DOI: https://doi.org/10.21323/2618-9771-2025-8-2-173-179

Received 18.12.2024
Accepted in revised 21.04.2025
Accepted for publication 25.04.2025

Available online at https://www.fsjour.com/jour
Original scientific article
Open access

IMPACT OF RED FLOUR BEETLE *TRIBOLIUM CASTANEUM* (HERBST) (COLEOPTERA: TENEBRIONIDAE) INFESTATION ON SOME QUALITY CHARACTERISTICS OF STORED WHEAT FLOUR

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KEY WORDS:
flour beetles, infestation, loss, storage periods, flour

ABSTRACT

This study examines the impact of *Tribolium castaneum* infestation on the quality of stored wheat flour by assessing insect population growth, weight loss, moisture content, colour parameters, and chemical composition along various infestation levels (0, 10, 20, and 40 pairs/kg) and storage durations (4, 6, and 8 months). Results indicate that *T. castaneum* populations and weight loss in flour increased significantly with higher infestation levels and prolonged storage. After 8 months, the highest infestation (40 pairs/kg) resulted in a maximum insect population of 638.5 insects/kg and 42.54% weight loss, underlining the importance of effective pest management. Moisture content also rose up along with infestation level and storage duration, reaching 14.56% at 40 pairs/kg after 8 months. Colour analysis showed a decline in lightness (L*) and an increase in a* and b* values, indicating quality deterioration. Chemical composition analysis revealed protein, lipid, and ash levels increased with infestation, while carbohydrate and fiber content decreased. Statistical analysis demonstrated significant differences in all parameters across infestation levels and storage periods, with notable changes occurring as storage progressed. The findings highlight the progressive quality degradation in flour due to *T. castaneum* infestation, thus emphasizing the need for improved storage practices and monitoring in order to mitigate weight loss, moisture increase, and nutritional deterioration in stored wheat flour products. These insights contribute to understanding pest-induced losses and suggest preventive strategies to preserve flour quality in storage environments.

Поступила 18.12.2024
Поступила после рецензирования 21.04.2025
Принята в печать 25.04.2025

https://www.fsjour.com/jour
Научная статья
Open access

ВЛИЯНИЕ ЗАРАЖЕНИЯ КРАСНЫМ МУКОМОЛЬНЫМ ЖУКОМ *TRIBOLIUM CASTANEUM* (HERBST) (COLEOPTERA: TENEBRIONIDAE) НА НЕКОТОРЫЕ КАЧЕСТВЕННЫЕ ХАРАКТЕРИСТИКИ ПШЕНИЧНОЙ МУКИ, НАХОДЯЩЕЙСЯ НА ХРАНЕНИИ

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КЛЮЧЕВЫЕ СЛОВА:
мучные жуки, заражение, потери, периоды хранения, мука

АННОТАЦИЯ

В этом исследовании изучается влияние заражения красным мукомольным жуком *Tribolium castaneum* на качество хранящейся пшеничной муки путем оценки роста популяции насекомых, потери веса муки, содержания влаги, параметров цвета и химического состава муки при различных уровнях заражения (0, 10, 20 и 40 пар/кг) и продолжительности ее хранения (4, 6 и 8 месяцев). Результаты показывают, что популяции жука *T. castaneum* и потеря веса муки значительно росли при более высоких уровнях заражения и длительном хранении. Через 8 месяцев самая высокая степень заражения (40 пар/кг) была представлена максимальным ростом популяции насекомых численностью 638,5 насекомых/кг, и потерей веса муки в объеме 42,54%, что подчеркивает важность эффективной борьбы с вредителями. Содержание влаги также росло наряду с уровнем заражения и продолжительностью хранения, достигнув 14,56% при 40 парах/кг через 8 месяцев. Цветовой анализ показал снижение светлоты (L*) и увеличение значений a* и b*, что свидетельствует об ухудшении качества. Анализ химического состава показал, что уровни содержания белка, липидов и золы увеличились при заражении, в то время как содержание углеводов и клетчатки снизилось. Статистический анализ продемонстрировал значительные различия во всех параметрах муки в зависимости от уровней заражения и периодов хранения, при этом по мере хранения происходили весьма заметные изменения. Результаты доказывают прогрессирующее ухудшение качества муки, вызванное заражением жуком *T. castaneum*, тем самым подчеркивая необходимость улучшения методов хранения и контроля состояния продукта для снижения потерь веса, предотвращения увеличения влажности и ухудшения питательных свойств хранящихся продуктов из пшеничной муки. Эти данные способствуют пониманию объема потерь, вызванных вредителями, и предлагают превентивные стратегии для сохранения качества муки в условиях складского хранения.

1. Introduction

Wheat is a primary food source for humans, serving as the essential raw material for flour production. Egypt is the largest importer of wheat globally, with imports reaching approximately 12.85 million tons in 2021 year [1]. In developing countries, improper storage of cereal grains, particularly wheat, facilitates infestations by insects. These insects are categorized into primary and secondary types. Primary insects can infest intact wheat grains, while secondary insects target grains that have already been damaged by primary insects, as well as wheat flour and its processed products. Poor threshing, insufficient

FOR CITATION: **Badran E. F., Abedelmaksoud T. G., Elshazly, E. A., Ahmed S. S.** (2025). Impact of red flour beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) infestation on some quality characteristics of stored wheat flour. *Food Systems,* 8(2), 173–179. https://doi.org/10.21323/2618-9771-2025-8-2-173-179

ДЛЯ ЦИТИРОВАНИЯ: **Бадран Е. Ф., Абедельмаксуд Т. Г., Эльшазли, Е. А., Ахмед С. С.** (2025). Влияние заражения красным мукомольным жуком *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) на некоторые качественные характеристики пшеничной муки, находящейся на хранении. *Пищевые системы*, 8(2), 173–179. https://doi.org/10.21323/2618-9771-2025-8-2-173-179

drying, and improper handling can also contribute to infestations [2,3].

Insect infestations are a major threat, leading to both qualitative and quantitative losses in cereals products. These losses arise from both the contamination caused by insects and the actual material they consume [4,5]. On average, insect infestations lead to a 5–35% weight loss in various stored grain products [6,7]. In some countries, weight losses in cereal grains due to insect pests can reach up to 50% of the total harvest [8]. These infestations also lead to reductions in the nutritional value and changes in the flavor of wheat flour. In particular, infestations can affect the proteins, carbohydrates, and lipids, thereby altering the characteristics of the raw materials [9]. Furthermore, metabolic changes, such as increased levels of purines, quinones, and uric acid excreted by insects into wheat flour, can negatively impact the organoleptic properties and the suitability of the products for processing and consumption [10–12]. Infestations can also promote fungal growth, including fungi that produce mycotoxins, leading to contamination of commodities with insect bodies and other residues, some of which may be toxic, repulsive, or allergenic [13]. Consequently, infested grains or flour are unsuitable for human consumption [2,14].

Wheat flour is susceptible to attack by various insects, including flour beetles such as the flour mill beetle (*Cryptolestes turcicus*), yellow mealworm (*Tenebrio molitor*), large flour beetle (*Tribolium destructor*), confused flour beetle (*Tribolium confusum*), and red flour beetle (*Tribolium castaneum*). These insects infest wheat flour, cereal products, and foods stored in the mills or warehouses [2,15,16]. Among them, *Tribolium castaneum* (Herbst) is a common secondary pest of wheat, that often infests flour and other processed food products [17]. This beetle has been reported to cause significant damage to foodstuffs such as biscuits, nuts, beans, pasta, cornflakes, and dried fruits [18]. The infestation by adults of *T. castaneum* contaminates the flour, adversely affecting its characteristics, including its viscous and elastic properties, and producing an unpleasant taste and colour. These adult beetles can secrete benzoquinones (BQs) from specialized glands, where the main components is methyl-1,4-benzoquinone (MBQ) and ethyl-1,4-benzoquinone (EBQ) [16].

The storage period is a critical factor influencing the quality of stored products. Extended storage, up to six months, affects parameters such as 1000-grain weight, falling number, and moisture content. Additionally, infestation levels tend to increase along with longer storage periods [19]. Physicochemical characteristics may also change during storage, affecting the usability of wheat flour for the various applications [20].

This research aims to investigate the *T. castaneum* populations and infestation levels and their effects on the quality and quantity of wheat flour by measuring weight loss, moisture content, color changes, and alterations in chemical composition under various storage periods. The findings will contribute to the prevention of commercial fraud in wheat flour.

2. Materials and methods

2.1. Insect cultures

The stock of *T. castaneum* was obtained from infested flour and maintained in the laboratory of stored grain insects at the Department of Entomology, Faculty of Agriculture, Cairo University. Mixed-age cultures of adults were reared on a wheat flour-based diet, which was prepared according to the method described by Carvalho et al. [9]. This diet consisted of 1000 g wheat flour, 100 g dried yeast, and 100 g milk powder. About 50 pairs of adults were placed in glass jars with a 1 kg capacity, each jar containing 500 g of the ration. The jars were covered with muslin cloth secured with rubber bands to prevent escape and incubated under optimal conditions (30 ± 2 °C and 65 ± 5% relative humidity) for 10 days to allow for egg laying. Eggs were collected daily by sieving through a 40 µm-mesh sieve. Approximately 500 eggs and 500 g of flour diet were then placed in glass jars and incubated under the same conditions until adult emergence. Adults (0–7 days old) were used for the trials in the experiments after three generations of rearing.

2.2. Experimental design

Wheat flour, obtained from a local market in the Giza governorate with an extraction rate of 72%, was sieved through a 40 µm-mesh sieve to eliminate impurities. The chemical researched components of sample flour were moisture (8.4%), ash (0.48%), protein (10.84%), lipid (0.92%), fiber (0.87%) and carbohydrates (68.9%). The flour was then stored at 4 °C for approximately one week prior to use to prevent insect infestation [21].

To study the effect of flour beetle infestation on the properties of flour, three infestation levels with newly emerged adults of *T. castaneum* were created, and their effect was studied at 4, 6, and 8 months of storage periods. About 48 kg of sterilized wheat flour were divided into one kilogram each and put into a glass jar (15 cm diameter and 25 cm length). These jars were divided into three groups of 16 jars each (one group of jars/storage period). They were artificially infested by 0, 10,20, and 40 pairs of newly emergence adults of *T. castaneum*, which were added into four treatments (4 replicates for each treatment). The jars were sealed with muslin cloth and secured with rubber bands to prevent escape of insects. They were stored in the laboratory under controlled conditions (30 ± 2 °C and 65 ± 5% relative humidity) for 4, 6, and 8 months, from March, 2022 to the end of October, 2022.

2.3. Weight loss

At the end of each storage period, i. e. in 4, 6 and 8 months, the jars containing the flour were sieved thoroughly wire 40 µm-mesh to separate and count the insect populations' progeny. Moisture content of each sample was measured by moisture meter tester Wile 55 (Farmcomp Oy, Finland) then the dry weight of infested and healthy ones and weight losses were calculated according to the following equations [22]:

$$\text{The Dry weight (\%)} = \frac{\text{The sample weight}(100 - \text{moisture content})}{100}, \quad (1)$$

$$\text{Weight loss \%} = \frac{\text{Dry weight of non infested flour} - \text{Dry weight of infested flour}}{\text{Dry weight of non infested flour}}. \quad (2)$$

2.4. Colour change

The colour of flour infested with *T. castaneum* at various infestation levels was assessed by measuring the CIE colour parameters (L*, a*, b*) over storage periods of 4, 6, and 8 months. These measurements were taken using a Minolta CR400 colorimeter (Konica Minolta, Japan). Flour samples (50 g/ replicate) were placed in a sample-holding cup, covered with a lid, and analyzed for color changes [23,24]. The L value represents lightness, ranging from 0 (black) to +100 (white); the value indicates redness or greenness, with a range from –100 (greenness) to +100 (redness); and the b value denotes yellowness or blueness, spanning from –100 (blueness) to +100 (yellowness) [25–27].

2.5. Chemical composition

To assess the impact of *T. castaneum* infestation over various storage periods, approximately 100 g of sieved wheat flour from each replicate were collected at the end of each storage interval. Prior to analysis the dry matter content was determined using the weight-dryer method. Subsequent analyses were performed on the air-dry mass, including measurements of moisture, crude protein, crude fat, crude ash, and crude fiber, following the methods outlined by AOAC [28]. Dry matter was determined by drying samples at 105 °C until a constant weight was achieved (method 945.15). Crude fat (ether extract, EE) was quantified using the Soxhlet extraction method with diethyl ether as the solvent (method 2003.06). Crude ash (CA) was measured by sample incineration in a muffle furnace at 550 °C for 8 hours (method 920.153). Crude protein (CP) was calculated as N × 6.25 using the Kjeldahl method, with distillation performed on a Büchi B-324 distillation unit (BüchiLabortechnik AG, Switzerland) (method 945.18). Crude fiber (CF) was determined as the residue after sequential treatment with 1.25% H_2SO_4 and 1.25% NaOH, utilizing an ANKOM220 FiberAnalyzer (ANKOM Technology, New York, NY, USA). Total carbohydrates were then calculated based on these measurements.

$$\text{Nitrogen free extract (NFE) (\%)} = 100 - \% \text{ (moisture +} \\ + \text{crude protein + crude fat + crude ash + crude fiber).} \quad (3)$$

2.6. Statistical analysis

Completely Randomized Design (CRD) was applied in this experiment. All data obtained for experiments were calculated and expressed as mean ± standard error and statistically analyzed by factorial analysis of variance (ANOVA) using (SPSS) software (Version 16, SPSS Inc., Chicago, IL, USA) as described by Snedecor and Cochran [29]. Differences among mean values were separated according to Tukey's Honestly Significant Difference (HSD) test using one-way analysis to detect the significance among the different infestation levels and storage periods at $P < 0.05$ level.

3. Results

3.1. Insect population and product weight loss

The data in the Tables 1 and 2 demonstrate the progressive increase in *T. castaneum* population and associated weight loss in wheat flour across different infestation levels (0, 10, 20, and 40 pairs/kg) and storage periods

(4, 6, and 8 months). The results indicate that insect population and weight loss in flour both increased significantly with higher infestation levels and extended storage periods. Specifically, after 4 months, the insect populations quantity were recorded as 292.25±6.2, 310.50±7.33, and 318.15±9.04 insects/kg at infestation levels of 10, 20, and 40 pairs/kg, respectively, with a marked increase to 638.50±24.32 insects/kg after 8 months at the highest infestation level (40 pairs/kg). Weight loss followed a similar trend; for instance, after 4 months, weight losses were 0.49%, 14.42%, 15.70%, and 18.19% at infestation levels of 0, 10, 20, and 40 pairs/kg, respectively. This increased to 1.75%, 34.60%, 34.85%, and 42.54% after 8 months at the same infestation levels, thus highlighting a substantial deterioration in flour quality over time along with higher infestation rates.

Table 1. **Mean number of *T. castaneum* adults at different storage periods (month) and infestation levels (pairs/kg)**

Таблица 1. **Среднее количество взрослых особей *T. castaneum* при различных сроках хранения (по месяцам) и различных уровнях заражения (пар/кг)**

Storage periods (month)	Infestation levels (pairs/kg)			
	0	10	20	40
4	0.00±0.00^{aD}	292.25±06.2^{cC}	310.50±07.33^{cB}	318.15±09.04^{cA}
6	0.00±0.00^{aC}	353.25±21.49^{bB}	383.00±11.60^{bAB}	397.50±21.9^{bA}
8	0.00±0.00^{aD}	461.75±29.7^{aC}	501.75±22.40^{aB}	638.50±24.32^{aA}

Means followed by the different letters are significantly different from each other at *P<0.05* (Tukey HSD test); Capital letters represent differences between infestation levels and small letters represent differences between storage periods.

Table 2. **Weight loss (%) of flour at different infestation levels (pairs/kg) of *T. castaneum* and storage periods (month)**

Таблица 2. **Потеря веса (%) муки при различных уровнях заражения (пар/кг) *T. castaneum* и различных сроках хранения (по месяцам)**

Storage periods (month)	Infestation levels (pairs/kg)			
	0	10	20	40
4	0.49±0.34^{bC}	14.42±0.41^{cB}	15.70±0.68^{cB}	18.19±0.64^{cA}
6	1.25±0.31^{abC}	20.76±0.51^{bB}	26.10±2.50^{bAB}	33.02±2.63^{bA}
8	1.75±0.12^{aC}	34.60±2.39^{aB}	34.85±1.62^{aB}	42.54±1.56^{aA}

Means followed by the different letters are significantly different from each other at *P*<0.05 (Tukey HSD test); Capital letters represent differences between infestation levels and small letters represent differences between storage periods.

Statistical analysis reveals significant differences in insect population between the control sample (0 pairs/kg) and all infestation levels across storage periods. Additionally, significant differences in insect populations were evident between storage periods across all infestation levels. Weight loss differences were notably significant (P<0.0001) between storage periods across all infestation levels and between infestation levels within each storage period, except between the 10 and 20 pairs/kg levels, which showed no statistically significant differences. These findings underscore the critical impact of infestation level and storage duration on both insect population growth and flour weight loss, suggesting the necessity for effective pest management in stored grain to preserve product quality.

3.2. Moisture content

Table 3 illustrates the effect of different infestation levels of *T. castaneum* and storage periods on the moisture content (%) of flour. A significant increase in moisture content was observed as both the storage time and infestation levels increased. The 4th month, the moisture content ranged from 12.59% at 0 pairs/kg to 13.43% at 40 pairs/kg, indicating that even at the initial stage of storage, insect infestation contributes to increased moisture levels, likely due to the metabolic activity of insects and associated microbial growth. By the 6th month, moisture content values significantly increased across all infestation levels, with values ranging from 13.03% to 14.11%. The highest moisture contents were recorded after 8 months of storage, with a maximum reaching of 14.56% at the 40 pairs/kg infestation level. Statistically, small letters indicate the significant differences between storage durations, while capital letters denote differences between infestation levels. The results suggest that prolonged storage and higher infestation intensities synergistically elevate flour moisture content, which could accelerate quality deterioration and increase the risk of microbial contamination. This highlights the importance of pest control and moisture monitoring during flour storage to preserve its quality and safety.

Table 3. **Effect of infestation levels of *T. castaneum* and storage periods on flour moisture content (%)**

Таблица 3. **Влияние уровня заражения жуком *T. castaneum* и сроков хранения на влажность муки (%)**

Storage periods (month)	Infestation levels (pairs/kg)			
	0	10	20	40
4	12.59±0.20^{bB}	12.85±0.25^{cB}	13.10±0.30^{bA}	13.43±0.25^{bA}
6	13.03±0.15^{aB}	13.51±0.10^{bB}	14.02±0.20^{aA}	14.11±0.15^{aA}
8	13.20±0.10^{aC}	14.04±0.10^{aB}	14.45±0.25^{aA}	14.56±0.20^{aA}

Means followed by the different letters are significantly different from each other at *P*<0.05 (Tukey HSD test); Capital letters represent differences between infestation levels and small letters represent differences between storage periods.

3.3. Colour

The data presented in the Table 4 demonstrates the impact of storage period and infestation levels by *Tribolium castaneum* on the colour parameters (L*, a*, and b*) of flour. The L* value, indicating lightness, significantly decreased along with increased infestation levels and longer storage durations. Flour stored for 4 months under non-infested conditions preserved the highest lightness (94.02±0.47), whereas the lowest L* value (81.59±0.58) was observed after 8 months at the highest infestation level (40 pairs/kg), indicating progressive darkening of the flour due to insect activity and associated degradation. The a* value, which reflects redness, showed a gradual increase with infestation and storage time. For instance, at 0 infestation, a* values remained relatively stable (3.55–3.64), but under 40 pairs/kg infestation, the value increased significantly to 5.01±0.17 after 8 months, indicating increased browning likely due to enzymatic reactions or insect contamination. Similarly, the b* values, representing yellowness, followed an increasing trend with storage time, particularly under high infestation. Notably, the highest b* value (8.82±0.76) was recorded in non-infested flour after 8 months, while the infested samples showed inconsistent but generally lower b* values, indicating that infestation may interfere with natural pigment stability or contribute to pigment loss. Statistical analysis revealed significant differences (P<0.05) among both storage periods (lowercase letters) and infestation levels (uppercase letters), emphasizing the combined effect of time and biotic stress on flour color quality. It is important to consider that the natural color of wheat can vary between the grain varieties, which may complicate the use of color changes as the sole indicator of quality degradation due to insect infestation. Therefore, color monitoring should be combined with other quality parameters — such as odor, moisture content, microbial load, and nutritional composition — for a more accurate and comprehensive assessment of flour quality during its storage.

Table 4. **Effect of storage periods and infestation levels with *T. castaneum* on the colour of flour**

Таблица 4. **Влияние сроков хранения и степени заражения жуком *T. castaneum* на цвет муки**

Storage periods (month)	Infestation levels (pairs/kg)			
	0	10	20	40
	Colour “L*”			
4	94.02±0.47^{aA}	91.52±0.37^{aB}	91.08±0.44^{aB}	90.05±0.54^{aB}
6	93.31±0.96^{aA}	89.52±0.43^{aB}	88.52±0.31^{bB}	88.1±0.20^{bB}
8	91.12±0.77^{aA}	87.48±0.68^{bB}	84.80±0.17^{cC}	81.59±0.58^{cD}
	Colour “a*”			
4	3.55±0.05^{aB}	4.14±0.06^{bA}	4.28±0.01^{bA}	4.18±0.02^{bA}
6	3.62±0.15^{aB}	4.61±0.07^{aA}	4.71±0.08^{abA}	4.54±0.09^{abA}
8	3.64±0.13^{aB}	4.76±0.14^{aA}	4.87±0.23^{aA}	5.01±0.17^{aA}
	Colour “b*”			
4	6.78±0.19^{bA}	5.18±0.14^{bB}	6.23±0.09^{bA}	6.11±0.22^{bA}
6	7.21±0.24^{abA}	6.04±0.17^{bB}	6.16±0.20^{bB}	7.05±0.34^{abBA}
8	8.82±0.76^{aA}	7.05±0.33^{aAB}	7.02±0.16^{aB}	7.10±0.12^{aAB}

Means followed by the different letters are significantly different from each other at *P*<0.05 (Tukey HSD test); Capital letters represent differences between infestation levels and small letters represent differences between storage periods.

3.4. Chemical composition

The chemical composition of wheat flour infested by *T. castaneum* was analyzed at varying infestation levels (0, 10, 20, and 40 pairs/kg) across the various storage durations (4, 6, and 8 months), as summarized in Figure 1. Results show distinct changes in the chemical composition correlated with both infestation levels and storage period. Generally, the levels of protein, lipid, and ash increased with infestation and duration, whereas carbohydrate and fiber content decreased.

Protein content, initially, protein content in control sample (0 pairs/kg) was 10.84%. After 4 months, protein levels increased to 11.65%, 11.93%, and 12.14% at 10, 20, and 40 pairs/kg, respectively. This trend continued, reaching 12.29%, 12.65%, and 12.98% after 6 months, with the highest protein content of 15.66% recorded after 8 months at 40 pairs/kg (Figure 1a). Lipid content, lipid levels in healthy, uninfested flour were 0.92%. Infested samples showed a gradual lipid increase, with levels of 1.01%, 1.19%, and 1.32% at 10, 20, and 40 pairs/kg, respectively, after 4 months. Lipid content further rose up to 1.12%, 1.35%, and 1.52% in the 8-month samples at the same infestation levels (Figure 1b). Fiber content, fiber content in control was 0.87%. Infestation levels of 10, 20, and 40 pairs/kg showed fiber levels of 0.75%, 0.65%, and 0.45%, respectively, after 4 months. Fiber continued to decline over storage time, with values of 0.56%, 0.32%, and 0.27% at these same infestation levels after 8 months (Figure 1c). Ash content, ash percentage also increased with infestation and storage. The control sample's ash level was 0.48%, while at 40 pairs/kg infestation, it rose to 0.55% after 4 months and reached 0.68% by 8 months (Figure 1d). Carbohydrate content, carbohydrate percentages decreased with infestation level and storage duration. Starting at 86.9% in control sample, carbohydrates fell down to 85.48%, 84.71%, and 83.88% after 4 months at 10, 20, and 40 pairs/kg, respectively. This reduction continued over time, with carbohydrate levels as low as 82.81%, 79.54%, and 77.94% after 8 months (Figure 1e). Statistical analysis showed that differences in all chemical compositions were significant across infestation levels and storage durations, though control values remained consistent over time without significant change.

4. Discussion

This study revealed a difference in qualitative and quantitative losses caused by various infestation levels with *Tribolium castaneum* during a long storage period. Generally, the insect population of this species increased with higher artificial infestation levels and extended storage

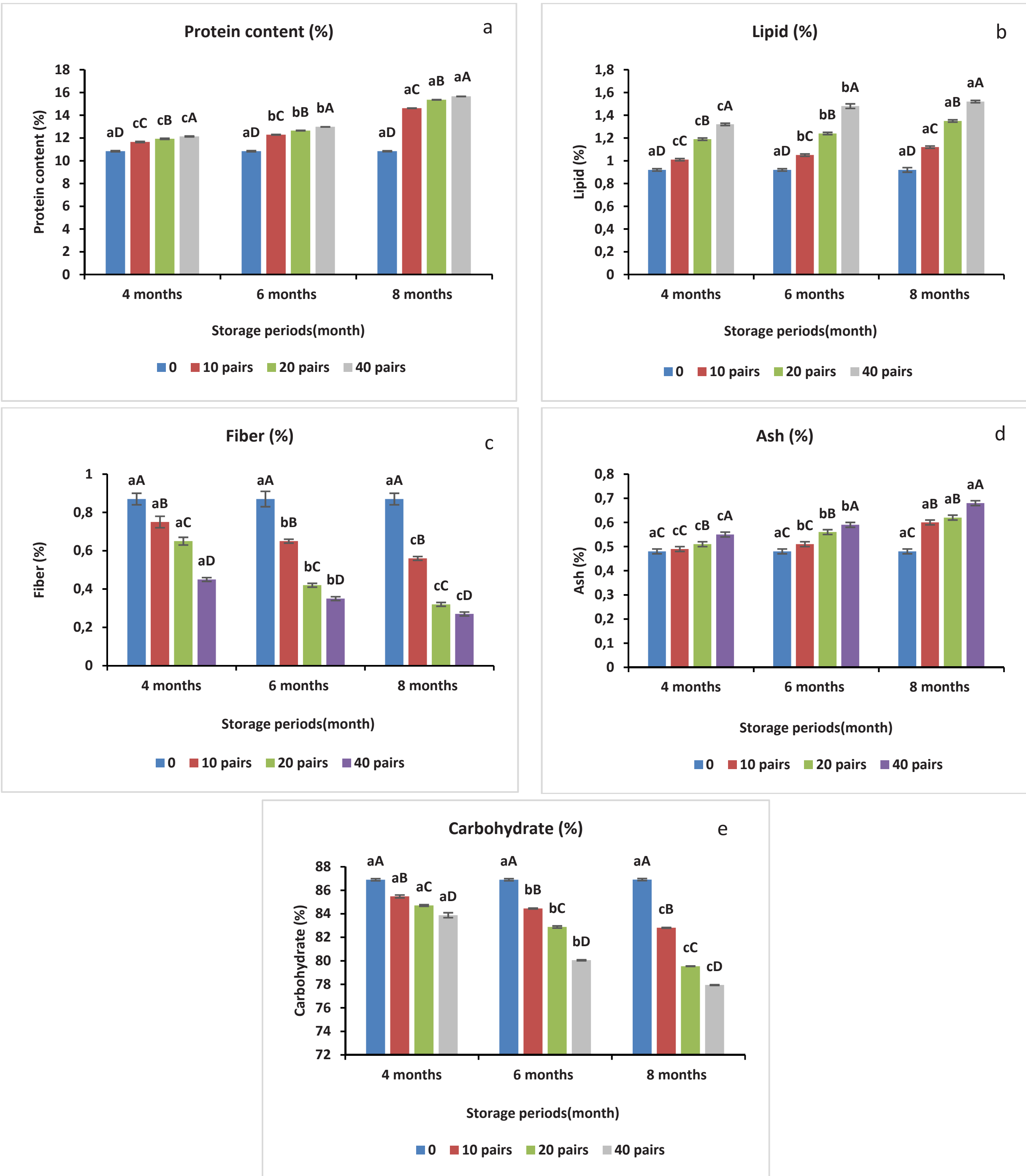

Figure 1. **Effect of flour infestation level (pairs/kg) with *T. castaneum* and storage periods (month) on chemical composition of flour**

Рисунок 1. **Влияние зараженности муки (пар/кг) жуком *T. castaneum* и сроков хранения (месяцы) на химический состав муки**

Capital letters represent differences between infestation levels and small letters represent differences between storage periods.

periods. The number of adult insects reached the highest population (638.50 insects) at the highest level of infestation (40 pairs/kg) at the end of the storage period (8 months). Our results agree with Gabarty and Abou El Nour [11], who found that the population of *Tribolium confusum* recorded 865 adults after two months of storage. In a study conducted by Keskin and Ozkaya [8], it was observed that the number of adult weevils (*Sitophilus granarius*) remained almost unchanged during the first two months, but when the storage period was extended to three months, the number of insects increased significantly.

In the present study, the weight losses caused by *T. castaneum* infestation were defined, revealing a positive correlation between the insect population and the product weight losses. At six months of storage, the weight losses were 20.76% at the low level of infestation (10 pairs/ kg) and reached 33.02% at level 40 pairs/kg. Also, our results indicate that the weight losses increased along with increasing storage periods. The weight loss caused by *T. castaneum* was 14.4% after 4 months of storage, then it reached 34.6% after 8 months at the same infestation level. These results agree with those of Musa and Lawal [30] who found the infestation with *T. castaneum* caused a 52.67% weight loss after four months. The increases in weight losses may be due to the difference in storage conditions or infestation levels. Also, Gabarty and Abou El Nour [11] stated that *T. confusum* caused an 11% weight loss after 2 months of storage. Additionally, Keskin and Ozkaya [8] found that *S. granarius* caused 39.25% weight loss after six months of storage. Hussain et al. [22] found that *Oryzaephilus surinamensis* caused weight losses of 18.11%. Also, Tadele et al. [31] found that maize weevil caused a loss of 5.47% in wheat flour, respectively. Odeyemi et al. [32] reported that the percentage of weight loss due to *T. castaneum* infestation in products manufactured from wheat flour ranged between 0.01–2.24%.

Moisture content is a critical parameter affecting the quality of stored products. In our study, we found that the moisture content of wheat flour increased with higher levels of infestation by *T. castaneum*, reaching 13.43% at 40 pairs/kg flour. The increase in moisture of wheat flour may be due to fragments and insect activity that facilitate the growth of microorganisms. This result aligns with the findings of Negi et al. [26], who reported that the moisture content of wheat flour increased up to 11.7% after infestation by *T. castaneum*. Additionally, Babarinde et al. [33] mentioned that the same insect increased moisture content in plantain chips. We found that moisture content increased with longer storage periods, from 13.43% after 4 months to 14.56% after 8 months. Our results agree with Mwazha [19] and Yigezu et al. [1], who mentioned that moisture content increased in correlation with longer storage periods in barley and wheat.

Colour is a crucial quality parameter of wheat flour, directly influencing consumers' preference and acceptability. Flour colour significantly impacts the colour of the end products [24,34]. The parameters L*, a*, and b* are used to assess product quality. Our results indicate that lightness (L*) decreased with increasing storage time in both healthy and *T. castaneum* infested flour. This means that the flour colour became pale. While a* and b* values increased along with longer storage periods. Increasing a* means that the flour became reddish in colour, and this may be due to increased benzoquinones secreted by *T. castaneum* adults. These findings are consistent with those of Anandakumar et al. [35], who observed a decrease in L* values in turmeric over certain time. Similarly, Fernandes et al. [36] reported significant increases in a* and b* values in chestnut samples during storage. Hashem et al. [37] recorded that the lightness value of chamomile flowers decreased to 54.9 degrees after 6 months of storage. Our study also confirmed that lightness decreased with higher levels of infestation with *T. castaneum*. The lightness value was 94.02 degrees in healthy flour, decreasing to 90.05 degrees at 40 pairs/kg. These results agree with Negi et al. [26], who recorded that infestation with *T. castaneum* decreased the lightness (L*) of flour. Furthermore, Duarte et al. [16] reported that infestation with *T. confusum* affected the colour of flour. The presence of insects, their fragments, excretions, and cast skins can alter the colour of wheat flour from white to pale white, resulting in slightly darker shade of the infested flour compared to uninfested flour [26]. The colour change also reduces the quality of the flour as well as the products made from it, which leads to its unsuitability to the consumer [9].

The chemical compositions in wheat flour are critical parameters for evaluating quality [38,39]. In this study, results confirmed that infestation by *T. castaneum* altered the chemical composition of wheat flour, with changes observed according to infestation level and storage period. Specifically, protein, lipid, and ash contents increased with higher infestation levels, while carbohydrate and fiber levels decreased. These findings align with the prior research by Taddese et al. [40], who noted increased protein and ash levels in wheat grains infested by *S. granarius* during 6-month storage. Similarly, Ahmedani et al. [41] found that *Trogoderma granarium* larvae infestation raised protein, lipid, and ash content in wheat grains after six months, while Babarinde et al. [33] observed the increased protein and fat in plantain chips infested by *T. castaneum*. Gabarty and Abou El Nour [11] also recorded increased protein in wheat infested by *C. cephalonia*, *E. kuehniella*, and *T. confusum*. These increases in protein, lipid, and ash content in infested grains may be attributed to presence of insect body parts, metabolic waste, and insect feeding habits [8]. Duarte et al. [10] recorded that the percentage of fat in *T. castaneum* adult reaches 7.24%, while the percentage of protein reaches 16.97%. The reduction in endosperm due to larval and adult feeding on grains can further explain the rise in protein content [42,43]

In this study, protein content increased progressively with storage, reaching 14.62%, 15.36%, and 15.66% at infestation levels of 10, 20, and 40 pairs/kg, respectively, after 8 months. Lipid content, which was initially 0.92% in the control, increased with infestation and storage period, reaching 1.12%, 1.35%, and 1.52% after 8 months of storage for infestation levels of 10, 20, and 40 pairs/kg, respectively. Mwazha [19] observed similar patterns in barley grains, and Naguib et al. [44] and Jood et al. [45] reported the comparable findings in wheat grains. Variations in lipid levels during storage may stem from lipid breakdown through hydrolytic reactions when moisture content exceeds 14% in flour stored in improper conditions, followed by oxidative rancidity [46].

Carbohydrate and fiber content showed a declining trend in infested flour compared to control sample. Initially, carbohydrate content in the control sample was 86.90%, but it decreased to 82.81%, 79.54%, and 77.94% at infestation levels of 10, 20, and 40 pairs/kg, respectively, after 8 months of storage. Similarly, fiber content, initially 0.87% in the control sample, dropped to 0.56%, 0.32%, and 0.27% after 8 months at the same infestation levels. These findings align with those of Ahmedani et al. [41], who observed carbohydrate reductions in *T. granarium* infested wheat from 81.04% to 74.97% over six months. Gabarty and Abou El Nour [11] also reported reductions in monosaccharides and disaccharides due to infestation by *C. cephalonia*, *E. kuehniella*, and *T. confusum*. Babarinde et al. [33] noted lower fiber levels in *T. castaneum* infested plantain chips compared to control samples, although Ahmedani et al. [41] found increased fiber content in *T. granarium* infested wheat grains over six months.

5. Conclusion

The study concludes that *Tribolium castaneum* infestation significantly deteriorates the quality characteristics of wheat flour. Higher infestation levels and longer storage times directly correlate with increased insect populations, weight loss, and moisture content. Also, even minimal *T. castaneum* infestations can substantially impact flour quality as affecting its colour, and chemical composition. This emphasizes the need for stringent pest management in the stored grain products to maintain flour quality.

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Contribution	**Критерии авторства**
Authors are equally relevant to the writing of the manuscript, and equally responsible for plagiarism.	Авторы в равных долях имеют отношение к написанию рукописи и одинаково несут ответственность за плагиат.
Conflict of interest	**Конфликт интересов**
The authors declare no conflict of interest.	Авторы заявляют об отсутствии конфликта интересов.