of octanol were added, followed by boiling for another 30min. The liquid was drained, and the crucibles were washed with 30mL of distilled water. Then, 10mL of acetone was added to each crucible, left to stand for 10min, and placed under vacuum. The crucibles were placed in an oven at 100°C for 24h.

After cooling, the crucibles were weighed and subjected to a muffle furnace treatment at 500°C for 3h. The final weight was recorded, and calculations were performed using Equation 3.

$$\% \text{ Crude Fiber} = \frac{W_1 - W_2}{W_0} \; x \; 100 \text{ Eq 3}$$

Where:

W_0 = Sample weight

W_1 = Crucible weight + dried sample

W_2 = Crucible weight + ashed sample

Fat Determination

To determine fat content, 2g of sample was weighed with 50mL of solvent and heated in a Goldfish apparatus at 55°C. After extraction, the solvent was allowed to boil until nearly all had transferred to the recovery vessel without burning the sample. The heating elements were lowered, and the beaker containing the fat residue was removed. The solvent was transferred to its original container. The beaker with fat was placed in an oven at 105°C for 30min to evaporate the remaining solvent completely. The beakers containing the fat were further heated at 100°C for 30min. Finally, the beakers were cooled to room temperature in a desiccator, and the fat percentage was calculated using Equation 4:

$$G = \frac{W_2 - W_1}{W_0} \; x \; 100 \text{ Eq 4}$$

Where:

G = Fat percentage

W_0 = Sample weight

W_1 = Empty beaker weight

W_2 = Beaker weight + fat

Protein Determination

Protein content in the samples was determined using the Kjeldahl method, following the standard protocol established in the National Food Safety Standard (NFSS, 2016). For the analysis, a nitrogen analyzer model 2300 (FOSS, Hillerød, Denmark) and a conversion factor of 6.25 were used, assuming that nitrogen represents approximately 16% of the protein content.

Results and Discussion

Aflatoxin Content

Fig. 2 showed that all vacuum-stored peanut samples exhibited low levels of total aflatoxins. The Caramelo-Iniap 382 variety had average concentrations of 1.77ppb in dry samples and 2.22ppb in fresh samples. Similarly, the Rosita Iniap-381 variety recorded concentrations of 2.30ppb in its dry state and 2.16ppb in its fresh state. However, the highest value was observed in fresh grains of the Rosita variety stored in pods, with an average total aflatoxin concentration of 16.56ppb, as shown in Fig. 2.

These results are relatively lower than those reported by Ginting et al. (2018), who, in their study on aflatoxin content in peanuts and processed foods, found values ranging from 9.40 to 26.30ppb in peanut grains and peanut tempeh, respectively. It is important to highlight that low moisture levels and a relatively dry storage environment inhibit *Aspergillus flavus* infection and aflatoxin production in peanut grains (Masaka et al., 2022). Additionally, it has been reported that high relative humidity (85%), along with temperatures between 25 and 30°C and a humidity range of 15–30%, promote fungal proliferation in samples (Ribeiro-De Araújo et al., 2015).

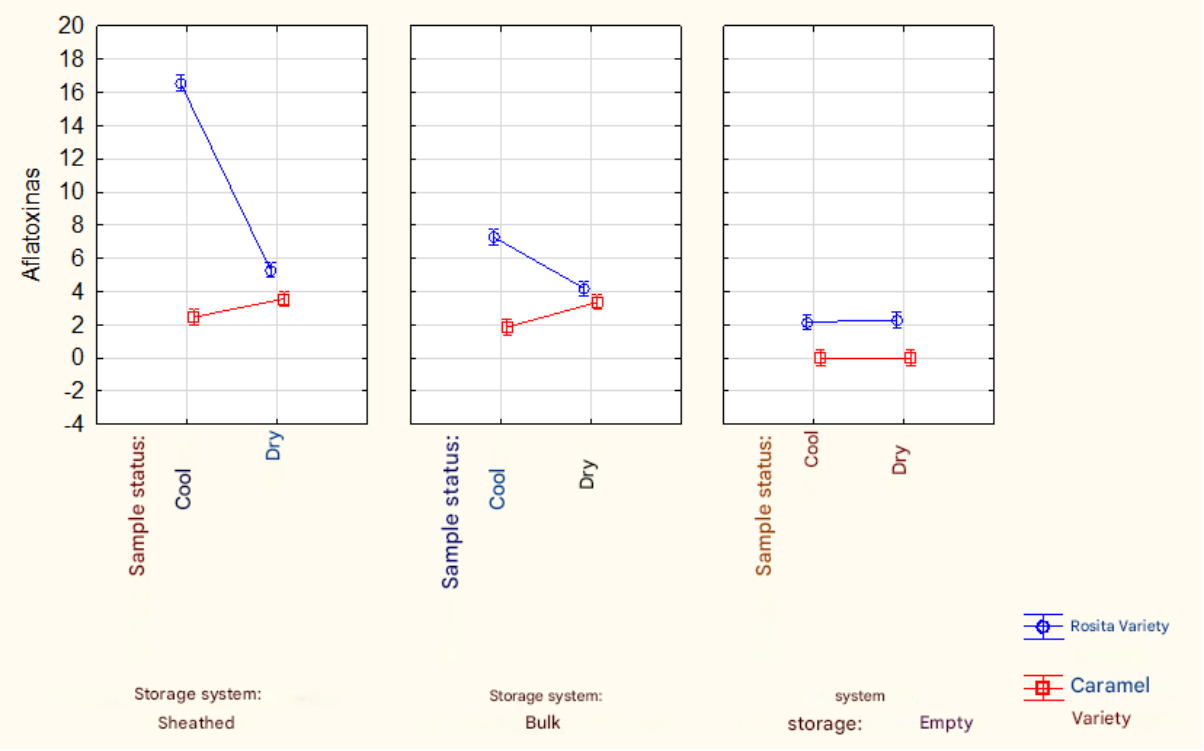

Fig. 2. Result of total aflatoxin content in the A*B*C interaction (Variety*Sample status*Storage system) calidad bromatológicos

Bromatological Analysis

Table 2 presents the results obtained from the bromatological analyses (moisture, dry matter, 0pH, ash, fiber, fat, and protein), where a significant difference ($P<0.05$) was observed between the treatment means.

In terms of moisture content, fresh and in-pod peanut samples exhibited the highest levels, with the Rosita Iniap-381 variety recording a peak value of 11.15%. In contrast, the lowest moisture values were found in vacuum-stored dry samples, averaging 2.04% and 1.95% for the Caramelo Iniap-382 and Rosita Iniap-381 varieties, respectively. Moisture content significantly influenced ($P<0.05$) aflatoxin variability in the samples, reaffirming the findings of Espinosa-Plascencia & Bermúdez-Almada (2022), who emphasized that moisture levels, physical quality, and air conditions are critical factors in controlling mold contamination and aflatoxin production. Additionally, the results of this study align with those reported by De Oliveira-Sá et al. (2020), who found moisture values ranging from 4.47 to 12.26% in peanut seeds. Various authors have highlighted that storing peanut seeds in their pods enhances long-term preservation by maintaining physiological characteristics and offering physical protection (Oliveira et al., 2020).

Fresh bulk-stored peanut samples exhibited the highest pH levels, with the Rosita Iniap-381 variety averaging 6.68. Conversely, the lowest pH was observed in dry and vacuum-stored samples of the Caramelo Iniap-382 variety, with a mean value of 6.02. These findings fall within the acceptable pH range for peanuts, as established by Bilal et al. (2020), who identified an optimal pH of 6.2. To sustain an appropriate pH and mitigate storage-related issues, it is essential to regulate moisture and temperature. Maintaining a dry and cool environment helps stabilize pH levels, as suggested by Curcio (2019).

Regarding acidity content, no statistically significant differences ($p>0.05$) were found across peanut varieties, sample conditions, and storage methods, with values ranging from 0.02 to 0.03%. Previous studies have determined acidity values between 0.02 and 0.2% before storage (Bonku & Yu, 2020). Furthermore, Fu et al. (2018) reported that peanuts stored in PET/AL/PA/PE bags retained low acidity levels, while those packaged in PE and PA/PE materials experienced a rapid increase in acidity, with values ranging from 0.3 to 0.9%.

Ash content varied significantly among storage methods, with vacuum-stored dry peanut samples exhibiting the highest levels, averaging 3.01% in the Rosita Iniap-381 variety. Conversely, the lowest ash content was recorded in fresh, in-pod, and bulk-stored samples of

the Rosita Iniap-381 and Caramelo Iniap-382 varieties, with mean values of 2.11 and 2.08%, respectively. Previous research has documented ash content in raw peanuts within the range of 2.37 to 2.54%, while roasted peanuts exhibited higher values between 4.04% and 4.13% (Kamuhu et al., 2019). Additionally, fresh in-pod peanuts have shown ash values fluctuating between 1.2 and 2.3% (Bonku & Yu, 2020).

Fiber content was notably higher in fresh peanut grains, particularly in the Rosita Iniap-381 variety, which contained 9.75% fiber. However, a significant reduction ($P<0.05$) was observed following the drying process, with fiber content decreasing to 7.50% in the same variety. These results diverge from the findings of Montero-Torres (2020), who reported a fiber content of approximately 3% in raw peanuts. Similarly, Bonku & Yu (2020) identified crude fiber levels ranging from 1.4% to 3.9%. However, the current study's findings are consistent with those of Çiftçi & Suna (2022), who reported fiber content of 8.50% in raw peanuts and 8.40% in roasted peanuts.

Fat content was highest in fresh in-pod peanut samples, with the Caramelo Iniap-382 and Rosita Iniap-381 varieties recording averages of 43.00% and 40.50%, respectively. Conversely, dry samples, whether bulk-stored or in-pod, exhibited the lowest fat content, with values averaging 22.25% and 21.50% for the Rosita Iniap-381 and Caramelo Iniap-382 varieties, respectively. Generally, peanuts are known for their high fat content, averaging approximately 48.75g/100 g (Çiftçi & Suna, 2022). It is also important to note that fat content decreases when peanuts are subjected to roasting.

Regarding protein content, fresh in-pod peanut samples of the Rosita Iniap-381 variety exhibited the highest protein levels, averaging 32.49%, followed by the Caramelo Iniap-382 variety, which recorded an average of 31.13% under similar conditions. The lowest protein content was observed in dry bulk-stored Caramelo Iniap-382 samples, averaging 21.79%. These results suggest a significant decrease in protein content as peanuts transition from fresh to dry states. Furthermore, these findings align with those of Wang et al. (2014), who reported that peanut seed protein content varies between 24 and 36% on a dry weight basis. More recent studies indicate that nutritional protein levels range between 20.7 and 25.3% (Alhassan et al., 2017).

Table 2. Significance test of the interaction A*B*C (Variety*Sample condition*Storage system).

Variety	State	System	Humidity	pH	Acidity	Ash	Fiber	Fat	Protein
Rosita Iniap-381	Fresh	In pod	11.15 A	6.11 G	0.02 A	2.11 F	9.50 AB	40.50 AB	32.49 A
Rosita Iniap-381	Fresh	Bulk	9.29 BC	6.68 A	0.03 A	2.51 BCDE	8.58 ABCD	34.25 BC	27.44 BCD
Rosita Iniap-381	Fresh	Vacuum-sealed	7.48 D	6.12 FG	0.02 A	2.60 BC	9.75 A	36.25 AB	29.48 ABC
Rosita Iniap-381	Dry	In pod	3.13 F	5.62 H	0.02 A	2.30 EF	8.25 BCD	24.75 D	26.46 BCDE
Rosita Iniap-381	Dry	Bulk	2.57 FG	6.42 D	0.03 A	2.58 BC	7.50 D	22,25 D	22.57 DE
Rosita Iniap-381	Dry	Vacuum-sealed	1.95 G	6.22 E	0.03 A	3.01 A	7.78 CD	27.75 CD	24.61 CDE
Caramelo Iniap-382	Fresh	In pod	10.15 B	6.52 BC	0.03 A	2.38 CDE	8.75 ABCD	43.00 A	31.13 AB
Caramelo Iniap-382	Fresh	Bulk	9.14 C	6.60 AB	0.03 A	2.08 F	8.75 ABCD	37.25 AB	27.44 BCD
Caramelo Iniap-382	Fresh	Vacuum-sealed	6.55 E	6.11 FG	0.02 A	2.57 BCD	9.00 ABC	35.25 B	23.15 DE
Caramelo Iniap-382	Dry	In pod	2.72 FG	6.64 A	0.02 A	2.63 BC	8.25 BCD	21.50 D	23.15 DE
Caramelo Iniap-382	Dry	Bulk	2.00 G	6.48 CD	0.03 A	2.31 DEF	7.75 CD	26.50 D	21.79 E
Caramelo Iniap-382	Dry	Vacuum-sealed	2.04 G	6.02 G	0.02 A	2.69 B	8.50 ABCD	34.75 BC	23.74 DE

The letters in the table represent significant differences within the group according to Tukey's multiple range test with a confidence level of 95%. (Each letter in each bar shows the significant difference ($P<0.05$). **Significant difference in row or column??**

Cluster analysis results

According to the analysis of variables related to proximity, as shown in Fig. 2, a close similarity is evident between Caramelo+dry+shelled vs. Rosita+dry+bulk, as well as between the latter and Rosita+dry+vacuum packed. This relationship is mainly attributed to the bromatological analyses performed (pH, ash, acidity, fiber, fat, protein) and the levels of total aflatoxins. On the other hand, treatments with a lower relationship were identified, such as Rosita+fresh+vacuum packed versus Rosita+fresh+shelled, despite belonging to the same variety and sample state. Variations attributed to the influence of humidity in these treatments were observed.

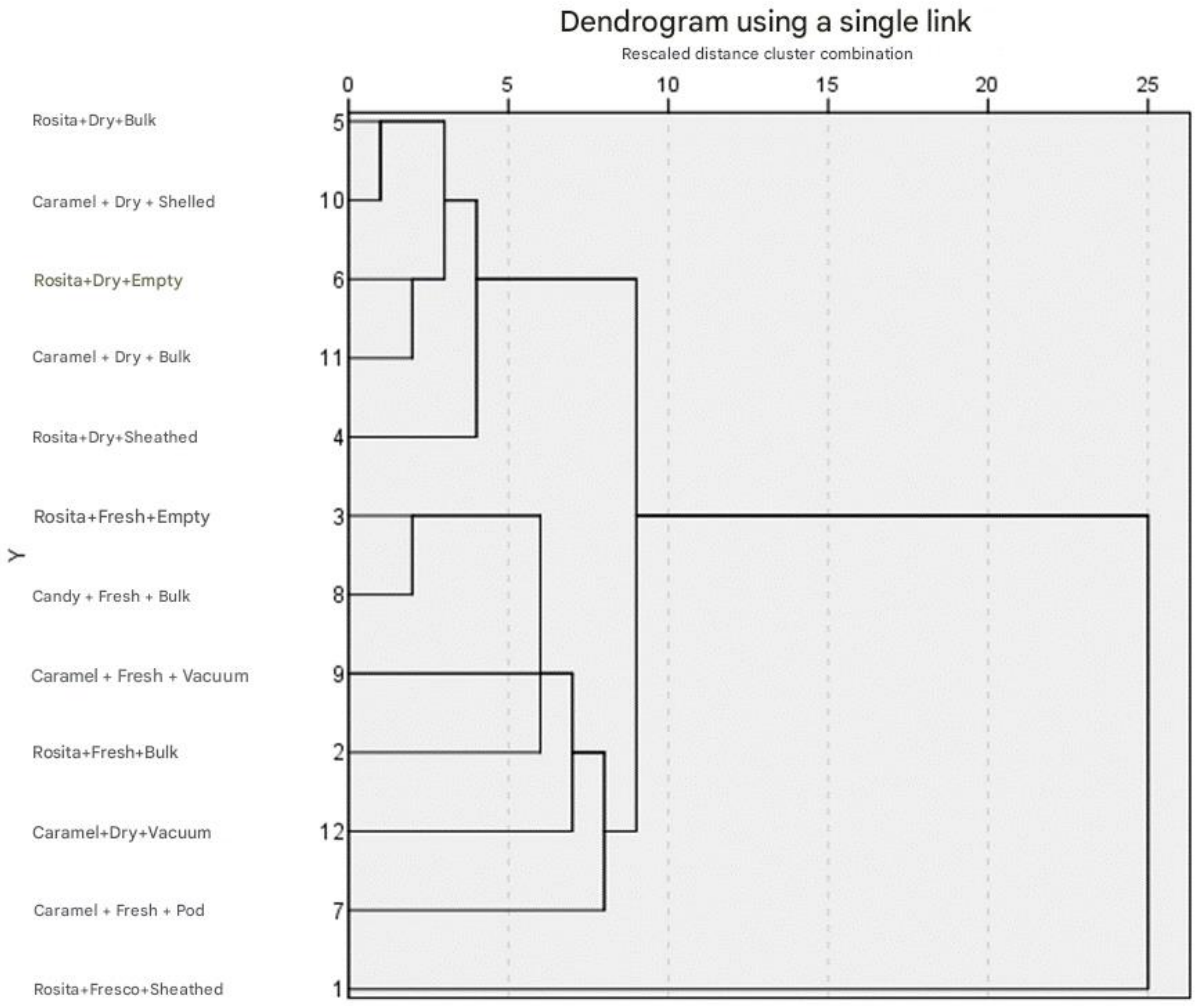

Fig. 3. Dendrogram of the minimum variance for the factors under study

Conclusion

The combination of variety, sample condition and storage system has a significant impact on the concentration of aflatoxins, with drying and vacuum storage being the most effective conditions to reduce their presence. This underlines the importance of considering these factors in the management of risks associated with aflatoxins. Regarding bromatological quality, it was observed that the Rosita and Caramelo peanut varieties, under different processing conditions, showed significant variations in their moisture content, pH and essential nutrients such as proteins, fats and fibre. The drying process considerably decreases the moisture content and affects other nutritional components. Likewise, the storage system influences the conservation of the nutritional properties of the final product. Therefore, bromatological quality tests and the variability in the contents observed reinforce the importance of controlling humidity and storage to preserve peanut quality.

Funding/Acknowledgement: ¿?

Authors' contributions: Juan Alejandro Neira Mosquera: Conceptualization, methodological design, data analysis, writing of the manuscript and general supervision of the study. Sungey Naynee Sánchez Llaguno: Literature review, data collection, statistical analysis and correction of the manuscript. Jhonnatan Placido Aldas Morejón: Data analysis, interpretation of results and contribution to the discussion. Karol Yannela Revilla Escobar: Experimental design, data validation and editing of the manuscript. Mary Carmen Morán Estrella anda Andrea Cristina Cortez Espinoza: Methodology, interpretation of results and critical review of the document. Madeleine Josenkha Nogales Delgado: Literature review, editing and formatting of the manuscript, reference management

Conflicts of Interest: The authors declare no conflict of interest.

Referencias Bibliográficas

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Some Naturally Occurring Substances: Food Items and Constituents, Heterocyclic Aromatic Amines and Mycotoxins. Lyon (FR): International Agency for Research on Cancer (1993). (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 56.) Food items and constituents. Available from: https://www.ncbi.nlm.nih.gov/books/NBK513568/

Alhassan, K., Agbenorhevi, J. K., Asibuo, J. Y., & & Sampson, G. O. (2017). Proximate composition and functional properties of some new groundnut accessions. Journal of Food Security, 5(1), 22-37. https://doi.org/ 10.12691/jfs-5-1-2

Bertioli, D., Jenkins, J., Clevenger, J., Dudchenko, O., Gao, D., Seijo, G., Leal-Bertioli, S., Ren, L., Farmer, A. D., Pandey, M., Samoluk, S. S., Abernathy, B., Agarwal, G., Ballén-Taborda, C., Cameron, C., Campbell, J., Chavarro, C., Chitikineni, A., Chu, Y., & Schmutz, J. (2019). The genome sequence of segmental allotetraploid peanut Arachis hypogaea. *Nature Genetics, 51*(5), 877-884. https://doi.org/10.1038/s41588-019-0405-z

Bilal, M., Xiaobo, Z., Arslan, M., Tahir, H. E., Azam, M., Junjun, Z., & Basheer, S. (2020). Rapid determination of the chemical compositions of peanut seed (Arachis hypogaea.) using portable near-infrared spectroscopy. *Vibrational Spectroscopy*, *110*, 103138. https://doi.org/10.1016/j.vibspec.2020.103138

Bonku, R., & Yu, J. (2020). Health aspects of peanuts as an outcome of its chemical composition. *Food Science and Human Wellness*, 9(1), 21-30. https://doi.org/10.1016/j.fshw.2019.12.005

Bishnu, P., De, P., Hayat, A., Roy, D., Das, S., & Mahato, M. K. (2022). Modern approaches in aflatoxin free groundnut production. *Advances in Agriculture Sciences*, *37*(24.10), 22271. https://doi.org/10.22271/ed.book.1896.

Çiftçi, S., & Suna, G. Ü. L. E. N. (2022). Functional components of peanuts (Arachis Hypogaea L.) and health benefits: A review. *Future Foods*, *5*, 100140. https://doi.org/10.1016/j.fufo.2022.100140

Curcio, N. V. (2019). Manual of good management practices for the production of organic vegetables. Inter-American Institute for Cooperation on Agriculture (IICA). https://doi.org/https://ciaorganico.net/documypublic/326_Manual_BP_Hortalizas_FINAL.pdf

De Oliveira-Sá, N., Soares-Wenneck, G., & Saath, R. (2020). Peanut storage with different water content conditions. *International Journal of Advanced Science and Engineering*, 6(1), 1-4.

Espinosa-Plascencia, A., & Bermúdez-Almada, M. D. (2022). Aflatoxins, a toxic substance that continues to be present in food and its biological effects on humans and animals. *TIP Journal of Chemical and Biological Sciences*, 26, 1-16. https://doi.org/10.22201/fesz.23958723e.2023.553

Fu, X., Xing, S., Xiong, H., Min, H., Zhu, X., He, J., ... & Mu, H. (2018). Effects of packaging materials on storage quality of peanut kernels. *Plos one*, *13*(3), e0190377. https://doi.org/10.1371/journal.pone.0190377

Ginting, E., Rahmianna, A. A., & Yusnawan, E. (2018). Aflatoxin and nutrient contents of peanut collected from local market and their processed foods. *IOP Conference Series: Earth and Environmental Science*, 102(1), 012031. https://doi.org/10.1088/1755-1315/102/1/012031

Ecuadorian Institute of Standardization [INEN]. (1987). *Ecuadorian Technical Standard NTE INEN 1464. Grains and cereals. Determination of helectrolytic weight.* Quito. https://www.academia.edu/33228266/INEN_TODAS_LAS_PUBLICADAS

Ecuadorian Institute of Standardization [INEN]. (1987). *Ecuadorian Technical Standard NTE INEN 1464. Canned vegetables. Determination of hydrogen ion concentration (pH).* Quito. https://es.scribd.com/document/583741194/INEN-para-pH

Ecuadorian Institute of Standardization [INEN]. (2013). Ecuadorian Technical Standard NTE INEN 2152. Solvents. Determination of acidity. Quito.

Ecuadorian Institute of Standardization [INEN]. (2012). *Ecuadorian Technical Standard NTE INEN 520. Flours of vegetable origin. Determination of ash.* Quito. https://es.scribd.com/doc/187738698/NTE-INEN-520-2012-Harina-Cenizas

Ismail, A. M., Raza, M. H., Zahra, N., Ahmad, R., Sajjad, Y., & Khan, S. (2024). Aflatoxins in Wheat Grains: Detection and Detoxification through Chemical, Physical, and Biological Means. *Life*, 14(4), 535. https://doi.org/10.3390/life14040535

KamLe, A., Mahato, D., Gupta, A., Pandhi, S., Sharma, N., Sharma, B., Mishra, S., Arora, S., Selvakumar, R., & Saurabh, V. (2022). Citrinin Mycotoxin Contamination in Food and Feed: Impact on Agriculture, Human Health, and Detection and Management Strategies. *Toxins, 14*(85). https://doi.org/10.3390/toxins14020085.

KamLe, M., Mahato, D., Gupta, A., Pandhi, S., Sharma, B., Dhawan, K., Mishra, S., Kumar, M., Tripathi, A., & Rasane, P. (2022). Deoxynivalenol: An Overview on Occurrence, Chemistry, Biosynthesis, Health Effects and Its Detection, Management, and Control Strategies in Food and Feed. *Microbiological Research, 13*(2), 292-314. https://doi.org/10.3390/microbiolres13020023.

Kamuhu, R., Mugendi, B., Kimiywe, J., & Njagi, E. (2019). Proximate analysis of raw and roasted groundnut (Arachis hypogaea L.): Red Valencia and. *International Journal of Food Science and Nutrition*, 4(4), 191-194.

Leyva, S. M., Mounier, J., Valence, F., Coton, M., Thierry, A., & Coton, E. (2017). Antifungal microbial agents for food biopreservation — A review. *Microorganisms, 5*(2), 1–37. https://doi.org/10.3390/microorganisms5030037

Liu, N., Wang, J., Jia, S., Chen, Y., & Wang, J. (2018). Effect of yeast cell wall on the growth performance and gut health of broilers challenged with aflatoxin B1 and necrotic enteritis. *Poultry Science, 97*, 477-484. https://doi.org/10.3382/ps/pex342

Mahato, D., Lee, K., KamLe, M., Devi, S., Dewangan, K., & Kumar, P. S. (2019). Aflatoxins in food and feed: An overview on prevalence, detection and control strategies. *Frontiers in Microbiology, 10*, 2266. https://doi.org/10.3389/fmicb.2019.02266

Marr, K., Platt, A., Tornheim, J., Zhang, S., Datta, K., Cardozo, C., & Garcia-Vidal, C. (2021). Aspergillosis complicating severe coronavirus disease. *Emerging Infectious Diseases, 27*, 18-25. https://doi.org/0.3201/eid2701.202896

Masaka, V. P., Ndlovu, N., Tshalibe, R. S., Mhande, T. C., & Jombo, T. Z. (2022). Prevalence of aflatoxin contamination in peanuts and peanut butter from an informal market, harare, Zimbabwe. *International Journal of Food Science*, *2022*(1), 3761078. https://doi.org/10.1155/2022/3761078

Medina, A., Gilbert, M. K., Mack, B. M., O'Brian, G. R., Rodríguez, A., Bhatnagar, D., Payne, G., & Magan, N. (2017). Interactions between water activity and temperature on the Aspergillus flavus transcriptome and aflatoxin B1 production. *International Journal of Food Microbiology, 256*, 36–44. https://doi.org/ 10.1016/j.ijfoodmicro.2017.05.020

Montero-Torres, J. (2020). Nutritional and economic importance of peanuts. *Journal of Agricultural and Natural Resources Research and Innovation*, 7(2), 34-45.

Oliveira, E., Borges-De Queiroz, B., Peixoto, C., Peixoto, C., Almeida, A., & Almeida, A. (2020). Times and forms of armazenamento in physiological quality of amendoim seeds. *Brazilian Scientific Iniciacao Magazine*. https://typeset.io/pdf/tempos-e-formas-de-armazenamento-na-qualidade-fisiologica-de-1jy3nc163m.pdf

Pandey, M. K., Kumar, R., Pandey, A. K., Soni, P., Gangurde, S. S., Sudini, H. K., Fountain, J. C., Liao, B., Desmae, H., Okori, P., Chen, X., Jiang, H., Mendu, V., Falalou, H., Njoroge, S., Mwololo, J., Guo, B., Zhuang, W., Wang, X., Liang, X., & Varshney. (2019). Mitigating aflatoxin contamination in groundnut through a combination of genetic resistance and post-harvest management practices. *Toxins, 11*(6), 315. https://doi.org/10.3390/toxins11060315

Pankaj, S., Shi, H., & Keener, K. (2018). A review of novel physical and chemical decontamination technologies for aflatoxin in food. *Trends in Food Science and Technology, 71*, 73–83. https://doi.org/10.1016/j.tifs.2017.11.007

Ribeiro-De Araújo, D., Cardoso-Almeida, F., Palmeira-Gomes, J., Figueiredo-Neto, A., & Cezar-Alves, N. (2015). Incidence of fungi and aflatoxin production in cryopreserved peanut seeds. *Ibero-American Journal of Postharvest Technology*, 16(1), 136-147.

Shabeer, S., Asad, S., Jamal, A., & Ali, A. (2022). Aflatoxin Contamination, Its Impact and Management Strategies: An Updated Review. *Toxins, 14*(5), 307. https://doi.org/10.3390/toxins14050307

Standard, N. F. (2016). National Health Commission of the People's Republic of China. National Food Safety Standard–determination Of Protein In Foods. GB 5009.5–2016. Standards Press of China: Beijing, China. 2016. http://down.foodmate.net/standard/yulan.php?itemid=50381

Sultana, T., Malik, K., Raja, N., Mashwani, Z., Hameed, A., Ullah, R., Alqahtani, A., & Sohail, E. (2024). Aflatoxins in Peanut (Arachis hypogaea): Prevalence, Global Health Concern, and Management from an Innovative Nanotechnology Approach: A Mechanistic Repertoire and Future Direction. *ACS Omega*, *9*(24), 25555–25574. https://doi.org/10.1021/acsomega.4c01316

Wang, L., Liu, H., Liu, L., Wang, Q., Li, Q., Du, Y., & Zhang, J. (2014). Protein Contents in Different Peanut Varieties and Their Relationship to Gel Property. *International Journal of Food Properties*, 17, 1560-1576. https://doi.org/10.1080/10942912.2012.723660