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Quality Analysis of The Wheat Grains Stored in Different Bins Over Time

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Grain quality maintenance and storage losses are a big challenge for the world. The losses and grain quality issues are attributed to the storage structures and conditions. Thus, there is a dire need to improve and evaluate the existing and newly developed structures. Keeping in view the necessity, this study was conducted to evaluate various storage structures to assess performance in preventing grain losses during storage. Six treatments, viz, EB (earthen bin), MB (metallic bin), ATFB (airtight ferrocement bin), FVFB (forced ventilated ferrocement bin), ATMB (airtight metallic bin), and FVMB (forced ventilated metallic bin) were replicated thrice in the randomized complete block design. The effect of storage periods with the interval of three months was also assessed. Six indicators were invoked to obtain the results, namely; stored grain temperature (°C), moisture content (%), germination (%), insect-pest infestation (%), weight loss due to insect infestation (%), aflatoxin level (µg kg-1). The results revealed that there is a significant association between storage structure, storage period, and grain quality. The traditional structures (EB and MB) were observed to affect the tested quality parameter significantly ($p > 0.05$). While modern structures (ATFB, FVFB, ATMB, and FVMB) maintained the quality parameters within the permissible limit. However, an airtight ferrocement bin (ATFB) showed significantly better results among all treatments. Therefore, farmers are suggested to utilize airtight ferrocement bins to store and maintain wheat grain quality for various purposes.

Keywords: Quality Parameters, Wheat Grains, Storage Bins, Insects, Storage Periods, Airtight Bins

Introduction:

Pakistan's agriculture sector plays a crucial role in the economy, contributing 19.3% to GDP and serving as the largest employer in terms of labor participation. Consequently, the majority of the population's livelihood is directly or indirectly dependent on it. Wheat, rice, sugarcane, maize, and cotton account for 21.73 percent of the agriculture sector's value addition and 4.20 percent of GDP [1]. Agricultural products must be stored from one harvest to the next, and sometimes beyond, for various reasons. Farmers store their crops for personal consumption, future sales, or seed preservation for the next planting season [2]. Storage losses of food grain are usually in the range of 1–2%, particularly in the developed countries, when grains are stored in well-managed silos with aeration and drying. However, it may be as high as 20–50% in the lesser developed countries, particularly in cover and plinth storage with poorly managed storage facilities [3]. Thus, savings of agricultural produce with proper storage is as good as additional production, which emphasizes the need for proper storage management [4]. According to the Food and Agriculture Organization of the United Nations (FAO), 17% of the world's food production today is destroyed during storage (10% by insects and 7% by mites, rodents, and diseases) [5]. It is vital to ensure product quality for the consumer to maximize profitability. As a result, standardization of scientific research and the industrial chain is required in this discipline.

Wheat is the most important staple food, with a high level of regular production and relatively consistent consumption throughout the year. Cereal storage is critical for conserving production amounts and ensuring adequate food for the human population [6]. Farmers have used a variety of techniques for grain storage [7]. Efficient post-harvest handling storage can help developing countries achieve socioeconomic empowerment. These storage structures are relatively inexpensive, environmentally beneficial, and give stored goods a long shelf life. With minimal modifications, these old storage systems can be adapted for modern storage rooms to protect food items from insect damage [8]. Grain storage's main goal is to retain the product's quality for as long as possible. Freshly harvested grains should be able to maintain their nutritional qualities for a long time while also preventing substantial degradation [9]. Grain composition and quality can change during storage, especially if environmental conditions are adverse [10].

In some regions, pest infestation during storage can cause cereal grain losses of up to 50% of the total yield [11]. Furthermore, grain storage losses contribute significantly to post-harvest losses and are one of the leading causes of food insecurity among smallholder farmers in developing nations [12]. Ensuring proper grain storage is not only vital for individual farmers but also for national and global food supply chains. Reducing storage losses helps stabilize market prices, minimize food waste, and strengthen food security policies. Governments and agricultural organizations should raise awareness and support the adoption of improved storage technologies to ensure long-term benefits for farming communities. Variations in the frequency and intensity of climatic events such as floods and droughts, as well as temperature and rainfall patterns, could have a considerable impact on agricultural production [13]. Temperature is another important environmental component that affects arthropods' physiological, life history, behavioral, and population activities [14]. Consequently, grain losses increase. Insect infestation of stored grains also leads to a drop in grain amount, as well as grain quality, weight loss, and decreased flour yield [15][16][17]. Whereas aflatoxins are a global public health and economic concern because they cause serious health and economic problems for consumers and farmers around the world [18].

The quality of wheat grains deteriorates over time due to various environmental factors such as temperature, humidity, and storage conditions. Different types of storage bins, including metal, concrete, and plastic, have varying impacts on grain quality due to differences in aeration, moisture control, and insulation. A significant amount of food grains is damaged after harvesting due to inadequate storage and processing facilities [19]. Traditionally, farmers use various grain storage methods, such as earthen bins, metallic bins, and bulk storage room structures, which are often inefficient. Smallholder farmers in developing countries use conventional grain storage structures and handling systems such as woven bags or cribs to store grain [20][21]. The storage deficit generally leads to qualitative and quantitative losses [22]. Understanding these effects is crucial for ensuring food security, minimizing post-harvest losses, and optimizing storage practices. However, there is limited research on the comparative quality analysis of wheat grains stored in different bins over time. This study aims to assess and compare the physical, chemical, and microbiological quality parameters of wheat grains stored in different bins to identify the most effective storage method for preserving grain quality.

Objectives:

1. To evaluate the changes in the physical, chemical, and microbiological quality of wheat grains over time under different storage bin types.
2. To identify the most effective storage bin type in preserving the quality of wheat grains.
3. To determine the key factors influencing the deterioration of wheat grains in various storage conditions.

Materials and Methods:

Experimental Area:

The current study evaluated various types of storage structures. The experiment was conducted at the Latif experimental farm, Sindh Agriculture University, Tandojam, Sindh Pakistan. The farm is located at 25°26'17.7"N, and 68°32'44.4"E. The storage structures were fabricated at the Laboratory of Farm Structures, Faculty of Agricultural Engineering, SAU, Tandojam.

Construction Methodology of Structures:

A total of six storage structures (Figure 1), including two traditional and four modern designs, were evaluated. The storage techniques and technologies discussed in this study are cost-effective and constructed using locally available materials. The characteristics and design details of each structure are provided in the following paragraphs.

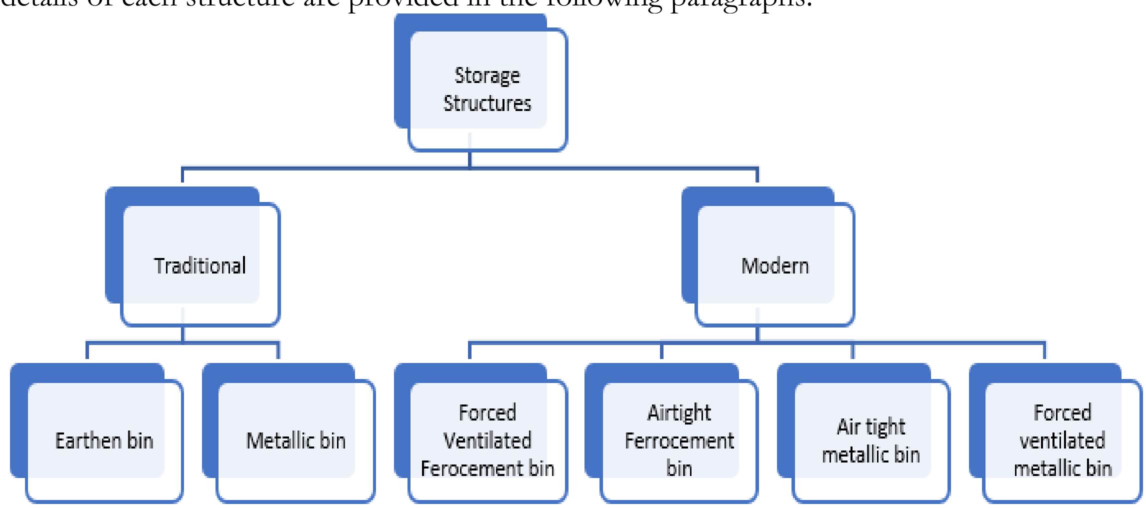

Figure 1. Types of storage structures evaluated in the present study

Earthen Bin (EB): It is usually circular and made of clay mixed with straw as the binding material to provide strength.

Metal Bin (MB): It is a cylindrical structure made of iron sheets of varying gauges depending upon the size of the bin.

Airtight Ferrocement Bin (ATFB): Ferrocement is the most adaptable form of reinforced concrete. It consists of fly ash, sand, cement (mortar), and closely spaced light reinforcing rods or wire mesh. It requires no skilled labor and is easy to handle. The primary function of the wire mesh and reinforcing rods is to serve as a lath, supporting the mortar in its plastic state and absorbing tensile stresses once it hardens. The mechanical behavior of ferrocement depends on the strength, quantity, type, and orientation of the reinforcing rods and wire mesh.

Forced Ventilated Ferrocement Bin (FVFB): The same procedure of construction was adopted to design a forced ventilated ferrocement bin with the addition of a forced ventilated air system at the bottom of the bin. Fans along with main and lateral ducts were provided at the bottom of the bin as per design calculation.

Airtight Metallic Bin (ATMB): A prototype airtight metallic bin was designed and developed using the galvanized metallic sheet. For insulation purposes, a rubber stopper was provided at the inlet, outlet, and all monitoring ports to make it airtight. The conical roof of the bin was fabricated similarly to the wall.

Forced Ventilated Metallic Bin (FVMB): The same procedure of construction was adopted to design a forced ventilated metallic bin with the addition of a forced ventilated air system at the bottom of the bin, A 12V DC Fan was operated during low humidity hours with 0.2 cfm /bushel.

Experimental design:

The experiment was carried out in a randomized complete block design. The effect of two factors, storage structures and storage period was recorded on the wheat grain quality and losses. The treatments were replicated thrice.

Preparation of the Wheat Grains for Storage Structures:

The freshly harvested wheat grain was obtained from the SAU Farms Tandojam, Pakistan. The wheat grains were cleaned manually and foreign matter such as stones, straw, and dirt was removed. Wheat grain samples were adjusted to a safe moisture level (wet basis) by sun drying or rehydration (18). These moisture levels were randomly selected taking into account the safe moisture level i.e. 12% [23]. Around 350 kg of wheat was stored in each structure.

Samples Collection and Analysis:

Grain sampling was carried out from the top, bottom, and middle of each storage structure (figure 2) using the sampling probe. The grain samples were thoroughly mixed to get a composite sample (24 & 25). The readings for each parameter (stored grain temperature, moisture contents, aflatoxin, insect infestation, weight loss, germination percentage) were taken 3 times.

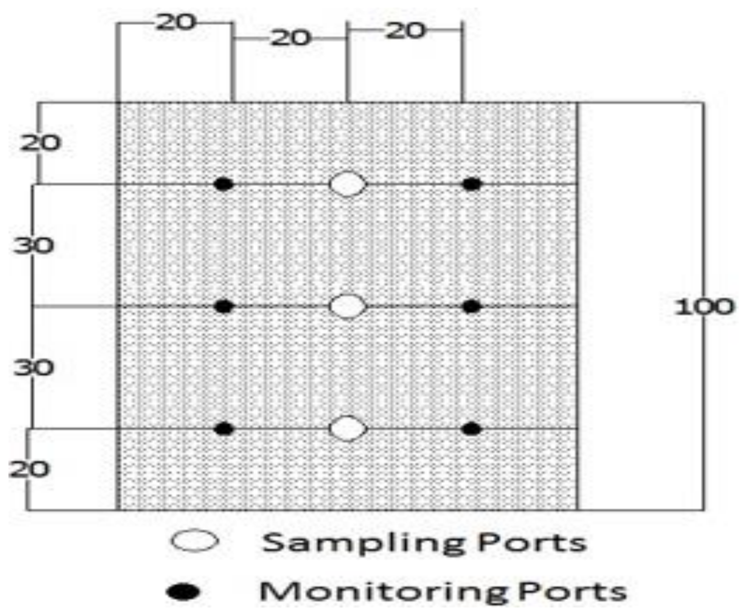

Figure 2. Schematic diagram of storage structures showing sampling and monitoring ports

Determination of Quality Parameters to Evaluate Storage Structures:

The quality parameters that were determined to assess the performance of developed structures are shown in Table 1.

Table 1. Quality parameters and their determination methods

S. No	Quality Parameters	Equipment	Formula/Method	Reference
1.	Stored grain temperature (°C)	Thermometer probe, Stopwatch	Direct reading	[20]
2.	Moisture content (%)	Weight balance, cans, Oven	$\frac{\text{wt. of sample} - \text{wt. of dried sample}}{\text{Wt. of sample}} x100$	[24]
3.	Germination (%)	Petty dish, filter paper, distilled water	$\frac{\text{No. of germinated seed}}{\text{Total no of seeds}} x100$	[24]
4.	Insect-pest infestation (%)	Sampling probe, tray	$\frac{\text{No. of insect} - \text{damaged grain}}{\text{Total no of seeds}} x100$	[25]
5.	Weight loss due to insect infestation (%)	Weight balance, cans	$\frac{\text{No. of insect} - \text{damaged grain}}{\text{Total no of seeds}} x100$	[26]
6.	Aflatoxin level ($\mu g\ kg^{-1}$)	High-performance liquid chromatography (HPLC)	HPLC method	[27]

Data Analysis:

Analysis of variance was conducted to evaluate differences among the developed structures. Multiple mean comparisons were performed using the LSD test at a 1% significance level using Statistix 8.1 software.

Results and Discussions:

Variation in Ambient Temperature and Relative Humidity Of Experimental Site:

A decreasing trend was observed in ambient temperature and relative humidity from July to January reaching a lowest value of 23.4 °C and 62%, respectively. From January, both ambient temperature and relative humidity increased gradually to the highest value of 40.21 °C and 68%, respectively (Figure 3). Traditional food grain storage and preservation techniques can be enhanced or adjusted as needed for successful grain storage to guarantee that agricultural potential is fully utilized to satisfy the world's growing food and energy demands [8]. Naturally, grains absorb moisture in humid environments. As a result, the storage structure's atmosphere is influenced by its surroundings. Changes in the environment have an effect on the biological, chemical, and physical characteristics of the grain in the storage bin [28].

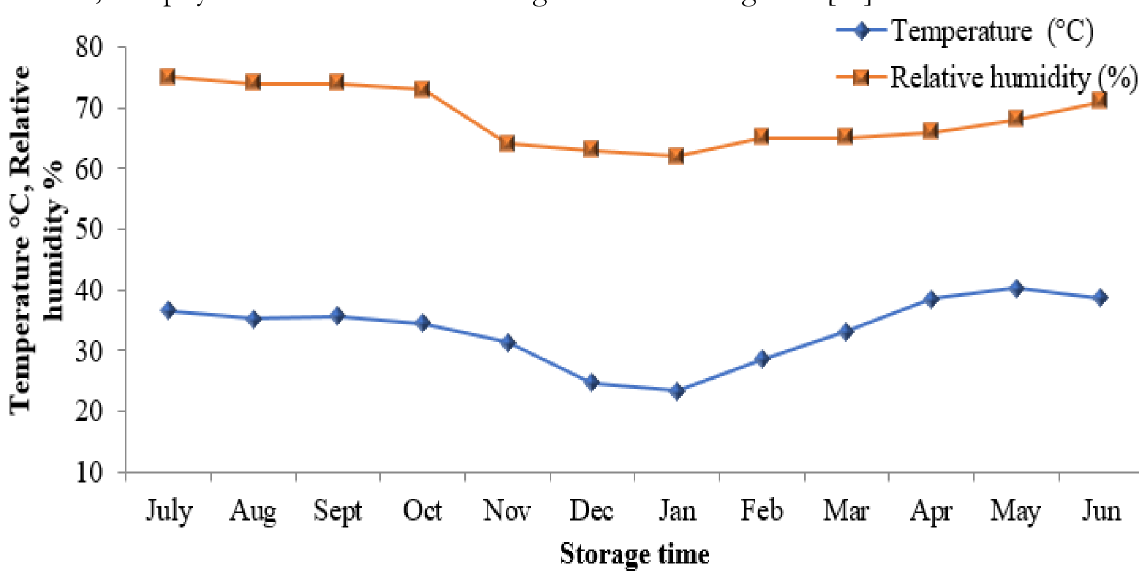

Figure 3. Variations in mean ambient temperature and relative humidity of the experimental site during storage

Table 2. Mean squares of quality parameters of wheat grains under the effect of storage systems and storage durations

SOV	Df	Moisture content (%)	Insect infestation (%)	Aflatoxins (μg kg^{-1})	Grain Temperature (°C)	Grain Weight loss (%)	Germination (%)
Replication	2	3.28247	0.219	9.333E-05	0.375	0.0001	0.03
Storage (S)	5	7.15562**	101.208**	30.4707**	3.914**	5.4994**	491.63**
Duration (D)	4	3.43088**	505.922**	121.729**	610.774**	11.2769**	2099.54**
S×D	20	0.57490**	23.030**	2.18490**	0.362**	0.9681**	122.60**
Error	58	0.03099	0.333	9.933E-04	0.029	0.0002	0.99
Total	89						

Highly significant at p<0.01

Grain Moisture Contents:

It is noteworthy from the results that storage structure and storage period have a significant effect ($p<0.01$) on grain moisture contents (table 2). The average results of grain moisture contents are presented in Figure 4 with an interval of three months. During study periods, higher moisture values (14.41 and 14.83%) were obtained in the storage under EB and MB as they were beyond the upper limit. Grain moisture was high due to variations in relative humidity and temperature conditions of the surrounding air. The differences between EM and MB, ATFB and FVMB, and FVFB and ATMB were non-significant after three months but remained significantly different across all comparisons with the same pattern. However, EB (after 6, 9, and 12 months), MB (after 6, 9, and 12 months), and ATFB (after 12 months) had significant differences. While, FVFB, ATMB, and FVMB showed non-significant differences over time. Modern structures invoked better results and ideal conditions for grain storage by which healthy grain is obtained. Under an Airtight Ferrocement Bin (ATFB) consistency in grain moisture contents was observed compared to all other treatments. The results are supported by the findings of Chattha et al. [20] as high grain moisture can also be due to variations in relative humidity and temperature conditions of the surrounding air. In the case of traditional bins, grain uptake moisture from the ground, and poor protection from the weather, and may cause the growth of mold and insects. According to Laca et al. [29], 13% moisture content is thought to be the ideal level for storing wheat, corn, barley, and rice. In high-humidity environments, Hruskova and Machova [30] noted a rise in the moisture of grain. Wheat seeds with an acceptable moisture content would be better suited for storage because the fungal activities and cell respirations could be kept under control. The findings regarding moisture content are consistent with earlier hypotheses made by Hell et al. [31], Hell et al. [32], and Lamboni and Hell [33]. These hypotheses suggested that the high moisture content of grain in traditional bins may be caused by the higher respiration of insects, fungi, and wheat grain. Since heavy infestations can increase moisture content and temperature, which could lead to a rise in the growth of toxic fungi, insects in grain also like these conditions, which can then encourage the development of mold.

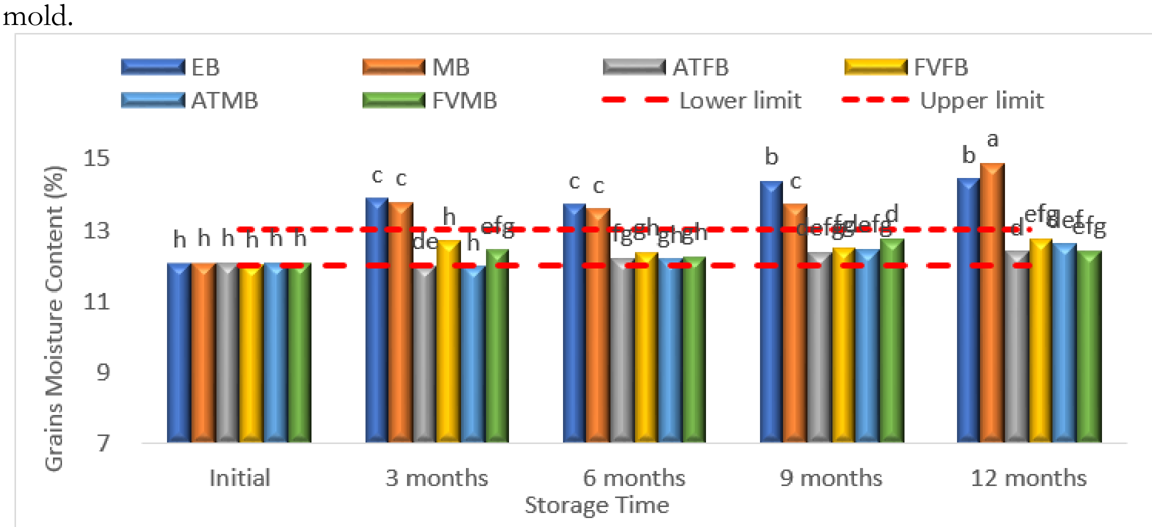

Figure 4. Effect of storage structures on moisture content (%) of wheat grains during storage period. Means denoted by different lowercase letters indicate significant differences between treatments ($p < 0.05$).

Stored Grain Temperature:

The results indicated that both storage structure and storage period have a significant impact ($p<0.05$) on grain temperature (Table 2). The average grain temperature results, recorded at three-month intervals, are presented in Figure 5. During study periods, grain temperature varied due to variations in relative humidity and temperature conditions of the surrounding air. The difference between EM and MB showed a significant difference over time while non-significant after 9 months. Temperature is one of the primary environmental elements influencing the physiological, life history, behavioral, and population processes of arthropods in conventional bins with minimal environmental protection [14]. Insect population growth is greatest between the optimum breeding temperatures of 25 and 32°C, but development slows between 13 and 24°C and 33 to 35°C. Lethal temperatures, which cause insects to cease feeding, slow down in development, and eventually die, are between 13 and 35 degrees Celsius. Insects perish more quickly when the conditions are extreme [34]. Ferreira et al. [35] observed that the composition of black beans did not change (P 0.05) as a result of time (12 months), temperature (11, 18, 25, and 32 °C), and moisture (14% and 17%) during storage. Depending on the temperature (5, 15, 25, and 35 °C) and storage duration, Paraginski et al. [36] reported no changes in the fundamental components of maize grains held at initial moisture of 14%. (12 months). Zhang et al. [37] also observed alterations after storage at 25 to 50 °C in the physiochemical properties of wheat. Quality degradation due to artificial aging during storage at 45 °C was noted by Tian et al. [38]. Modern structures invoked better results and ideal conditions for grain storage by which healthy grain is obtained.

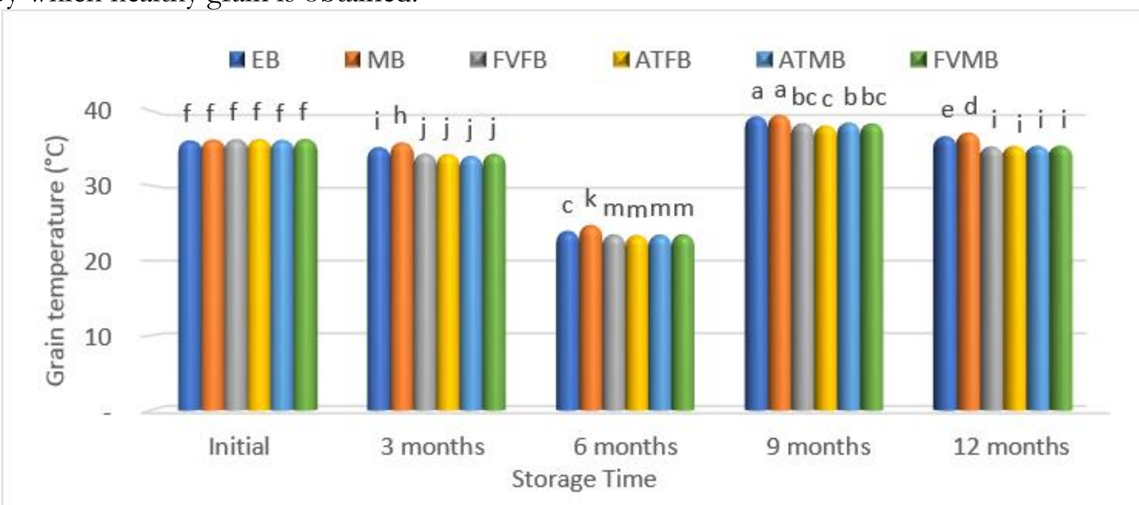

Figure 5. Effect of storage structures on grain temperature (°C) of wheat grains during the storage period. Means denoted by different lowercase letters indicate significant differences between treatments ($p < 0.05$).

Aflatoxin:

Aflatoxins represent a global public health and economic concern as they are responsible for significant adverse health and economic issues affecting consumers and farmers worldwide. The results indicate that storage structure and storage period significantly affect ($p<0.05$) the aflatoxin levels in wheat grain (Table 2). Initially, there was no aflatoxin of grains stored in various structures. After 3 months, 9 months, and twelve months the aflatoxin of grains was significantly different in all structures. However, after 6 months, the FVFB and FVMB maintained the aflatoxin at the same level and showed a non-significant difference. As shown in Figure 6, the highest aflatoxin levels were detected in traditional bins (EB and MB) due to elevated moisture content. The findings of the present study on insect infestation are in line with previous findings that excessive moisture content during storage causes seed aging, storage insect pests, and aflatoxin contamination [39]. According to Williams et al. [40], underdeveloped countries, where almost 4.5 billion people are at risk of chronic aflatoxin exposure, are particularly vulnerable to food grain contamination with fungi that produce aflatoxins. According to Bewley et al. [41] guidance, 13% seed moisture concentrations or above are the baselines for fungal growth and aflatoxin contamination for cereal seeds like wheat. Aflatoxin contamination was increased due to high seed moisture contents (14%) in super bags and regular porous bags. The study by Hell et al. [32], which claimed that aflatoxin-producing molds grow in normally stored grains under high temperatures and RH, also supports the findings. Additionally, ATFB outperforms the tested structures due to its airtight quality material consumption even after a year in storage. Similarly, several studies [39][42][43] revealed that storing food grains in hermetic bags has proven to be the best way to lower aflatoxin contamination and stored grain pest infestation. Relatively, modern structures (ATFB, FVFB, ATMB, and FVMB) maintained the grain moisture within permissible limits and thus controlled the aflatoxin, However, ATFB showed the best result among all storage structures in controlling aflatoxin.

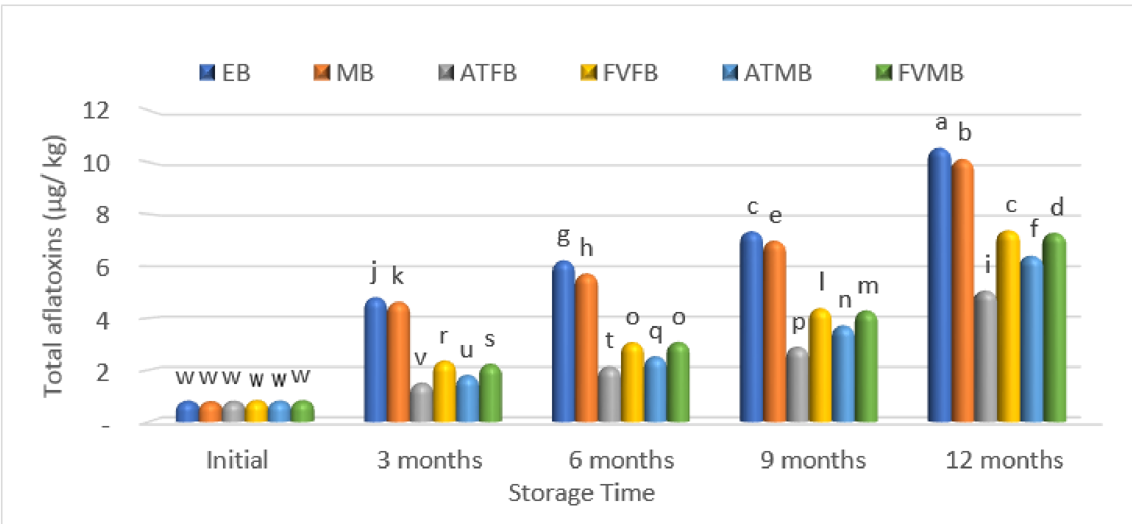

Figure 6. Effect of storage structures on aflatoxin (µg/ kg) of wheat grain during the storage period. Means denoted by different lowercase letters indicate significant differences between treatments ($p < 0.05$).

Insect Infestation:

The results highlight that storage structure and storage period significantly impact ($p<0.05$) insect infestation in wheat grain (Table 2). At the start of the experiment, the wheat grains were free from insects. After 3 months, 6 months, 9 months, and twelve months the grains were infested with insects. The difference between EB and FVFB was non-significant after 3 months and both structures infested the insects by the same amount. While ATMB and FVMB were significantly different. However, both structures (ATMB and FVMB) had non-significant differences against MB, ATFB, and FVFB after three months. However, EB (after 6 months), MB (after 6 months), FVFB (after 9 months), FVMB (after 9 months), and ATFB (after 12 months) had non-significant differences (figure 7). Ahmad [42] emphasized that an increase in storage time led to an increase in the insect population, which in turn caused an increase in wheat loss. Temperature is one of the primary environmental elements influencing the physiological, life history, behavioral, and population processes of arthropods in conventional bins with minimal environmental protection [14]. Insect population growth is greatest between the optimum breeding temperatures of 25 and 32°C, but development slows between 13 and 24°C and 33 to 35°C. Lethal temperatures, which cause insects to cease feeding, slow down in development, and eventually die, are between 13 and 35 degrees Celsius. Insects perish more quickly when the conditions are harsh [34]. The findings of the current study regarding insect infestation are consistent with those made previously by Dubale et al. [44], who noted an increase from 2.42- 20.75% during the storage period under standard storage methods (zombies and sacks). Similarly, it has been noted that infection of millet grains with flour beetles and less severe grain borer increased with longer storage times [45]. The provision of optimum storage conditions and environmental protection methods under ATFB, FVFB, ATMB, & FVMB, on the other hand, assisted society in maximizing its benefits by utilizing various ideas. However, even after a year of storage, ATFB continues to produce the best results of any treatment. The findings of Bradford et al. [46] and Afzal et al. [39] provide additional support for the findings. The main idea of hermetic bag technology is to block off the oxygen supply inside the bags, which reduces insect pest infestation and is effective for grain storage. The essential idea behind the dry chain is to dry seeds to a low moisture content that is secure enough to maintain seed viability before packaging them in hermetic containers to maintain continuous drying [46][39]. If the grain was clear of insects before storage, airtight seed bags could keep it from insect damage for up to nine months [47]. Figure 7 shows that wheat stored under traditional bins (EB and MB) was highly affected by insects concerning time. Under these methods, maximum insect infestation was observed over time. On the other hand, modern techniques showed relatively less insect infestation. Under an airtight ferrocement bin (ATFB) minimum infestation was observed compared to all other treatments. Therefore, it is recommended that good hygiene practices be used to combat the infestation of grains.

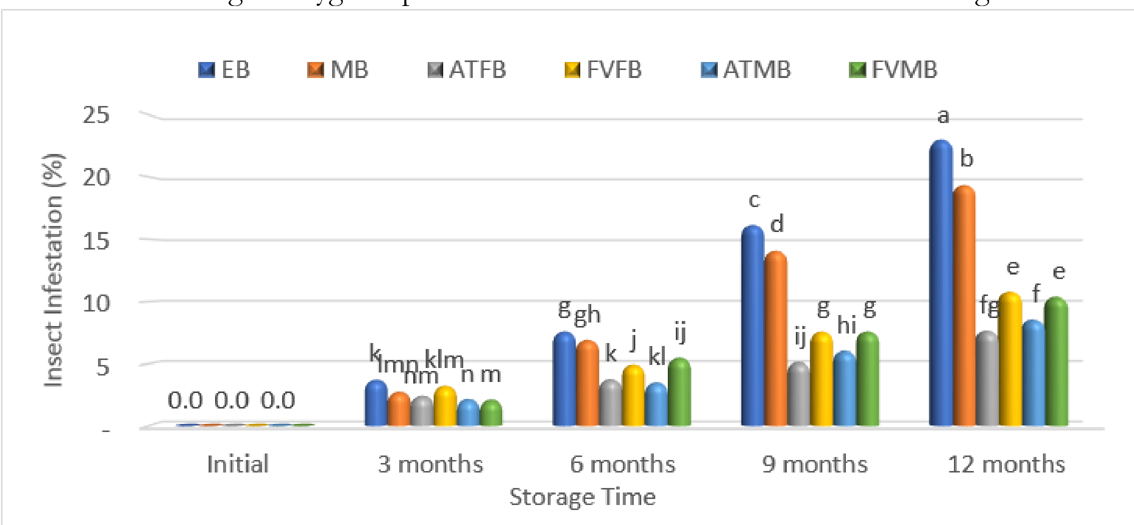

Figure 7. Effect of storage structures on Insect infestation percentage of wheat grain during storage period. Means denoted by a different lowercase letter indicate significant differences between treatments ($p < 0.05$).

Weight Loss:

It is noteworthy from the results that storage structure and storage period have a significant effect ($p<0.05$) on weight loss in wheat grain (table 2). Throughout the storage period, there was an increasing trend in grain weight loss, with the greatest rise in grain weight loss seen in samples from traditional bins (EB, MB) rather than modern bins (ATFB, FVFB, ATMB, and FVMB). The difference between FVFB, ATMB, and FVMB was non-significant after 3 months and retained the same amount of weight loss. While EB, MB, and ATFB were significantly different. However, FVMB (after 6 months), ATMB (after 6 months), FVFB (after 12 months), and FVMB (after 12 months) had non-significant differences (figure 8). For smallholder farmers in developing countries, grain storage loss is one of the main causes of food insecurity and a significant contributor to post-harvest losses [22]. The current study's findings on grain weight loss are consistent with earlier research by other researchers, including Phillips [48], who noted that inadequate environmental protection during storage creates a favorable environment for insects. Postharvest losses attributed to stored-product insects are estimated up to 9% in developed countries to 20% or more in developing countries. The findings of the current study are also in line with those of Sayed et al. [49], who found a correlation between weight loss of stored grains and insect infestation level. Structures produced better outcomes and appropriate grain storage conditions, resulting in healthy grain. The current findings are also consistent with earlier research by Abdullahi et al. [50] and Javed et al. [51], which demonstrated that insects can result in a significant economic loss by reducing the quantity and quality of stored seeds and by increasing the cost of treatment and preventative measures. Modern structures invoked better results and ideal conditions for grain storage by which healthy grain is obtained. Under an airtight ferrocement bin (ATFB) minimum weight loss was observed compared to all other treatments. This shows the good characteristics of the ATFB.

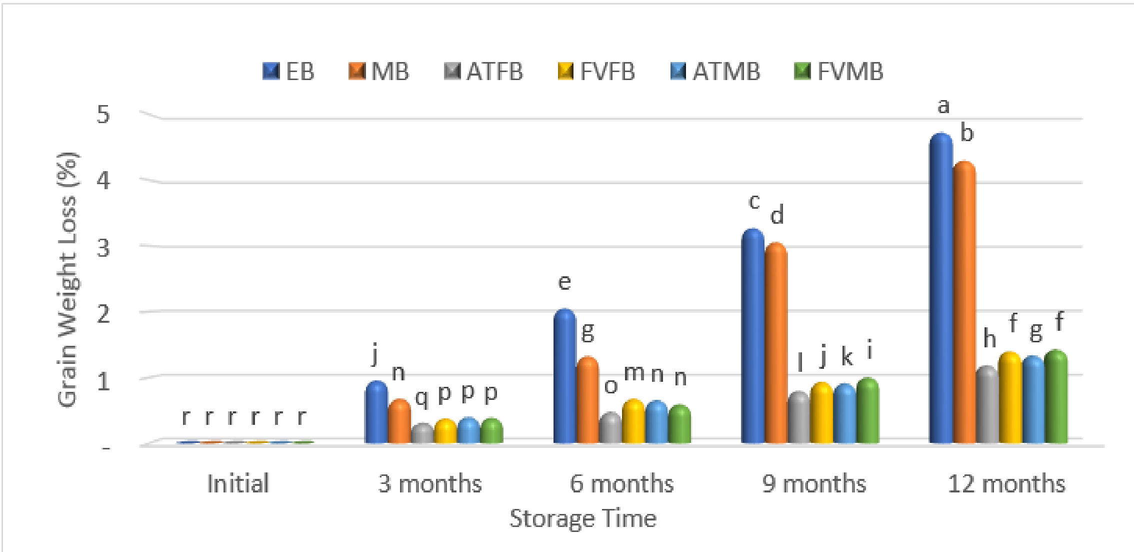

Figure 8. Effect of storage structures on grain weight loss percentage of wheat grain during the storage period. Means denoted by different lowercase letters indicate significant differences between treatments ($p < 0.05$).

Seed Germination:

It is observed from the results that storage structure and storage period have a significant effect ($p<0.05$) on seed germination percentage in the wheat grain (table 2). Initially, the germination percentage was the same but gradually declined throughout the storage period under different storage structures. The difference between MB, ATFB, and ATMB was non-significant after 3 months, while EB, FVFB, and FVMB were significantly different. However, MB (after 6 months), FVFB (after 6 months), ATMB (after 6 months), ATFB (after 9 months), and ATMB (after 9 months) had non-significant differences. While, the EB, MB, ATFB, and ATMB showed significant differences over time (figure 9). Modern structures invoked better results and ideal conditions for grain storage by which healthy grain is obtained. Improved plant stands in the field and higher yields and increased productivity would follow from greater seed germination [52]. The data on seed germination is supported by Vales [52], who reported that during eight months of storage, 77.0% of the seeds had germinated. These numbers fall within the permissible range (>75% defined by the seed industry), and they agree with the results of ATFB, FVFB, ATMB, and FVMB. Seed viability can be maintained for up to 9 months after harvesting when stored at 15°C, but only for 3 months when stored at 30°C. The findings of Owolade et al. [53], Rani et al. [54], and Ahmed et al. [55], who found that high grain moisture and temperature are inversely related to grain germination %, provide additional support for the findings. Additionally, Mobolade et al. [21] research showed that conventional methods for food grain storage and preservation can be enhanced or changed as needed for efficient grain storage, ensuring that agricultural potential is fully realized to meet the growing food and energy demands of the world. Therefore, even after a year, ATFB has produced the best performance out of all the modified storage bins with very minor modifications. Under an airtight ferrocement bin

(ATFB) maximum germination percentage was observed compared to all other treatments. This shows the good characteristics of the ATFB. FVFB and FVMB are also not different and have the same trend concerning storage time.

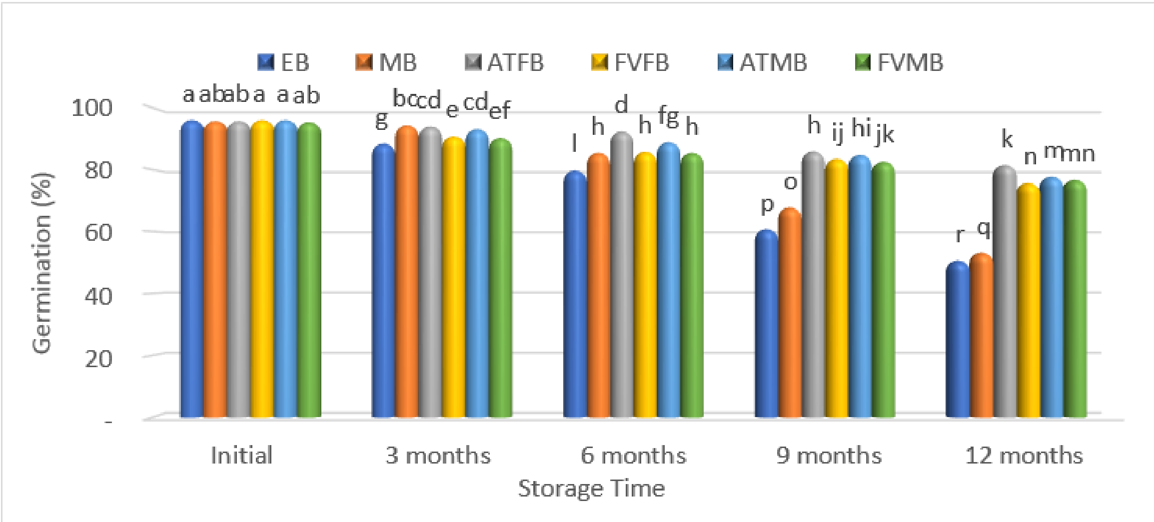

Figure 9. Effect of storage structures on Germination percentage of wheat grain during the storage period. Means denoted by different lowercase letters indicate significant differences between treatments ($p < 0.05$).

Conclusions:

The study emphasizes the critical role of proper storage methods in preserving wheat grain quality and minimizing losses. Poor storage conditions lead to significant deterioration over time, affecting both grain safety and market value. Among the storage methods analyzed, airtight and ventilated bins proved to be more effective in maintaining grain quality, with airtight ferrocement bins showing the best results. These bins offer a durable and cost-effective solution, protecting wheat from moisture, pests, and spoilage. By adopting airtight ferrocement bins, farmers can reduce post-harvest losses, enhance food security, and ensure better profitability. Investing in proper storage infrastructure is essential for sustainable grain management and long-term agricultural success. Future research should investigate smart storage solutions incorporating sensors and IoT-based monitoring for real-time quality assessment.

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References:

[1] M. N. M. Dr. Imtiaz Ahmad, Ms. Naila Abbas Dar, Dr. Naseem Faraz, Mr. Zille Hasnain, Dr. Nazia Gul, Mr. Omer Farooq, Dr. Shahzada M. Naeem Nawaz, "Pakistan Economic Survey, Finance Division, Economic Advisor's Wing, Islamabad, Pakistan," *Gov. Pakistan*, 2022, [Online]. Available: https://www.finance.gov.pk/survey/chapters_23/Economic_Survey_2022_23.pdf

[2] O. Barna, O., Burluc, R.M. and Baston, "Studies regarding the effect of temperature storing of Flamura 85 wheat on the rheological properties of dough," *Ann. Food Sci. Technol.*, vol. 10, no. 2, pp. 359–362, 2009.

[3] Digvir S. Jayas, "Storing Grains for Food Security and Sustainability," *Agric. Res.*, vol. 1, pp. 21–24, 2022, doi: https://doi.org/10.1007/s40003-011-0004-4.

[4] R. K. Vishwakarma, S. N. Jha, A. K. Dixit, A. Kaur, A. Rai, and T. Ahmed, "Assessment of harvest and post-harvest losses of major pulses in India," *Agric. Econ. Res. Rev.*, vol. 32, no. 2, p. 247, 2019, doi: 10.5958/0974-0279.2019.00036.3.

[5] G. J. S. Ioannis G. Stathas, Anastasios C. Sakellaridis, Marina Papadelli, John Kapolos,

Konstantinos Papadimitriou, "The Effects of Insect Infestation on Stored Agricultural Products and the Quality of Food," *Foods*, vol. 12, no. 10, p. 2046, 2023, doi: https://doi.org/10.3390/foods12102046.

[6] A. L. Darka Hamel, Vlatka Rozman, "Storage of Cereals in Warehouses with or without Pesticides," *Insects*, vol. 11, no. 12, p. 846, 2020, doi: https://doi.org/10.3390/insects11120846.

[7] U. S. H. and J. G. A. S. S. Hosakoti, S. S. Doli, "Methods of Storage of Grains by Farmers and Losses during Storage," *Int. J. Agric. Stat. Sci.*, vol. 9, no. 1, pp. 235–239, 2013, [Online]. Available: https://connectjournals.com/pages/articledetails/toc017796

[8] Y. R. Adesina Jacobs Mobolade , Nameirakpam Bunindro, Dinabandhu Sahoo, "Traditional methods of food grains preservation and storage in Nigeria and India," *Ann. Agric. Sci.*, vol. 64, no. 2, pp. 196–205, 2019, doi: https://doi.org/10.1016/j.aoas.2019.12.003.

[9] Francis Fleurat-Lessard, "Qualitative reasoning and integrated management of the quality of stored grain: a promising new approach," *J. Stored Prod. Res.*, vol. 38, no. 3, pp. 191–218, 2002, doi: https://doi.org/10.1016/S0022-474X(01)00022-4.

[10] L. M. A. Jon González-Torralba a, Silvia Arazuri, Carmen Jarén, "Influence of temperature and r.h. during storage on wheat bread making quality," *J. Stored Prod. Res.*, vol. 55, pp. 134–144, 2013, doi: https://doi.org/10.1016/j.jspr.2013.10.002.

[11] W. B. Józef Fornal, Tomasz Jeliński, Jadwiga Sadowska, Stanisław Grundas, Jan Nawrot, Anna Niewiada, Jerzy R. Warchalewski, "Detection of granary weevil Sitophilus granarius (L.) eggs and internal stages in wheat grain using soft X-ray and image analysis," *J. Stored Prod. Res.*, vol. 43, no. 2, pp. 142–148, 2007, doi: https://doi.org/10.1016/j.jspr.2006.02.003.

[12] A. S. Ashish Manandhar, Paschal Milindi, "An Overview of the Post-Harvest Grain Storage Practices of Smallholder Farmers in Developing Countries," *Agriculture*, vol. 8, no. 4, p. 57, 2018, doi: https://doi.org/10.3390/agriculture8040057.

[13] S. V. Arun Khatri-Chhetri , P.K. Aggarwal, P.K. Joshi, "Farmers' prioritization of climate-smart agriculture (CSA) technologies," *Agric. Syst.*, vol. 151, pp. 184–191, 2017, doi: https://doi.org/10.1016/j.agsy.2016.10.005.

[14] R. A. Vaclav Stejskal, Tomas Vendl, Zhihong Li, "Minimal Thermal Requirements for Development and Activity of Stored Product and Food Industry Pests (Acari, Coleoptera, Lepidoptera, Psocoptera, Diptera and Blattodea): A Review," *Insects*, vol. 10, no. 5, p. 149, 2019, doi: https://doi.org/10.3390/insects10050149.

[15] N. G. Karta Kaske Kalsa a, Bhadriraju Subramanyam, Girma Demissie, Rizana Mahroof, Admasu Worku, "Evaluation of postharvest preservation strategies for stored wheat seed in Ethiopia," *J. Stored Prod. Res.*, vol. 81, pp. 53–61, 2019, doi: https://doi.org/10.1016/j.jspr.2019.01.001.

[16] R. I. Sánchez-MariñEz, M. O. Cortez-Rocha, F. Ortega-Dorame, M. Morales-Valdes, and M. I. Silveira, "End-Use Quality of Flour from Rhyzopertha dominica Infested Wheat," *Cereal Chem.*, vol. 74, no. 4, pp. 481–483, Jul. 1997, doi: 10.1094/CCHEM.1997.74.4.481.

[17] S. C. Hazim Özkaya, Berrin Özkaya, "Technological properties of a variety of soft and hard bread wheat infested by Rhyzopertha dominica (F.) and Tribolium confusum du Val," Journal of Food Agriculture and Environment. Accessed: Mar. 08, 2025. [Online]. Available: https://www.researchgate.net/publication/237600867_Technological_properties_of_a_variety_of_soft_and_hard_bread_wheat_infested_by_Rhyzopertha_dominica_F_and_Tribolium_confusum_du_Val

[18] P. L. Abdoulie Jallow, Huali Xie, Xiaoqian Tang, Zhang Qi, "Worldwide aflatoxin contamination of agricultural products and foods: From occurrence to control," *Compr.*

Rev. Food Sci. Food Saf., 2021, doi: https://doi.org/10.1111/1541-4337.12734.

[19] K. A. I. Shakeel Hussain Chattha, Benish Nawaz Mirani, Shakeel Ahmed Soomro, "Comparative study of different storage methods for postharvest preservation of wheat grain," Science Technology and Development. Accessed: Mar. 08, 2025. [Online]. Available: https://www.researchgate.net/publication/324161608_Comparative_study_of_different_storage_methods_for_postharvest_preservation_of_wheat_grain

[20] S. H. Chattha, C. M. Hasfalina, M. R. Mahadi, B. N. Mirani, and T. S. Lee, "QUALITY CHANGE OF WHEAT GRAIN DURING STORAGE IN A FERROCEMENT BIN," *Agric. Food Sci.*, 2015.

[21] D. Kandel, P., Kharel, K., Njoroge, A., Smith, B.W., Díaz-Valderrama, J.R., Timilsina, R.H., Paudel, G.P. and Baributsa, "On-Farm Grain Storage and Challenges in Bagmati Province, Nepal," *Sustainability*, vol. 13, no. 14, p. 7959, 2021, doi: https://doi.org/10.3390/su13147959.

[22] A. Rodrigues Ribeiro and P. dos Santos Leite, "AQUISIÇÃO DE ALIMENTOS POR VIA INSTITUCIONAL EM MATO GROSSO – UMA INTERPRETAÇÃO DO PROGRAMA DE AQUISIÇÃO DE ALIMENTOS – PAA PELA COMPANHIA NACIONAL DE ABASTECIMENTO – CONAB, E SUA ABRANGÊNCIA NO PERÍODO DA PANDEMIA EM 2020.," Sep. 2022, doi: 10.29327/SOBER2022.485800.

[23] A. N. Kaaya and W. Kyamuhangi, "Drying Maize Using Biomass-Heated Natural Convection Dryer Improves Grain Quality During Storage," *J. Appl. Sci.*, vol. 10, no. 11, pp. 967–974, May 2010, doi: 10.3923/JAS.2010.967.974.

[24] A. T. M. Silindile P. Miya, "Crude Protein and Proline in Dry Bean Seed Respond to Weeding and Soil Fertility Regimes," *Int. Rules Seed Test.*, vol. 215, 2015, [Online]. Available: https://www.scirp.org/reference/referencespapers?referenceid=1605177

[25] H. . Wambugu, P.W., Mathenge, P.W., Auma, E.O. and Van Rheenen, "Efficacy of traditional maize (Zea mays L.) seed storage methods in western Kenya.," *African J. Food, Agric. Nutr. Dev.*, vol. 9, no. 4, 2009, doi: 10.4314/ajfand.v9i4.43882.

[26] K. L. . Harris and C. J. . Lindblad, "Postharvest grain loss assessment methods : a manual of methods for the evaluation of postharvest losses," *Am. Assoc. Cereal Chem.*, p. 193, 1978, Accessed: Mar. 08, 2025. [Online]. Available: https://books.google.com/books/about/Postharvest_Grain_Loss_Assessment_Method.html?id=CFIhAQAAMAAJ

[27] G. S. Giray, Belma Girgin, GozdeEngin, A. BasakAydın, Sevtap, "Aflatoxin levels in wheat samples consumed in some regions of Turkey," *Food Control*, vol. 18, no. 1, pp. 23–29, 2007, doi: https://doi.org/10.1016/j.foodcont.2005.08.002.

[28] B. Alabadan and O. Oyewo, "Temperature Variations within Wooden and Metal Grain Silos in the Tropics during Storage of Maize (Zea Mays)," *Agric. Food Sci.*, 2005.

[29] S. S. P. Adriana Laca, Zoe Mousia, Mario Díaz, Colin Webb, "Distribution of microbial contamination within cereal grains," *J. Food Eng.*, vol. 72, no. 4, pp. 332–338, 2006, doi: https://doi.org/10.1016/j.jfoodeng.2004.12.012.

[30] D. M. M. Hrušková, "Changes of wheat flour properties during short term storage," *Czech J. Food Sci.*, vol. 20, no. 4, pp. 125–130, 2020, doi: 10.17221/3522-CJFS.

[31] K. Hell, K. F. Cardwell, and H. M. Poehling, "Relationship between Management Practices, Fungal Infection and Aflatoxin for Stored Maize in Benin," *J. Phytopathol.*, vol. 151, no. 11–12, pp. 690–698, Nov. 2003, doi: 10.1046/J.1439-0434.2003.00792.X.

[32] P. F. Kerstin Hell, Charity Mutegi, "Aflatoxin control and prevention strategies in maize for Sub-Saharan Africa," African Journal of Microbiology Research. Accessed: Mar. 08,

2025. [Online]. Available: https://www.researchgate.net/publication/267698721_Aflatoxin_control_and_prevention_strategies_in_maize_for_Sub-Saharan_Africa
[33] Y. Lamboni and K. Hell, "Propagation of mycotoxigenic fungi in maize stores by post-harvest insects," *Int. J. Trop. Insect Sci.*, vol. 29, no. 1, pp. 31–39, Mar. 2009, doi: 10.1017/S1742758409391511/METRICS.
[34] R. H. P. Fields, Subramanyam Bhadriraju, "Extreme temperatures," Hagstrum. Accessed: Mar. 08, 2025. [Online]. Available: https://www.researchgate.net/publication/303249099_Extreme_temperatures
[35] Paraginski, Vanier, Elias, and M. Oliveira, "Physicochemical, antioxidant and cooking quality properties of long-term stored black beans: effects of moisture content and storage temperature," *Agric. Food Sci.*, 2017.
[36] M. C. E. Ricardo Tadeu Paraginski, Nathan Levien Vanier a, Jose De Jesus Berrios, Maurício de Oliveira, "Physicochemical and pasting properties of maize as affected by storage temperature," *J. Stored Prod. Res.*, vol. 59, pp. 209–214, 2014, doi: https://doi.org/10.1016/j.jspr.2014.02.010.
[37] S.-B. Zhang, Y.-Y. Lv, Y.-L. Wang, F. Jia, J.-S. Wang, and Y.-S. Hu, "Physiochemical changes in wheat of different hardnesses during storage," *J. Stored Prod. Res.*, vol. 72, pp. 161–165, 2017, doi: https://doi.org/10.1016/j.jspr.2017.05.002.
[38] P.-P. Tian, Y.-Y. Lv, W.-J. Yuan, S.-B. Zhang, and Y.-S. Hu, "Effect of artificial aging on wheat quality deterioration during storage," *J. Stored Prod. Res.*, vol. 80, pp. 50–56, 2019, doi: https://doi.org/10.1016/j.jspr.2018.11.009.
[39] D. B. Irfan Afzal, Muhammad Amir Bakhtavar, Muhammad Ishfaq, Muhammad Sagheer, "Maintaining dryness during storage contributes to higher maize seed quality," *J. Stored Prod. Res.*, vol. 72, pp. 49–53, 2017, doi: https://doi.org/10.1016/j.jspr.2017.04.001.
[40] A. D. Williams Jonathan H, Phillips Timothy D, Jolly Pauline E, Stiles Jonathan K, Jolly Curtis M, "Human aflatoxicosis in developing countries: a review of toxicology, exposure, potential health consequences, and interventions," *Am. J. Clin. Nutr.*, vol. 80, no. 5, pp. 1106–1122, 2004, doi: https://doi.org/10.1093/ajcn/80.5.1106.
[41] B. Finch-Savage, "Seeds: Physiology of development, germination and dormancy (3rd edition) - J.D. Bewley, K.J. Bradford, H.W.M. Hilhorst H. Nonogaki. 392 pp.Springer, New York – Heidelberg – Dordrecht – London2013978-1-4614-4692-7," *Seed Sci. Res.*, vol. 23, no. 4, pp. 289–289, Dec. 2013, doi: 10.1017/S0960258513000287.
[42] L. L. M. D.T. Martin, D. Baributsa, J.E. Huesing, S.B. Williams, "PICS bags protect wheat grain, Triticum aestivum (L.), against rice weevil, Sitophilus oryzae (L.) (Coleoptera: Curculionidae)," *J. Stored Prod. Res.*, vol. 63, pp. 22–30, 2015, doi: https://doi.org/10.1016/j.jspr.2015.05.001.
[43] C. W. Scott B. Williams, Dieudonne Baributsa, "Assessing Purdue Improved Crop Storage (PICS) bags to mitigate fungal growth and aflatoxin contamination," *J. Stored Prod. Res.*, vol. 59, pp. 190–196, 2014, doi: https://doi.org/10.1016/j.jspr.2014.08.003.
[44] B. Dubale, S. Waktole, A. Solomon, B. Geremew, and M. R. Sethu, "Influence of agro-ecologies, traditional storage containers and major insect pests on stored maize (Zea mays L.) in selected Woredas of Jimma zone," *Asian J. Plant Sci.*, vol. 11, no. 5, pp. 226–234, 2012, doi: 10.3923/AJPS.2012.226.234.
[45] S. P.C. Mali, "Effect of storage environment and storage material on qualitative and quantitative losses in pearl millet," Annals of Arid Zone. Accessed: Mar. 08, 2025. [Online]. Available: https://www.researchgate.net/publication/287282484_Effect_of_storage_environment_and_storage_material_on_qualitative_and_quantitative_losses_in_pearl_millet
[46] P. B. Kent J. Bradford, Peetambar Dahal, "Using Relative Humidity Indicator Paper to

Measure Seed and Commodity Moisture Contents," *Agric. Environ. Lett.*, 2016, doi: https://doi.org/10.2134/ael2016.04.0018.

[47] C. N. D. F.E. Dowell, "Reducing grain storage losses in developing countries," *Qual. Assur. Saf. Crop. Foods*, vol. 9, no. 1, 2017, doi: https://doi.org/10.3920/QAS2016.0897.

[48] T. W. Phillips and J. E. Throne, "Biorational approaches to managing stored-product insects," *Annu. Rev. Entomol.*, vol. 55, no. Volume 55, 2010, pp. 375–397, Jan. 2010, doi: 10.1146/ANNUREV.ENTO.54.110807.090451/CITE/REFWORKS.

[49] G. H. A. T. S. Sayed, F. Y. Hirad, "Resistance of Different Stored Wheat Varieties to Khapra Beetle, Trogoderma granarium (Everest) and Lesser Grain Borer, Rhizopertha dominica (Fabricus)," *Pakistan J. Biol. Sci.*, vol. 9, no. 8, pp. 567–1571, 2006, doi: 10.3923/pjbs.2006.1567.1571.

[50] U. R. S. G. Abdullahi , R. Muhamad, O. Dzolkhifli, "Damage potential of Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) on cocoa beans: Effect of initial adult population density and post infestation storage time," *J. Stored Prod. Res.*, vol. 75, pp. 1–9, 2017, doi: https://doi.org/10.1016/j.jspr.2017.11.001.

[51] M. S. Mudassar Javed, Muhammad Zeeshan Majeed, Abdul Khaliq, Muhammad Arshad, Muhammad Hannan Ahmad, "Quantitative losses in some advanced genotypes of barley incurred by Tribolium castaneum L. (Herbst.)," Int. J. Agron. Agri. Res. Accessed: Mar. 08, 2025. [Online]. Available: https://innspub.net/quantitative-losses-in-some-advanced-genotypes-of-barley-incurred-by-tribolium-castaneum-l-herbst/

[52] L. L. M. M.I. Vales, G.V. Ranga Rao, H. Sudini, S.B. Patil, "Effective and economic storage of pigeonpea seed in triple layer plastic bags," *J. Stored Prod. Res.*, vol. 58, pp. 29–38, 2014, doi: https://doi.org/10.1016/j.jspr.2014.01.004.

[53] O. Owolade, J. Olasoji, and C. Afolabi, "Effect of storage temperature and packaging materials on seed germination and seed-borne fungi of sorghum (Sorghum bicolor (L.) Moench .) in South West Nigeria," *African J. Plant Sci.*, vol. 5, no. 15, Dec. 2011, doi: 10.5897/AJPS11.209.

[54] C. V. K.-A. P.R. Rani a, V. Chelladurai, D.S. Jayas, N.D.G. White, "Storage studies on pinto beans under different moisture contents and temperature regimes," *J. Stored Prod. Res.*, vol. 52, pp. 78–85, 2013, doi: https://doi.org/10.1016/j.jspr.2012.11.003.

[55] T. A. Mukesh Rathore, Jai Prakash Gupta , Sudheer Kumar Pathak, "Effect of Storage Containers to Stabilize the Seed Quality in Wheat (Triticum aestivum L.)," *Int. J. Environ. Clim. Chang.*, vol. 12, no. 11, pp. 2729–2735, 2022, doi: 10.9734/ijecc/2022/v12i1131261.