Online ISSN: 2588-3526
Journal of Wildlife and Biodiversity

Volume 8(1): 308-326 (2024) (http://www.wildlife-biodiversity.com/) **Research Article**

Efficacy of different cereals on the development of *Tribolium castaneum*

Shahar Bano*[1], Fakhra Soomro[1], Waheed Ali Panhwar[2], Sajjad Ali Larik[1], Paras Soomro[1]

[1]Department of Zoology, Shah Abdul Latif University, Khairpur Pakistan
[2] Department of Zoology University of Sindh Jamshoro Pakistan
*Email: Shaharbanu.m98@gmail.com

Received: 16 August 2023 / Revised: 10 November 2023 / Accepted: 19 November 2023/ Published online: 19 November 2023.
How to cite: Bano, S., Soomro, F., Ali Panhwar, W., Ali Larik, S., Soomro, P. (2024). Efficacy of different cereals on the development of *Tribolium castaneum*, Journal of Wildlife and Biodiversity, 8(1), 308-326. **DOI**: https://doi.org/10.5281/zenodo.10206973

Abstract

The commercial availability of the cereals has been increasing due to the availability of low-gluten however; management of the cereals with its relation and susceptibility was poorly described. The efficacy of the development of *Tribolium castaneum* was analyzed on six different cereals i.e. wheat, rice, corn, cowpea, sorghum and barley flour. The cereals were collected from two different sources i.e. Flour mills (Source-I) and Grocery stores (Source-II) to assess the level of infestation. It was noticed that the total duration from egg to adult remains fastest on wheat flour, i.e. 41.8±0.80 days followed by sorghum flour 52.9±0.90 days and slowest on cowpea flour 65.5±1.00 days. The study of morphometric parameters of *Tribolium castaneum* as a result of feeding on different cereals showed statistically significant effects on the length, and breadth of different larval instars, pupa and Adult stages. The highest total larval length and breadth was recorded on wheat flour (42.80mm and 17.4mm) followed by Sorghum flour (41.40mm and 14.6mm) while the lowest total larval length and breadth was recorded on cowpea flour (28.0mm 8.1mm) followed by corn flour (30.70mm and 8.3mm). The results of this study indicated that higher rate of infestation on wheat and less on cowpea flour as compared to other cereals. Time for 50% to 90% of eggs to adult development was fastest on wheat i.e. (2.9±1.01 and 4.3±2.37) and slowest on cowpea flour i.e. (5.5 ±1.0 and 7.5±1.76). There was extensive variation in the efficacy of the different cereals with relation to the level of gluten increases the risk of insect infestation.

Keywords: *Tribolium castaneum*, postharvest, cereals, Infestation, Sodium, nutritional contents.

Introduction

The red flour beetle, *T. castaneum* (Coleoptera: Tenebrionidae), is a significant pest affecting various stored products in tropical and subtropical regions. This pest is responsible for worldwide commodity damage (Mehmood et al., 2018). It infests a wide range of food items, causing substantial harm to grocery stores, flour mills, and warehouses (Bakhtawar et al., 2013). The red flour beetle is particularly destructive to wheat flour, which is rich in gluten. Therefore, there is a growing demand for alternative cereals with lower gluten content (Heller, 2009; Cureton et al., 2009). Cereals like sorghum, corn, rice, and cowpeas, which have lower gluten content, are increasingly sought after. However, these alternative cereals are vulnerable to infestation by insect pests, leading to significant economic losses amounting to billions of dollars each year (Brown, 2009).

The market for gluten-free alternatives to wheat flour has been expanding due to the rise in coeliac disease diagnoses and consumer demand for low-gluten and gluten-free options (Heller, 2009; Bogue et al., 2008). For instance, in 2007, the gluten-free market in the United Kingdom was valued at GBP-74 million (approximately USD 93 million), and in 2006, the market in the United States was valued at USD 696 million. As of 2019, the gluten-free market is valued at USD 21.61 billion, with an expected 9.2% growth by 2027 (Arthur et al., 2019). This expanding market includes alternative cereals like sorghum, corn, rice, and innovative products made from coffee, bananas, nuts, and root vegetables such as cassava and potatoes (Bogue et al., 2008).

After harvesting, grains are stored and processed, making them susceptible to insect infestation, resulting in significant damage and substantial annual revenue losses for producers. Extensive research has focused on insect growth and development in traditional cereal grains like wheat and rice, including whole seeds, milled flours, and milling fractions and byproducts (Arthur et al., 2020; Gerken and Campbell, 2020). However, with the increasing variety of cereals used in the food industry, there is limited knowledge about the development of stored product insects on these alternative cereals and the potential risks they pose to this rapidly growing industry.

T. castaneum (Coleoptera: Tenebrionidae) is a major pest of wheat and rice flour (Rustamani and Khatri et al., 2014; Campbell et al., 2010). It is also a secondary pest that feeds on various stored products and has been found to survive on a variety of food supplies. This pest exhibits high fecundity on wheat flour and can thrive on different wheat strains (Sarwar et al., 2011 and Chapman, 2013). A diet enriched with folic acid promotes the growth and development of *T. castaneum*, while low levels of phosphorus (0.075%) in the diet are insufficient for population growth. Conversely, high levels (3.075%) of phosphorus are toxic to the closely related species, *T. confusum* (Coleoptera: Tenebrionidae) (Fraenkel and Blewett, 1947). The addition of yeast to wheat flour enhances the reproduction and survival of *T. castaneum* (Chaudhry et al., 1962). Furthermore, *T. castaneum* exhibits high fecundity on wheat flour with added yeast compared to millet, barley, rice, sorghum, and soybean. In particular, sorghum and soybean flour resulted in the lowest fecundity (Naseri et al., 2017). Although *T. castaneum* is a primary pest of wheat flour, it has a broad host range and has been associated with various food supplies such as rice, millet, sorghum, and corn (Sokaloff, 1966).

In many areas of Pakistan, *T. castaneum* is a primary concern in the sustainable storage of wheat. Severe infestations result in moldy and discolored flour, producing a foul odor and rendering it unsuitable for human consumption (Wagan et al., 2019). *T. castaneum* exhibits high progeny output on millet, sorghum, and maize flour (Kayode et al., 2014; Campbell and Hagstrum, 2002), as well as on starch-rich cowpea flour with low mortality rates (Fields, 2006). It also shows high progeny output on white flour, wheat flour, and rice flour (Wong and Lee, 2006), along with whole wheat flour, corn flour, and brown rice flour (Franklin et al., 1966). However, *T. castaneum* has poor progeny production on semolina, cassava or yam meals (Weston and Gourd, 2000), protein-rich pea flour (Fields, 2006), soy flour (Franklin et al., 1966), tapioca, and potato starch (Wong and Lee, 2006). Additionally, it exhibits poor feeding and development on cowpea flour (Fabres et al., 2014). Different varieties of wheat or barley produce variable results for *T. castaneum*. For example, there is a range of fecundity and hatching rates on different barley varieties (Namin and Naseri, 2017), while developmental times increase on pelletized frog feed and crumbled poultry feed (Fardisi et al., 2019). Larval weight gain is slow on dried distiller's grain (Fedina and Lewis, 2007). Progeny output varies among rice flour milling fractions, with higher output on rice flour, milled whole rice kernels, brown rice, milled broken kernels, and rice bran, but lower output on rough rice hulls, paddy rice dust, and milled rice dust (Campbell and Runnions, 2003; Sinha and Sinha, 1992; Hell et al., 2000; Dars et al., 2001). These findings suggest that not only does the type of commodity matter, but also its size and shape. Moreover, commercial flour products made from corn, rice, wheat, and soybean show lower population density but faster developmental rates compared to non-commercial flour of the same commodity (Astuti et al., 2020).

The present study emphasizes the impact of cereal type on insect development and growth. Therefore, understanding the growth and development and fecundity of insect pests on different types of cereals in relation to gluten content will help determine which flour varieties are more susceptible.

Materials and methods

Flour Test

During this study, six different cereals were selected, namely wheat, rice, corn, cowpea, sorghum, and barley. These cereals were collected from two different sources, which are flour mills/warehouses (Source-I) and grocery stores (Source-II) in the year 2022. Wheat, rice, and sorghum were collected in their whole-grain form and ground into fine flour in the laboratory. Corn, cowpea, and barley were collected in powder form from Source-I. As they were sticky, there was no need for pre-sieving (Table 1) (Gerken and Campbell, 2020).

Culture of Insects

After collection, 250 grams of infested cereal was poured into plastic jars (500 g). The jars were covered with muslin cloth secured with a rubber band and brought to the laboratory to establish a stocked culture. The cereals were sieved through 60 and 80-mesh sieves to count the eggs and developmental stages. Insects were reared on a standardized diet consisting of 5% Brewer's yeast added to the cereals to maintain the stocked culture. The population of *T. castaneum* was maintained at 37°C with a relative humidity of 65% to 80% on a 16-hour day and 8-hour night cycle.

Oviposition

To assess the hatching and development of *T. castaneum* eggs in various flours and estimate the number of eggs laid by females when direct counting is not feasible, eggs and flour were returned to their vials and held at 30°C and 65% relative humidity. If a flour was pre-sieved, it was sieved through a 60-mesh sieve to ensure uniformity. The number of eggs in each flour was counted using a dissecting microscope. Equal volumes of each cereal type (flour) were placed into separate (20-ml) vials. Adult female *T. castaneum*, aged between 2-4 weeks, were collected from the main stocked culture. These females were placed in glass vials with the standard diet for 2-4 days. Vials were covered with cotton cloth to allow for airflow. After a suitable period (e.g., week 4), the number of eggs laid by females on different flours was counted and recorded. This count helps evaluate a female's recognition and acceptance of a particular flour as a substrate for egg-laying. Progeny counts (larvae) were recorded weekly for a total of 8 weeks. At the end of the 8-week period, any remaining larvae were also counted.

Development

To test the ability of *T. castaneum* to develop from egg to adult on different cereals, the cereals used in the experiment were not pre-sieved. They were measured in grams and placed into (20 ml) vials. To collect the eggs, 2 to 4-week-old female adults were taken from the main stocked culture and allowed to lay eggs for 48 hours on a cereal that had been pre-sieved through an 80-mesh sieve. The eggs were sieved out using a 60-mesh sieve, and a cluster of five eggs was placed in each vial with flour. The vials were capped with a small piece of cotton and kept at 30°C, 65% relative humidity, and a 16-hour day and 8-hour night cycle. After 6 weeks, the vials were examined to check the egg hatching and the developmental stages. Each developmental stage as larva, pupa, or adult was recorded. This process was repeated weekly for a total of 8 weeks. The collected data on egg counts, oviposition, and progeny counts were likely analyzed to understand the hatching and development rates of eggs and progeny in different cereals. Statistical analysis may be employed to identify significant differences in the different cereals.

Nutritional Analysis of Eggs and Progeny of *T. castaneum*

During the present study, a combined nutritional analysis of the selected cereals, including wheat, rice, corn, cowpea, sorghum, and barley from Source-I (flour mills/warehouses) and Source-II (grocery stores/supermarkets), was performed on oviposition and development of eggs and progeny. A dry powder of 20 grams of eggs and progeny was used for the analysis of nutritional parameters such as sodium, saturated fat, calories from fat, fiber, protein, and carbohydrates. The nutritional tests were performed at the Pakistan Council Scientific Institute of Research in Karachi, Pakistan.

Results and discussion

The experiment was conducted in 2022 in District Khairpur to examine the efficacy of different cereals on the development of *T. castaneum*. We considered six cereals: wheat, rice, corn, cowpea, sorghum, and barley, collected from two different sources - flour mills and warehouses (Source-I), and grocery stores and supermarkets (Source-II). Our aim was to assess the infestation rate and its effects on the growth and development of the pest (Table 1). In a related study, Gerken and Campbell (2020) focused on the oviposition and development of *T. castaneum*, a significant pest of wheat and rice. They used 18 commercially available flours for their experiments, including almond, amaranth, barley, buckwheat, cassava, coconut, corn, garbanzo, millet, oat, potato, quinoa, rice, rye, sorghum, spelt, teff, wheat, to investigate infestation levels and their impact on the pest's growth and development (Weston & Gourd, 2000; Shafique et al., 2006).

The life cycle of *T. castaneum* consists of egg, larva, pupa, and adult stages (refer to Figure 1). The larval stage consistently goes through six instars. An observation of the morphometric analysis of various developmental stages of *T. castaneum* on different cereals reveals significant differences. The greatest variation in egg length was observed in wheat flour (2.4mm), followed by sorghum flour (1.9mm), while the smallest difference in egg length was seen in cowpea flour (0.5mm), followed by corn flour (0.8mm). In contrast, the breadth of the eggs displayed significant differences across all cereals, ranging from 0.9mm to 0.7mm, 0.6mm to 0.6mm, and 0.4mm to 0.3mm, respectively.

A relationship between the length of the first and sixth instars was observed, with the highest differences seen in wheat flour (5.5 mm and 9.6 mm) and sorghum flour (4.9 mm and 9.1 mm), followed by rice flour (3.9 mm and 8.7 mm) and barley flour (4.1 mm and 8.5 mm). These findings are in line with those reported by Sunder et al. (2021). They noted that the length from the first to the sixth instar was observed on YLM-17 (1.09 mm and 5.06 mm) and GT-10 (1.07 mm and 5.05 mm). Additionally, the length of the second, third, fourth, and fifth instars showed significant differences, ranging from 6.1 to 5.7, 7.1 to 6.2, 7.6 to 6.9, and 8.5 to 7.7 mm, respectively. However, the smallest difference in length from the first to the sixth instar was observed in cowpea flour (2.8 mm and 7.2 mm), followed by corn flour (3.1 mm and 7.9 mm). The breadth of the larvae significantly differed in all instars, with measurements ranging from 1.9 to 0.3, 2.5 to 1.1, 2.7 to 1.2, 3.2 to 1.81, 3.4 to 1.87, and 3.7 to 2.4 mm. The greatest difference was observed when reared on wheat flour, while the smallest difference was noted in cowpea flour (Table 2).

The pupal length was highest in wheat flour (10.3 mm), significantly different from rice flour (8.4 mm) and barley flour (9.1 mm), while pupal breadth was greatest in wheat flour (4mm), followed by sorghum flour (3.6mm), with the smallest pupal breadth recorded on cowpea flour (6.7mm) and corn flour (7.2mm). These results align with those reported by Devi and Devi (2015), who described a pupal length and width of 3.18 to 4.12 mm and 1.07 to 1.15 mm, respectively.

The body length and breadth of male and female adult *T. castaneum* exhibited significant differences among the cereals. Body length ranged from 12.3 mm to 11.7 mm, with the longest body length observed in wheat flour (12.3 mm), followed by sorghum flour (11.7 mm). The shortest body length was noted in cowpea flour (8.5 mm), followed by corn flour (9.6 mm), differing significantly from the other cereals. The breadth of adult *T. castaneum* was shortest on cowpea flour (3.2 mm), differing significantly from corn flour (3.8 mm), while the greatest breadth was observed on wheat flour (5.7 mm) compared to other cereals (Table 2). These findings are consistent with Sunder et al. (2021), who reported variations in adult male and female length and breadth. The duration of the developmental stages of *T. castaneum* on six different cereal varieties was noted. The fastest egg hatching was recorded on wheat flour, taking approximately 3±0.55 weeks. In contrast, sorghum flour exhibited the slowest egg hatching rate at 4.4±0.81 weeks. The slowest egg hatching rate was recorded on cowpea flour (5.6±1.17), followed by corn flour, while rice flour displayed an average egg hatching rate of 5.2±1.16, followed by barley flour at 4.6±0.83 weeks (occurring across all life stages). The hatching of the first instar larvae was fastest on wheat flour (3.8±0.66 weeks) and slowest on cowpea flour (5.9±0.56 weeks), with similar variations observed in the other cereals (Table 3).

The correlation of nutritional analysis of *T. castaneum* eggs and progeny from (Source-I) and (Source-II) revealed interesting relationships. The number of eggs laid was positively correlated with calories from fats, proteins, and carbohydrates in (Source-I), but negatively correlated with saturated fats, sodium, and fibers. For (Source-II), there was a negative correlation between sodium and calories from fat, and a positive correlation between the number of eggs laid and protein, carbohydrates, fiber, and saturated fats. Saturated fats, carbohydrates, and sodium were negatively correlated with (Source-I), whereas calories from fats, fiber, and protein were positively correlated. For progeny, saturated fats, carbohydrates, and sodium were all negatively correlated, while calories from fats, fiber, and protein were all positively correlated (Source-I). The number of progeny was negatively correlated with sodium and positively correlated with fiber, carbohydrate, protein, calories from fat, and saturated fat (Source-II) (Table 5).

Finally, there is a significant difference in egg development between (Source-I) and (Source-II) when using various cereal flours, such as wheat, rice, corn, cowpea, sorghum, and barley. The least significant difference was found in wheat flour at (50.33) for (Source-I), followed by rice at (37.17) and sorghum flour at (45.00). However, cowpea, corn, and barley flours were not available from (Source-I), so these three flours were obtained from (Source-II). Notably, wheat flour from (Source-I) proved to be the most suitable for egg development compared to (Source-II) (Fig. 2a). Furthermore, there was a significant difference in progeny development between (Source-I) and (Source-II) when using various cereal flours, including wheat, rice, corn, cowpea, sorghum, and barley. Similarly, the least significant difference was found in wheat flour at (59.66) for (Source-I), followed by rice at (45.13) and sorghum flour at (56.75) for (Source-I). Cowpea, corn, and barley flours were again obtained from (Source-II) as they were unavailable from (Source-I). Just as with egg development, wheat flour from (Source-I) was the most suitable for progeny development compared to (Source-II) (Fig. 2b).

These findings are consistent with the observations made by Gerken and Campbell in 2020. They found that Teff flour and laboratory wheat flour attracted the most egg-laying. Buckwheat flour from (Source-I) and rice flour from (Source-II) also showed significant egg-laying rates. In contrast, the fewest eggs were laid on both sources of cassava and amaranth, as well as on both sources of potato and quinoa. The number of adult progeny emergence was a critical outcome related to the type of flour used, and this difference was highly significant. The highest number of progeny emerged from wheat, (Source-II) millet, and teff, while no progeny emerged from almond, amaranth, cassava, coconut, or potatoes. When comparing millet and oat sources, (Source-I) had a higher number of progeny emerging as compared to (Source-II) (Khatak et al., 1986).

Conclusion

The present study concludes that Tribolium castaneum undergoes the fastest development in wheat flour, rich in gluten, and the slowest in cowpea flour, a gluten-free cereal. Additionally, it was observed that cereals from (Source-I) were highly infested and caused more damage compared to those from (Source-II) due to their better condition and physical fitness. However, it's worth noting that wheat flour is highly susceptible to insect infestation owing to its high nutrient concentration, which attracts *Tribolium castaneum*. In contrast, cowpea flour is generally considered less susceptible to *Tribolium castaneum* infestation due to its lower nutrient concentration. Furthermore, a comparison of population emergence between 50% and 90% revealed that it was highest in wheat flour and lowest in cowpea flour. To mitigate the impact of *Tribolium castaneum* on cereals, proper storage practices, including temperature and moisture control, as well as effective pest control measures, are crucial. In summary, understanding the efficacy of *Tribolium castaneum* infestation on different cereals is essential for ensuring food safety, preserving nutritional quality, and preventing economic losses in the grain storage and food processing industries.

Acknowledgements

The authors and co-authors are grateful to those who directly or indirectly helped us during the research work.

Table 1. Shows the mean and standard error of various cereals from Source-I and Source-II

Flour	Plant Family	Domesticated Year ago	Gluten Level		Flour Form		Pre-sieved for growth Willingness.	
			Source-I	Source-II	Source-I	Source-II	Source-I	Source-II
Wheat	Poaceae	10000	High	Low	Grain form	Powder frorm	Yes	No
Rice	Poaceae	9000	None	None	Grain form	Flour form	Yes	No
Cow-peas	Poaceae	4000	-	None	-	Powder form	-	Yes
Corn	Poaceae	9000	-	None	-	Flour form	-	Yes
Sorghum	Poaceae	6000	Low	Low	Grain form	Flour form	Yes	No
Barley	Poaceae	9000	-	low	-	Powder form	-	Yes

Table 2. Morphometric analysis of various developmental stages of *Tribolium castaneum* on different cereals.

Flour varieties	Eggs		First Instar		Second Instar		Third Instar		Fourth Instar		Fifth Instar		Sixth Instar		Average Larval measurement		Pupa		Adult	
	Length (mean) Mm	Breadth (mean) Mm	Length (mean) mm	Breadth (mean) Mm	Length (mean) mm	Breadth (mean) mm	Length (mean) mm	Breadth (mean) mm	Length (mean) mm	Breadth (mean) mm	Length (mean) mm	Breadth (mean) mm	Length (mean) mm	Breadth (mean) mm	Length (mean) mm	Breadth (mean) mm	Length (mean) mm	Breadth (mean) mm	Length (mean) mm	Breadth (mean) mm
Wheat	2.4mm	0.9mm	5.1 mm	1.9mm	5.9mm	2.5mm	6.5mm	2.7mm	7.6mm	3.2mm	8.5mm	3.4mm	9.2mm	3.7mm	42.80mm	17.4mm	10.3mm	4mm	12.3mm	5.7mm
Rice	1.3mm	0.5mm	3.9mm	0.5mm	4.3mm	1.0mm	5.3mm	1.7mm	6.4mm	2.5mm	7.2mm	2.3mm	8.7mm	3.2mm	34.90mm	11.1mm	8.4mm	2mm	10.2mm	4.3mm
Corn	0.7mm	0.4mm	3.1mm	0.4mm	3.2mm	0.93mm	4.7mm	1.3mm	5.7mm	1.6mm	6.9mm	1.9mm	7.9mm	2.5mm	30.70mm	8.3mm	7.2mm	1.4mm	9.6mm	3.8mm
Cow-peas	0.5mm	0.3mm	2.8mm	0.3mm	2.7mm	1.1mm	4.5mm	1.2mm	5.2mm	1.81mm	6.2mm	1.87mm	7.2mm	2.4mm	28.00mm	8.1mm	6.7mm	1.2mm	8.5mm	3.2mm
Sorghum	1.9mm	0.7mm	4.9mm	1.6mm	5.7mm	2.0mm	6.3mm	2.3mm	7.3mm	2.8mm	8.3mm	3.1mm	9.0mm	3.5mm	41.40mm	14.6mm	9.8mm	3.6mm	11.7mm	5.2mm
Barley	1.6mm	0.6mm	4.2mm	0.7mm	4.8mm	1.5mm	5.8mm	1.9mm	6.9mm	2.6mm	7.6mm	2.9mm	8.5mm	3.1mm	38.10mm	12.7mm	9.1mm	2.7mm	11.2mm	4.7mm
All the values are means of five replications																				

Table 3. Duration of developmental stages of *Tribolium castaneum* cultured on different cereals.

Life stages		Wheat Flour	Rice Flour	Corn Flour	Cow-peas Flour	Sorghum Flour	Barley Flour
		Mean±S.E	Mean±S.E	Mean±S.E	Mean±S.E	Mean±S.E	Mean±S.E
		Range	Range	Range	Range	Range	Range
Egg	Mean±S.E	3±0.55	5.2 ± 1.16	5.1± 1.08	5.6 ± 1.17	4.4± 0.81	4.6 ± 0.83
	Range	1-3 days	2-7days	2-8days	3-9 days	2-5 days	2-6days
First instar	Mean±S.E	3.8 ± 0.66	4.2 ± 0.58	5.2± 0.73	5.9 ± 0.56	3.5 ± 0.81	5.1± 0.93
	Range	2-3days	2-5days	3-5days	4-6 days	2-4 days	3-4days
Second instar	Mean±S.E	3.3 ± 0.54	5.6 ± 0.78	5.3 ± 0.86	5.3 ± 0.62	4.5 ± 1.07	4.5 ± 0.59
	Range	2-4days	3-6days	3-7 days	4-7days	2-6 days	3-6days
Third instar	Mean±S.E	4.4 ± 0.60	5.8 ± 0.66	6.4 ± 0.81	7.2 ± 0.86	4.6± 0.97	4.9 ± 0.51
	Range	4-6days	2-8days	4-8 days	5-10days	3-7 days	3-9days
Fourth instar	Mean±S.E	3.8± 0.80	5.2 ± 0.63	5.4 ± 1.21	5.3± 0.94	5.6 ± 0.68	5.8± 1.16
	Range	5-6days	2-7days	2-8 days	3-9days	4-7days	2-7days
Fifth instar	Mean±S.E	3.4 ±0.40	5.5 ± 0.80	7 ± 1.14	7.6 ±1.21	6.2 ± 0.73	5 ± 0.84
	Range	3-5days	3-9days	2-9days	4-11 days	5-8days	3-7 days
Sixth Instar	Mean±S.E	5.9 ± 0.75	6.5 ± 0.63	8 ± 0.71	8.6 ± 0.93	7.7 ± 0.54	8.2 ± 0.66
	Range	4-8days	5-9days	6-10 days	7-12 days	6-9 days	6-10 days
Total Larval Period		24 ± 0.63	32 ± 0.70	37.3 ± 0.91	39.9 ± 0.85	32.1 ± 0.80	33.5 ± 0.78
Pupa	Mean±S.E	6.8 ± 0.97	8.2 ± 1.07	9.4 ± 1.08	9.2 ± 1.43	7.8± 1.39	7 ± 1.05
	Range	3-9days	5-10days	6-12 days	5-13 days	3-9days	4-10days
Adult	Mean±S.E	7.4 ± 1.93	9.6± 1.03	10 ± 1	10.8 ± 1.32	8.6± 1.12	8.8 ± 0.85
	Range	5-10days	6-12days	7-13 days	6-14 days	4-11days	5-12 days
Total development period		41.8± 0.80	54.9± 0.83	61.8± 0.96	65.5 ± 1.00	52.9 ± 0.90	53.9± 0.82

Table 4. showing the conversion time of (eggs into adults) 50% to 90% population for all cereals tested.

Flours	Time to Hatch	
	Expected weeks to 50%± Standard Error	Expected weeks to 90%± Standard Error
Wheat	2.9±1.01	4.3±2.37
Rice	4.0±1.11	5.4±1.86
Corn	4.7 ±1.58	6.8±1.66
Cow-peas	5.5±1.0	7.5 ± 1.76
Sorghum	3.2±1.06	4.6± 1.59
Barley	3.5±0.97	5.1 ±1.55

Table 5. Showing correlation of nutritional analysis of the *Tribolium castaneum* eggs and progeny from source-I and source--II

Parameters	Egg		Progeny	
	Source-I Grocery stores	Source-II Flour mills	Source-I Grocery stores	Source-II Flour mills
	(n-20)grams	(n-20)grams	(n-20)grams	(n-20) grams
	Correlation coefficient		Correlation coefficient	
Saturated fats	-0.26	0.22	-0.32	0.29
Calories from fats	0.32	-0.12	0.35	0.42
Crude fiber	-0.18	0.25	-0.28	0.34
Protein	1.20	0.98	0.18	0.29
Sodium	-0.17	-0.37	-0.22	-0.27
Carbohydrates	0.78	1.05	-0.46	0.52

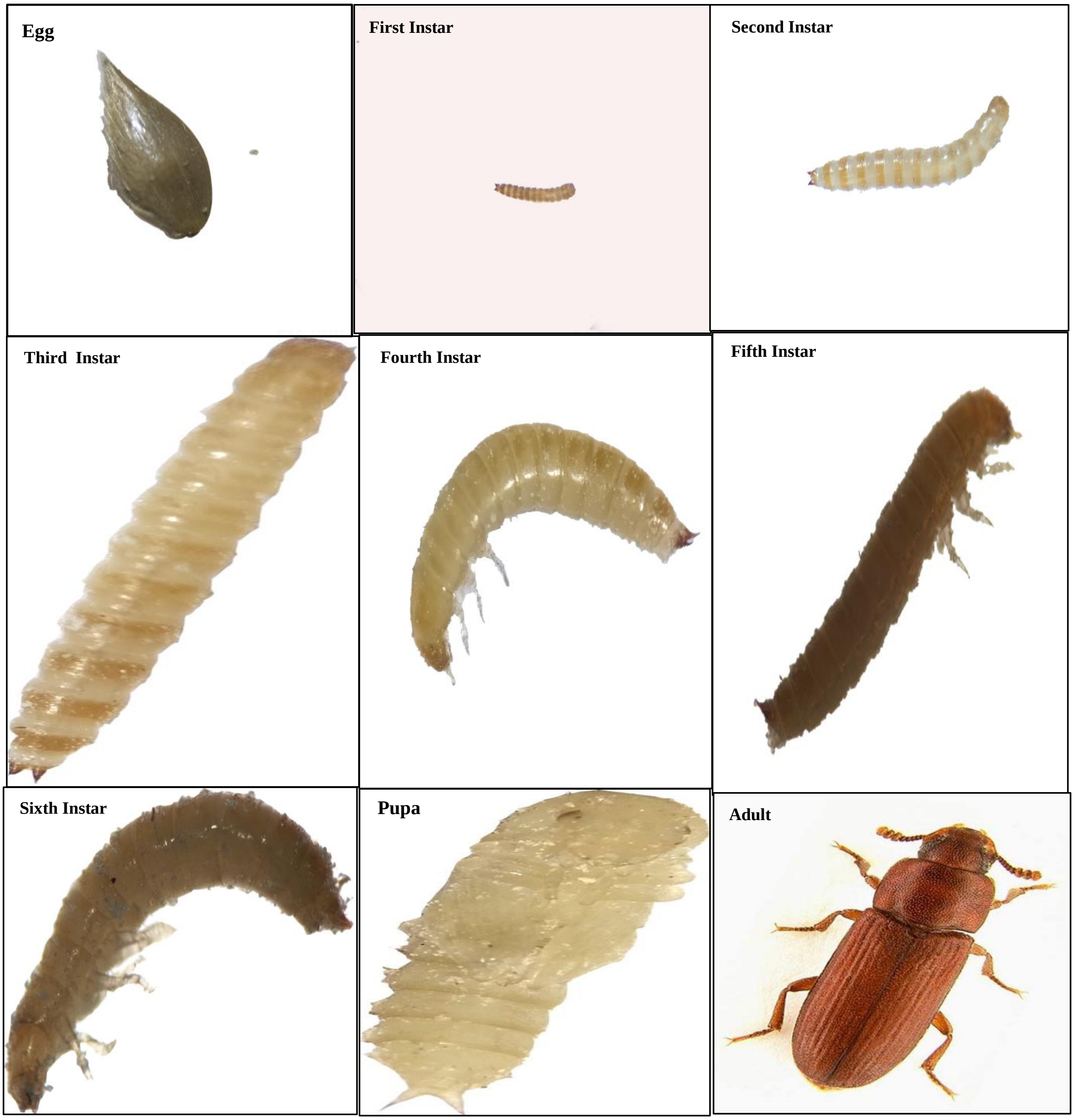

Figure 1. showing the post-embryonic developmental stages of *Tribolium castaneum* (fig. a to i)

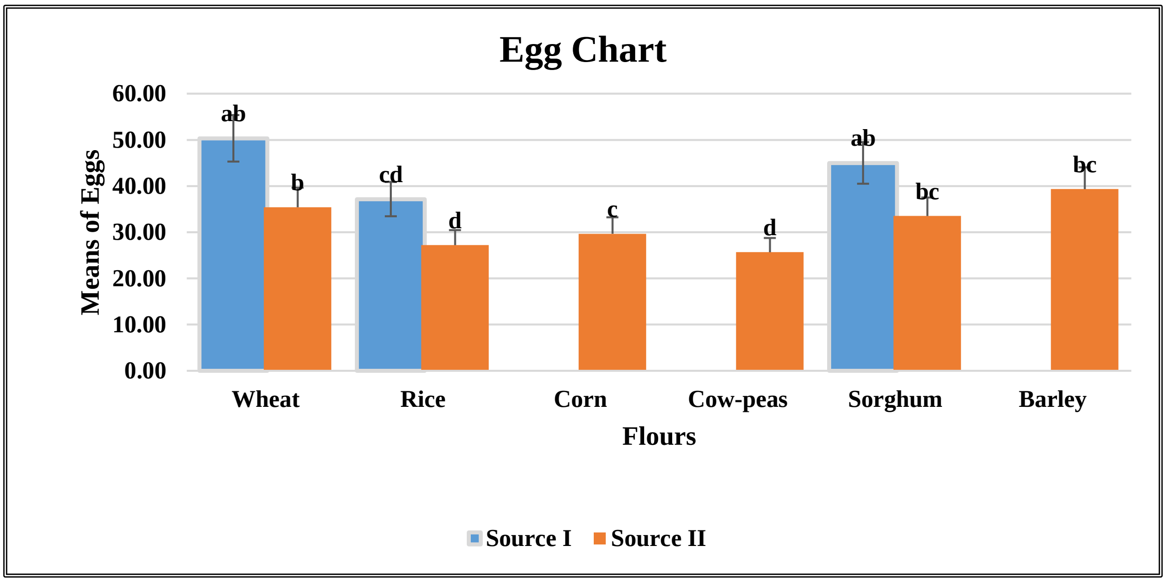

Figure 2.(a) shows the significance difference of egg development from source-I and source-II on various cereal flour. (a, b, c, d—letters indicate significant differences).

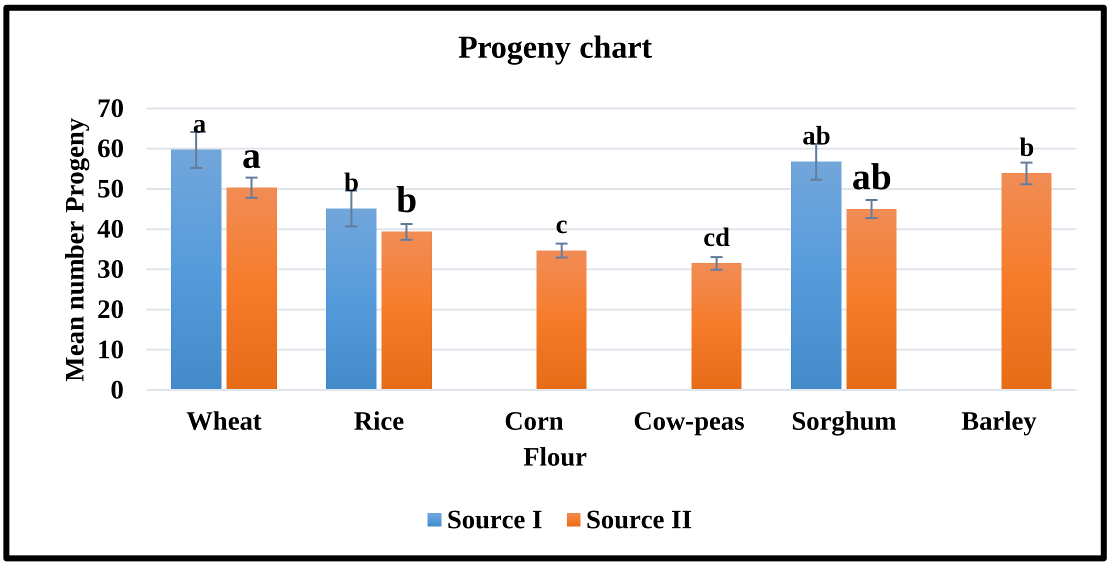

Figure 2.(b) shows the significance difference of progeny development from source-I and source-II on various cereal flour. (a, b, c, d—letters indicate significant differences).

References

Ali, A., & Sarwar, M. (2011). Evaluating resistance of wheat germplasms to attack by red flour beetle, Tribolium castanbeum (Herbst)(Coleoptera). *Pak.J.Zoology*, 793-797.

Astuti, L. P., Rizali, A., Firnanda, R., & Widjayanti, T. (2020). Physical and chemical properties of flour products affect the development of Tribolium castaneum. Journal of Stored Products Research, 86. https://doi.org/10.1016/j.jspr.2019.101555.

Arthur, F. H., Bean, S. R., Smolensky, D., Gerken, A. R., Siliveru, K., Scully, E. D., & Baker, N. (2020). Development of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) on sorghum milling fractions. *Journal of Stored Products Research*, *87*. https://doi.org/10.1016/j.jspr.2020.101606

Bakhtawar, M. (2013). Role of storage facilities for insect pest control strategies in Punjab, Pakistan. *Journal of Stored Products and Postharvest Research*, *4*(4), 55–60. https://doi.org/10.5897/jsppr2013.0153.

Brown, S. J., Shippy, T. D., Miller, S., Bolognesi, R., Beeman, R. W., Lorenzen, M. D., Bucher, G., Wimmer, E. A., & Klingler, M. (2009). The red flour beetle, *Tribolium castaneum* (Coleoptera): A model for studies of development and pest biology. *Cold Spring Harbor Protocols*, *4*(8). https://doi.org/10.1101/pdb.emo126

Buckman, K. A., Campbell, J. F., & Subramanyam, B. (2013) Tribolium castaneum (Coleoptera: Tenebrionidae) associated with rice mills: Fumigation efficacy and population rebound. Journal of Economic Entomology, 106(1), 499–512.https://doi.org/10.1603/EC12276.

Bogue, J., & Sorenson, D. (2008). The marketing of gluten-free cereal products. In *Gluten-free cereal products and beverages* (pp. 393-411). Academic Press.

Campbell, J. F., & Hagstrum, D. W. (2002). Patch exploitation by Tribolium castaneum: movement patterns, distribution, and oviposition. *Journal of Stored Products Research*, *38*(1), 55-68.

Cureton, P., & Fasano, A. (2009). The increasing incidence of celiac disease and the range of gluten-free products in the marketplace. *Gluten-Free Food Science and Technology*, 1-15.

Chaudhary, K. D., & Lemonde, A. (1962). Phosphorus in the nutrition of Tribolium confusum Duval. *Canadian Journal of Zoology*, *40*(3), 375-380.

Dars, F. & Rustamani, Maqsood & Khuhro, R.D. & Baloch, H.B.. (2001). Effect of wheat grain moisture on infestation of red flour beetle, *Tribolium castaneum* (Herbst.). *Pakistan Journal of Zoology*. 33. 189-192.

Devi, M. B., & Devi, N. V. (2015). Biology of rust-red flour beetle, Tribolium castaneum (Herbst)(Coleoptera: Tenebrionidae). In *Biological Forum* (Vol. 7, No. 1, pp. 12-15). Satya Prakashan.

Fabres, A., de Campos Macedo da Silva, J., Fernandes, K. V., Xavier-Filho, J., Rezende, G. L., & Oliveira, A. E. A. (2014). Comparative performance of the red flour beetle Tribolium castaneum (Coleoptera: Tenebrionidae) on different plant diets. *Journal of pest science*, *87*, 495-506.

Fardisi, M.; Mason, L.J.; Ileleji, K.E. (2017). The susceptibility of animal feed containing Dried Distiller's Grains with Solubles to *Tribolium castaneum* (Herbst) infestation. *J. Stored Prod*. Res., 72, 59–63.

Fedina, T. Y., & Lewis, S. M. (2007). Effect of Tribolium castaneum (Coleoptera: Tenebrionidae) Nutritional Environment, Sex, and Mating Status on Response to

Commercial Pheromone Traps. In *J*.Econ. Entomol (Vol. 100, Issue 6).https://academic.oup.com/jee/article/100/6/1924/2198801

Fields, P.G. (2006) Effect of *Pisum sativum* fractions on the mortality and progeny production of nine stored-grain beetles. *J. Stored Prod*. Res., 42, 86–96.

Fraenkel, G.; Blewett, M. (1947) the importance of folic acid and unidentified members of the complex in the nutrition of certain insects. *Biochem. J.*, 41, 469–475.

Gerken, A. R., & Campbell, J. F. (2020). Oviposition and development of Tribolium castaneum herbst (coleoptera: Tenebrionidae) on different types of flour. Agronomy, 10 (10 October). https://doi.org/10.3390/agronomy10101593

Gerken, A.R., Scully, E.D., Campbell, J.F. (2018). Red flour beetle (Coleoptera: Tenebrionidae) response to volatile cues varies with strain and behavioral assay. J.Environ. Entomol. 47, 1252–1265.

Hassan, M. W., Iqbal, J., & Jamil, M. (2018). Comparative study of *Tribolium castaneum* H. (coleoptera: Tenebrionidae) occurred on different wheat varieties in Pakistan. *Pakistan Journal of Scientific and Industrial Research Series B: Biological Sciences*, *61*(1), 47–51. https://doi.org/10.52763/pjsir.biol.sci.61.1.2018.47.51

Heller, L. (2009) Commercial Aspects of Gluten-Free Products. In Gluten Free Food Science and Technology; Gallagher, E., Ed.; Wiley-Blackwell: Chichester, UK,; pp. 99–106.

Kayode, O., Adedire, C. O., & Akinkurolere, R. (2014). INFLUENCE OF FOUR CEREAL FLOURS ON THE GROWTH OF TRIBOLIUM CASTANEUM HERBST (COLEOPTERA: TENEBRIONIDAE). *ResearchGate*. https://www.researchgate.net/publication/341756708.

Mahroof, R., Subramanyam, B., & Eustace, D. (2003). Temperature and relative humidity profiles during heat treatment of mills and its efficacy against *Tribolium castaneum* (Herbst) life stages $ 0 0 2 2-4 7 4 X (0 2) 0 0 0 6 2-0. In *Journal of Stored Products Research* (Vol. 39).

McKay, T.; Bowombe-Toko, M.P.; Starkus, L.A.; Arthur, F.H.; Campbell, J.F. (2019), Monitoring of *Tribolium castaneum* (Coleoptera: Tenebrionidae) in rice mills using pheromone-baited traps. *J. Econ. Entomol.* 112, 1454–1462. [CrossRef] [PubMed]

Maqsood, Khattak SU, Khalil SK, Hussain, Hamed M. (1988) Combined infestation and losses caused by three storage insects in Pak-81 wheat variety. 25:2326.

Mehmood, K., Husain, M., Aslam, M., Ahmedani, M. S., Aulakh, A. M., & Shaheen, F. A. (2018). Changes in the nutritional composition of maize flour due to Tribolium castaneum infestation and application of carbon dioxide to manage this pest. Environmental Science and Pollution Research, 25(19), 18540–18547. https://doi.org/10.1007/s11356-018-2063-6.

Nadeem, S., Hamed, M., & Shafique, M. (2011). Feeding preference and developmental period of some storage insect species in rice products. *Pakistan Journal of Zoology*, *43*(1).

Naseri, B.; Borzoui, E.; Majd, S.; Mozaffar Mansouri, S. (2017) Influence of different food commodities on life history, feeding efficiency, and digestive enzymatic activity of *Tribolium castaneum* (Coleoptera: Tenebrionidae). *J. Econ. Entomol*. 110, 2263–2268.

Navarro, S. (2008). Development of Hermetic Storage Technology in Sealed Flexible Storage Structures. https://www.researchgate.net/publication/228500389\.

Pakhtunkhwa, K., & Zafarullah Khan, M. (2016). Analysis of wheat grain quality and losses in house storages of farming community in district swabi Impact of Farm Services

Centre Approach on Empowerment of Farming community in KP-Pakistan View project. https://www.researchgate.net/publication/307605607.

Rustamani, M. A., Khatri, I., Sultana, R., & Laghari, M. H. (2014). Population Fluctuation of Red Flour Beetle, *Tribolium castaneum* (Herbst.) (Coleoptera: Tenebrionidae) on Different Cereal Foods in Laboratory. In *Pakistan J. Zool* (Vol. 46, Issue 6).

Shafique, M., Ahmad, M., & Chaudry, M. A. (2006). Feeding preference and development of Tribolium castaneum (Herbst.) in wheat products. *Pakistan Journal of Zoology*, *38*(1), 27.

Sokoloff, A.; Franklin, I.R.; Overton, L.F.; Ho, F.K. (1966), Comparative studies with *Tribolium castaneum* (Coleoptera, Tenebrionidae) Productivity of *T. castaneum* (Herbst) and *T. confusum* Duv. on several commercially-available diets. *J. Stored Prod*. Res. 1, 295–311.

Wagan, S., Shah, M. A., Muzafar, A., Shaikh, A. M., Mansoor, C., & Shah, A. (2019). Evaluate the susceptibility of some store rice varieties to the infestation of red flour beetle *Tribolium castaneum. ~ 1635 ~ Journal of Entomology and Zoology Studies*, *7*(3), 1635–1638.

Weston, P. A., & Rattlingourd, P. L. (2000). STORED-PRODUCT AND QUARANTINE ENTOMOLOGY Progeny Production by *Tribolium castaneum* (Coleoptera: Tenebrionidae) and Oryzaephilus surinamensis (Coleoptera: Silvanidae) on Maize Previously Infested by Sitotroga cerealella (Lepidoptera: Gelechiidae). In *J. Econ. Entomol* (Vol. 93, Issue 2). https://academic.oup.com/jee/article/93/2/533/768247

White, N. D. C., & Loschiavo, S. R. (1988). Ovposition and larval development of the rbd flour beetle and the rusty grain beetle on ground and ball-milled kernels of various cereal cultivars. In *Can. J. Plant Sci.* (Vol. 682).

Wong, N.; Lee, C.Y. (2001) Relationship between population growth of the red flour beetle *Tribolium castaneum* and protein and carbohydrate content in flour and starch. *J. Econ. Entomol*.104, 2087–2094.