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Research Article

On-Farm evaluation of different storage materials for the management of four stored grain insect pests on stored wheat

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ABSTRACT

Four standard storage bags, namely polyethylene, polypropylene, hermetic bag, and jute bag, were evaluated for the management of insect pests of stored grains. Efficacy parameters were recorded as percent weight losses, damaged grain percentage, and population buildup over time intervals. Already infested wheat was stored in four bag types at two locations to record the effectiveness of each bag. Results showed that damages such as percent weight loss and percent grain damage made by insects were more in polyethylene as compared to polypropylene, jute, and the hermetic bag. Populations were recorded dead only in the hermetic bag at each time interval. The hermetic bag proved lethal for stored grain insect pests' development, and insect populations were found 100% dead in hermetic bags with no single account of a live insect over all-time intervals, viz. 30, 60, and 90 d. Grain moisture fluctuated in all bags while in a hermetic bag, grain moisture decreased and then became constant. All types of damages were recorded more at Grain Market Bahawalnagar which is a hotter place than the Rice Research Institute, Kala Shah Kaku. Results indicated that the hermetic bag proved to be the best material for stored grains insect pests' management.

Keywords: *Tribolium castaneum*; *Sitophilus oryzae*; *Sitophilus granaries*; insect pest management; storage materials.



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INTRODUCTION

Cereal grains are the most important source of dietary carbohydrates and proteins for humans globally (McKevith, 2004). Almost 10-40% of stored cereal grains are damaged qualitatively and quantitatively every year by insect pests in tropical and subtropical regions of developed and underdeveloped countries (Madrid et al., 1990; Shaaya et al., 1997; Tripathi et al., 2009). The annual monetary losses are estimated to be more than US\$ 4 billion annually (FAO, 2010). Among different control techniques, fumigation has been far more effective for stored grain insect pest management despite serious limitations (Mills, 1983; Tylor, 1989; Bell & Wilson, 1995; Bell, 2000; Caddick, 2004). This led to concerns over protectant residues (organophosphorus, fumigants, and pyrethroid insecticides), insecticide resistance development in insect pests (Champ & Dyte, 1976; Zettler, 1991; Arthur & Zettler, 1992; Arthur, 1996; Zettler & Arthur, 1997) and researchers stressed adopting new and emerging approaches to manage stored grain insect pests (Ghareeb et al., 2025). Different grain storage bags such as burlap, gunny, jute, paper, plastic, polythene, and hermetic bags, are used for the storage of products. Recently,

are being used as packaging material more rapidly as compared to paper and cardboard packages (Riudavets et al., 2007). Plastic bags are convenient for customers and are easy to handle and carry, as those are lightweight (Kindle, 2001; Connolly, 2011). Plastic packaging offers protection against insect infestations and helps maintain cleanliness by preventing contamination during storage and use (Paine & Paine, 1993). Almost all stored grain commodities are attacked by insect pests except frozen or preserved food items. Insects infiltrate packed food material during the dispersal phase i.e., during transportation, storage, and supply (Licciardello et al., 2013). Insects get close to food items as penetrators or invaders. If they can puncture through piercing mouthparts and get entry into the food item, they are penetrators (Highland, 1984), and if they are unable to get penetration and find some entry existence to get into packaging material, they are called invaders (Highland, 1991). *T. castaneum*, *S. granarius*, and *S. oryzae* are penetrators of stored products.

Plastic materials have different strengths against the penetration ability of insect pests such as PVC (polyvinylchloride), which is ineffective against almond moth larva and Indian meal moth, but PP (Polypropylene) proved effective for chocolate packages against these pests (Browditch, 1997). Polyethylene (PE) rapper is capable of resisting the penetration of common bean weevil (Pacheco & Wiendle, 1989) while Shukla et al. (1993) revealed that rice weevil, lesser grain borer, saw-tooth grain beetle, khapra beetle, cowpea weevil, and red rust flour beetle can penetrate polyethylene films with more than 0.08 mm thickness.

It is, therefore, to be concerned that ideal plastic packaging is that which keeps food safe from stored grain insect pests. Ideal packaging material should be resistant to insect pest penetration and infiltration. If a stored commodity is already infested with some stored insect pest species, it must curb it within a very short time to avoid the losses. Oxygen is the most essential element of life. There are studies on if, oxygen supply is cut off, the stored insects go under dormancy or are killed due to the high concentration of CO₂ and less availability of O₂. So, halting the supply of oxygen into stored material can kill the whole population of insect pests infesting the stored product and make them unable to multiply and damage the stored grains. Damages incurred to stored products depend upon the packaging materials and their thickness to resist the insect pest penetration. Combined results of damage percentage and population buildup would reveal the best material for stored grain insect pests' management without the use of any chemical for food products. Therefore, the purpose of this study was to evaluate the effectiveness of different storage materials against insect pests of stored grains.

MATERIALS AND METHODS

Study Sites

The present study was conducted at grain storage room, Rice Research Institute, Kala Shah Kaku (RRI, KSK), Sheikhpura (31° 44' 17" North, 74° 15' 49" East) and Grain Market Bahawalnagar (29° 59' 34" N 73° 15' 13" E) Punjab, Pakistan from July to September, 2017.

Food Material

Already infested wheat with stored grain insect pests (var. Faisalabad 2008) was selected in this study. One quintal (1008 kg) of already infested wheat was poured onto a tarpaulin sheet. Twelve samples, each of one kg, were taken from these to record the insect pests' population. For the pretreatment percent weight loss and percent grain damage record, twelve primary samples (each of 20 g) were taken. The data was recorded from these twelve samples, and then an average was recorded for four samples for pre-treatment data. In the same way, post-treatment data were recorded for percent grain damage and percent weight loss. Twelve samples were taken for a true representation of dependent variables and to reduce the chances of pseudo-replication and standard error. Separate procedures were run for each location.

Identification of Insect Specimens

Insect collection was carried out by passing the samples through a 3/16 inch (4.76 mm) round-hole sieve. The separated insects were preserved at -20 °C for 72 hours and later examined under a microscope for identification using published taxonomic keys. The pretreatment samples confirmed the presence of *T. castaneum* and *S. granarius*.

Storage Bag Preparation

The experiment utilized four storage materials: polyethylene bags (Zia Plastics, Lahore, Pakistan), polypropylene bags (Syed Plastics, Lahore, Pakistan), jute bags (Shahi Jute, Lahore, Pakistan), and hermetic bags (International Rice Research Institute, Philippines, IRRI), each with a capacity of 100 kg. Infested wheat was placed in these bags, which were secured with a double knot and sealed using two plastic fasteners. Separate sets of bags were prepared at each experimental site. Environmental parameters, including relative humidity (%) and temperature (°C), were monitored

daily at the observatory over a three-month period. To ensure statistical reliability and avoid pseudo-replication, each treatment was replicated four times.

Grain Moisture Determination

Grain moisture content was measured using the oven-drying technique. Wheat grains were first milled into flour. The hot air oven was preheated for one hour to eliminate residual moisture from the plates. Subsequently, 2 g of wheat flour was placed in the oven and heated for another hour. After drying, the sample plate was transferred to a desiccator for 5–10 minutes before being reweighed. The moisture content was calculated using the following formula as prescribed by ASABE standards (Standard, 2012);

$$\text{Moisture Percentage} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Final weight}} \times 100$$

Estimation of Mortality

Mortality data were recorded after 30, 60, and 90 days of the experiment for each storage bag. Whole bags were sieved to record the insect population per kg. When no live insect was observed in the samples, the whole bag was poured onto a tarpaulin spreadsheet in sunlight. Live insects were visually observed, if any. The spreadsheet was kept for half an hour in sunlight so that if any living insect was there, it might move in search of shade. Upon no living insect observation, the whole population was assumed dead.

Damaging Variables due to Insect Pests in Storage Bags

Prior to data collection, grains within each storage bag were homogenized by manual shaking for five minutes. From each replication, four subsamples of 20 g were taken to assess grain damage. Observations were recorded at 30-day intervals over a period of 90 days. The percentage weight loss of the substrate was calculated using the following formula:

$$\text{Weight loss (\%)} = \frac{(W_u \times N_d) \times (W_d \times N_u)}{W_u \times (N_u + N_d)} \times 100$$

Where W_u = Weight of undamaged grain; N_u = Number of undamaged grain; W_d = Weight of damaged grain, and N_d = Number of damaged grain.

The percent damage to grains was calculated by following the formula;

$$\text{Percent damaged grains} = \frac{\text{Number of damaged grains}}{\text{Total number of grains in sample}} \times 100$$

Estimation of Population Buildup

At each time interval, each bag sample was passed through a 3/16 inch (4.76 mm) round-hole sieve to estimate the number of insects present per wheat bag. Insects collected after sieving were counted and divided by the total weight of each bag in kg to obtain the per kg insect population for each bag.

Economics for each Bag

At the end of the experiment, economics was evaluated for each bag to estimate the gains and losses associated with each bag. The higher the resultant value means the maximum gains while the lower the value, the more damages associated with the bag. The wheat grain losses were recorded from different storage bags over the specified time, and their value was determined from the market. The pretreatment and post-treatment value of wheat and the cost of storage bags were analyzed for determining the economics of hermetic bags and then compared with the other bags (polypropylene bag, jute bag, and polyethylene bag).

$$\text{Economic gains} = (I_q - \text{PWL}) \times \text{FP} - (\text{MC} + I_{vq} + \text{PWL value})$$

Where I_q = Initial quantity, PWL = Percent weight loss, I_{vq} = Initial value of the commodity per 100 kg, MC = management cost and FP = Final price/kg.

Statistical Analysis

The CRD three-way factorial analysis of variance (ANOVA) was performed on three treatments (time, location, and bag) to find out the impact on damaged grain percentage and population build-up using Statistix (Software 8.1) (Tallahassee, FL). Similarly, the moisture contents and percent weight losses in grain were subjected to the same analysis. Treatment effects on wheat moisture content were assessed by comparing the mean values of the measured parameters using the least significant difference test at the 5% significance level ($P < 0.05$).

RESULTS AND DISCUSSION

Grain Moisture

The results were highly significant for storage bags ($F = 1645.07$; d.f. = 3, 63; $P < 0.01$), time intervals ($F = 53.08$; d.f. = 3, 63; $P < 0.01$), and bags \times time intervals interaction ($F = 213.07$; d.f. = 9, 63; $P < 0.01$). Grain moisture was increased from 11.7% to 13.475% (jute bag), 13.775% (polyethylene bag) and 13.5% (polypropylene bag), while reduced to 9.675% in hermetic bag at 90 days at RRI, KSK (Table 1). While for Grain Market Bahawalnagar, the results were highly significant for storage bags ($F = 5920.58$; d.f. = 3, 63; $P < 0.01$), time intervals ($F = 170.50$; d.f. = 3, 63; $P < 0.01$), and bags \times time intervals interaction ($F = 707.68$; d.f. = 9, 63; $P < 0.01$). While moisture was increased from 11.7% to 12.975% (jute bag), 13.725% (polyethylene bag) and 13.425% (polypropylene bag), while reduced to 9.70% in hermetic bag at 90 days at grain market Bahawalnagar (Table 2).

Table 1. Interaction among treatments at 95% confidence interval for percent weight loss, percent grain damage, population buildup and grain moisture at Rice Research Institute, Kala Shah Kaku, Pakistan.

Storage bags	Time intervals	Percent damaged grains	Weight loss (%)	Population buildup	Grain moisture
HB	0	2.77 \pm 0.07 f	1.13 \pm 0.07 f	7.25 \pm 0.24 h	11.70 \pm 0.02 i
	30	3.34 \pm 0.19 f	1.35 \pm 0.08 f	0.00 \pm 0.00 i	9.70 \pm 0.00 j
	60	3.38 \pm 0.07 f	1.40 \pm 0.06 f	0.00 \pm 0.00 i	9.70 \pm 0.02 j
	90	3.38 \pm 0.04 f	1.37 \pm 0.03 f	0.00 \pm 0.00 i	9.70 \pm 0.02 j
JB	0	2.77 \pm 0.07 f	1.13 \pm 0.07 f	7.25 \pm 0.24 h	11.70 \pm 0.02 i
	30	11.81 \pm 0.38 e	5.68 \pm 0.24 e	9.25 \pm 0.13 g	12.28 \pm 0.02 h
	60	18.61 \pm 0.47 d	9.52 \pm 0.36 d	12.25 \pm 0.02 f	12.75 \pm 0.01 e
	90	27.85 \pm 0.79 b	12.83 \pm 0.47 c	19.75 \pm 0.55 c	12.98 \pm 0.02 d
PP	0	2.77 \pm 0.07 f	1.13 \pm 0.07 f	7.25 \pm 0.24 h	11.70 \pm 0.02 i
	30	12.95 \pm 0.89 e	6.45 \pm 0.24 e	9.50 \pm 0.14 g	12.40 \pm 0.02 g
	60	22.16 \pm 0.55 c	10.41 \pm 0.39 d	14.25 \pm 0.43 e	13.10 \pm 0.02 c
	90	29.90 \pm 0.92 ab	15.08 \pm 0.82 b	22.50 \pm 0.66b	13.43 \pm 0.01 b
PE	0	2.77 \pm 0.07 f	1.13 \pm 0.07 f	7.25 \pm 0.24 h	11.70 \pm 0.02 i
	30	12.87 \pm 0.43 e	6.58 \pm 0.07 e	10.50 \pm 0.43 fg	12.50 \pm 0.02 f
	60	19.65 \pm 0.47 c	12.19 \pm 0.48 c	17.50 \pm 0.032 d	13.38 \pm 0.03 b
	90	31.69 \pm 0.73 a	17.45 \pm 0.72 a	26.50 \pm 0.043 a	13.73 \pm 0.01 a

Where HB= hermetic bag, JB= jute bag, PP= polypropylene bag, and PE= polyethylene bag. Means within a column followed by same letter (s) are not significantly different while means within a row followed by same letter(s) are not statistically significant (LSD test $P < 0.05$).

Table 2. Interaction among treatments at 95% confidence interval for percent weight loss, percent grain damage, population buildup and grain moisture at Grain Market, Bahawalnagar, Pakistan.

Storage bags	Time intervals	Damaged grains (%)	Weight loss (%)	Population buildup	Grain moisture (%)
HB	0	3.84 \pm 0.54 g	1.58 \pm 0.22f	8.25 \pm 0.43 e	11.70 \pm 0.02 g
	30	5.19 \pm 0.53 fg	1.82 \pm 0.17 f	0.00 \pm 0.00 f	9.68 \pm 0.01 h
	60	4.10 \pm 0.23 fg	1.72 \pm 0.11 f	0.00 \pm 0.00 f	9.68 \pm 0.02 h
	90	4.03 \pm 0.45 fg	1.64 \pm 0.18 f	0.00 \pm 0.00 f	9.68 \pm 0.02 h
JB	0	3.84 \pm 0.54 g	1.58 \pm 0.22f	8.25 \pm 0.43 e	11.70 \pm 0.02 g
	30	6.06 \pm 0.41 efg	2.74 \pm 0.20 ef	8.75 \pm 0.13 e	12.03 \pm 0.01 f
	60	10.61 \pm 0.34 cd	4.88 \pm 0.23 cd	10.75 \pm 0.55 cd	12.35 \pm 0.09 de
	90	15.85 \pm 0.60 b	8.04 \pm 0.34 b	12.25 \pm 0.52 c	13.48 \pm 0.02 b
PP	0	3.84 \pm 0.54 g	1.58 \pm 0.22f	8.25 \pm 0.43 e	11.70 \pm 0.02 g
	30	6.84 \pm 0.30 ef	3.36 \pm 0.12 e	8.75 \pm 0.31de	12.13 \pm 0.01 ef

	60	10.60 ± 0.37 cd	5.24 ± 0.19 cd	11.50 ± 0.43 c	12.38 ± 0.09 d
	90	16.59 ± 0.23 b	8.07 ± 0.17b	14.00 ± 0.61 b	13.50 ± 0.04 b
PE	0	3.84 ± 0.54 g	1.58 ± 0.22f	8.25 ± 0.43 e	11.70 ± 0.02 g
	30	8.01 ± 0.61 de	3.95 ± 0.32 de	11.25 ± 0.24 c	12.25 ± 0.01 de
	60	12.84 ± 0.62 c	5.46 ± 0.31 c	14.75 ± 0.38 b	12.68 ± 0.09 c
	90	19.77 ± 0.60 a	9.33 ± 0.46 a	18.50 ± 0.25 a	13.78 ± 0.02 a

Where HB= hermetic bag, JB= jute bag, PP= polypropylene bag, and PE= polyethylene bag. Means within a column followed by same letter(s) are not significantly different while means within a row followed by same letter(s) are not statistically significant (LSD test $P < 0.05$).

The percent grain moisture contents in hermetic bag were decreased after 30 days and then remained constant till the end of the experiment, while other storage bags were kept on receiving moisture from the surrounding environment throughout the rainy season. Punctures were observed on the polyethylene bag which showed that it received moisture due to punctures and insect's activity.

Percent Weight Loss

The results were highly significant for storage bags ($F = 416.68$; d.f. = 3, 63; $P < 0.01$), time intervals ($F = 8.33$; d.f. = 3, 63; $P < 0.01$), and bags × time intervals interaction ($F = 53.79$; d.f. = 9, 63; $P < 0.01$). Percent weight loss was increased from 1.58% to 8.07% (jute bag), 9.33% (polyethylene bag) and 8.07% (polypropylene bag), and 1.64% (hermetic bag) at 90 days at RRI, KSK (Table 1). While for Grain Market Bahawalnagar, the results were highly significant for storage bags ($F = 202.86$; d.f. = 3, 63; $P < 0.01$), time intervals ($F = 59.15$; d.f. = 3, 63; $P < 0.01$), and bags × time intervals interaction ($F = 37.00$; d.f. = 9, 63; $P < 0.01$). Percent weight loss was increased from 1.13% to 12.83% (jute bag), 17.453% (polyethylene bag) and 15.08% (polypropylene bag), and 1.36% (hermetic bag) at 90 days (Table 2). The results showed significantly increasing trend in percent grain weight loss among storage bags over time intervals. More damages were recorded at Grain Market Bahawalnagar than RRI, KSK site in different storage bags.

Percent Damaged Grains

The results were highly significant for storage bags ($F = 49.75$; d.f. = 3, 63; $P < 0.01$), time intervals ($F = 44.74$; d.f. = 3, 63; $P < 0.01$), and bags × time intervals interaction ($F = 13.89$; d.f. = 9, 63; $P < 0.01$). Percent damaged grains were increased from 3.843% to 15.845% (jute bag), 19.773% (polyethylene bag) and 16.585% (polypropylene bag), and 4.03% (hermetic bag) at 90 days at RRI, KSK (Table 1). While for Grain Market Bahawalnagar, the results were highly significant for storage bags ($F = 275.0$; d.f. = 3, 63; $P < 0.01$), time intervals ($F = 208.58$; d.f. = 3, 63; $P < 0.01$), and bags × time intervals interaction ($F = 50.66$; d.f. = 9, 63; $P < 0.01$). Percent damaged grains were increased from 2.77% to 27.845% (jute bag), 31.69% (polyethylene bag) and 28.898% (polypropylene bag), and 3.375% (hermetic bag) at 90 days at Grain Market Bahawalnagar (Table 2). The results indicated an increasing trend in percent damaged grains among storage bags over time intervals. More damaged grains were recorded at Grain Market Bahawalnagar than RRI, KSK.

Population Buildup

The results were highly significant for storage bags ($F = 416.68$; d.f. = 3, 63; $P < 0.01$), time intervals ($F = 8.33$; d.f. = 3, 63; $P < 0.01$), and bags × time intervals interaction ($F = 53.79$; d.f. = 9, 63; $P < 0.01$). Insect population was increased from 8.25 to 12.25 (jute bag), 18.5 (polyethylene bag) and 14 (polypropylene bag), and 0.00 (hermetic bag) at 90 days at RRI, KSK (Table 1). While for Grain Market Bahawalnagar, the results were highly significant for storage bags ($F = 309.49$; d.f. = 3, 63; $P < 0.01$), time intervals ($F = 256.21$; d.f. = 3, 63; $P < 0.01$), and bags × time intervals interaction ($F = 51.76$; d.f. = 9, 63; $P < 0.01$). Population was increased from 7.25 to 19.75 (jute bag), 26.5 (polyethylene bag) and 22.5 (polypropylene bag), while all dead in hermetic bag at 90 days at Grain Market Bahawalnagar (Table 2). The results indicated that hermetic bag proved most effective against stored grain insect pest. Whole population of insects recorded dead at 30 days' interval and effect remained the same for all time intervals on both locations. Other treatments were proved ineffective against stored grain pests.

The storage bags × time interval × location interaction showed that percent grain weight loss was not increased over time intervals in the hermetic bag. It remained constant for the hermetic bag after 30, 60, and 90-days intervals. Percent weight loss was increased over time intervals for all other treatments: jute bag, polyethylene bag, and polypropylene bag. Similarly, the percent grain damage due to insects was increased from 0 to the 30-day time interval and then remained constant for the 60 and 90-day time intervals for the hermetic bag. Percent of grain damage was increased in all other bags over time intervals. The population buildup was also recorded in all storage bags except the hermetic

bag. Hermetic bags proved lethal for insect pest development. Grain moisture remained reduced in the hermetic bag at both locations for 30 d and did not fluctuate for the rest of the experiment duration.

For effectiveness against percent grain weight loss, percent grain damage, and population buildup, the order of the storage bags was hermetic bag > jute bag > polypropylene bag > polyethylene bag. The highest damages were recorded in polyethylene bag, followed by jute bag, polypropylene bag, and hermetic bag, respectively. The comparison of mean difference showed that the hermetic bag was significantly different from other storage bags in respect of percent grain weight loss, percent grain damage, and population buildup of insects. All types of damages ceased to progress after a 30-day interval, as all the population was dead inside the hermetic bag. Polypropylene bag and jute bags were significantly different from the hermetic bag and polyethylene but were at par with each other in all aspects of damage except population buildup, where the hermetic bag was significantly different from all other storage bags (Table 1, 2).

The percent grain weight loss kept on increasing from the start of the experiment and significantly differed from 0 days to 30, 60, and 90-day time intervals. Similarly, at 30, 60, and 90-day time intervals, percent weight loss significantly differed from all other respective storage bags. Similarly, the percentage of grain damage kept on increasing for each time interval significantly. However, the population buildup treatment combinations at time interval 0 days at the 5% level of significance were insignificant to the 30, and 60-day time intervals but significant to the 90-day time interval. Similarly, the 30-day time interval was significant to 60 and 90 days but insignificant to the 0-day time interval. Overall, time interval had a positive impact on all sorts of damages i.e., percent weight loss, percent grain damage and population buildup (Table 1, 2).

Insects

Initially, *T. castaneum* and *S. granarius* were identified in the pretreatment wheat. However, at the end of the experiment, *S. oryzae* were recorded in all bags except the hermetic bag at RRI, KSK and *T. granarium* was recorded in treatments except the hermetic bag at the Grain Garket Bahawalnagar in addition to early identified stored grain pests.

Economic Gains

Economics results indicated that the hermetic bag is the most economical with the least losses i.e., US\$ 4.77, followed by polypropylene (\$8.71), jute (\$9.01) and polyethylene bag (\$11.54). The value of the commodity reduced in all other storage bags due to poor quality but was retained in the hermetic bag. Hence, it proved the most economical management tool for stored grain insect pests under monsoon conditions with the least percent weight loss and the highest retail value for the stored commodity (Table 3).

Table 3. Economic losses analysis for the storage materials over the period of three months.

Bags	lq (Kg)	PWL (%)	lvq (USD/100 Kg)	MC (USD/100 Kg)	FP (USD/100 Kg)	Economic losses
HB	100	1.752	19.8	2.74	19.523	-4.77
JB	100	8.807	19.8	0.79	12.175	-9.01
PE	100	9.525	19.8	0.43	11.575	-11.54
PP	100	8.410	19.8	0.27	12.55	-8.71

*1 USD=164PKR, Where HB= hermetic bag, JB= jute bag, PP= polypropylene bag, and PE= polyethylene bag. Negative values indicate the economic losses due to insect pests associated with different bags over time.

The insect pest growth is dependent upon environmental factors of the study area. Hence, the abiotic factors are crucial for the activity, survival, and multiplication of insect pests. In this study, the temperature and relative humidity conditions of the both places were high enough to allow the activity, and growth of insects successfully without any abiotic stress throughout the experiment period. It is proven that insect pest can successfully develop and maintain their activity at temperatures above 21°C (Storey et al., 1979) (Figure 1). In the Kala Shah Kaku region, wheat and rice are typically cultivated in an annual rotation, with wheat occasionally substituted by other crops for weed management. Rice, a major Kharif crop, is generally sown in nurseries from 2nd fortnight of May till mid-June and transplanted to rice fields in June–July. Wheat harvest and storage occur in April and May, with grain kept either in open fields, silos, drums, or storage bags. The initial moisture content of wheat in this study was 11.7%, a level favorable for insect activity, as grain moisture below 10% is generally unsuitable for most insect pests (Storey et al., 1979). In hermetic bags, grain moisture decreased to 9.6% after 30 days and remained stable over the 90-day storage period. By contrast, wheat stored in polypropylene, polyethylene, and jute bags exhibited a continuous increase in moisture content, corresponding to

fluctuations in environmental relative humidity, which rose during the monsoon season due to rainfall. Because stored grain tends to equilibrate its moisture with the surrounding atmosphere (Pixton & Warburton, 1971), noticeable fluctuations were observed, particularly in polyethylene and polypropylene bags. Three insect species—*S. granarius*, *S. oryzae*, and *T. castaneum*—were detected in wheat samples collected from the storage bags. The damage to grains was mainly associated with *S. oryzae* and *S. granarius*, as they are recognized as primary pests of stored cereals. In

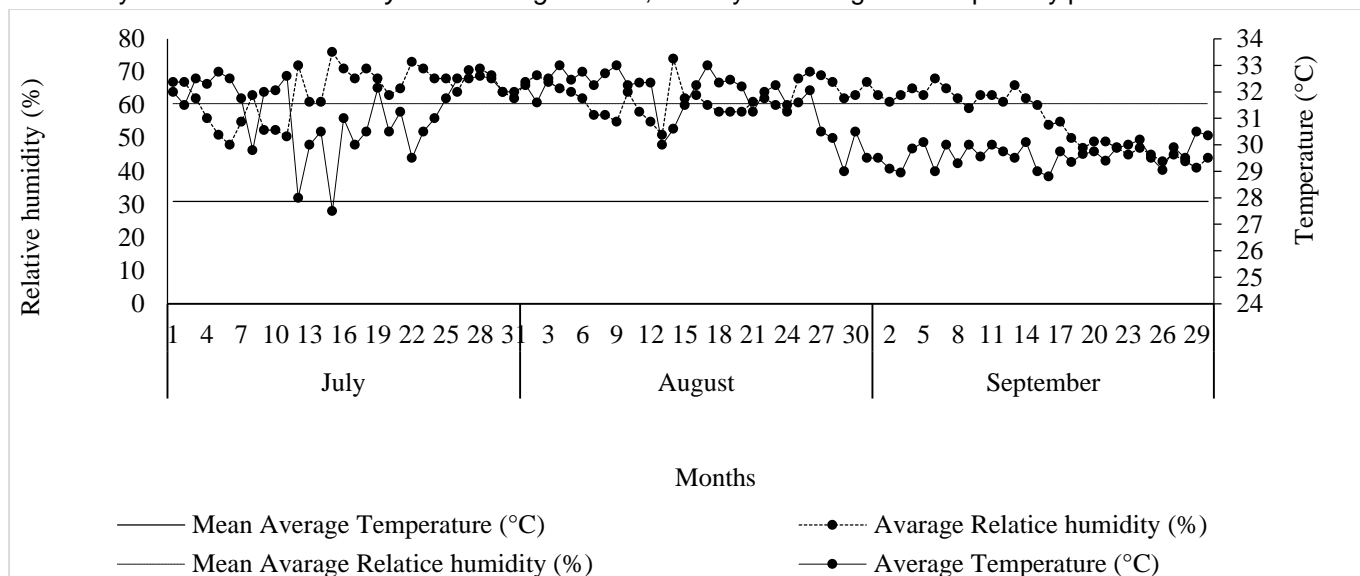


Figure 1. Average relative humidity (%) and temperature (°C) for three months of study at Rice Research Institute, Kala Shah Kaku Pakistan

contrast, *T. castaneum* is considered a secondary pest, feeding primarily on grains that have already been damaged (Mullen et al., 2012). The present studies showed that jute, polypropylene, and polyethylene bags were vulnerable to stored grain insect pests, but the hermetic bag is resilient to insect pest damage and abiotic factors. This resistant character of hermetic bag to weather and insect pest is in agreement with studies of Atta et al. (2019) and Rizwan et al. (2022). In all storage bags, insect pests increased with time, but the hermetic bag proved lethal for pest population buildup. Hence, damages ceased to escalate further inside the hermetic bag. Likhayo et al., (2016) reported the very slow increase in insect pest population in Super Grain IV-R bags compared to in the metal silo due to the hermeticity of the Super Grain bags. Holes due to insect pests were observed in polypropylene with the naked eye, which was ultimately the reason for losing the hermetic conditions.

Polypropylene and jute bags were porous bags that hindered airflow at more or less the same level. While the hermetic bag was thick enough to resist any inflow/ outflow of air and insect pests. Thickness may be the decisive factor to cope with the penetration ability of insect pests. Polyethylene was less thick as compared to a hermetic bag. The damages were more in thin or less thick packaging as compared to thick material. The number of holes in the polyethylene bag was observed due to *S. oryzae* as compared to *T. castaneum* because the former is the primary pest and penetrator. Chung et al., (2011) showed that the thickness of the packaging substance is one of the most crucial factors that decides the both penetration and evasion of insects. Similar findings were reported by Lie et al., (2014) that the thin packaging materials were more vulnerable to insect invasions, and further cover usage with packing material imparted more resistance than when used alone (Mullen & Mowery, 2000). These findings are in agreement with Riudavets & Salas (2007), who reported polyethylene bags as susceptible packaging compared to the other packaging films. Thickness affects the ability of stored grain insect pests to penetrate and evade in the form of holes and scratches, and polyethylene was also reported to be susceptible to the attack of insect pests (Cline, 1978; Highland & Wilson, 1981). These holes visible to the naked eye, were made for ventilation and searching for food (Riudavets et al., 2007). These holes were due to *Sitophilus spp.*, which, when exposed to an oxygen-depleted environment, can bore through materials as thick as 35 mm. (Li, 1988).

In this study, the highest grain weight loss (9.12%) was observed in polyethylene bags after 90 days of storage, whereas Likhayo et al. (2016) documented up to 32.1% loss in polyethylene bags after 150 days. The population ratio of *T. castaneum* dropped as compared to weevils with time in tested storage bags, and hence the damages were recorded more after a 90-days interval. Kim & Kossou (2003) described a strong positive correlation between percent

grain weight loss and escalation in the weevil population. The findings of this study revealed that storing wheat in non-hermetic bags led to greater economic losses due to increased grain damage, weight reduction, and pest population growth, ultimately causing both quantitative and qualitative deterioration and lowering market value. These outcomes align with previous reports highlighting the effectiveness of hermetic bags in managing insect pests of stored grains (Amadou et al., 2016; Atta et al., 2019; Obeng-Akrofi et al., 2023).

CONCLUSION

Hermetic bags were found to be the most effective storage material for minimizing wheat damage caused by *T. castaneum*, *S. oryzae*, *S. granarius*, and *T. granarium*. They offer a non-chemical alternative for managing stored-grain insect pests. The greater thickness of hermetic bags also restricts the penetration ability of *S. oryzae*, thereby reducing punctures and holes in the grain. Based on these findings, hermetic storage can be recommended as a sustainable method for controlling insect pests in stored wheat.

AUTHOR'S CONTRIBUTION

Muhammad R, BA, MT and AMS designed the experiment. Muhammad R, MI, and BA conducted the experiment. AMS supervised the experiment the experiment. Muhammad R and Misbah R analyzed the data, wrote the initial and final draft. All authors approved the final draft.

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AVAILABILITY OF DATA AND MATERIAL

All the data is presented in analyzed farm in tables in the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

All authors agreed for its publication.

CONFLICT OF INTERESTS

The authors have no conflict of interest.

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