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Effects of storage methods, storage duration and different geographical locations on quality of stored wheat (*Triticum aestivum*) in sindh, Pakistan

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Key words: Storage structures; Districts; Wheat; Period; Quality.

Abstract

Wheat grain stored in traditional structures was sampled from four selected districts of Sindh from July 2013 to July 2014 at 3 months interval and was analysed for quality deterioration over time. The maximum ambient temperature was noted in district Shaheed Benazir Abad followed by Sukkur, Hyderabad and Badin districts whereas the maximum relative humidity was observed in district Badin followed by Sukkur, Shaheed Benazir Abad and Hyderabad. The grain temperature followed the pattern of the ambient temperature and was higher than the ambient temperature during whole storage period. Moisture content, insect infestation and aflatoxin content showed an increasing pattern with prolonged storage. Among the storage structures the lowest grain temperature and moisture content were recorded in earthen bin whereas the highest in room structure and bulk covered, respectively. The highest percentage of insect infestation and aflatoxin content was observed in grains stored in room structure whereas, maximum test weight and seed germination capacity were recorded in grain samples taken from earthen bin. The levels of aflatoxins detected in stored wheat from survey districts were far above the internationally accepted standards and that the farmers were at risk of ill health through consuming contaminated wheat. It was concluded that the quality of wheat stored using traditional storage methods in surveyed districts was low and that these storage methods were inadequate for protecting stored wheat from pests. Modification of these structures or replacing with better designed storage structures can stop deterioration and improve grain quality and storability.

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Introduction

Wheat (*Triticum aestivum*) is one of the important cereal crop produced and consumed around the world. It is a staple food of Pakistani peoples and contributes more than 60% of the total protein and calorie needs and about 80% of total nutritional intake (Bostan and Naeem, 2002). In Pakistan, wheat is grown on an area of about 8693 thousand hectares and the whole wheat production of the country is about 24.2 million tons with an average yield of 2787 kg ha^{-1} (GOP, 2013), that contributes 10.1% to the value addition and 2.2% to GDP.

For constant availability of agricultural products to be consumed as food, and for stabilizing the economy of any country it becomes most important to maintain a good continuous supplying of quality food grains. Therefore storage of grain is necessary so that grains supply could be maintained on a regular basis from one harvest season to the next harvest season to meet the food and seed requirements (Tefera *et al.*, 2011). Anwar *et al.* (2006) reported that about 25-30% of wheat produced is procured by the government and stored for 6 to 12 months, in order to meet the food requirements of the urban population of the country. The remaining 70 to 75% of the wheat produced is kept in house stores by farmers in rural areas, for meeting their food, feed and seed requirements, and also by the traders for storage at small scale levels. Farmers in developing countries rely on traditional storage methods. Traditional storage structures expose grain to rodents and insect attack, and provide favourable climatic conditions for their proliferation, as well as for that of microorganisms, thus leading to substantial post-harvest losses (Ngamo *et al.*, 2007). Many farmers sell off their grain immediately after harvest to avoid damage by storage pests and consequently receive low prices (Proctor, 1994).

Usually grain quality is assessed by its germination capacity, weight, fungal contamination, insect infestation and nutritional content. The storage parameters affecting the quality of stored grain are temperature, seed moisture content, relative humidity, storage period, and several other biological factors (Jayas and White, 2003). The high grain moisture content (above 12%), high atmospheric temperature (25 to 35°C) and relative humidity (above 60%) during storage create the environment favourable for proliferation of insect species (Ahmad *et al.*, 1998). Insect infestation was found to be a serious problem in stored grains and is responsible for worldwide losses of stored grains of up to 10-40 % per annum. In the few months of the storage under optimal conditions, infestation level of 15% resulted in 24% loss in viability and 2.6% loss in weight of wheat grains (Prasad *et al.*, 1977). In Pakistan, Ahmed (1984) investigated that 10 to 15% loss of wheat grains was due to the attack of insects whereas, Nasir *et al.* (2003) have found that the treatments with lower moisture content (9%) showed no infestation during storage of cereals in polypropylene bags for 60 days. The highest dry matter loss, fungal infestation, decreased test weight and lowest germination capacity were recorded in seeds stored at 20-22% moisture content (Weinberg *et al.*, 2008; Karunakaran *et al.*, 2001).

The major microbial contamination in stored grains is fungal infection which also changes the quality of grains. Fungi and insects can produce losses up to 35% in less developed countries (Hodges *et al.*, 2011). Both the rate of fungal spoilage and the production of mycotoxins are influenced by water availability and temperature (Magan *et al.*, 2003). Rise in seed moisture and storage time increases the rate of fungal invasion and decreases rate of germination (Onesironsan, 1982). Fungal infestation in hot and humid environment results in reduction of grain quality such as change in colour, taste, smell, nutritional value, germination ability and leads to the production of different metabolites which are toxic in nature (White and Jayas, 1993; Iqbal *et al.*, 2010) and about 33% of grain samples from different ecological zones in were contaminated with aflatoxin in Nigeria (Udoh *et al.,* 2000) and Pakistan (Firdous *et al.* 2012; Iram *et al.,* 2014). The deterioration of wheat grain in traditional storage structures over storage periods in the study area was not clearly known. Thus, the objective of this study was to investigate the effects of geographic location, storage methods and storage period on the quality of stored grain.

Materials and methods

Study sites

The study was carried out in four selected districts of Sindh, Pakistan for 12 months from July 2013 to July 2014 on newly harvested wheat grain to assess the grain deterioration in various storage structures. Four districts namely Hyderabad, Sukkur, Badin and Shaheed Benazir Abad, which are major wheat growing areas in Sindh province of Pakistan, were selected for the study (Fig. 1 and Table 1). The geographical locations of the study sites were described on the basis of their climate and wheat production according to Government of Sindh (2008). The Shaheed Benazir Abad district has the highest area under wheat followed by Sukkur, Badin and Hyderabad. Annual relative humidity is ranged from 58 – 85%, 74 – 81%, 58 – 80% and 54 – 85% in Shaheed Benazir Abad, Badin, Hyderabad and Sukkur, respectively. The higher ambient temperature is found in the district of Shaheed Benazir Abad followed by Sukkur, Hyderabad and then Badin. Maximum annual rainfall received in district Shaheed Benazir Abad and others are shown in Table 1.

Table 1. Description of survey districts.

Description	Districts			
	Hyderabad	**Sukkur**	**Badin**	**Shaheed Benazir Abad**
Coordinates	25°18'05"N, 68°28'37"E	27°31'30"N 69°11'32"E	24°45'53"N 68°48'39"E	26°14'22"N 68°24'12"E
Elevation, m	18.0	60.0	11.0	33.0
Annual total rainfall, mm	241.9	99.4	177	243.4
Annual ambient temperature, °C				
Minimum	11.5	6.90	10.3	5.00
Maximum	40.8	42.8	39.4	44.3
Annual relative humidity, %	58 - 80	54 - 85	74 - 81	58 - 85
Area under wheat, hectares	11733	44583	28346	80590
Production of wheat, million tons	37042	164813	76770	292346

Source: Government of Sindh (2008).

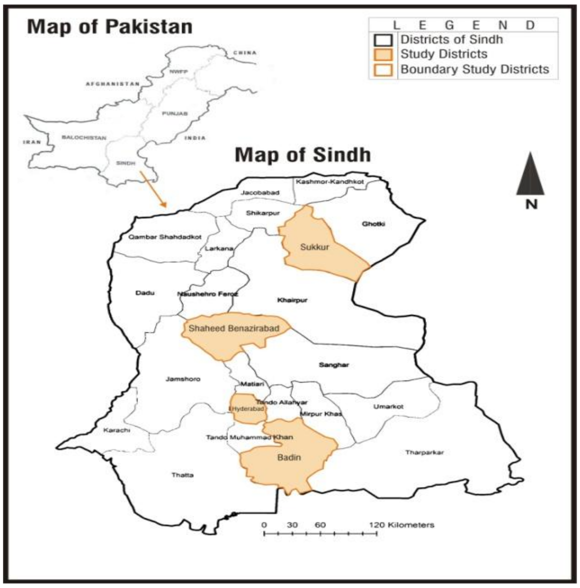

Fig. 1. Map of Pakistan and survey districts (Hyderabad, Sukkur, Badin and Shaheed Benazir Abad) of Sindh province.

Storage structures

Farmers in the districts of Sindh commonly store wheat grain for their food and seed purpose in the traditional structures of variable dimensions until it is consumed. These storage structures were selected for the study. The details of these structures are as below:

1. *Earthen bin*: It is usually circular in shape and made of clay mixed with straw as the binding material to provide strength.

2. *Metallic bin*: It is a cylindrical shaped structure made of iron sheets of varying gauge depending upon the size of the bin.

3. *Bamboo/straw bin*: It is made of woven straw mat or date palm leaves and bamboo or wooden poles of variable size and shape. The base on which the

structure is constructed is made up of bricks or stones up to 2-3 feet above ground level. Straw mats and thatch are fixed on the wooden skeleton using ropes. The top of the structure is covered with straw mat and thatch and sometimes these structures are plastered with mud to make them somewhat air tight.

4. *Bulk covered with mud*: Farmers simply dump the grain on the ground and cover it using straw and mud plaster to avoid grain losses. Ditches are dug around the structure in order to drain rain water.

5. *Bags covered with plastic sheet*: Farmers stack the bags in rectangular or pyramidal forms and covered then from all sides and top with plastic sheets or tarpaulin. Polypropylene and gunny bags are the most widely used grain packaging materials in Sindh province of Pakistan. Gunny bag is made of woven jute fibers whereas polypropylene bag made up of woven plastic fibers. The bags may be stacked on permanent concrete floor or brick floor built 2-3 feet above the ground level.

6. *Close room type structure*: It is usually made of burnt bricks masonry construction with mud or cement mortar. It may be composed of multiple rooms closed from all sides and of variable dimensions. It has walls, floor, roof, windows, doors and ventilators. The bags are stacked on the floor or on dunnage with space to circulate air around the bags.

Experimental design

A factorial experimental design was used for this study. The fixed factors were structure type (Earthen bin, metallic bin, bamboo/straw bin, bulk covered method, bags covered method and room type structure), location type (Shaheed Benazir Abad, Sukkur, Hyderabad and Badin) and storage time (0, 3, 6, 9 and 12 months). Each treatment combination had three replications (random factor).

Sampling of the grain for evaluation

The total of six different types of storage structures were studied in each selected district and grain samples were collected from 1st July, 2013 to 1st July, 2014 (twelve months) at an interval of three months. A total 3 kg sample of wheat grain was taken from each storage structure using the grain sampler from top (1kg), middle (1kg) and bottom (1kg) of the structure. Repeated samples from the grain top surface to the bottom of structure were bulked together. The grain samples were kept separately in plastic bags, labeled, sealed and brought to the Seed Testing Laboratory and Laboratory of Food Science and Technology, Sindh Agriculture University Tandojam for quality analysis. The quality analysis tests were conducted for the following parameters and the reading for each parameter was taken three times to get the average value.

Quality assessment parameters

1. *Stored grain temperature (°C)*: In order to monitor the temperature of stored grain three thermometer probes were inserted at three different positions for about 15 minutes inside each storage structure. The temperature readings from thermometer probe were recorded at 12 pm at an interval of three months.

2. *Moisture content (%)*: The moisture content was determined in each grain sample by drying a 3g sample in an air forced draft oven at a temperature of 105± 5 °C till to constant weight. The procedure of AACC (2000) method No. 44-15A was followed for the estimation of moisture content in each sample. The moisture content of the grain sample was determined on a weight basis using the following formula:

$$\text{Moisture Content} = \left(\frac{\text{weight of grain sample} - \text{weight of dried grain sample}}{\text{weight of grain sample}}\right) x100$$

3. *Seed germination capacity (%)*: Standard procedures of ISTA (1996) were applied to conduct this test. One hundred wheat seeds were randomly collected from each storage structure and kept in petri

dishes lined with filter paper and moistened with 4ml of distilled water in three replicates. The petri dishes containing wheat seeds were then incubated at 25°C temperature for five to seven days to let them germinate. The germinated seeds were visually counted on the basis of their appearance of radicle, whereas percentage germination was calculated as given bellow:

$$\text{Germination (\%)} = \left(\frac{\text{No. of germinated seed}}{\text{Total no. of seeds}}\right) \times 100$$

4. *Insect infestation (%)*: 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 number of insect damaged and undamaged grains by the presence of hole in each grain. The insect damaged grains percentage was calculated by the given formula:

$$\text{Insect damaged grains (\%)} = \left(\frac{\text{No. of insect damaged grain}}{\text{Total no. of grains}}\right) \times 100$$

5. *Aflatoxin content (µg/ kg)*: 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.

6. *Test weight or test density (Kg/ hL)*: The test weight was obtained with the method No.55-10 given in AACC (2000) for each grain sample in which one litter vessel was filled and levelled with wheat grains and weighed on digital balance.

The ambient temperature and relative humidity during the experimental period of selected storage locations were determined with dry and wet bulb thermometers.

Statistical Analysis

Analysis of variance was done using the three factorial design model (6 structures x 4 districts x 5 periods) for studying the effect of all the three independent variables on the various dependent variables (Germination, test weight, moisture content, aflatoxins, temperature and insect infestation). Comparison of means was done by the least significant difference (LSD) method at 5% probability level following the procedures of Steel and Torrie (1980).

Results

Fluctuations in ambient temperature and relative humidity

The relative humidity and ambient temperature in the study districts for the period of grain storage from 1 July, 2013 to 1 July, 2014 are given in Table 2. The average maximum ambient temperature (38.07 °C) was in the Shaheed Benazir Abad whereas, the mean relative humidity was up to 78% in the Badin district throughout the study period.

Table 2. Relative humidity (RH, %) and ambient temperature (T, °C) of selected locations, recorded at 12 pm during storage period.

Months	Hyderabad		Shaheed Benazir Abad		Sukkur		Badin	
	T,°C	RH,%	T,°C	RH,%	T, °C	RH,%	T,°C	RH,%
1 July, 2013	38.10	78.00	44.09	75.00	41.38	76.00	35.28	82.00
1 August, 2013	36.80	77.00	41.10	75.00	39.80	76.00	33.60	81.00
1 September, 2013	35.92	76.00	39.97	77.00	39.13	78.00	34.80	80.00
1 October, 2013	35.00	70.00	39.20	78.00	35.60	79.00	33.30	78.00
1 November, 2013	33.91	66.00	38.95	79.00	34.60	80.00	32.92	78.00
1 December, 2013	24.80	63.00	26.90	80.00	25.60	81.00	23.80	74.00
1 January, 2014	24.60	60.00	25.96	80.00	24.92	83.00	22.80	74.00
1 February, 2014	28.80	70.00	29.80	78.00	29.40	80.00	28.20	75.00
1 March, 2014	32.01	72.00	34.01	75.00	33.00	78.00	31.60	76.00
1 April, 2014	39.40	72.00	42.30	62.00	40.40	63.00	38.20	78.00
1 May, 2014	40.40	74.00	45.63	60.00	43.80	61.00	38.80	78.00
1 June, 2014	37.80	75.00	45.00	62.00	42.20	65.00	37.10	80.00
1 July, 2014	35.80	77.00	41.98	74.00	38.51	75.00	33.90	81.00
Mean	34.10	71.54	38.07	73.46	36.03	75.00	32.64	78.00

Comparison of storage structures alone

The results for grain temperature, moisture content, insect infestation, aflatoxins, test weight and germination capacity in different storage structures across storage time and districts showed significant differences (Table 3). Among the storage structures, room structure had maximum (36.08 ºC) grain temperature while minimum grain temperature (36.02 ºC) was noted in the earthen bin. Grain stored in bulk covered had higher moisture content (14.72%). Insect infestation was highest (12.55%) when the grain stored in room structure whereas, the minimum insect infestation 6.550% was recorded from grain stored in earthen bin. The maximum aflatoxins content of 8.35µg/ kg was recorded from grain stored in room structure as compared to earthen bin (5.11µg/ kg). The higher test weight (71.80 kg/ hL) and germination (82.68%) were recorded in earthen bin.

Table 3. Means of quality parameters evaluated in the wheat storage experiment based on storage type, geographic location and storage period.

Treatments	Parameters					
	Grain temperature ºC	Grain moisture %	Insect infestation %	Aflatoxins µg/kg	Test weight Kg/hL	Seed germination %
Storage type						
Earthen bin	36.02 f	14.64 f	6.550 f	5.110 f	71.80 a	82.68 a
Metallic bin	36.06 c	14.65 e	7.750 e	5.770 e	71.67 b	77.60 e
Bamboo/straw bin	36.04 e	14.67 d	10.55 c	7.350 c	71.19 d	81.60 b
Bulk covered	36.05 d	14.72 a	8.750 d	6.290 d	71.46 c	76.25 f
Bags covered	36.07 b	14.68 c	11.30 b	7.830 b	70.98 e	80.30 c
Room type structure	36.08 a	14.70 b	12.55 a	8.350 a	70.86 f	79.03 d
LSD (0.05)	0.0022	0.0029	0.2780	0.0300	0.0140	0.2850
Geographic location						
Shaheed Benazir Abad	39.20 a	14.61 c	9.530	6.130 c	71.48 b	80.41 b
Sukkur	36.69 b	14.82 b	9.600	7.420 b	71.22 c	78.76 c
Hyderabad	35.09 c	13.94 d	9.500	5.700 d	71.70 a	81.72 a
Badin	33.25 d	15.33 a	9.670	7.880 a	70.97 d	77.42 d
LSD (0.05)	0.0018	0.0024	NS	0.0244	0.0115	0.2325
Storage period						
Initial	39.93 b	14.41 e	0.000 e	0.860 e	74.04 a	96.22 a
3 months	36.19 d	14.54 c	3.170 d	4.080 d	73.38 b	93.25 b
6 months	25.23 e	14.50 d	7.920 c	7.330 c	72.54 c	85.13 c
9 months	40.66 a	14.84 b	15.54 b	9.690 b	70.21 d	68.92 d
12 months	38.26 c	15.10 a	21.25 a	11.95 a	66.48 e	54.38 e
LSD (0.05)	0.0020	0.0026	0.2534	0.0273	0.0129	0.2600

Means followed by the same letter in each column are not different significantly according to least significant difference (LSD) at 5% probability level.

Effect of geographic location alone

The results for grain temperature, moisture content, aflatoxins, test weight, and germination capacity in different districts across storage time and storage structures showed significant differences (Table 3). The maximum grain temperature (39.20ºC) was found when grain stored in Shaheed Benazir Abad as compared with other districts. Grain stored in Badin had higher moisture content (15.33%). Maximum aflatoxins content (7.88 µg/ kg) was noted when grain stored in different structures of Badin. Grain stored in different structures of Hyderabad had maximum value of test weight (71.7 kg/ hL) and germination capacity (77.42%). Insect infestation under the effect of study districts indicated non-significant differences and ranged from 9.50 to 9.67% in grain stored in different study districts.

Effect of storage period alone

Grain storage time had significant effect on grain temperature, moisture content, insect infestation, aflatoxins content, test weight, and germination capacity across storage structures and districts (Table 3). The results indicated that the grain temperature followed the pattern of the ambient temperature during whole storage period. The highest value of grain temperature (40.66°C) was recorded at 9 months of storage whereas, maximum increase in moisture content (15.10%) was observed at 12 months of storage. Storage period increased insect infestation throughout the experiment. Highest insect infestation (21.25%) was detected in grains stored at 12 months with the aflatoxin level increased from the value of 0.86 to 11.95 µg/ kg i.e. from initial to 12 months storage period. Germination decreased continuously with the increase of storage period. The values of seed germination decreased up to 54.38% after 12 months of storage. Test weight of grain also decreased throughout the storage time.

Comparison between treatments combining storage type, storage time and geographic location

Interactive effect of district x storage structure had significant effect on grain temperature, moisture content, aflatoxins, test weight, and germination capacity (Table 4).

Table 4. Temperature, moisture, insect infestation, aflatoxin, test weight and germination capacity of wheat grain under interactive effect of geographic location and storage structure.

Study district	Storage structure	Grain temperature °C	Grain moisture %	Insect infestation %	Aflatoxins, µg/ kg	Test weight, Kg/hL	Germination %
Shaheed Benazir Abad	Earthen bin	39.17 e	14.57 q	6.60	4.680 r	71.88 c	83.00 c
	Metallic bin	39.20 c	14.58 p	7.60	5.280 p	71.76 e	79.00 jk
	Bamboo/straw bin	39.18 d	14.60 o	10.6	6.680 k	71.28 k	82.40 d
	Bulk covered	39.18 d	14.65 m	8.60	5.520 o	71.56 g	76.93 m
	Bags covered	39.21 b	14.60 o	11.4	6.980 h	71.10 l	81.00 f
	Room structure	39.22 a	14.63 n	12.4	7.640 f	70.92 n	80.13 gh
Sukkur	Earthen bin	36.64 j	14.79 l	6.60	5.720 n	71.68 f	81.80 e
	Metallic bin	36.70 h	14.80 k	7.60	6.340 l	71.56 g	76.73 m
	Bamboo/straw bin	36.67 i	14.81 j	10.4	8.120 e	71.06 m	80.60 fg
	Bulk covered	36.67 i	14.86 g	8.80	6.940 hi	71.37 i	75.60 n
	Bags covered	36.71 g	14.83 i	11.4	8.460 c	70.86 o	79.60 hi
	Room structure	36.72 f	14.84 h	12.8	8.920 b	70.76 q	78.20 l
Hyderabad	Earthen bin	35.05 o	13.89 w	6.40	3.880 t	72.14 a	85.46 a
	Metallic bin	35.09 m	13.93 v	7.80	4.620 s	72.02 b	79.40 ij
	Bamboo/straw bin	35.07 n	13.94 u	10.6	6.340 l	71.58 g	84.00 b
	Bulk covered	35.08 n	13.97 r	8.60	5.100 q	71.80 d	78.40 l
	Bags covered	35.10 l	13.95 t	11.2	6.920 i	71.38 i	82.13 de
	Room structure	35.11 k	13.96 s	12.4	7.320 g	71.26 k	80.93 f
Badin	Earthen bin	33.21 u	15.27 f	6.60	6.160 m	71.49 h	80.46 fg
	Metallic bin	33.25 r	15.29 e	8.00	6.840 j	71.33 j	75.26 n
	Bamboo/straw bin	33.24 t	15.32 d	10.6	8.240 d	70.82 p	79.40 ij
	Bulk covered	33.24 s	15.36 a	9.00	7.600 f	71.09 l	74.06 o
	Bags covered	33.26 q	15.33 c	11.2	8.960 b	70.58 r	78.46 kl
	Room structure	33.27 p	15.35 b	12.6	9.500 a	70.47 s	76.86 m
LSD at 5%		0.00437	0.00578	NS	0.0598	0.0282	0.5696
S.E		0.00222	0.00293	0.2818	0.0304	0.0143	0.2891

Means followed by the same letter in each column are not different significantly according to least significant difference (LSD) at 5% probability level.

Higher grain temperature (39.22°C) was recorded from room structure under district Shaheed Benazir Abad. Maximum grain moisture content (15.36%) was noted from grain stored in bulk covered under Badin. The highest grain aflatoxin content (9.5 µg/ kg) was observed from room structure under Badin while, the lowest aflatoxin level (3.88 µg/ kg) was noted from the grain stored in earthen bin under Hyderabad. Maximum test weight (72.14 kg/ hL) and seed germination (85.46%) were recorded from the grain stored in earthen bins under Hyderabad. Interactive effect of district and storage structure showed non-significant effect on insect infestation and exhibited values between 6.40% and 12.80%.

Grain temperature, moisture content, aflatoxins, test weight, and germination capacity under the interactive effect of district and storage time showed significant differences among the treatments (Table 5). The greater grain temperature (44.30 °C) was observed from grain stored in various structures under Shaheed Benazir Abad at loading. However, lower (23.45 °C) grain temperature was noted in Badin at 6 months of storage. The greater grain moisture content (15.94%) was found from grain stored in various structures in Badin at 12 months while lower (13.52%) grain moisture content was established under Hyderabad at 6 months. The higher aflatoxin level (13.8 µg/ kg) was established from grain stored in various structures under Badin at 12 months, while the Sukkur ranked second with 13 µg/ kg at the same period. The lowest aflatoxin value was recorded 0.667 µg/ kg in grains in Badin at the time of storage. The maximum test weight (73.58 kg/ hL) was detected from stored grains under Hyderabad at 3 months of storage. In Shaheed Benazir Abad at loading the germination rate was found 96.05% which decreased up to 56% at 12 months. Insect infestation under the interactive effect of storage time x districts showed non-significant differences and determined values between 0% and 21.5%.

Table 5. Temperature, moisture, insect infestation, aflatoxin, test weight and germination capacity of wheat grain under interactive effect of geographic location and storage time.

Study district	Storage period	Grain temperature (°C)	Grain moisture (%)	Insect infestation (%)	Aflatoxins (µg/ kg)	Test weight (Kg/hL)	Germination (%)
Shaheed Benazir Abad	Initial	44.30 a	14.01 p	0.000	0.933 p	74.02 b	96.05 a
	3 month	39.55 g	14.54 l	3.167	3.900 o	73.50 d	93.83 b
	6 month	26.75 q	14.74 k	7.833	6.350 k	72.76 g	86.16 e
	9 month	42.82 b	14.80 h	15.50	8.683 h	70.08 k	70.00 i
	12 month	42.54 c	14.95 g	21.17	10.78 e	66.73 m	56.00 m
Sukkur	Initial	41.60 d	14.30 n	0.000	0.967 p	74.04 ab	96.11 a
	3 month	36.03 l	14.76 j	3.167	4.183 m	73.31 e	92.83 c
	6 month	25.57 r	14.95 g	8.000	8.017 i	72.46 h	84.83 f
	9 month	40.96 e	15.12 d	15.67	10.92 d	70.07 k	67.00 j
	12 month	39.26 h	14.97 f	21.17	13.00 b	66.20 n	53.00 n
Hyderabad	Initial	38.31 j	14.10 o	0.000	0.867 q	74.02 ab	96.44 a
	3 month	35.43 n	13.75 r	3.167	4.017 n	73.58 c	94.00 b
	6 month	25.14 s	13.52 s	7.667	5.917 l	73.11 f	87.00 d
	9 month	39.96 f	13.82 q	15.50	7.483 j	70.63 j	73.66 h
	12 month	36.57 k	14.51 m	21.17	10.20 f	67.15 l	57.50 l
Badin	Initial	35.50 m	15.20 c	0.000	0.667 r	74.05 a	96.27 a
	3 month	33.73 p	15.09 e	3.167	4.233 m	73.10 f	92.33 c
	6 month	23.45 t	14.78 i	8.167	9.050 g	71.81 i	82.50 g
	9 month	38.89 i	15.60b	15.50	11.67 c	70.05 k	65.00 k
	12 month	34.65 o	15.94 a	21.50	13.80 a	65.81 o	51.00 o
LSD at 5%		0.00399	0.00528	NS	0.0546	0.0258	0.520
S.E		0.00203	0.00268	0.2573	0.0277	0.0131	0.264

Means followed by the same letter in each column are not different significantly according to least significant difference (LSD) at 5% probability level.

Interactive effect of storage structure and storage time showed significant effect on grain temperature, moisture content, insect infestation, aflatoxins, test weight, and germination capacity (Table 6). Higher grain temperature (40.69 °C) was noted in room structure at 9 months of storage while, the minimum temperature (25.19°C) was established from earthen bin at 6 months of storage. The highest moisture content (15.19%) was found in the grain samples taken from bulk covered at 12 months of storage. The greater insect infestation (27%) was observed in grains stored in room structure at 12 months, which was followed by bags covered (25%) at the same period. However, minimum insect infestation of 1.750 and 2.250% was found in earthen bin and metallic bin, respectively at 3 months of storage. Higher grain aflatoxins (14.35 µg/ kg) was found in samples taken from room structure at 12 months and least (3.075 µg/ kg) was recorded in samples from earthen bin at 3 months (Table 6). Higher test weight (73.80 kg/ hL) and germination capacity (94.5%) of grain samples were noted from earthen bin at 3 months of storage.

Table 6. Temperature, moisture, insect infestation, aflatoxin, test weight and germination capacity of wheat grain under interactive effect of storage structure and storage time.

Storage period	Storage structure	Grain temperature (°C)	Grain moisture (%)	Insect infestation (%)	Aflatoxins (µg/ kg)	Test weight (Kg/hL)	Germination (%)
Earthen bin	Initial	39.92 i	14.40 u	0.000 t	0.900 yz	74.06 a	96.16 ab
	3 month	36.15 t	14.48 r	1.750 s	3.075 x	73.80 c	94.50 c
	6 month	25.19 z	14.43 s	4.000 pq	4.775 r	73.07 g	89.25 g
	9 month	40.61 f	14.81 k	11.00 k	7.300 o	70.94 n	74.00 m
	12 month	38.21 o	15.04 f	16.00 h	9.500 j	67.12 t	59.50 s
Metallic bin	Initial	39.93 gh	14.41 u	0.000 t	0.875 z	74.05 ab	96.00 b
	3 month	36.19 r	14.51 p	2.250 s	3.800 w	73.72 d	92.25 f
	6 month	25.24 w	14.48 r	6.250 o	5.800 q	72.95 i	82.75 k
	9 month	40.67 c	14.81 k	13.00 j	8.175 n	70.71 o	65.75 q
	12 month	38.27 l	15.05 e	17.25 g	10.20 g	66.92 u	51.25 w
Bamboo/ straw bin	Initial	39.93 g	14.40 tu	0.000 t	0.925 yz	74.02 b	96.75 a
	3 month	36.18 s	14.53 o	3.750 q	4.525 t	73.17 f	94.00 cd
	6 month	25.21 y	14.50 q	9.000 m	8.350 m	72.50 k	87.25 h
	9 month	40.65 e	14.83 j	17.00 g	10.08 h	69.94 q	72.25 n
	12 month	38.24 n	15.07 d	23.00 c	12.85 c	66.30 w	57.75 t
Bulk covered	Initial	39.92 hi	14.40 u	0.000 t	0.750 z	74.02 b	96.25 ab
	3 month	36.18 s	14.57 l	3.000 r	4.025 v	73.50 e	92.25 f
	6 month	25.22 x	14.55 n	7.500 n	6.750 p	72.67 j	81.00 l
	9 month	40.65 d	14.86 g	14.00 i	8.775 k	70.46 p	63.00 r
	12 month	38.24 m	15.19 a	19.25 e	11.15 f	66.65 v	48.75 x
Bags covered	Initial	39.93 gh	14.41 t	0.000 t	0.975 y	74.02 b	96.25 ab
	3 month	36.20 q	14.54 n	3.750 q	4.450 u	73.05 g	93.50 de
	6 month	25.25 v	14.51 p	9.750 l	8.700 l	72.10 l	86.00 i
	9 month	40.68 b	14.84 i	18.00 f	11.40 e	69.64 r	70.25 o
	12 month	38.28 k	15.09 c	25.00 b	13.63 b	66.10 x	55.50 u
Room structure	Initial	39.93 gh	14.40 tu	0.000 t	0.725 z	74.03 b	95.91 b
	3 month	36.22 p	14.56 m	4.500 p	4.625 s	73.00 h	93.00 e
	6 month	25.26 u	14.53 o	11.00 k	9.625 i	71.95 m	84.50 j
	9 month	40.69 a	14.85 h	20.25 d	12.40 d	69.56 s	68.25 p
	12 month	38.30 j	15.13b	27.00 a	14.35 a	65.75 y	53.50 v
LSD at 5%		0.004890	0.00646	0.6207	0.0669	0.0316	0.6368
S.E		0.002482	0.00328	0.3151	0.0339	0.0160	0.3233

Means followed by the same letter in each column are not different significantly according to least significant difference (LSD) at 5% probability level.

Discussion

The change in environmental conditions provided favorable conditions for the production of insect, mould and other micro-organisms which deteriorate grain quality during storage. For the safe and satisfactory grain storage it is most important to keep the grains below the levels of optimum moisture and temperature for these pests. However with the changes in environmental conditions the temperature and humidity inside the bin changes. It is therefore the storage bins environment depends solely upon the environmental conditions outside the bin. The temperature and humidity percentage of surrounding had a maximum influence on the quality of grains (Alabadan and Oyewo, 2005). In the present study, it was observed that the moisture content and temperature were optimum for the growth of insects and fungi. These pests start to grow when the temperature reach 18 °C and continue to increase in numbers even at 25 - 35 °C inside (Ilelejia *et al*., 2007). Abba and Lovato (1999) suggested that grains be stored at 20 °C temperature, 40 to 50% relative humidity and 11.5% moisture content.

The results of the present study indicated that storage types, storage time, geographic locations and their interaction exhibited a significant effect on the temperature of stored grain. The maximum grain temperature in room structure can be attributed to high respiration rate, higher moisture content without any movement of air through the structure. In all the structures, the grain temperatures were higher than the outside temperature for the whole period. This may be due to release of heat by respiration of grains and insects. Variations in temperature of storage structures are due to both internal (respiration warmness of grain, insects, mites and fungi) and external (fluctuations in solar radiation and ambient temperature) sources of heat. The heat transmission process within the stored grains is slow due to the low thermal conductivity of grain and lower air flow also caused the limited heat transfer between the grains. This causes the temperature variation in stored grain thereby affecting the quality of grain. Moreover, the variations in ambient air flow and stored grain causes natural convection within stored grains, which causes the movement of moisture from warm to cold regions. This movement of moisture in the grain bulk may create spots with conditions suitable for grain deterioration (Jia, 1995; Khankari *et al*., 1994). The present study results are also correlated with those of Sawant *et al*. (2012) who reported that after 5th month of storage up to 12th month, the temperature of grains was observed increased from the optimal temperature. The reason behind the increase of temperature of grains was due to insects' invasion inside the storage structure.

Moisture content of wheat grain increased with the progress of storage period and the maximum increase was detected at 12 months of storage. Grain stored in bulk covered had considerably highest moisture percentage. The minimum moisture percentage was noted in Hyderabad (Table 3). The main reason behind the increase of moisture content was aerobic respiration of wheat grains. The increase in grain moisture content can also be due to variation in relative humidity and optimum temperature throughout storage (Hruskova and Machova, 2002). This causes the oxidation of carbohydrates (Hexoses) and yield carbon dioxide, water and energy (Pence *et al.,* 1988). Therefore, wheat spoilage occurs because of grains mass loss as well as due to high humidity conditions. High respiration rate of fungi and insects in infested grains is also responsible for high moisture content. Water is one of the end products of respiration (metabolism of microbes) which add in the moisture content inside the storage structure (Stephen and Olajuyigbe, 2006; Mills, 1983).

There was no insect infestation observed on the wheat grain before storage. Storage period increased insect infestation throughout the experiment and the highest rate of insect infestation was noted in grains at 12 months of storage (Table 3). The highest percentage of insect infestation was observed in grains stored in the room structure, followed by bags covered, bamboo/straw bin, bulk covered, metallic bin and then earthen bin. However, geographic location had no effect on insect infestation of stored wheat. The highest concentration of insects in room structure can be attributed to high temperature and moisture conditions in this structure, which favours growth of the insects. The conditions including high temperature and raised humidity levels are responsible for growth and development of insects inside the stored grains (McFarlane, 1989). It was observed that the development of insects slows down below 27°C and the insects thrive best between 32-

35°C (Kraszpulski, 1985) Several studies have stated main reason for grain losses in traditional granaries is the non-existence of hygienic conditions (Ngamo, 2000). The residues of old grains left inside the storage structures always become the major cause of contamination of newly loaded grains. According to Haile (2006) it is the common practice of farmers to keep the old grains along with newly harvested grains, through which the insects of old grains reach to the new grains and results in grain infestation.

The initial aflatoxin content observed in the wheat grain before storage was 0.86 µg/ kg which progressively increased throughout the storage duration (12 months) in all types of structures and the highest contamination ratio was noted at 12 month of storage. The highest rate of increase of level of aflatoxins was observed in the room structure followed by bags covered, bamboo/straw bin, bulk covered and then metallic bin, whereas the lowest infestation was noted in the earthen bin. The district wide data revealed that in Badin the afflatoxin attack was higher on grains as compared with other districts (Table 3). This suggests that the wheat was already infected when it was stored. This might have been caused by field fungi. Grain crops may be attacked by fungi in the field which can then develop rapidly during storage when conditions are suitable in growing mycotoxins (Turner *et al.*, 2005). The current findings are according to the results of Udoh *et al.* (2000) and Saleemullah *et al.* (2006) who showed that longer storage time of grains significantly increased aflatoxin contents of grains as compared to short storage periods. Aflatoxins grow rapidly within the temperature range of 20 °C to 44 °C (Farrel and Hodges, 2004) and at 25 °C and 32 °C (Shanahan *et al.*, 2003). 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.

Test weight of stored wheat grain showed a decreasing trend with the passage of time and highest reduction rate was noted at the end of the storage period (Table 3). However, with respect to the structures effect, the highest rate of decrease of test weight was found in grain samples taken from room structure followed by bags covered, bamboo/straw bin, bulk covered, metallic bin and then earthen bin. Grain stored in different structures under Hyderabad had highest test weight as compared with other districts. The reduction in test weight could be due to higher moisture percentage of the wheat grains throughout storage period. It is assumed that high moisture content causes wheat grains to undergo Self-digestion (autolytic digestion) which results in nutrients loss (mainly carbohydrates) to yield energy for respiration, thereby affecting the test weight of seeds. The results regarding the test weight are also supported by Karaoglu *et al.* (2010) and Muir and Sinha (1998) who stated the increase in temperature, storage time and seed moisture percentage lead to a significant loss in test weight of grains. Gonzalez-Torralba (2013) who observed a decrease in test weight of wheat with rise in seed moisture level during storage at 15 and 30 °C temperature with relative humidity of 55 and 75% for 240 days, although the marked variation was caused by a joint effect of high temperature and high relative humidity. The test weight is also decrease by the rise in the microbes and insects activities (Pomeranz *et al.,* 1986). The reason behind that are the insects and fungi grow upon feeding the carbohydrate content (starch) present inside the endosperm of grains which reduce the test weight and increase the grain damage.

Seed germination capacity decreased continuously with the prolonged storage in all types of structures and the rate of decrease was highest at the end of the storage period (Table 3). The highest rate of seed germination was observed in samples from earthen bin. Among the study districts, Hyderabad had maximum rate of seed germination and the minimum rate was found under Badin. The decrease of germination capacity of the stored wheat can be attributed to higher moisture and temperature conditions. A number of studies have found that high storage moisture content and high storage temperature are some factors that negatively correlate with loss of seed viability (Weinberg *et al.*, 2008; Rani *et al.*, 2013). The loss in seed germination might also be due to destruction of seed embryo by insects and fungi (Wambugu *et al.*, 2009; Dubale *et al.,* 2012).

Conclusion

In conclusion, the extent of grain deterioration stored in traditional structures varies with geographic location, storage period and types of structures. The quality of wheat stored using traditional storage methods in the surveyed districts was low and that these storage methods were inadequate for protecting stored wheat from pests. The grain temperature was higher than the ambient temperature throughout the storage period. Moisture content, insect infestation and aflatoxin content showed an increasing pattern with prolonged storage. However, test weight and seed germination showed a decreasing trend with the passage of time. Modification of these structures or replacing with well designed storage structures can stop or delay deterioration and maintain grain quality and storability. Such storage structure would maintain grain moisture and temperature at lower levels that do not favour development of spoilage organisms. Thus, there is a strong need of improved structures for wheat grain storage in the study area.

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