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Food grain losses associated with indigenous storage methods and development of storage facilities for food security

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Abstract

The deterioration of wheat grains in terms of various quality parameters was observed during storage in traditional and designed structures for 12 months. As a result of the laboratory analysis and statistical data evaluation, protein (11.78%), lipid (2.4%), ash (1.76%) and starch (64.87%) were found maximum in grain samples taken from straw-clay bin followed by concrete block bin, ferrocement bin, earthen bin, bulk covered and room type store after 12 months of storage. The highest moisture (15.12%), insect-damage (26%), fungi (25%) and aflatoxin (13.3 µg kg^{-1}) was observed in grains stored in room store followed by bulk covered, earthen bin, ferrocement bin, concrete bin and straw-clay bin.

Introduction

The most staple among cereal crops produced and consumed worldwide is the Wheat (Triticum aestivum) which provide 20% of the calories of the daily food intake (Wiese, 1987). Pakistan ranked as the 8th among the largest wheat producing countries which contributes up to 3.17% in the worldwide wheat production out of 3.72% wheat growing region (Shuaib *et al*., 2007). Wheat is grown on an area of 8693 (000) hectares in Pakistan with the production of 24.2 million tons. The average yield of wheat was recorded 2787 kg ha-1 contributing 10.1% in the value addition and 2.2% to the Gross Domestic Product (Government of Pakistan, 2013). It has a most important role in the diet of Pakistani people, contributes about 80% of the calories and 60% of the total proteins required by the body (Bostan and Naeem, 2002).

The regular availability of agricultural outputs is most important, i.e. the production and supply of the quality food grains to the consumers to make and sell different byproducts as well as to the farmers for sowing and growing healthy wheat grains will help to stabilize the economy of Pakistan. The storage of the wheat grains has a distinct role in the rising economies of many developing and developed countries (Ellis *et al*., 1992). Therefore, grain must be stored under proper conditions in order to maintain the necessary nutritional and rheological properties for usage by the milling and baking industry. The absence of well-designed grain storage methods and the lack of proper postharvest management systems force the farmers to sell their grain at the cheapest rates after harvest to evade the postharvest losses of the wheat grains with molds / pathogens etc. (Kimenju *et al*., 2009).

Grain quality characteristics can be deteriorated either by biotic (insects and fungi) or abiotic (temperature and moisture) factors. Fungi and insects can produce losses up to 35% in less developed countries (Hodges *et al*., 2011). The rate of fungal spoilage (losses in nutritional value and germination, discoloration, odors, deterioration in baking and milling quality) is influenced by high moisture and temperature conditions (Magan *et al*., 2003). Undesirable high humidities and temperatures also favor the development of insect pests. Insufficient storage methods tend to reduce the amounts of fat, vitamins, proteins and carbohydrates due to the attack of molds, rodents and insects (Lamboni and Hell, 2009). Bashir *et al*. (2013) reported that the deterioration of nutritional and rheological properties

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of the stored wheat mainly occurs due to insect infestation after six months of storage. In this study, wheat grains from various storage structures were examined for the nutritional changes after 12 months in order to achieve the most appropriate and safest type of structure for storing whea, yet affordable to rural dwellers.

Materials and Methods

Study area and wheat seeds

The present research was carried out at farmer level in Sukkur district of Sindh province of Pakistan to investigate the effectiveness of traditional grain storage methods on the quality of the stored wheat in 2013-14. The newly harvested wheat seeds were taken from the farmer's field and evaluated for moisture, insect damage, fungi, aflatoxin, protein, fat, ash and starch. These initial values of the data were used as the baseline reference. The grains were cleaned manually to remove foreign matter, for example, stones, straw, dirt and debris. All the storage structures were then completely filled with wheat grains and the results were calculated after storage of 12 months.

Traditional grain storage methods

Farmers in the Sukkur district of Sindh commonly store wheat grains for their food and seed purpose in the traditional structures of variable dimensions until it is consumed. The details of these structures are as below:

- Earthen bin: It is made up of straw mixed with clay which enhances binding capacity and provide strength. These types of structures are generally circular in shape (Figure 1a).
- Room type structure: The burnt bricks and mud or cement mortar is usually used in its construction and can be composed of multiple rooms of variable dimensions closed from all the sides. It contains ventilators, doors, windows, roof, floor and walls where the bangs are stacked on the floor or dunnage with space to allow air circulation (Figure 1b).
- Bulk covered: The farmers usually dump the harvested grain on the plain ground and cover it with mud and straw mixed plaster in order to avoid grain losses. The small ditches are also dug around them, which did not allow rainwater to stand around (Figure 1c).

Figure 1. Three different types of traditional grain storage methods used in the study (a-Earthen bin, b-Room type structure, c-Bulk covered)

Designed grain storage bins

The cylindrical type of storage structures, i.e., ferrocement, concrete block and straw-clay bins were constructed on the Latif Farm, Sindh Agriculture University Tandojam from the easily available materials by keeping the storage capacities required by local farmers of Sindh province, Pakistan (Figure 2). All the bins had the same dimensions and grain storage capacity of 2500 kg.

Figure 2. Three different types of designed grain storage bins used in the study (a-Straw-clay bin, b-Concrete block bin, c-Ferrocement bin)

Concrete block bins were constructed by using hollow concrete blocks whereas the ferrocement bins were constructed with cement, sand mortar and light reinforcing rods or wire mesh which were closely spaced throughout the structure. However, straw-clay bins were made up of clay and rice straw. The outlet and inlet of grains were provided at the bottom and the top of every structure wall, respectively. The floor of the bins was kept above the ground level by providing polyethylene sheets and the course layer of damp proof bitumen between two layers of cement concrete to protect grain from moisture uptake or surface water

The top of the bins was designed as a conical shape with slopes of 30° and were kept overhung from the wall to avoid direct heat from sunlight as well as to protect from destruction made by heavy rains. The heat insulating materials, including straw layer or thatch and sheets of asbestos were used to make the roof of the bins to protect stored grains from daytime heat and remain cool overnight which prevents moisture condensation and migration inside the structures.

Grain sampling

A total 3 kg sample of wheat grains was taken from each storage structure using the grain sampler from top (1kg), middle (1kg) and bottom (1kg) of the structure. The grain samples were then altogether mixed in order to get a composite sample. The analysis of quality parameters of the collected samples was completed at the research facility of the Pakistan Council of Scientific and Industrial Research (PCSIR), Hyderabad. Moreover, relative humidity and ambient temperature of the study area were noted monthly for whole storage duration using dry and wet bulb thermometers.

Measurement of grain quality characteristics

Wheat grains were tested for moisture, protein, fat, and ash and starch contents according to the procedure described in AACC (2000), methods No. 44- 15A, 46-10, 30-25, 32-10 and 08-01, respectively. Insect damage was assessed by the counting method as described by Wambugu *et al*. (2009). From each storage structure about two hundred wheat grains were randomly collected and visually observed for a number of insect damaged and undamaged grains by the presence of holes in each grain. The examination for fungi in the stored wheat was carried out by the seed plating technique. The percentage of seeds infected was calculated by shaking about 100 kernels for 1 min in 2% sodium hypochlorite (NaOCl) solution, washing twice with sterile refined water, and plating on malt agar (MSAT) containing 6% sodium chloride in addition to Tergitol (Stroshine *et al*., 1984). After incubation for 5-7 days at room temperature (25-27°C), the fungi growing in each grain were recognized and the percentage of fungal incidence was noted. Wheat grain samples obtained from each storage structure were analyzed for level of aflatoxin contamination using the high performance liquid chromatography (HPLC) method following the methodology described by Giray *et al*. (2007) with minor modifications.

Data analysis

The experiment was laid out in completely randomized design (CRD) with three replications and standard deviations (SD) were computed according to the method of Steel and Torrie (1980). Means were compared with LSD test at 5% probability level.

Results and discussion

The freshly harvested wheat grains were dry (13% average moisture) and showed no evidence of insect damage (no holes, no insects present). They had high average protein (11.80%), fat (2.94%), ash (2%) and starch (65.8%). They had 4% fungal infected grains and about 0.8 μg kg^{-1} aflatoxin level. The relative humidity and ambient temperature of the experimental site for the storage period from July, 2013 to July, 2014 are given in Figure 3. The ambient temperature was recorded in range, from 25.96 to 45.63°C with a mean value of 38.07°C, whereas the relative humidity was ranging from 60 to 80% with an average value of 73.46% throughout the storage period. This range of temperature and humidity is optimum for the development of insects and fungi, which damage the grain and result in loss of grain quality and quantity. Growth and development of most of the insect pests occur at 25-35°C (Ilelejia *et al*., 2007). Whereas, according to Yigezu *et al*. (2010) the optimum temperature for the growth of stored product insects was in between 10-40°C. However, much of the grain quality deterioration and contamination have been associated with inadequate storage methods (Gourama and Bullerman, 1995).

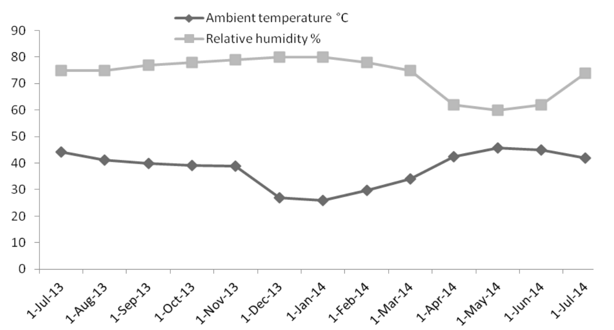

Figure 3. Relative humidity and ambient temperature of the study area

Moisture content of grain was significantly increased in all the storage structures after 12 months of storage (F=35164; $P \leq$0.000). Moisture content of grain after 12 months of storage in earthen bin, bulk covered, room structure, ferrocement bin, straw-clay bin and concrete bin was 14.88%, 14.97%, 15.12%, 12.6%, 12.55% and 12.57% respectively (Table 1). This increase in moisture content might be due to insects, fungi and grains that respires and release heat, CO2 and water. The rise in grain moisture can also be due to the change in relative humidity of the surroundings. The data of current research are also relevant to the achievement of Jood *et al*. (1996) who recorded 75% of insect infestation causes the increase in moisture levels inside the contaminated grains as compared with control and the grains with lower infestation levels. Sawant *et al*. (2012) also observed rise in moisture content with increased storage periods of contaminated grains. Masum *et al*. (2010) evaluated that the tin and polyethylene containers were less permeable to moisture than gunny bags. The grains stored in gunny bags with moisture content of 16.23% increased up to 25.4%. However, the grains stored in tin container retained in good quality throughout the storage time, but increased with the passage of time.

Insect damage of the grains after 12 months of storage was significantly increased in all the structures (F=91.8; $P \leq$0.000), having 15%, 18%, 26%, 11%, 8% and 9% insect damage in the grains stored in earthen bin, bulk covered, room structure, ferrocement bin, straw-clay bin and concrete bin, respectively (Table 1). The maximum insect damage percentage in room structure may be because of high temperature and moisture conditions in this structure. Arain *et al*. (1995) evaluated 6 types of traditional storage structures (metal bins, gunny bags, pallies , pacci kothies, kacchi kothies and bharollas) for their comparative suitability for storage of wheat grains. It is apparent from the results that stored wheat at farm level is best protected against insect infestation in metal bins. The results are further supported by the findings of Mali and Satyavir (2005) who observed that the insect damage increased by the storage period and was high on seeds stored in jute bags and tin containers as compared to polyethylene bags.

Fungal incidence was significantly increased in the stored grain after 12 months of storage (F=54.3; $P \leq$0. 000), having 17%, 20%, 25%, 13%, 9% and 11% fungi in the grains stored in earthen bin, bulk covered, room structure, ferrocement bin, straw-clay bin and concrete bin, respectively (Table 1). The maximum fungal attack on a room type structure may be due to high temperature and moisture conditions. The results are supported by the findings of Malaker *et al*. (2008) who observed fungal prevalence gradually increased in all containers (bamboo dole, earthen pitcher, tin container and polyethylene bag) at 25-30°C except refrigerator at 10°C. Similarly, Paraginski *et al*. (2014) have stated that the percentage of grain infected by molds significantly increased in the third month of storage for the maize stored at 15, 25 and 35°C. The maize stored at 35°C presented the highest percentage of grain infected by molds in the 6th month of storage.

Aflatoxin content was significantly increased in the stored grain after 12 months of storage (F=14496; $P \leq$0. 000). The maximum aflatoxin level (13.3 µg kg^{-1}) was noted from grain stored in a room type structure followed by bulk covered (10.2 µg kg^{-1}), while the minimum value (4.6 µg kg^{-1}) of aflatoxin was observed in straw-clay bin (Table 1). The highest increase of aflatoxins was found in room structure can be because of high temperature and moisture conditions. Saleemullah *et al*. (2006) who found prolonged storage of cereals and nuts collected from local markets of NWFP, Pakistan for 18 months significantly increased aflatoxin contents of seeds

Table 1. Moisture, insect-damage, fungi and aflatoxin of wheat grain under the effect of storage methods after 12 months storage (Means ± S.D)

Storage methods	Parameters			
	Moisture content (%)	Insect-damage (%)	Fungi or Mold (%)	Aflatoxin (µg kg^{-1})
Earthen bin	14.88± 0.03^{c}	15± 2^{c}	17± 1^{c}	8.6± 0.02^{c}
Bulk covered	14.97± 0.01^{b}	18± 1^{b}	20± 2^{b}	10.2± 0.03^{b}
Room structure	15.12± 0.02^{a}	26± 1^{a}	25± 1^{a}	13.3± 0.02^{a}
Ferrocement bin	12.60± 0.01^{d}	11± 2^{d}	13± 3^{d}	6.7± 0.01^{d}
Straw-clay bin	12.55± 0.01^{e}	8± 1^{e}	9± 1^{e}	4.6± 0.03^{f}
Concrete block bin	12.57± 0.01^{e}	9± 1de	11± 1de	5.8± 0.02^{e}
LSD (0.05)	0.0218	2.1788	2.5159	0.0818
CV	0.09	8.45	8.93	0.56

Mean values ± standard deviation of three replicates within each column sharing similar letters are not significantly different by LSD test at P≤0.05

Table 2. Protein, lipid, ash and starch content of wheat grain under the effect of storage methods after 12 months storage (Means ± S.D)

Storage methods	Parameters			
	Protein (%)	Lipid(%)	Ash (%)	Starch (%)
Earthen bin	8.91± 0.01[d]	1.91± 0.02[d]	1.59± 0.01[d]	61.70± 0.03[d]
Bulk covered	8.82± 0.02[e]	1.83± 0.01[e]	1.52± 0.02[e]	61.40± 0.01[e]
Room structure	8.58± 0.02[f]	1.75± 0.01[f]	1.40± 0.01[f]	60.60± 0.01[f]
Ferrocement bin	11.51± 0.01[c]	2.22± 0.02[c]	1.63± 0.03[c]	64.67± 0.02[c]
Straw-clay bin	11.78± 0.02[a]	2.40± 0.01[a]	1.76± 0.01[a]	64.87± 0.01[a]
Concrete block bin	11.64± 0.01[b]	2.32± 0.01[b]	1.67± 0.02[b]	64.82± 0.01[b]
LSD (0.05)	0.0281	0.0272	0.0317	0.0205
CV	0.15	0.74	1.11	0.02

Mean values ± standard deviation of three replicates within each column sharing similar letters are not significantly different by LSD test at $P \leq 0.05$

as compared to short storage periods (2 - 3 months). The results are supported by the findings of Kaaya and Kyamuhangire (2006) who recorded highest aflatoxin percentage in samples of maize grains from farmers in mid-altitude moist zone than those from the mid-altitude dry zone.

After 12 months of storage protein of the stored grain was significantly decreased ($F=29949$; $P \leq 0.000$). Protein content was higher (11.78%) when the grain stored in straw-clay bin followed by 11.64% in a concrete bin. The minimum protein content was noted (8.58%) in room store (**Table 2**). The loss of protein of stored grain may be due to the presence of high temperature and humidity which enhance the activity of proteolytic enzymes (endopeptidases and exopeptidases). This may also be because of fungi and insect infestation in the stored grain. The earlier study of Nasir *et al*. (2003) showed a decrease in protein content of wheat grains with higher moisture during storage in polypropylene bags for 60 days. The results are also supported by the findings of Sur *et al*. (1993) who recorded a decrease in protein content of wheat samples during storage for 135 days at room temperature (34.8°C) and relative humidity (66.7%). Lamboni and Hell (2009) found a reduction in the amount of proteins in stored grain can occur as a result of infestation of insects, molds and rodents where inadequate storage technologies apply.

Fat or lipid percentage was significantly decreased in the stored grain after 12 months of storage ($F=976$; $P \leq 0.000$). The maximum fat content (2.40%) of wheat grain was noted in straw-clay bin followed by concrete bin (2.32%), whereas the lowest fat content (1.75%) was determined in room store (Table 2). This could be because of attack of fungi and insect on the stored grain. Reed *et al*. (2007) found a decrease in fat content of maize grain during storage at temperatures of 25°C and relative humidity of 85% for 2 months due to deterioration by mold. Muangkaeo *et al*. (2005) also found a decrease in fat content of grain during storage in plastic bags at 9.65% moisture content for a period of 5 months under controlled temperature (16°C) and relative humidity (65%).

Ash percentage was significantly decreased in the stored grain after 12 months of storage ($F=141$; $P \leq 0.000$). The higher ash content (1.76%) was recorded from grain stored in straw-clay bin followed by concrete bin (1.67%), ferrocement bin (1.63%), earthen bin (1.59%), bulk covered (1.52%) and room store (1.40%) as shown in Table 2. The loss of grain ash content can be attributed to the presence of high insect and fungi in the stored grain. Saleemullah *et al*. (2006) observed a decrease in ash content, both in cereals and nuts due to inoculation with fungi. The results are also supported by the study of Bamaiyi *et al*. (2006) who found the ash content of cowpea grain in the control after 3 months storage was higher than the insect infested grains and it decreased with storage period.

Starch content was significantly decreased after 12 months of storage in all the structures ($F=88726$; $P \leq 0.000$). The high starch content (64.87%) was determined when grain was stored in straw-clay bin, while the concrete bin ranked second which was observed at 64.82%. The least starch content (60.6%) was found in grain stored in room store (Table 2). This can be due to high fungi and insect infestation in the stored grain. The loss of starch content can also be attributed to the presence of high temperature and moisture conditions. Bhattacharya and Raha (2002) reported that during storage of maize, groundnut and soybean seeds for 1 year, a gradual loss of carbohydrate content in all the seeds was recorded. The findings of Strelec *et al*. (2010) showed a significant decrease in starch content of the wheat stored at elevated temperatures (40 and 25°C) and relative humidity of 45%, during 1 year of storage. However the maximum decrease in starch content was observed for wheat grain kept at a higher temperature.

Conclusion

It may be concluded from this study that quality of wheat grains during storage is affected by different types of storage methods. Straw-clay, concrete block and ferrocement bins for wheat storage are the most economical and appropriate storage type in terms of the protection of stored wheat quality (low fungal incidence, insect-damage and aflatoxin level, and high protein, ash, lipid and starch of grains) as compared to earthen bin, bulk covered and room structure. Construction of these bins does not require high expertise, trainings and modern technologies, the ordinary person with little technical knowledge in the rural villages can easily build up at low cost. Designed bins are suitable for retaining better quality of wheat grains than traditional structures. Hence, the adoption of these bins must be encouraged in the developing countries to reduce the grain losses and to raise the food security, poverty alleviation and national economy.

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