Original Article
Food Science and Technology

ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.5327/fst.570

Impact of storage systems on fumonisin B1 contamination in maize processed for animal feed

José Henrique da Silva TAVEIRA[1], Marcicléia Pereira ROCHA[2], Janderson do Carmo LIMA[3*], Pedro Rogério GIONGO[1], Lincon Rafael da SILVA[1], Thiago Henrique de OLIVEIRA[1], Maxwel Vieira MARCIANO[2], Luisa Pereira FIGUEIREDO[4]

Abstract

Maize is a globally important crop, but its quality can be compromised by fungal contamination and fumonisin production. This study quantified fumonisin B1 concentrations in maize stored in metal silos and bag silos during processing for animal feed. Samples were collected at three stages—whole grain, ground grain, and finished feed—and analyzed using enzyme-linked immunosorbent assay. Storage systems significantly affected fumonisin B1 levels ($p < .01$), with maize from bag silos exhibiting concentrations approximately six-fold higher (2187.5 ppb) than those from metal silos (376.7 ppb). Processing stages did not significantly affect contamination levels. Although all concentrations were below the Brazilian regulatory limits, concentrations in bag silos exceeded European limits, indicating potential risks to animal health and trade. These findings highlight the need to improve storage infrastructure and preventive measures to ensure feed quality and minimize economic losses.

Keywords: maize storage; fumonisin B1; food safety.

Practical Application: Identify risks in bag silos and guide safe practices for maize storage.

1 INTRODUCTION

Maize (*Zea mays* L.) is the most widely cultivated grain globally, accounting for approximately 36% of total grain production, followed by wheat, rice, and soybean, with Brazil being a leading producer. According to the Brazilian National Food Supply Company (Companhia Nacional de Abastecimento [CONAB], 2025), maize production in Brazil for the 2024/2025 crop season is estimated at 122.76 million Mg, with approximately 34 million Mg exported.

Maize grain is widely used in human and animal diets due to its nutritional properties (Alvarenga et al., 2022). According to the Food and Agriculture Organization (FAO, n.d.), approximately 57% of global maize production is used for animal feed. In animal nutrition, maize serves as a primary source of energy and protein, particularly for poultry, swine, and cattle (Li et al., 2024; Melo-Durán et al., 2021).

Maize grain quality is critical for ensuring adequate nutrient concentrations and the absence of toxic substances, particularly mycotoxins. Mycotoxins are fungal metabolites that adversely affect animal and human health (Balendres et al., 2019). Several mycotoxins can contaminate maize grains, with fumonisins, produced by *Fusarium* species, being particularly significant. In Brazil, fumonisin production is associated with the presence of *Fusarium verticillioides* (syn. *F. moniliforme*) (Carvalho et al., 2016).

Fusarium verticillioides, a fungus in the family Nectriaceae (Ascomycota) (Mycobank, n.d.), persists in crop residues as mycelium or chlamydospores and is commonly associated with maize seeds (Tanaka, 2001). Symptoms in maize cobs include white streaks on the pericarp, followed by color changes ranging from pink to dark brown. In advanced infection stages, a cottony fungal growth, consisting of mycelium and spores, becomes visible (Carvalho et al., 2016).

Fumonisins produced by *F. verticillioides* cause acute toxicity in various animals, particularly poultry, swine, and horses, and may result in mortality. Affected animals exhibit reduced feed intake and, in cattle, decreased milk production, along with digestive tract irritation and hemorrhages, immune deficiencies, reproductive alterations, and impaired bone marrow and spleen regeneration (Prestes et al., 2019).

Monitoring mycotoxin concentrations in grains is essential for establishing prevention strategies for both human and animal consumption. The Mycotoxicological Analysis Laboratory (LAMIC) at the Federal University of Santa Maria (UFSM)

Received: Oct. 02, 2025.
Accepted: Oct. 07, 2025.
[1]*Universidade Estadual de Goiás, Quirinópolis, Goiás, Brazil.*
[2]*Universidade Estadual de Goiás, São Luís de Montes Belos, Goiás, Brazil.*
[3]*Universidade Estadual de Goiás, Posse, Goiás, Brazil.*
[4]*Universidade Federal de Lavras, Minas Gerais, Brazil.*
*Corresponding author: janderson.lima@ueg.br
Conflict of interest: nothing to declare.
Funding: Financial resource originating from Call for Proposals No. 01/2023, Grant Agreement No. 51957428, SEI process No. 202300020012435.

maintains a database providing updated statistics on prevalent mycotoxins in Brazil, including their concentrations in foods, ingredients, and feeds (LAMIC, n.d.; Oliveira et al., 2015). A maximum limit of 5,000 ppb is established for fumonisins in maize grains. More than 15 fumonisin homologs (FBs) are known and characterized, with FB1, FB2, and FB3 being the most abundant; FB1 exhibits the highest toxicity and often co-occurs with FB2 and FB3 (Damiani et al., 2019).

Storage methods and feed production processes can increase mycotoxin formation in maize grains. The most commonly used maize storage systems are bulk silos (vertical and horizontal) and polyethylene bag silos. Grain mass temperature and moisture are the primary factors affecting storage quality. Consequently, technologies to maintain these parameters within the grain mass during storage have been the focus of numerous studies aimed at preserving grain quality over extended periods and preventing its deterioration (Paraginski et al., 2015).

Bag silo storage is a low-cost, rapidly implemented, and logistically flexible option, suitable for high-yield harvest periods and areas with limited conventional infrastructure. It enables on-farm maize storage, facilitating gradual distribution and reducing immediate costs. Bag silos maintain the physical and sanitary quality of clean grains at the recommended moisture content (13%) for temporary storage of up to 18 months. Their effectiveness depends on proper sealing, installation on flat areas, and protection against perforation (Silva et al., 2022).

The objective of this study was to quantify fumonisin concentrations in maize grains stored in metal silos and bag silos during animal feed production, to identify potential contamination through fumonisin B1 quantification.

1.1 Relevance of the work

Quantification of fumonisin B1 in different maize storage systems highlights the importance of postharvest infrastructure in maintaining grain quality for animal feed. Results indicate that bag silos significantly increase mycotoxin contamination, exceeding international thresholds and posing risks to animal health and competitiveness in global markets. This study contributes to promoting safer storage practices and developing preventive measures to ensure sustainability and feed safety.

2 MATERIAL AND METHODS

The experiment was conducted in Palminópolis, Goiás, Brazil (16°47′45″S, 50°09′54″W) from July to December 2020. The experimental design was a factorial arrangement with two storage systems and three sampling stages during feed processing, with four replications.

2.1 Origin of storage samples

Maize grains were sampled from vertical metal silos and polyethylene bag silos at the animal feed production sector of the Palminópolis Mixed Agroindustrial Cooperative (COOMAP).

2.2 Sample collection during processing

During processing, three maize samples were collected at different locations in the feed production facility—whole grain in the warehouse, ground grain during milling, and finished feed—on different days, from vertical metal silos and polyethylene bag silos. The average storage duration for both storage systems was approximately 6 months.

Whole grains were sampled using a cylindrical probe inserted into the grain mass at five locations, collecting 1kg of material. This material was then homogenized, quartered, and a 300g subsample was obtained. Ground grain and finished feed were sampled using a pelican sampler, with 2kg collected and reduced to 300g after homogenization.

2.3 Moisture content and impurities

Moisture content was determined using the official method of the Brazilian Ministry of Agriculture and Livestock (MAPA), involving direct moisture measurement in a forced-air circulation oven at 105 ± 3 °C for 24 h (Brasil, 2011). Impurity content was quantified using the official method of MAPA, as described in Normative Instruction No. 22, dated July 28, 2005 (Brasil, 2005).

2.4 Sample analysis

Maize samples were stored in polyethylene bags and sent to the Mycology and Mycotoxins Laboratory (LAMICO) at the School of Veterinary Medicine, Federal University of Minas Gerais (UFMG), for fumonisin detection. Fumonisin B1 was detected and quantified using the enzyme-linked immunosorbent assay (ELISA), which relies on specific antibody–antigen interactions. The results of each analysis included the detected mycotoxin concentration (ppb), limit of detection (LOD, ppb), and limit of quantification (LOQ, ppb) (Sokolovic et al., 2022).

2.5 Statistical analysis

Fumonisin concentrations, determined by ELISA in two storage systems and three maize processing stages (whole grains, ground grains, and finished feed), were subjected to analysis of variance (ANOVA) followed by Tukey's test ($p < .05$) for mean comparison using SISVAR version 5.6 (Ferreira, 2011).

3 RESULTS AND DISCUSSION

Grain moisture content from both bag silos and metal silos was 13%, meeting the standards for commercialization established by the Brazilian Ministry of Agriculture and Livestock (Brasil, 2011). Although stored conditions can influence grain quality, impurity levels in the analyzed samples were below 1%, complying with Normative Instruction No. 22/2005 for maize intended for commercialization (Brasil, 2005).

ANOVA indicated a highly significant effect of storage systems ($p < .01$), whereas processing stage and the interaction between factors showed no significant effect ($p > .05$) (Table 1). These results demonstrate that the storage system significantly affects fumonisin concentrations in maize grains. The data indicate that the storage system was the main source of variation in fumonisin contamination, consistent with previous studies identifying inadequate storage as a major contributor to elevated mycotoxin levels in grains (Di Domenico et al., 2015; Faroni et al., 2005).

The average fumonisin B1 concentration in maize grains stored in bag silos was 2187.50 ppb, approximately six times higher than that in metal silos (376.67 ppb) (Table 2). This difference indicates that both systems maintain fumonisin levels within the limits established by Normative Instruction No. 60/2011 (Brasil, 2011), considering the grain moisture content of 13% in this study. Although the observed values were below the maximum limit established by Brazilian legislation (5 mg kg^{-1} or 5,000 ppb) for fumonisins in maize (Brasil, 2011), concentrations found in bag silos represent a potential risk to animal health. Moreover, according to European legislation, the maximum limits for the sum of fumonisins in maize established by Regulation (EU) 2023/915 are 4.0 mg kg^{-1} or 4,000 ppb (European Commission, 2023).

Control of environmental variables is more effective in metal silos and directly influences the quality of the stored product. Paraginski et al. (2015) emphasize that metal silos, with more efficient aeration and temperature control systems, limit the growth of toxigenic fungi such as *Fusarium verticillioides*, the primary producer of fumonisins in maize (Carvalho et al., 2016). Variations in fumonisin contamination may result from grain mass temperature (Paraginski et al., 2015), storage system, and other factors, including impurity levels and environmental conditions (Di Domenico et al., 2015).

Although bag silos represent a viable low-cost alternative during harvest peaks, primarily due to the limited static storage capacity in Brazil, they may have limitations for use on rural properties and in large, intermediate, and port storage units. According to Forbes Agro (Fatorelli, 2025), static storage capacity in Brazil for 2025 is estimated at 210.1 million Mg, compared to a projected grain harvest of 322.3 million Mg, resulting in a deficit of approximately 112.2 million Mg.

Studies indicate that internal temperature fluctuations, continuous exposure of bag silos to solar radiation during the day and low nighttime temperatures, polyethylene film perforations, and management errors can promote moisture migration within the grain mass and subsequent fungal colonization (Faroni et al., 2005; Silva et al., 2022). Additionally, during storage, grain respiration releases heat and water vapor, increasing internal moisture and accelerating deterioration processes (Suleiman et al., 2013). These physical environmental factors and grain mass physiological processes intensify maize grain deterioration.

These results align with those of Oliveira et al. (2015), who reported greater variability in mycotoxin concentrations in samples from less controlled storage systems. The absence of significant effects from sampling stages during processing indicates that, if grains arrive with low contamination and adequate quality, the industrial stages of feed production do not induce substantial contamination risks. This observation confirms that the postharvest and storage phase is the critical control point for managing fumonisins in the production chain, as emphasized by Balendres et al. (2019) in a review of mycotoxins in agricultural commodities.

Studies indicate that fumonisin concentrations of approximately 2,000 ppb can induce adverse effects in swine and poultry, including reduced production performance, liver damage, and immune alterations (Prestes et al., 2019). Additionally, fumonisins in maize for animal feed present a substantial risk to animal health and production performance, particularly under inadequate storage conditions.

Several studies document adverse effects, including reduced weight gain and feed efficiency in swine, accompanied by diarrhea, anemia, and liver and kidney alterations (Popescu et al., 2022); chronic hepatotoxicity with histological alterations and elevated hepatic enzymes in ruminants; immunosuppression, diminishing vaccine response, and increasing infection susceptibility (Hussein & Brasel, 2001); liver tumors in sheep and hematological alterations such as elevated bilirubin and serum enzymes in goats (Hussein & Brasel, 2001); reduced egg production, mortality, and liver lesions in poultry (Popescu et al., 2022); mortality in horses within approximately 24 h after the onset of clinical signs (Echenique et al., 2019); and formation of carcinogenic metabolites with genotoxic potential. Other effects include oxidative liver and kidney damage, metabolic compromise, and decreased milk production in dairy cows (Popescu et al., 2022) and reproductive disorders such as abortion and lymphoid organ atrophy in swine (Kumar et al., 2017).

Table 2. Means of fumonisin B1 concentrations in maize samples from different storage systems.

Storage system	Fumonisin B1 (ppb)
Metal silos	376.67A
Bag silos	2187.50B

Means followed by the same letter are not significantly different according to Tukey's test ($p < .01$)

Table 1. Analysis of variance for the effect of storage systems, processing stage, and their interactions with fumonisin B1 concentration in maize grains (ppb).

Source of Variation	Degrees of freedom	Mean square	*p*-value
Storage system	1	19674704.17	.0000*
Processing stages	2	498116.67	.2143
S × P	2	667466.67	.1341
Error	23	296506.94	
CV	42.37%		

S: storage system; P: processing stages; CV: coefficient of variation. *Significant at the 1% probability level.

Thus, implementation of preventive management strategies, including rapid drying, strict moisture control, and proper aeration, is indispensable for minimizing economic losses and ensuring feed safety. Moreover, maize quality in animal feed directly affects nutrient digestibility and utilization (Li et al., 2024). Thus, even subclinical fumonisin concentrations can adversely affect animal productivity. These results demonstrate the value of mycotoxin analyses as both regulatory requirements and strategic tools for supply chain management.

From an agronomic and logistical perspective, the results highlight the need for investment in storage infrastructure that controls temperature and maintains optimal grain moisture content. Although bag silos provide a viable alternative for regions with limited vertical silo capacity, these data indicate that bag silos should be used cautiously for limited storage periods, preferably as a temporary measure. According to Faroni et al. (2005), even under controlled conditions, grain physical integrity deteriorates rapidly in environmental conditions with insufficient temperature regulation, promoting the production of fumonisin and other mycotoxins.

The ELISA method for fumonisin detection and quantification has proven effective and suitable for monitoring large sample volumes. This method provides high sensitivity, good reproducibility, and low cost, facilitating routine analysis in storage facilities and feed production plants (Sokolovic et al., 2022). Although techniques such as high-performance liquid chromatography (HPLC) offer greater precision, ELISA is widely used as a screening tool in reference laboratories, including LAMIC (Oliveira et al., 2015).

These results have direct implications for producers and the animal feed industry, highlighting the need for adequate storage practices to prevent economic losses and risks to animal and human health. Fumonisin contamination, even at low levels, can interact synergistically with other mycotoxins, such as aflatoxins and zearalenone, enhancing their toxic effects (Balendres et al., 2019). Thus, these findings can inform the planning of integrated mycotoxin control strategies, including regular monitoring, postharvest management, and the adoption of suitable storage technologies.

4 CONCLUSIONS

Storage systems significantly affect mycotoxin concentrations in maize, with metal silos exhibiting lower fumonisin B1 levels than bag silos, even under optimal moisture conditions.

The processing stages of feed production did not introduce substantial additional contamination risks regarding fumonisin B1 levels.

Fumonisin B1 monitoring via ELISA is efficient and feasible, emphasizing the need for preventive management and suitable storage infrastructure to mitigate risks to animal health and minimize economic losses in the supply chain.

ACKNOWLEDGMENTS

The authors acknowledge Goiás State University for the financial resources provided under Call No. 01/2023, Support Agreement No. 51957428, SEI process No. 202300020012435.

REFERENCES

Alvarenga, I. C., Dainton, A. N., & Aldrich, C. G. (2022). A review: nutrition and process attributes of corn in pet foods. *Critical Reviews in Food Science and Nutrition*, *62*(31), 8567–8576. https://doi.org/10.1080/10408398.2021.1931020

Balendres, M. A. O., Karlovsky, P., & Cumagun, C. J. R. (2019). Mycotoxigenic fungi and mycotoxins in agricultural crop commodities in the Philippines: a review. *Foods*, *8*(7), Article 219. https://doi.org/10.3390/foods8070249

Brasil. (2005). *Instrução Normativa Nº 22, de 25 de novembro de 2005*. Aprova o regulamento técnico para rotulagem de produto de origem animal embalado. Diario Oficial da União.

Brasil. (2011). *Instrução Normativa Nº 60, de 22 de dezembro de 2011*. Define o padrão oficial de classificação do milho, considerando seus requisitos de identidade e qualidade, a amostragem, o modo de apresentação e a marcação ou rotulagem, nos aspectos referentes à classificação do produto. Ministério da Agricultura, Pecuária e Abastecimento. Diário Oficial da União.

Carvalho, R. V., Pereira, O. A. P., & Camargo, L. E. A. (2016). Doenças do milho. In H. Kimati, L. Amorin, A. Bergamin Filho, L. E. A. Camargo, & J. A. M. Rezende (Eds.), *Manual de fitopatologia* (5th ed., Vol. 2., pp. 549–560). Agronômica Ceres.

Companhia Nacional de Abastecimento. *Boletim da Safra de Grãos: 12º Levantamento -Safra 2024/25*. CONAB. Retrieved September 4, 2025, from https://www.gov.br/conab/pt-br/atuacao/informacoes-agropecuarias/safras/safra-de-graos/boletim-da-safra-de-graos/12o-levantamento-safra-2024-25/12o-levantamento-safra-2024-25

Damiani, T., Righetti, L., Suman, M., Galaverna, G., & Dall'asta, C. (2019). Analytical issue related to fumonisins: A matter of sample comminution? *Food Control*, *95*, 1–5. https://doi.org/10.1016/j.foodcont.2018.07.029

Di Domenico, A. S., Danner, M. A., Busso, C., Christ, D., & Coelho, S. R. M. (2015). Análise de trilha da contaminação por aflatoxinas em grãos de milho armazenados. *Pesquisa Agropecuária Brasileira*, *50*(6), 441–449. https://doi.org/10.1590/S0100-204X2015000600002

Echenique, J. V. Z., Estima-Silva, P., Pereira, D. B., Marques, L. S., Ribeiro, L. S., & Schild, A. L. Leukoencephalomalacia in horses associated with immature corn consumption. *Ciência Rural*, *49*(3), Article e20180925. https://doi.org/10.1590/0103-8478cr20180925

European Commission. (2023). *Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006 (Text with EEA relevance)*. Official Journal of the European Union. http://data.europa.eu/eli/reg/2023/915/oj

Faroni, L. R. D., Barbosa, G. N. O., Sartori, M. A., Cardoso, F. S., & Alencar, E. R. (2005). Avaliação qualitativa e quantitativa do milho em diferentes condições de armazenamento. *Engenharia na Agricultura*, *13*(3), 193–201.

Fatorelli, L. (2025, February 6). *Supersafra de grãos pode levar Brasil a recorde de déficit de armazenagem em 2025*. Forbes Agro. https://forbes.com.br/forbesagro/2025/02/forbes-mulher-agro-supersafra-de-graos-pode-levar-brasil-a-recorde-de-deficit-de-armazenagem-em-2025/

Ferreira, D. F. (2011). Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, *35*(6), 1039–1042. https://doi.org/10.1590/S1413-70542011000600001

Food and Agriculture of the United Nations. (n.d.). *Food Balances: 2020*. FAO. Retrieved March 27, 2024, from https://www.fao.org/faostat/en/#data/FBS

Hussein, H. S., & Brasel, J. M. (2001). Aflatoxin: hazard to livestock and poultry production. *Animal Feed Science and Technology*, *96*(1–2), 1–26. https://doi.org/10.1016/S0377-8401(01)00323-1

Kumar, P., Mahato, D. K., Kamle, M., Mohanta, T. K., & Kang, S. G. (2017). Aflatoxin: a global concern for food safety, human health and their management. *Frontiers in Microbiology*, *7*, Article 2170. https://doi.org/10.3389/fmicb.2016.02170

Laboratório de Análises Micotoxicológicas. (n.d.). *O que são Micotoxinas?* Universidade Federal de Santa Maria. Retrieved March 27, 2024, from https://www.lamic.ufsm.br/site

Li, K., Bai, G., Teng, C., Liu, Z., Liu, L., Yan, H., Zhou, J., Zhong, R., Chen, L., & Zhang, H. (2024). Prediction equations of the metabolizable energy in corn developed by chemical composition and enzymatic hydrolysate gross energy for roosters. *Poultry Science*, *103*(2), Article 103249. https://doi.org/10.1016/j.psj.2023.103249

Melo-Durán, D., Perez, J. F., González-Ortiz, G., Villagómez-Estrada, S., Bedford, M. R., Graham, H., & Sala-Oriol, D. (2021). Growth performance and total tract digestibility in broiler chickens fed different corn hybrids. *Poultry Science*, *100*(8), Article 101218. https://doi.org/10.1016/j.psj.2021.101218

Mycobank. (n.d.) *Fusarium moniliforme var. lactis*. Retrieved March 28, 2024, from https://www.mycobank.org/page/Name%20details%20page/field/Mycobank%20%23/352101

Oliveira, M. S., Diel, A. C. L., Rauber, R. H., Fontoura, F. P., Mallmann, C. A., Dilkin, P., & Mallmann, C. A. (2015). Free and hidden fumonisins in Brazilian raw maize samples. *Food Control*, *53*, 217–221. https://doi.org/10.1016/j.foodcont.2014.12.038

Paraginski, R. T., Rockenbach, B. A., Santos, R. F., Elias, M. C., & Oliveira, M. (2015). Qualidade de grãos de milho armazenados em diferentes temperaturas. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *19*(4), 358–363. https://doi.org/10.1590/1807-1929/agriambi.v19n4p358-363

Prestes, I., Rocha, L., Nuñez, K., & Nuñez, N. (2019). Principais fungos e micotoxinas em grãos de milho e suas consequências. *Scientia Agropecuaria*, *10*(4), 559–570. https://doi.org/10.17268/sci.agropecu.2019.04.13

Popescu, R. G., Rădulescu, A. L., Georgescu, S. E., & Dinischiotu, A. (2022). Aflatoxins in feed: types, metabolism, health consequences in swine and mitigation strategies. *Toxins*, *14*(12), Article 853. https://doi.org/10.3390/toxins14120853

Silva, M. S. G., Silva, G. N., Silva, M. G. C., Sousa, A. H., Barbosa, D. R. S., Faroni, L. R. D., Camilo, K. P., Brás, P. V., Ribeiro, A. C. M., & Carvalho, M. S. (2022). Alternative method of maize grain quality maintenance for small farmers through hermetic storage. *Research, Society and Development*, *11*(15), Article e565111537071. https://doi.org/10.33448/rsd-v11i15.37071

Sokolovic, M. (2022). HPLC and ELISA methods for detection and quantification of fumonisins in naturally contaminated maize. *Food Analytical Methods*, *5*, 2263–2273. https://doi.org/10.21203/RS.3.RS-1908427/V1

Suleiman, R. A., Rosentrater, K. A., & Bern, C. J. (2013). *Effects of deterioration parameters on storage of maize* (Paper No. 131593351). American Society of Agricultural and Biological Engineers. https://doi.org/10.13031/aim.20131593351

Tanaka, M. A. S. (2001). Sobrevivência de Fusarium moniliforme em sementes de milho mantidas em duas condições de armazenamento. *Tropical Plant Pathology*, *26*(1), 60–64. https://doi.org/10.1590/S0100-41582001000100010