Jewel Journal of Scientific Research (JJSR) 9(1&2): 59–66, 2024
©Federal University of Kashere-Nigeria (Print ISSN: 2384 – 6267, Online ISSN 2756-651X)
https://journals.fukashere.edu.ng/index.php/jjsr

Impact of Temperature Degrees and Periods of Exposure on Adult Emergence and Mortality of Red Flour Beetle, *Tribolium castaneum* Herbst [Coleoptera: Tenebrionidae] on Sorghum Flour

[*1]Oaya, C. S. and [2]Barde, R.
[1]Department of Crop Science, Adamawa State University, P. M. B. 25, Mubi, Adamawa State, Nigeria.
[2]Department of Horticultural Technology, Federal Polytechnic, Mubi, Adamawa State, Nigeria.
***Corresponding Author**: oaya897@adsu.edu.ng; +1238036265575

Abstract
The impact of temperature degrees and time of exposure on Red Flour Beetle, *Tribolium castaneum* was evaluated in the Laboratory of the Department of Crop Science, Adamawa State University, Mubi. The beetles were exposed to different temperature degrees of 50, 55, 60, 65 and 70℃ and varying exposure periods of 10, 15, 20 and 25 minutes respectively. The results obtained shows that, increase in both temperature degrees and time of exposure resulted in an increase in average mean adult mortality of *T. castaneum* (50℃/20 = 65%; 60℃/10 = 37%; 60℃/15 = 100%; 65℃/10 = 85.7%; 65℃/15 = 100%; 70℃/15 = 100%). Similarly, the average mean adult emergence of *T. castaneum* and percentage loss of Sorghum flour were significantly decreased ($P<0.05$) with increasing temperature levels and exposure times as shown by the results (50℃/15 = 97.00%; 60℃/15 = 79.00%; 70℃/15 = 50.20% and 50℃/15 = 39.00%; 60℃/15 = 36.00%; 70℃/15 = 21.00%). There was no significant negative effect of temperature and exposure time on Sorghum flour which suggested that, thermal treatment of stored produce and products is one of the effective physical control methods of insect pests especially within the storage environment. Therefore, it is recommended for adoption and use to farmers and householders alike especially in the study area.

Keywords: Temperature, mortality, emergence, stored-products insects, germination, red flour beetle

Received: 23th Mar., 2024 *Accepted:* 30th June, 2024 *Published Online:* 20th July, 2024

Introduction

The vulnerable period of stored product is during the storage which can cause detrimental loss in both quantity and quality. Pest attacking stored products can cause 20-30% losses in tropical countries (Suleiman and Kurt, 2015). Red flour beetle (*Tribolium castaneum*) (Coleoptera: Tenebrionidae) is one of the stored product insect pests that can cause losses on a wide range of durable stored products including barley, corn, flour, millet, wheat, potatoes, sweet potatoes, dried fruit, nut and sorghum (Pointer *et al.*, 2021). This species is an important cosmopolitan insect pest on grain processing and storage (Trebels *et al.*, 2020). *T. castaneum* can be a major pest on flour mills, stored biscuit industry, and retail stores (Campbell and Hagstrum, 2020). This pest causes more serious damage to the processed cereals in the form of flour rather than whole-grain (Zakka *et al.*, 2014). The infestation by this insect pest cause unpleasant smell due to the benzoquinone secretion from its abdominal gland (Campbell *et al.*, 2022).

Management and control methods of Stored-product insect pests to prevent economic losses have been used by many workers (Ipsita *et al.,* 2014). The use of chemical pesticides has been employed in storage, which had positive effect on the pests, but are associated with numerous problems and have continued to remain hazardous to man and the environment. Consumer and environmental concerns over the use of chemical control method have generated interest in non-chemical alternatives such as desiccation, impact, exclusion and elevated temperatures (Banks and Fields, 1995), since they do not have residual effects on food and the environment. High temperature has been used extensively to manage insects using different methods such as hot air, radio frequencies, microwave and fluidized beds (Tidswell *et al.,* 2021; Beckett and Fields, 2017). It has been reported that, insect pests die due to exposure to high temperature levels (Fields, 1992). There has been a lot of research on Conventional Heat Treatment for disinfestation of number of stored commodities (Alice *at al.,* 2014; Ansari *et al.,* 2018; Kayama *et al.,* 2021; Matsumura *et al.,* 2022; Wang and Tang, 2015; Teuscher *et al.,* 2017). There are a few studies that have reported the effect of extreme temperature for the management of *Tribolium castaneum.* Temperature greater than 82℃ is required in the host media to control the immature stages of flour beetles (Pointer *et al.,* 2021). Egg, larva and pupa of beetles are trapped in the seed and therefore, they are excellent target for management using elevated temperatures (Matsumura *et al.,* 2022). The present study was designed to identify, different temperature-exposure time combinations needed to kill *T. castaneum* in the stored. Moreover, the work collected baseline data in the Laboratory on the effect of exposure time and temperature degrees on adult mortality, adult emergence, oviposition, seed swelling, seed germination potentials and storage loss percentages due to *T. castaneum*.

Materials and Methods

The Study Area

The experiment was carried out in the Laboratory of the Department of Crop Science (Crop Protection Division), Faculty of Agriculture, Adamawa State University, Mubi. Mubi is located in the Northern Guinea Savanna Agro-ecological Zone of Nigeria between latitude $10^{o}10'$ and 10^{o} 30' North of the Equator and between longitude 13^{o} 10' and 13^{o} 30’ East of Greenwich meridian and at an altitude of 696m above sea level. The annual mean rainfall of Mubi is 965mm, and a minimum temperature of 12.48^{+-0}C during harmatan period and 38.27^{o+-}C maximum in June (Adebayo *et al.,* 2020). The work commenced from April to July, 2022 under the effect of five different temperature degrees (50, 55, 60, 65 and 70˚C) and time of exposure, 10, 15, 20 and 25 minutes respectively. Sorghum flour commonly used in the study area was obtained from the Mubi Main Market and selected for the insect pest’s culture and sample preparation study as reported by Abdullah *et al.* (2016). The insect culture was prepared and grown in the Laboratory at a temperature of 32 ± 2℃, 12: 12 L: D and 70% RH kept in plastic jar of 1kg.

Preparation of Sorghum Flour Used

The flour of Sorghum (*Sorghum bicolor* (L.) Moench) local variety Fara-fara obtained from the Mubi main Market was selected for the study. The whole flour of sorghum was sieved and cleaned from husks, dust or any inert materials. The conditioned sample was then stored at room temperature in a sealed bag in the Laboratory of the Department of Crop Science, Adamawa State University, Mubi which was subsequently used for the experiment.

Culture of Test Insect

The test insect *T. casteneum* selected for the study was cleaned and sterilized (heating at 70 ºC for 1hr) wheat flour was placed in glass jar separately to reabsorb moisture. 400gm sorghum flour was transferred to separately sterilized culture jars. Adults of Red flour beetle (250-300) from previous culture were added to the jar and the jar sealed with muslin and placed at 30±2℃ and

75±5% RH. After two weeks, the insects were sieved out, discarded or transferred to another jar. Adult insects of flour beetle 10-15 days after emergence were used for the experiment, according to (Saidana, 2007).

Oven and temperature treatment of samples

For the high temperature treatment, samples were treated with conveyor of high temperature energy using a JSR Oven (Model: Json-250, Desc: Natural convection oven, Volts: 220 VAC' 50/60HZ, Watts: 2.5kV' 11.4A' IP). Samples were exposed to different temperature degrees (50, 55, 60, 65 and 70℃). Each degree of temperature was carried out at different exposure periods (10, 15, 20 and 25 minutes) for all treatments of conveyor for the determination of adult emergence and mortality and loss caused by *T. castaneum.*

Determination of Adult Mortality

The experiment was carried out with Sorghum flour sample. Batches of 10 pairs (10-15 days old of *T. confusum* adults) were placed in Petri dishes (9 cm in diameter containing 20gm Sorghum flour. The sample was subjected to high temperature conveyor energy at different temperature degrees (50, 55, 60, 65 and 70℃) and different exposure periods (10, 15, 20 and 25 minutes) on adults. After one hour of treatment, the percentages of live and dead insects were counted. The sample was held at room temperature for three hours and the insects were checked for mortality again.

Determination of Adult Emergence and Weight loss after Storage

Batches of 500 adults of Red flour beetles (10-14 days old) were placed on sterilized related sample (800gm of sorghum flour) in separately glass jar. After one week, all adult insects were removed. The infested culture of flour were kept as samples (20gm) and placed in Petri dishes. The samples were treated with conveyor exposed to different temperature degrees (50, 60 and 70℃) at three deferent exposure times (10, 15 and 20 minutes). Samples were cooled to room temperature and were transferred to glass jars (0.4L), covered with muslin cloth and placed under Laboratory conditions. The number of F1 emerged adults were counted after 6 weeks. After three months, the means of emerged adults were counted and the loss in weight of the sorghum flour was calculated using the following equation:

Loss (%) = $W1-W2/W1\times 100$

Where:

W1: weight of the sample before the treatment and the storage.

W2: weight of the sample after the treatment and the storage.

The reduction percentage in the number was calculated by the following equation:

Reduction (%) = $EC-ET/EC\times 100$

Where:

EC: mean of number emerged adult in control.

There were three replicates for the adult emergence and mortality experiments. Control mortality was determined by allowing the sample and the insects to pass on the conveyor at zero degree.

Statistical analysis

Data obtained were statistically analyzed using Finney (1971) software. Comparisons among the means of the various treatments were performed, using the revised Least Significant Difference (LSD) at < 0.05 level of probability.

Results

Adult mortality of *T. castaneum* increased with increase in temperature level and exposure time (Table 1) at ($P < 0.05$). Moreover, adult stage of *T. castaneum* was susceptible to higher levels of oven energy and shorter time of exposure. Adult mortality of *T. castaneum* measured after conveyor heating at 50℃ for 10, 15, 20 and 25 minutes of exposure periods were recorded as 1.8, 13.2, 65.0 and 100.0 percent. Similarly, Complete adult mortalities were achieved at temperature levels of 55, 60, 65, 70℃ and times of exposure of 10, 15, 20 and 25 minutes respectively as presented in Table 1. Increase in temperature level or exposure time resulted in an increase in average adult mortality.

Table 1: Effect of Temperature and Time of Exposure on Adult Mortality of *T. castaneum*

Temperature (℃)	Adult mortality (%) after certain exposure time (min) ± SD			
	10	**15**	**20**	**25**
50	1.8 ± 0.1	13.2 ± 2.0	65.0 ± 4.6	100.0
55	1.8 ± 0.3	17.8 ± 4.7	100 ± 00	-------
60	37.0 ± 4.0	100.0 ± 00	--------	-------
65	85.7 ± 8.2	100.0 ± 00	--------	-------
70	100 ± 00	-------	--------	-------
LSD <0.05	A:	2.58		
	B:	3.40		

A: LSD <0.05 for the effect of exposure time comparisons.
B: LSD <0.05 for the effect of different temperature degree comparisons.
#Angular transformation was done for the percentage values.
#All the obtained data were statistically analyzed using Costat (1986) Software.

Similarly, the effect of temperature levels and times of exposure on adult emergence and loss of sorghum flour after 3 months by red flour beetle on infested samples are given in Table 2. Adult emergence of *T. castaneum* from infested sample decreased with increase in temperature degrees and times of exposure. After treating the infested samples with three high temperature degrees (50, 60 and 70℃) and three different periods of exposure (10, 15 and 20 minutes) for 6 weeks and 3 months respectively, the mean number of emerged adults of *T. castaneum* were 97.0, 79.0 and 50.5 and percentage mean loss of Sorghum flour after 3 months were 39.0, 36.0 and 21.0. Loss of Sorghum flour was significantly reduced (P< 0.05) with increase in temperature degree and times of exposure as presented in Table 2.

Table 2: Effect of Temperature and Time of Exposure on Adult Emergence of *T. castaneum on* infested Sorghum flour

Temperature (^{0}C)	Exposure Time	Mean Emerged Adults from infested Sorghum Flour			% Loss of Sorghum Flour after 3 Months	
		6Weeks±SD	**3Months±SD**	**Mean**	**%±SD**	**Mean**
Control		56.5±8.3	210.5±9.0	198.50	46.8±0.0	46.80
50	10	52.0±73	168.5±9.1		33.6±3.0	
	15	46.2±23	148.7±8.5	97.00	31.5±1.2	39.00
	20	43.1±4.2	137.1±37		25.4±2.1	
60	10	42.3±2.6	146.2±8.6		28.7±2.0	
	15	36.4±3.0	138.4±1.1	79.00	27.0±1.1	36.00
	20	25.2±8.2	110.5±1.0		24.2±3.0	
70	10	35.1±1.4	122.2±7.3		27.5±1.3	
	15	25.0±4.1	114.3±6.1	50.20	24.3±1.5	21.00
	20	00.0±00	00.0±00		0.6±0.2	
LSD	A:			3.95		1.25
	B:			3.00		3.92
	C:			10.40		

#Means followed by the same letters are not significantly different at $P\leq0.05$.
A: LSD for the effect of temperature degree comparisons.
B: LSD for the effect of exposure times (10, 15 and 20 min) comparisons.
C: LSD for the effect of emergence time (6 weeks and 3 months) comparisons.

Discussion

Thermal treatment has been extensively investigated by several researchers or workers over time as an alternative method of controlling insect pests particularly in the storage environment. In the current study, high temperature degrees and different exposure times were evaluated under Laboratory condition for the management of stored product insect pest, *T. castaneum*. At higher temperature levels, shorter exposure time was required to kill the beetles. On the other hand, low temperature level and high exposure times were required to kill insects. For example, at 70 and 70℃, 10 minutes exposure period was needed to achieve 100% mortalities of *T. castaneum* adults. Whereas, 30 minutes exposure times, 50℃ temperature was enough to achieve 100% mortalities of *T. castaneum* adults. Increased temperature levels had significant effect on mortality; exposure times estimated for 100% mortality were decreased among the insects tested. These results are in agreement with (Strang, 1992; Watters, 1996; Loganathan *et al.,* 2011; Koyama *et al.,* 2021). All these studies used different species and strain of insects, different sources of heat, different rates of heating and the insects were reared and tested on different stored products. Further research is required to determine which of these factors is responsible for the differences in insects' specific tolerance to heat.

There is a wide variation between species in their ability to survive at high temperature (Fields, 1992; Strang, 1992; Ipsita *et al.*, 2013; Teuscher *et al.,* 2017). At high temperature, 54 and 55℃, the time required to kill 90% of young larvae of *S. paniceum* was 0.06 h, whereas it was took 1.3, 0.63 and 0,25h, to kill 99% of *T. castaneum*, *L. serricorne and T. confusum,* respectively (Abdelghany *et al.,* 2010). In the present study *T. castaneum* was more susceptible to high temperature and shorter exposure time. Different species of insects have different susceptibilities to the high temperature treatment that the survival at 49℃ of adult *O. surinamensis = T. confusum < O. Mercator = Cathartus quadricollis < Gibbium psylloides = S. granarium < Trogoderma variable = T. castaneum = S. oryzae < R. dominica = C. pusillus < Lasioderma serricorne (*Campbell *et al.,* 2022). Insects die by exposure to high temperature degrees, because of their limited physiological capacity to thermo-regulate (Fields, 1992). Higher temperature presumably increased the respiratory and metabolic rates of exposed insects and thus caused more rapid mortality from increased stress due to low oxygen (Aller *et al*., 2000; George and Thomas, 2001; Pointer *et al.,* 2021).

In the present investigation, infested samples exposed to different temperature degrees for different exposure periods resulted in 100% mortality at higher temperature degree and high exposure time. The mean numbers of emerged adults and emergence percentage were decreased with increasing temperature levels and exposure times. This in conformity with the findings of (Lale and Vidal, 2003; Tidwell *et al*., 2021) who reported that, exposure of *C. maculatus* adults to solar heat at a temperature of 50℃ for 2, 4 and 6 hours decreased the oviposition, retarded egg development and 100% adult mortality in *Vigna subterranean*. 100% adult mortality was observed in black gram seeds when exposed to different exposure periods to sun light (Alice *et al.,* 2013). Emergence of red flour beetle decreased with increase in temperature and exposure time (Boina and Subramanyam, 2004; Campbell *et al.* 2022). The effect of sun light on the population build-up of *Bruchidius atrolineatus* and *C. maculatus* was registered by (Doumma, 2006; Ansari *et al.,* 2018). It is evident from the present study that high temperature provided adequate protection of stored products against infestation by *T. castaneum.* It offers great prospect for successful protection of stored products and produce against insect pests attack for small and medium scale storage which requires little or no extra financial investment.

Conclusion

It is evident from the results of this study that, high temperature is effective in the management of stored product against insect pests. The results of the study also showed significant reduction in the economic losses associated with *T. castaneum* infestation which in turn minimized the level of damage to stored products in storage. It is also apparent that, the use of heat and manipulated time of exposure to manage insect pests of stored products and produce could serve as an appropriate alternative to the incessant use of synthetic insecticides which over time has been certified as harmful to man, the livestock and the environment.

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