Pakistan J. Zool., pp 1-8, 2026. **DOI**: https://dx.doi.org/10.17582/journal.pjz/20250113191226

Effect of Variety and Cracked Kernels on Damage Caused by *Trogoderma granarium* Everts to Wheat, its Survival and Control by Phosphine Fumigation

Muhammad Sarfraz Aslam[1], Muhammad Waqar Hassan[1]*, Ghulam Sarwar[2] and Tanveer Hussain[3]

[1]*Department of Entomology, Faculty of Agriculture and Environment, Islamia University of Bahawalpur, Bahawalpur*
[2]*Department of Botany, Faculty of Chemical and Biological Sciences, Islamia University of Bahawalpur, Bahawalpur*
[3]*Institute of Forest Sciences, Faculty of Agriculture and Environment, Islamia University of Bahawalpur, Bahawalpur*

Article Information
Received 13 January 2025
Revised 15 August 2025
Accepted 30 August 2024
Available online 28 August 2026
(early access)

Authors' Contribution
MSA conducted research work and wrote initial draft of manuscript. MWH supervised research and edited and wrote final manuscript. GS helped in study design and data analysis. TH reviewed manuscript finally before submission.

Key words
Stored grain pests, Varietal screening, Weight loss, Insect control, Phosphine fumigation, Cereals

ABSTRACT

Wheat (*Triticum aestivum*) is the major cereal crop that is consumed in largest amount than other cereal crops in the world. *Trogoderma granarium* is the important stored grains pest of wheat. Seven parameters; weight of damaged grains, numbers of damaged grains, weight of undamaged grains, numbers of undamaged grains, percentage weight loss, survival and mortality of *T. granarium* were studied to conclude the effect of cracked kernels and wheat varieties. Present study was conducted in the laboratory of Entomology of the university. Culture was maintained under the optimum condition of 30 ± 2 °C and 65 ± 5% R.H. In all varieties, weight of damaged grains increased with increase in percentage of cracked kernels (T_1-T_5). Maximum weight was recorded in T_5 (100% cracked kernels) except in Faisalabad in which maximum weight of damaged grains was recorded in T_2 (50% cracked kernels). Similarly, number of damaged grains due to *T. granarium* attack increased with increase in degree of cracked kernels. Conversely undamaged grains weight decreased with increase in percentage of cracked kernels. In our results overall percent survival of *T. granarium* larvae infesting different varieties ranges as Aas > Zincol > Fakher e bakhar > Ghazi > Faisalaabad 2008 > Anaj > Jouhar. There was no significant effect recorded in mortality of *T. granarium* due to phosphine under the effect of percentage of cracked kernels. Maximum mortality due to phosphine was in Fakher e Bakhar (87 %) followed by Jouhar (83.33 %) at T_3 (50 % cracked kernels). Minimum mortality was recorded in Fakhar e Bakhar (39%) at T_4 (75 % cracked kernels).

INTRODUCTION

Wheat (*Triticum aestivum*) is cultivated about more than 250 million hectares throughout the world larger than for any other crop and world trade is greater for wheat than for all other crops combined. Human food consumption is 2/3 on wheat in the world. It is staple food for 80% population of the world. Gluten and protein that are found in wheat form bubble of carbon dioxide, (Hanson *et al*., 1982). Dough produce by wheat flour is better from other cereals in their unique properties (Orth and Shellenberger, 1988).Wheat contains major nourishment for human compared with other food sources. It is the best cereal food having major diet component *i.e.* starch, carbohydrate, protein, lipids and other mineral. Its flour is easily edible, digestible and palatable. Wheat is successfully grown between the latitudes of 30° and 60°N and 27° and 40°S. This crop is grown from sea level to 3000 masl to 4570 masl in altitudes in Tibet (Percival, 1921). According to CIMMYT during the past two decades, Iqbal *et al*. (2009) reported that wheat production is technologically feasible in much warmer areas. The optimum growing temperature is about 25°C with minimum and maximum growth temperatures of 3° to 4°C and 30° to 32°C, respectively. It can be grown in most locations where precipitation ranges from 250 to 1750 mm (Leonard and Martin, 1963). In Pakistan wheat is used as a staple food. Wheat production in the 2021/22

* Corresponding author: waqar.hassan@iub.edu.pk
0030-9923/2026/0001-0001 $ 9.00/0

marketing year (May–April) is forecast at 26.0 million metric tons (MMT) nearly three percent higher than the revised wheat production of 25.2 MMT a year ago. There have been reports of locust attacks from Punjab and Sindh but the wheat crop is largely unaffected (USDA, 2021).

Khapra beetle *Trogoderma granarium* Everts (Coleoptera: Dermestidae) is one of the most dangerous pests of stored wheat and other stored grain products in hot and dry conditions. Firstly it was reported in India in 1894 by Cotes and considered one of the worst species in the world in amongst 100 worst species (Lowe *et al*., 2000). About 134 species of *Trogoderma* were reported in the world and 12 were found in storage places. Number of old and recent identification keys are available for identification of *T. granarium* (Singh *et al*., 2017). Identification is based on adult's genitalia or larval mouthparts examination. It is commonly found in hot zones of bulk, godowm, granaries, bins, silos and farm houses throughout the world.

T. granarium usually has four to five generations per year and it can have 12 generations under suitable conditions. The female can lay 50 to 100 eggs which are loosely scattered on host material. Larvae are able to hide in cracks and crevices of shipping containers bulk cargo holds and packing material. *T. granarium* can stay in diapause for up to 6 years until the onset of suitable conditions for development (Burges, 1962). Length of larvae is 1.6 to 1.8 mm and width is 0.25 to 0.3 mm having yellowish white colour on body. Head and body hair are in brown colour. There are two type of hairs on the body; simple hairs and barbed hairs. Simple hairs are small, stiff and directed upward. Barbed hairs born on abdominal tergites in pair. Mature larva length is almost 6 mm and breadth is 1.5 mm (Golizadeh and Abedi, 2017). Larval period is between 20 and 40 days (Ismeal, 2017). Pupa is white in colour. Male pupa is smaller than female having length 3.5 mm to 5 mm. Adult is oval oblong in shape. Adult is 1.6 to 3.0 mm long and 0.9 to 1.7 mm wide. Male is smaller in size than female. Male having dark reddish-brown colour and female is lighter in colour. Life cycle from egg to adult *i.e.* from 26 days to 220 days depend on the environmental conditions (Singh *et al*., 2017).

It causes huge economic loss due to its potential to cause loss in store grain by feeding and heating of grain. It causes severe damage between 5 % to 30 % weight loss and 73 % in extreme cases in most favourable conditions. The damage caused by *T. granarium* to stored wheat grain may reach to 73 %. Its severe infestation cause nutrients depletion in grains and decrease in starch, carbohydrates, protein, sugars, fat, vitamins riboflavin, thiamine and lipids. It is found throughout the world in hot and dry climate of Asia, Africa, Eurasia and USA. Host ranges are wheat, maize, cotton, rice, millet, barely, sorghum, groundnut and dry stored products. Its larvae can live for up to three years in starvation condition. It can survive on food at low moisture contents. *T. granarium* is the serious threat to our food safety and food security. Barbed hairs remain in the grain which cause serious hazards to the human health (French and Venette, 2005). Cast skin may cause problem during handling of infested grains. Ingesting contaminated products with body parts, setae and cast larval skin result in asthmatics, highly allergenic and gastro-intestinal irritation (Pruthi and Singh, 1950).

Its unpleasant fragments in wheat flour is also major issue for milling industry (Perez-Mendoza *et al*., 2003). FDA has formed defect action level of 75 insects fragments per 50 g of flour. Larvae start to feed on germ plasm and embryo of seed or any weak point and proceed inward and later on feed on kernels or entire grain and make the grain hollow. In heap, it remains upper 50 cm layer of grain. It fills infested grain with cast skin and excreta. It damages seed that have rough appearance. Such seed are unfit for human consumption and loss of germination due to contamination (Ahmedani *et al*., 2009). Loss of vitamins and increased level of uric acid has been reported due to infestation of *T. granarium* in grains.

T. granarium damages stored wheat by reducing weight and grade of the grain. The control and eradication of *T. granarium* is difficult, which may reduce its susceptibility to some control methods (Ahmedani *et al*., 2007). Phosphine gas fumigation, deltamethrin and malathion are widely used to control *T. granarium* in Turkey.

Predator *Xylocoris flavipes* belongs to order Hemiptera, family Anthocoridae has been found prey on *T. granarium*. *Bacillus thuringiesis* used against *T. granarium*. In developing countries, oil of neem *Azadirachta indica* control khapra beetle (Usman *et al*., 2018). Heat treatment is applied in those countries where summer temperature exceeds 40 °C and more little energy is required with low energy cost to maintain temperature 60 °C. *T. granarium* is exposed at 60 °C for 30 min to kill 100 % of all stages. The emerging adults were sterile if pupae were placed at 45 °C for 48 h (Burges, 2008). Heat dosage of at least 120 min at 55 °C at the site of infestation is enough to eliminate *T. granarium*. Complete mortality of *T. granarium* was observed at 25-30 °C and greater than 60 % of CO_2 after 17-30 days. *T. granarium* can be eliminated if we expose it at 80 % CO_2 at 20-30 °C for 16 days. In France, Indonesia and South Africa several grains and pulses are commercially treated with irradiation and UVC to control *T. granarium* because eggs and pupae are most sensitive. For this purpose gamma equipment electron beam accelerators and radioisotopes elements such as cobalt 60 are used (Ghanem and Shamma, 2007).

Aluminium phosphide and methyl bromide fumigation that are used to control stored grain pest but *T. granarium* has developed resistance against phosphine (Navarro, 2006). Before use of fumigation malathion, synthetic pyrethriod and deltamethrin were used as a protective insecticide against *T. granarium* throughout the world. *T. granarium* has developed resistance against deltamethrin (Hafiz *et al*., 2018). The use of same insecticide for long periods leads to the evolution of insecticide resistance in stored-grain pests (Champ, 1985). *Tribolium castaneum* (Herbst) and *Sitophilus* spp. have developed resistance due to extensive use of malathion (Dyte and Blackman, 1970).

Keeping in view the economic significance associated with damages caused by *T. granarium* in different cereals especially wheat. Current study was designed to check effect of percentage of cracked kernels and varieties of wheat on damage to wheat. Effect of these factors shall also be evaluated on fumigation efficacy of phosphine against *T. granarium*.

MATERIALS AND METHODS

The contemporary experimental investigation was conducted in stored grain research laboratory of Entomology in Faculty of Agriculture and Environmental Science, The Islamia University Bahawalpur in 2020.

Collection and mass rearing of insects

For preparation of culture, different mixed age culture of *T. granarium* was reared on healthy wheat grains for insect free infestation. Before using the grains, wheat samples were subjected to phosphine fumigation to ensure that there is no more any undetected population of insects.

The fumigated grains in one kg quantity were placed in three jars having uniform size. The jars were covered with muslin cloth with the help of rubber band and placed in the laboratory of Entomology at 25±5°C and 60±5% relative humidity for conditioning. After fortnight drying of seed when moisture level of grains was reached at 10-12 %, grains were used as rear medium for *T. granarium*.

Collection of wheat seeds

Seeds of seven wheat varieties that are commonly grown in Pakistan *viz*., Jouhar, Faisalabad-2008, Ghazi, Zincol, AAS-2011, Anaj and Fakhar-e-Bakhar were collected from the Federal Seed Certification and Rectification Department X-block, Bahawalpur.

Sampling

Fifteen sample (60 g) of each variety was cleaned by sieving through mesh sieves and fumigated with aluminium phosphide tablets to ensure the possibility of previous infestation, if any. For phosphine fumigation, all vials in single layer were placed uniformly in fumigation trunk having volume 0.7 m^3. One tablet of 3-g Aluminium Phosphide was placed in centre for 6 h. Survival and mortality were recorded after 6 h. For each variety, three replicates each of 4 g the following five treatments were set up. T1 comprised of healthy grains of wheat. T2 had 1 g 25 % cracked kernels and 3 g 75 % healthy grains. T3 comprised of 2 g 50 % cracked kernels and 2 g 50 % healthy grains. T4 consisted of 3 g 75 % cracked kernels and 1 g 25 % healthy grains. T5 comprised of 100% cracked kernels. Grains were put in vials having 4 cm length and 3 cm diameter.

Exposing wheat seeds to T. granarium *infestation*

The cracked grains after weighing were placed in plastic vials. For 48 h grain were exposed to air to obtain uniform moisture. Then 10 larvae with uniform size of 3rd and 4th instar were collected from prepared culture and put in each vial. All cups were placed at 30±5°C, 65±5 % R.H. All vials were placed in open place in the laboratory to ensure proper aeration and to avoid accumulation of Carbon dioxide produced as a result of biotic respiration.

Weight loss

The number and weight of undamaged and damaged grains were recorded for calculation of weight loss (Gwinner *et al*., 1996).

$$\text{Percent weight loss} = \frac{(Wu \times Nd) - (Wd \times Nu)}{Wu \times (Nd + Nu)} \times 100$$

Where, Wu is weight of undamaged grains, Wd is weight of damaged grains, Nu is numbers of unhealthy grains, and Nd is numbers of damaged grains. Excretion, grain dust and shed skin were separated by sieve.

Population growth

Four parameters were studied for measuring the population growth *i.e*. percent of larvae lived, percent of larvae dead, percent of adult lived and percent of adults dead.

$$\text{Percentage of larvae dead} = \frac{\text{No of larvae dead}}{\text{Total larvae in sample}} \times 100$$

$$\text{Percentage of larvae lived} = \frac{\text{No of larvae lived}}{\text{Total larvae in sample}} \times 100$$

$$\text{Percentage of adults dead} = \frac{\text{No of adults dead}}{\text{Total adults in sample}} \times 100$$

$$\text{Percentage of adults lived} = \frac{\text{No of adults lived}}{\text{Totals adults in sample}} \times 100$$

RESULTS

Weight of damaged and undamaged grains

Table I shows the weight of damaged and undamaged

grains of different wheat varieties by *Trogoderma granarium.* In variety Jouhar, maximum weight of damaged grains was 1.41±0.03 at T5 and minimum weight of damaged grains was 0.51±0.07 at T2 (P < 0.05). In variety Faisalabad 2008, maximum weight of damaged grains was 1.59±0.98 at T2 and minimum weight of damaged grains was 0.38±0.12 at T1 (P < 0.05). In variety Ghazi, maximum weight of damaged grains was 1.11±0.06 at T5 and minimum weight of damaged grains was 0.43±0.08 at T1 (P < 0.05). In variety Zincol, maximum weight of damaged grains was 1.20±0.11 at T5 and minimum weight of damaged grains was 0.68±0.36 at T1 (P < 0.05). In variety Aas 2011, maximum weight of damaged grains was 0.88±0.06 at T5 followed by 0.86±0.05 at T5 and minimum weight of damaged grains was 0.45±0.06 at T1 (P < 0.05). In variety Anaj, maximum weight of damaged grains was 1.32±0.16 at T4 followed by 1.14±0.14 at T5 and minimum weight of damaged grains was 0.32±0.08 at T1 (P < 0.05). In variety Fakhar e Bakhar, maximum weight of damaged grains was 1.42±0.34 at T5 and minimum weight of damaged grains was 0.39±0.06 at T1 (P < 0.05).

Number of damaged and undamaged grains

In variety Jouhar, maximum weight of undamaged grains was 3.44±0.09 at T2 and minimum weight of undamaged grains was 2.48±0.01 at T5 (P < 0.05). In variety Faisalabad, maximum weight of undamaged grains was 3.57±0.12 at T1 and minimum weight of undamaged grains was 2.64±0.04 at T5 (P < 0.05). In variety Ghazi, maximum weight of undamaged grains was 3.51±0.08 at T1 and minimum weight of undamaged grains was (2.68±0.05) at T5 (P < 0.05). In variety Zincol, maximum weight of undamaged grains was 3.29±0.35 at T1 and minimum weight of undamaged grains was 2.64±0.08 at T5 (P < 0.05). In variety Aas, maximum weight of undamaged grains was 3.48±0.03 at T1 and minimum weight of undamaged grains was 3.02±0.04 at T3 (P < 0.05). In variety Anaj, maximum weight of undamaged grains was 3.61±0.11 at T1 and minimum weight of undamaged grains was 2.62±0.16 at T4 (P < 0.05). In variety Fakhar e Bakhar, maximum weight of undamaged grains was 3.25±0.33 at T1 and minimum weight of undamaged grains was 2.40±0.31 at T5 (P < 0.05) (Table I).

In variety Jouhar, maximum number of damaged grains was 70.33±3.17 at T_5 and minimum number of damaged grains was 16.33±1.85 at T_1 ($P < 0.05$). In variety Faisalabad 2008, maximum number of damaged grains was 68.66±12.99 at T_5 and minimum number of damaged grains 14.33±3.38 at T_1 ($P < 0.05$). In variety Ghazi, maximum number of damaged grains was 62.66±2.02 at T_5 and minimum number of damaged grains 13.66±3.17 at T_1 ($P < 0.05$). In variety Zincol, maximum number of damaged grains was 69.66±3.17 at T_5 and minimum number of damaged grains 12.00±1.52 at T_1 ($P < 0.05$). In variety Aas 2011, maximum number of damaged grains was 41.66±3.84 at T_5 and minimum number of damaged grains (11.33±1.33) at T_1 ($P < 0.05$). In variety Anaj, maximum number of damaged grains was 72.66±12.19 at T_4 followed by 62.66±10.71 at T_5 and minimum number of damaged grains 11.33±2.84 at T_1 ($P < 0.05$). In variety Fakhar e bakhar, maximum number of damaged grains was 58.33±7.51 at T_5 and minimum number of damaged grains 10.33±1.20 at T_1 ($P < 0.05$) (Table I).

The maximum number of undamaged grains in variety Jouhar was 115.67±6.88 at T4 and minimum number of undamaged grains was 81.6±1.45 at T1 (P < 0.05). In variety Faislabad 2008, maximum number of undamaged grains was 132.33±12.71 at T4 and minimum number of undamaged grains was 103.33±6.76 at T1 (P < 0.05). In variety Ghazi, maximum number of undamaged grains was 116.33±11.05 at T5 and minimum number of undamaged grains was 87.66±3.17 at T1 (P < 0.05). In variety Zincol, maximum number of undamaged grains was 141.67±11.31 at T5 and minimum number of undamaged grains was 85.66±8.68 at T1 (P < 0.05). In variety Aas 2011, maximum number of undamaged grains was 126.00±3.46 at T5 and minimum number of undamaged grains was 75.00±4.58 at T2 (P < 0.05). In variety Anaj, maximum number of undamaged grains was 110.00±8.08 at T5 and minimum number of undamaged grains was 89.00±1.52 at T2, (P < 0.05). In variety Fakhar e Bakhar, maximum number of undamaged grains was 111.00±10.11 at T3 and minimum number of undamaged grains was 73.33±0.66 at T1 (P < 0.05) (Table I).

Weight loss of grains

Table II shows the percent weight loss of cracked grains of different wheat varieties caused caused by infestation of *Trogoderma granarium.* In variety Jouhar, maximum percent weight loss of grains was 11.73±0.81 at T3 and minimum percent weight loss of grains was 1.36±1.67 at T1 (P < 0.05). In variety Faisalabad 2008, maximum percent weight loss of grains was 11.70±1.76 at T3 and minimum percent weight loss of grains was 3.04±0.96)at T1 (P < 0.05). In variety Ghazi, maximum percent weight loss of grains was 10.63±1.06 at T4 and minimum percent weight loss of grains was 2.77±0.88 at T1 (P < 0.05). In variety Zincol, maximum percent weight loss of grains was 10.62±3.38 at T3 and minimum percent weight loss of grains was 2.80±0.66 at T5 (P < 0.05). In variety Aas 2011, maximum percent weight loss of grains was (10.34±2.85) at T2 and minimum percent weight loss of grains was 1.86±0.89 at T1, (P < 0.05). In variety Anaj 2011, maximum

Table I. Effect of variety and cracked Kernels of wheat on the damage caused by *Trogoderma granarium* in terms of loss of weight and number of damaged and undamaged grains (Mean±SEM).

Treat-ments	N	Jouhar	Faisalabad 08	Ghazi	Zincol	Aas 2011	Anaj	Fakhar e Bakhar
Weight of damaged grains								
T1	3	0.61±0.05 a	0.38±0.11 a	0.43±0.08 b	0.68±0.36 a	0.45±0.06 b	0.32±0.08 b	0.39±0.06 b
T2	3	0.51±0.07 a	1.59±0.98 a	0.58±0.11 b	0.90±0.06 a	0.85±0.14 a	0.81±0.08 ab	0.76±0.10 ab
T3	3	0.86±0.06 a	0.88±0.07 a	0.66±0.03 ab	0.78±0.08 a	0.86±0.05 a	0.90±0.17 ab	0.68±0.11 ab
T4	3	0.81±0.17 a	0.90±0.12 a	0.88±0.16 ab	0.98±0.02 a	0.79±0.04 ab	1.32±0.16 a	1.04±0.16 ab
T5	3	1.41±0.03 b	1.20±0.05 a	1.11±0.06 a	1.20±0.11 a	0.88±0.06 a	1.14±0.14 a	1.42±0.34 a
Total	15	0.84±0.09	0.99±0.20	0.73±0.07	0.91±0.08	0.76±0.05	0.90±0.10	0.86±0.12
Number of damaged grains								
T1	3	16.33±1.85 c	14.33±3.38 c	13.66±3.17 c	12.00±1.52 a	11.33±1.33 b	11.33±2.84 b	10.33±1.20 c
T2	3	23.00±2.30 c	32.00±1.52 bc	28.33±2.02 bc	34.66±3.84 b	31.66±4.48 a	41.33±7.35 ab	30.00±2.88 bc
T3	3	42.00±2.08 b	53.00±4.04 ab	36.66±2.33 bc	49.00±7.63 ab	39.66±3.28 a	51.33±9.40 ab	30.33±4.25 bc
T4	3	44.33±5.48 b	61.00±8.14 ab	49.66±7.83 ab	53.33±6.35 ab	35.00±2.08 a	72.66±12.19 a	47.66±5.20 ab
T5	3	70.33±3.17 a	68.66±12.99 a	62.66±2.02 a	69.66±3.17 a	41.66±3.84 a	62.66±10.71 a	58.33±7.51 a
Total	15	39.20±5.20	45.80±5.99	38.20±4.78	43.73±5.52	31.86±3.14	47.86±6.60	35.33±4.75
Weight of undamaged grains								
T1	3	3.33±0.02 ab	3.57±0.12 a	3.51±0.08 a	3.29±0.35 a	3.48±0.03 a	3.61±0.11 a	3.25±0.33 a
T2	3	3.44±0.09 a	3.23±0.02 ab	3.38±0.12 a	3.02±0.05 a	3.07±0.14 b	3.16±0.08 ab	3.22±0.09 a
T3	3	3.14±0.06 b	2.99±0.04 bc	3.17±0.06 ab	3.13±0.07 a	3.02±0.04 b	3.04±0.14 ab	3.22±0.06 a
T4	3	3.10±0.07 b	2.99±0.04 bc	2.90±0.08 bc	2.89±0.05 a	3.18±0.06 ab	2.62±0.16 b	2.84±0.16 a
T5	3	2.48±0.01 c	2.64±0.04 c	2.68±0.05 c	2.64±0.08 a	3.07±0.06 b	2.72±0.18 ab	2.40±0.31 a
Total	15	3.10±0.09	3.08±0.08	3.13±0.08	2.99±0.08	3.16±0.05	3.03±0.10	2.98±0.12
Number of undamaged grains								
T1	3	81.67±1.45 b	103.33±6.76 a	87.66±3.17 a	85.66±8.68 c	75.33 ±1.85 a	89.33±4.80 a	73.33±0.66 a
T2	3	95.67±6.11 ab	123.33±2.60 a	110.33±11.39a	97.66 ±5.84 bc	75.00±4.58 b	89.00±1.52 a	83.66±5.36 a
T3	3	94.67±2.96 ab	114.33±4.91 a	105.33±0.88 a	122.33±2.33ab	98.00±14.01ab	102.67±5.17a	111.00±10.11a
T4	3	115.67±6.88 a	132.33±12.71a	109.00±5.00 a	126.00±3.05ab	117.00±6.65 a	98.33±5.52 a	102.33±14.16a
T5	3	113.67±3.52 a	122.00±74.37a	116.33 ±11.05a	141.67±11.31a	126.00±3.46 a	110.00±8.08a	84.00±13.20 a
Total	15	100.27±3.83	119.07±5.52	105.73±3.86	114.67±26.03	98..26±6.25	97.86±3.24	90.86±5.28

Means with different lower-case alphabets is significantly different at P: 0.05. T_1: 100 % Sound grains, T_2: 25 % cracked grains, T_3: 50 % cracked grains, T_4: 75 % cracked grains, T_5: 100 % cracked grains.

Table II. Percent weight loss (Mean±SEM) due to *T. granarium* under the effect of cracked kernels and wheat varieties.

Treat-ments	N	Jouhar	Faisalabad 2008	Ghazi	Zincol	Aas 2011	Anaj	Fakhar e Bakhar
T1	3	1.36±1.67 c	3.04±0.96 a	2.77±0.88 b	7.64±10.45 a	1.86±0.89 a	3.53±1.26 a	1.58±0.63 a
T2	3	7.66±0.94 ab	8.21±23.68 a	6.89±0.87 a	4.02±5.50 a	10.34±2.85 a	13.95±2.92 a	8.85±2.82 a
T3	3	11.73±0.81 a	11.70±1.76 a	10.43±0.82 a	10.62±3.38 a	8.72±2.11 ab	13.40±1.18 a	5.17±2.25 a
T4	3	9.19±1.78 a	11.24±3.12 a	10.63±1.06 a	5.76±3.86 a	4.09±1.20 ab	13.39±2.79 a	7.67±2.49 a
T5	3	2.98±0.24 bc	7.54±3.74 a	8.47±0.52 a	2.80±0.66 a	3.26±0.88 ab	9.32±4.56 a	6.42±2.21 a
Total	15	6.58±1.133	3.06±5.05	7.84±0.83	3.11±2.67	5.66±1.10	10.72±1.50	5.94±1.07

See Table I, for treatment groups and statistical details.

percent weight loss of grains was 13.95±2.92 at T2 and minimum percent weight loss of grains was 3.53±1.26 at T1 ($P < 0.05$). In variety Fakhar e Bakhar, maximum percent weight loss of grains was 8.85±2.82 at T2 and minimum percent weight loss of grains was 1.86±0.89 at T1 ($P < 0.05$).

Survival of T. granarium

In variety Jouhar, maximum survival of *T. granarium* was 63.33±6.66 at T2 and minimum survival of *T. granarium* was 43.33±3.33 at T3 ($P < 0.05$). In variety Faisalabad 2008, maximum survival of *T. granarium* was 80.00±5.77 at T4 and minimum survival of *T. granarium* was 66.66±6.66 at T1 ($P < 0.05$). In variety Ghazi, maximum survival of *T. garanarium* was 83.33±12.01 at T2 and minimum survival of *T. granarium* was 60.00±0.00 at T1 ($P < 0.05$). In variety Zincol, maximum survival of T. granarium was 86.66±3.33 at T5 and minimum survival of *T. granarium* was 73.33±3.33 at T1 ($P < 0.05$). In variety Aas 2011, maximum survival of *T. granarium* was 93.33±6.66 at T2 and minimum survival of *T. granarium* was 80.00±15.27 and 80.00±0.00 in both T4 and T5 ($P < 0.05$). In variety Anaj, maximum survival of *T. granarium* was 86.66±3.33 at T2 and minimum survival of *T. aranarium* was 63.33±8.81 at T3 ($P < 0.05$). In variety Fakhar e Bakhar, maximum survival of *T. granarium* was 90.00±10.00 at T4 and minimum survival of *T. granarium* was 56.66±3,33 at T3 ($P < 0.05$) (Table III).

Effect on mortality of T. granarium

In variety Jouhar, maximum mortality of *T. granarium* was 83.33±8.33 at T3 and minimum mortality of *T. granarium* was 60.00±10.81 at T2 ($P < 0.05$). In variety Faisalabad 2008, maximum mortality of *T. granarium* was 67.22±4.33 at T2 and minimum mortality of *T. granarium* was 53.63±5.75 at T4 ($P < 0.05$). In variety Ghazi, maximum mortality of *T. granarium* was 66.82±8.29 at T3 and minimum mortality of *T. granarium* was 53.33±5.30 at T4 ($P < 0.05$). In variety Zincol, maximum mortality of T. granarium was 65.27±1.38 at T5 and minimum mortality of *T. granarium* was 56.01±3.61 at T4, ($P < 0.05$). In variety Aas 2011, maximum mortality of *T. granarium* was 58.14±11.04 at T4 and minimum mortality of *T. granarium* was 43.98±3.61 at T2 ($P < 0.05$). In variety Anaj, maximum mortality of *T. granarium* was 61.11±20.03 at T4 and minimum mortality of *T. granarium* was 41.66±8.92 at T2 ($P < 0.05$). In variety Fakhar e Bakhar, maximum mortality of *T. granarium* was 87.77±6.18 at T3 and minimum s mortality of *T. granarium* was 39.52±6.19 at T4 ($P < 0.05$) (Table IV).

Table III. Survival (Mean±SEM) of *T. granarium* under the effect of cracked kernels and wheat varieties.

Treatment	N	Jouhar	Faisalabad 2008	Ghazi	Zincol	Aas 2011	Anaj	Fakhar e Bakhar
T1	3	56.66±3.33 a	66.66±6.66 a	60.00±0.00 a	73.33±3.33 a	83.33±3.33 a	70.00±10.00 a	76.66±6.66 a
T2	3	63.33±6.66 a	73.33±12.01 a	83.33±12.01 a	80.00±15.27 a	90.00±5.77 a	86.66±3.33 a	86.66±3.33 a
T3	3	43.33±3.33 a	76.66±8.81 a	76.66±12.01 a	80.00±10.00 a	93.33±6.66 a	63.33±8.81 a	56.66±3,33 a
T4	3	60.00±10.00 a	80.00±5.77 a	80.00±10.00 a	83.33±3.33 a	80.00±15.27 a	73.33±12.01 a	90.00±10.00 a
T5	3	60.00±11.54 a	76.66±8.81 a	76.66±12.01 a	86.66±3.33 a	80.00±0.00 a	70.00±5.77 a	66.66±17.63 a
Total	15	56.66±3.47	74.66±3.50	75.33±4.45	80.66±3.44	85.33±3.36	72.66±3.83	75.33±4.96

See Table I, for treatment groups and statistical details.

Table IV. Mortality (Mean±SEM) of *T. granarium* due to phosphine fumigation under the effect of cracked kernels and wheat varieties.

Treatments	N	Jouhar	Faisalabad 2008	Ghazi	Zincol	Aas 2011	Anaj	Fakhar e Bakhar
1	3	75.55±7.77 a	63.88±7.34 a	66.66±9.66 a	63.69±4.16 a	52.31±5.33 a	53.70±6.67 a	51.85±4.52 a
2	3	60.00±10.86 a	67.22±4.33 a	60.74±3.22 a	65.18±7.51 a	43.98±3.61 a	41.66±8.92 a	54.16±10.48 a
3	3	83.33±8.33 a	65.74±5.63 a	66.82±8.29 a	58.09±0.95 a	46.66±3.33 a	56.38±8.28 a	87.77±6.18 a
4	3	71.66±6.00 a	53.63±5.75 a	53.33±5.30 a	56.01±3.61 a	58.14±11.04 a	61.11±20.03 a	39.52±6.19 a
5	3	63.88±7.34 a	65.27±1.38 a	66.03±5.31 a	65.27±1.38 a	54.16±4.16 a	44.04±9.74 a	61.66±7.26 a
Total	15	70.88±3.81	63.15±2.38	62.71±2.82	61.65±1.90	51.05±2.71	51.38±4.85	58.99±5.08

See Table I, for treatment groups and statistical details.

DISCUSSION

Usually, weight of damaged grains due to *T. granarium* was found maximum in treatment containing 100 % cracked grains in all wheat varieties while minimum weight of damaged grains was in treatments containing 0 % cracked grains. Number of damaged grains due to *T. granarium* was found maximum in treatments containing 100 % cracked grains and minimum numbers of damaged grains were recorded in treatment (Control) containing 0 % cracked grains in all seven varieties.

Our results can be compared with those of Anthanassiou *et al*. (2016). They studied population growth of *T. granaraium* on different commodities by taking 0 % cracked kernels, 5 % cracked kernels, 10 % cracked kernels, 25 % cracked kernels, 50 % cracked kernels and 100 % cracked kernels. They reported that increase with the percentage of cracked kernels; population growth of *T. granarium* increased by 3.7 % more in 100 % cracked kernels.

Similarly, weight of undamaged grains by *T. granarium* was found maximum in treatment containing 0 % cracked grains while minimum weight of undamaged grains was recorded in treatment containing 100 % cracked in five out of seven varieties. Numbers of undamaged grains was found maximum in treatment containing 100 % cracked grains in four out of seven varieties and minimum numbers of undamaged grains was recorded in treatment (Control) containing 0 % cracked grains in five out of seven wheat varieties.

In similar experiment, Ahemadani *et al*. (2011) reported quantitative loss up to 20 % under natural condition for the period of six months. *T. garanarium* larvae showed varying levels of preference to different wheat varieties. Wafaq-2001 was found the most resistant variety among all varieties that they used for experiment. Significant numbers of damaged grains, weight loss and progeny development were recorded. Moisture content (R = 0.83) was also correlated to weight loss.

In our studies among all varieties, percent weight loss was recorded minimum in control treatment containing no broken grains. In our results overall percent survival of *T. garanarium* larvae infesting different varieties ranges as Aas > Zincol > Fakhar e Bakhar > Ghazi > Faisalabad 2008 > Anaj > Jouhar.

Similar study was found by Sayed *et al*. (2006) who conducted studies on resistance of different wheat varieties that was varietal factor against *T. garanarium*. He reported maximum resistance in variety Mehran-89 and maximum susceptibility in variety TJ-787 against *T. garanarium* for different parameters of weight of damaged grains, percent weight loss and population growth of *T. garanarium*.

There was no significant effect of cracked kernels on percent survival of *T. granarium* larvae because it can feed on sound ground grains equally well although it preferred more broken grains. Mortality of *T. granarium* due to phosphine fumigation in the same set of different wheat varieties was not affected significantly.

DECLARATIONS

Acknowledgments

The authors are grateful to Federal Seed Certification and Rectification Department X-block, Bahawalpur for provision of certified seeds of varieties for this research work.

Funding

This study was carried out using laboratory facilities of the Department of Entomology, The Islamia University of Bahawalpur, without any external financial support.

Generative AI and AI-assisted technology statement

No generative AI or AI-assisted technologies were used in the preparation of this manuscript.

Statement of conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Ahmedani, M.S., Khaliq, A., Tariq, M., Anwar, M. and Naz, S., 2007. Khapra beetle (*Trogoderma granarium* Everts): A serious threat to food security and safety. *Pak. J. agric. Sci*., **44**: 481–493.

Ahmedani, M.S., Haque, M.I., Afzal, S.N., Aslam, M. and Naz, S., 2009. Varietal changes in nutritional composition of wheat kernel (*Triticum aestivum* L.) caused by Khapra beetle infestation. *Pak. J. Bot.*, **41**: 1511–1519.

Ahmedani, M.S., Haque, M.I., Afzal, S.N., Naeem, M., Hussain, T. and Naz, S., 2011. Quantitative losses and physical damage caused to wheat kernel (*Triticum aestivum* L.) by khapra beetle infestation. *Pakistan J. Bot.,* **43**: 659-668.

Athanassiou, C.G., Kavallieratos, N.G. and Boukouvala, M.C., 2016. Population growth of the khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae) on different commodities. *J. Stored Prod. Res.,* **69**: 72-77. https://doi.org/10.1016/j.jspr.2016.05.001

Burges, H.D., 1962. Studies on the Dermestid beetle *Trogoderma granarium* Everts. V. Reactions of diapause larvae to temperature. *Bull. entomol.*

Res., **53**: 193–213. https://doi.org/10.1017/S0007485300048057

Burges, H.D., 2008. Development of the Khapra beetle, *Trogoderma granarium*, in the lower part of its temperature range. *J. Stored Prod. Res.,* **44**: 32–35. https://doi.org/10.1016/j.jspr.2005.12.003

Champ, B.R., 1985. Occurrence of resistance to pesticides in grain storage pests. Pesticides and humid tropical grain storage systems (ed. B.R. Champ and E. Highly). *Aust. Centre Int. Agric. Res. Proc.,* **14**: 229–255.

Dyte, C.E. and Blackman, D.G., 1970. The spread of insecticide resistance in *Tribolium castaneum* (Herbst) (Coleoptera, Tenebrionidae). *J. Stored Prod. Res.*, **6**: 255–261. https://doi.org/10.1016/0022-474X(70)90015-9

French, S. and Venette, R.C., 2005. *Mini risk assessment Khapra beetle,* Trogoderma granarium *(Everts)* [Coleoptera: Dermestidae]. USDA APHIS, Raleigh, NC.

Ghanem, I. and Shamma, M., 2007. Effect of non-ionizing radiation (UVC) on the development of *Trogoderma granarium* Everts. *J. Stored Prod. Res.,* **43**: 362–366. https://doi.org/10.1016/j.jspr.2006.09.002

Gwinner, J., Harnisch, R. and Mük, O., 1996. Manual on the prevention of post-harvest grain losses. In Post-Harvest ProtectionProject GTZ Eschborn; FRG: Eschborn, Germany. pp. 338.

Hafiz, A., Riaz, T. and Shakoori, F.R., 2018. Deltamethrin induced changes in the activities of various esterases in deltamethrin-resistant populations of *Trogoderma granarium*. *Pakistan J. Zool.,* **50**: 1474-1475. https://doi.org/10.17582/journal.pjz/2018.50.4.1475.1482

Hanson., H., Borlaug, N.E. and Anderson, R.G., 1982. *Wheat in third world*. West vies Press, Boulder, CO, USA.

Iqbal, M.M., Hussain, S.S., Goheer, M.A., Sultana, H., Salik, K.M., Mudasser, M. and Khan, A.M., 2009. *Climate change and wheat production in Pakistan: Calibration, validation and application of CERES-Wheat model*. Islamabad: Global Change Impact Studies Centre.

Leonard, W.H. and Martin, J.H. 1963. *Cereal crops.* MacMillan Publishing, New York, NY, USA.

Lowe, S., Browne, M., Boudjelas, S. and De Poorter, M., 2000. *100 of the world's worst invasive alien species: a selection from the global invasive species database* (Vol. 12). Invasive Species Specialist Group Auckland.

Navarro, S., 2006. Modified atmospheres for the control of stored-product insects and mites. *Insect Manage. Fd. Storage Proc.*, pp. 105–146. https://doi.org/10.1016/B978-1-891127-46-5.50016-7

Orth, R.A. and Shellenberger, J.A., 1988. Origin, production, and utilization of wheat. *Wheat Chem. Technol.*, **3**: 1–14.

Percival, J., 1921. The wheat plant; a monograph, Duck worth and Co. London. https://doi.org/10.5962/bhl.title.25683

Perez-Mendoza, J., Throne, J.E., Dowell, F.E. and Baker, J.E., 2003. Detection of insect fragments in wheat flour by near-infrared spectroscopy. *J. Stored Prod. Res.,* **39**: 305–312. https://doi.org/10.1016/S0022-474X(02)00021-8

Pruthi, H.S. and Singh, M., 1950. *Pests of stored grain and their control*. 18 (Part 4, Special Number. (Third Revised Edition)).

Sayed, T.S., Hirad, F.Y. and Abro, G.H., 2006. Resistance of different stored wheat varieties to Khapra beetle, *Trogoderma granarium* (Everest) and lesser grain borer, *Rhizopertha dominica* (Fabricus). *Pak. J. biol. Sci.*, **9**: 1567–1571. https://doi.org/10.3923/pjbs.2006.1567.1571

Singh, A., Chand, P., Vishwakarma, R. and Singh, C.K., 2017. Khapra beetle (*Trogoderma granarium* Everts): A food security threat. *Bull. Env. Pharm. Life Sci.*, **6**: 1–6.

USDA, 2021. *Grain and feed annual*. Islamabad. Pakistan.

Usman, K., Muhammad, U.F., Muhammad, F.A. and Umar, N., 2018. Khapra beetle: A review of recent control methods. *Curr. Inves. Agric. Curr. Res.*, **5**: 730–733. https://doi.org/10.32474/CIACR.2018.05.000222