



Efficacy of high temperatures on the different stages of *Callosobruchus maculatus* (F.) (Coleoptera: Chrysomelidae)

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Abstract

The cowpea beetle, *C. maculatus* infests the pulses both in the field and during storage. Thermal disinfestation was investigated as safe physical control method for larvae, pupae and adults of *C. maculatus* by exposing the infested cowpea seeds to three different temperature regimes (40, 50 and 60 °C) for various exposure periods. A complete mortality (%) of adults *C. maculatus* was achieved after 20 min at 60 °C while 40 °C was 83% mortalities at 50 and 40 °C after 55 and 1800 min of exposure times, respectively. The progeny number decreased with increasing both of the exposure time and the temperature degree. The sub-lethal time (LT₅₀) required for 50% kill of the adults population was 1566, 60.0, 16.1 min at 40, 50 and 60 °C. Larvae were the most susceptible stage to heat compared to the pupal and adult stage at different temperature degrees. Pupal and adult stages were the most heat tolerant stages. No bad effects were observed on cowpea seeds germination (%) at tested higher temperatures.

Keywords: coleoptera: chrysomelidae, *C. maculatus*

Introduction

Pulses play an important role as an energy source for the human-being with a significant amount of carbohydrates and fats. They also play an important role in soil fertility (Vishwanatha *et al.*, 2011) [19]. The cowpea beetle, *Callosobruchus maculatus* (F.) (Coleoptera: Chrysomelidae) is one of the important economic pests of legume seeds because it infests legume seeds both in field and storage (Southgate, 1984). Damage caused by larval feeding on seeds can reduce germination potential and yield besides lowering poor nutritional quality (De Sa *et al.*, 2014) [7]. The pest is one of the cosmopolitan pests of cowpea seeds, *Vigna unguiculata* causing a serious damage during storage conditions. The insect multiplies very fast in storage on the cowpea seeds due to its short generation time and causing sever weight losses of up to 60 % (Ahmady, *et al.*, 2016) [1]. Temperature influences the development and growth of insects. Heat treatments have received increased interest in the recent years to disinfest stored commodities and this approach is expected to continue with the impending removal of restrictions on insecticides residues (Mahroof *et al.*, 2003) [13]. Temperature is the most critical biotic factor influencing the population dynamics and the timing of biological events of insects (Danilevskii, 1965; Angilletta, 2009) [6, 3]. Insects development takes place within very narrow range of temperature and the thermal range varies according to insect species. Development of insects is sensitive to temperature change (Ahn *et al.*, 2016) [2]. The present investigation planned to test high temperatures and exposure time on the mortality of the different life stages of *Callosobruchus maculatus* on cowpea seeds.

Materials and methods

1. Test insects

The cowpea beetles, *C. maculatus* used in the study were obtained from an infested cowpea seeds bought from a local market in Giza Governorate, Egypt. Beetles were reared on a commercial cowpea seeds at 30± 1 °C and 60± 5% R.H., at

the Stored Grain Insect Pests Department, Plant Protection Research Institute (PPRI), ARC, Egypt. Ten adults pairs were reared in small glass jars, half filled, with cowpea seeds and covered with double cloth layer and firmly tightened with rubber bands to prevent the beetle escape. Jars were kept at the previous conditions for adult mating and oviposition. Adult parents were removed after five days. The newly emerged adults started to emerge from the cowpea seeds after three weeks and were used for the experimental purposes.

2. Exposure of different life insect stages on cowpea seeds to the different high temperatures.

2.1. Adult mortality at different temperatures.

To study the effect of different higher temperatures on the mean developmental period (MDP), progeny number, weight loss (%) and germination (%) of *C. maculatus* adults. Five replicates of twenty five cowpea seeds, each put in a small glass jar of 7×3 cm diameter and weighted before infestation. Each replicate was infested with five pairs of newly emerged adults of *C. maculatus* (0–24 h old age). The seeds were exposed after infestation to 40 °C for 4, 6, 12, 18, 24 and 30h; 50 °C for 35, 40, 45, 50 and 55 min; 60 °C for 10, 15, 17 and 20 min. After heat treatment, adult mortality was recorded after 1, 2 and 3 days, Five replicates were left as control for comparison. Adults were discarded after the last exposed different exposure period. All replicates were re-incubated for observing the latent thermal effect on adult progeny, weight loss (%) and seeds germination (%).

2.2. Exposing treated larval and pupal stages to different thermal treatments.

The freshly emerged adults were allowed to put eggs on 500g of cowpea seeds for only 8h then isolated. Group of five infested seeds, each with single eggs was selected randomly and dissected daily to confirm the present insect stage of development until adult's emergence. Seeds with single eggs also isolated and used for further experiments

with larval and pupal. Twenty-five seeds were collected and put in a small glass jar of 7×3 cm diameter and weighted. The immature larval stage of one week old, was exposed to 40°C for 4, 8, 12, 16 and 20h; 50°C for 35, 40, 45, 50 and 55 min; 60°C for 5, 10, 15 and 20 min. The immature pupae (seeds with windows) were exposed to 40°C for 5, 10, 15, 20 and 25h; 50°C for 45, 50, 55 and 60 min; 60°C for 10, 15, 20 and 25 min. Total progeny number, MDP, weight loss (%) and seeds germination (%) were recorded and compared with the control. Seed weight loss (%) was determined by weight difference method. The weighting replicates before and after infestations were determined as described by Salama and Youssef (2004)^[17] as follow:-

$$\text{Weight loss (\%)} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100$$

Initial weight

Seeds germination of cowpea seeds was tested at the end of the experiment. Four replicates, each replicate of one hundred seeds selected randomly of the different thermal treatments from each exposure time, each of 20 infested cowpea seeds were chosen randomly from all treatments and planted in 9-cm diameter Petri dishes containing moistened cotton pads. A control cowpea seeds were also done for comparison. After one week, number of the germinated seeds was recorded and the germination (%) was calculated as Ilike *et al.*, (2013).

$$\text{Seed germination (\%)} = \frac{\text{No. of the germinated seeds}}{\text{Total seed number used}} \times 100$$

Statistical analysis

The obtained data were analyzed statistically by using a computer program named SAS (Proc ANOVA SAS Institute, 2000). Estimated LT₅₀, LT₉₀ and slopes were calculated according to Finney (1971) using LDP line program (www. Ehab soft.com).

Results and Discussion

Table (1) shows the adult mortality of *C. maculatus* exposed to three different high temperatures (40, 50 and 60°C) for different exposure periods. Results depend on the exposure periods and the test temperature. Mortality of adult stage was increased with increasing the exposure period increased the adult mortality (%). Combination of the higher temperatures with the longest exposure period gave a complete adult mortality (%) of *C. maculatus* adults (100.0). At 60°C, the mean developmental period (MDP) was 21.0 days after 10.0 and 15.0 min, while it was 23.0 days after 17.0 min. No progeny number appeared after thermal exposure for 20.0 min at 60°C and increased to 115.0 adults after 10.0 min exposure period compared with the control (136.0). Weight loss (%) reached 44.9% after 10.0 min and decreased gradually with increasing the exposure period. Seed germination (%) ranged between 53.0-93.0 % in the all treatments compared with the control which recorded 40.0 %. Adult mortality was 3.3% after 35.0 min at 50°C and increased to 40.0% after 55.0 min after 3days post-treatment. The mean developmental period (MDP) was 23.3 days after 35.0 min while it was 25.6 days after 55.0 min. Progeny number was reduced (2.0) after 55.0 min while it was 63.0 adults after 35 min compared to the control (136.0). Weight loss (%) was 0.3% after 55.0 min compared to the control (46.0%). Seed germination (%) ranged between 47.5-92.5 % in the all rates compared with control which recorded 40.0 %. At 40°C, adult mortality of *C. maculatus* was affected after 3 days (Table, 1). It was reduced (5.0%) after 4.0 h and increased to 63.3.0% after 30 h. The mean developmental period (MDP) was 21.0 days after 4.0 h while it was 24.6 days after 24 h. The total progeny number was reduced to 12.0 adults after 24.0 h while it was 85.0 adults after 4.0 h. Weight loss (%) was reduced to about 5.3 after 24 h while it reached 39.7% after 4.0 h. Germination (%) ranged from 55-80.0 % with non-significant differences.

Table 1: Effect of high temperatures (60, 50 and 40°C) on the adult mortality of *C. maculatus* adults on cowpea seeds.

At 60°C							
Exposure periods (minutes)	Adult mortality (%) after			MDP (days)	Total Progeny number	Weight Loss (%)	Seed germination (%)
	1 day	2 days	3 days				
10 min	3.0 ±0.2	3.0±0.0	7.0±1.6	21.0±0.0a	115.0±1.5a	44.9±1.1a	53.0±3.5b
15min	8.3±6.1	20.0±11.5	27.0±13.0	21.0±0.5a	83.0±13.3a	39.2±1.6b	58.0±2.0b
17 min	42.0±12.3	60.0±13.6	67.0±6.6	23.0±0.3a	10.0±4.6b	4.1±2.1c	88.0±6.1a
20 min	97.0±3.3	100.0± 0.0	100.0±0.0	-	0.0±0.0b	0.0±0.0c	93.0±6.3a
Control	0.0 ±0.0	0.0±0.0	3.0±1.6	20.6±0.3a	136.0±33.2a	46.0±2.3a	40.0±8.2b
LSD (0.05%)	-	-	-	-	51.0	5.2	24.3
At 50°C							
35 min	2.0±1.6	3.0±1.7	3.3±1.6	23.3±0.3c	63.0±5.6b	22.1±9.6b	47.5±6.1b
40min	7.0±2.7	7.0±2.8	8.0±1.6	23.6±0.3c	56.0±3.9b	18.8±8.4b	50.0±4.1b
45 min	13.3±1.7	16.6±3.3	18.3±4.4	24.0±0.5bc	36.0±5.1bc	16.5±2.8bc	58.0±2.0b
50 min	16.0±4.5	18.0±4.4	23.0±3.3	25.0±0.0a	25.0±2.1bc	5.0±0.9bc	80.0±4.0a
55 min	18.3±7.3	31.6±7.2	40.0±5.7	25.6±0.4ab	2.0±1.5c	0.3±0.1c	92.5±2.0a
Control	0.0 ±0.0	0.0±0.0	3.0±1.6	20.6±0.3d	136.0±33.2a	46.0±2.3a	40.0±8.2b
LSD (0.05%)	-	-	-	1.2	43.3	16.4	21.0
A 40°C							
4h	2.0±1.6	2.0±0.0	5.0±1.6	21.0±0.0c	85.0±10.6b	39.7±3.1ab	55.0±4.1bc
6h	2.0±1.3	5.0±1.6	8.0±1.6	21.6±0.3bc	75.0±1.5b	37.5±1.2ab	58.0±2.0bc
12h	7.0±1.6	8.3±1.5	17±4.4	22.6±0.3b	40.0±5.8bc	28.3±9.0b	70.0±8.2ab
18h	8.3±4.4	15±2.9	22.0±6.7	24.0±0.6a	22.3±9.3c	11.1±2.5c	73.0±10.2ab

24h	18.0±3.3	23.0±3.2	28.3±1.7	24.6±0.3a	12.0±2.5c	5.3±1.4c	75.0±4.1ab
30h	63.3±3.3	70.0±0.0	83.0±3.3	25.3±	2.0±	1.9±	92±6.1a
Control	0.0 ±0.0	0.0±0.0	3.0±1.6	20.6±0.3c	136.0±33.2a	46.0±a	40.0±8.2a
LSD (0.05%)	-	-	-	1.1	46.2	13.0	27.4

Exposure of *C. maculatus* larvae at 40, 50 and 60°C for different exposure periods was studied. Table (2) shows effects of higher temperature (60°C) on the larval stage of *C. maculatus*. At 60 °C, there is non- significant difference in the mean developmental period (MDP). Increasing the exposure period to 20 min prevented adult emergence of the progeny while adults emerged (21.0) after 5.0 min exposure period. Larval stage mortality (%) was 6.0% after 50.0 min and increased to 100 after 20.0 min. Weight loss (%) was reached to zero value after 20.0 min exposure period while it reached 9.3% after 5.0 min. Seed germination (%) increased with increasing the exposure periods and it ranged between 53.0 – 88.0% after 5 min and 20 min respectively, compared with the control (40.0 %). At 50 C°, the mean growth period (MDP) was 25.3 days after 35.0 min while it was 30.0 days after 55.0 min. The F1 Progeny was 21.0

adults after 35.0 min exposure and reduced to 4.0 compared to the control (24.3). Larval stage mortality (%) was 16.0% after 35.0 min and reached to 85.0% after 55 min exposure. Weight loss (%) ranged between 1.5-8.4% after exposure period 55.0 and 35.0 respectively, compared to the control (12.7%). Seed germination (%) range from 57.5 – 90.0% after exposure for 35.0 and 55.0 min respectively, compared control (40.0 %).At 40 °C, no significant differences were found among the mean developmental period (MDP). No progeny number after exposure for 20.0 h, while it was 18.0 adults after 4 h. Larval stage mortality (%) was ranged from 29.0 to 100% after exposure period to all treatment. Weight loss (%) was completely reduced (0.0) after 20.0 h exposure while it was reached 9.9% after 4 h. Seed germination (%) was ranged from 52.5 – 88.0% after 4 h and 20 h respectively, compared with the control (40.0 %).

Table 2: Effect of high temperatures (60, 50 and 40°C) on the larval and pupal stage of *C.maculatus* on cowpea seeds the cowpea seeds with the after the 19 days of the initial infestation.

At 60°C					Seed Germination (%)
Exposure periods	MDP (days)	Total progeny number	Larval mortality (%)	Weight loss (%)	
5 min	23.6±0.3a	21.0±2.6a	6.0±4.8c	9.3±0.9a	53.0±2.0cd
10 min	24.0±0.0a	18.0±7.3a	14.0±8.1c	7.9±3.5a	65.0±4.1bc
15 min	26.0±0.8a	7.0±3.7b	60±9.8b	2.0±4.6b	78.0±2.0ab
20 min	0.0±0.0	0.0±0.0b	100.0±0.0a	0.0±0.0b	88.0±2.0a
Control	22.6±0.3a	24.3±0.7a	2.6±1.3c	12.7±3.6a	40.0±8.2d
LSD (0.05%)	-	8.1	19.8	5.7	19.5
At 50°C					
35 min	25.3±1.5c	21.0±0.8ab	16.0±6.1ed	8.4±0.5ab	57.5±2.0bc
40 min	26.3±1.4bc	17.0±0.7bc	29.0±5.8cd	6.1±1.1bc	62.5±2.0b
45 min	27.0±1.0b	14.0±0.3c	44.0±4.0c	5.2±1.7bc	72.5±2.0ab
50 min	29.3±1.2a	9.0±0.3d	63.0±4.8b	2.1±0.5bc	85.0±4.1a
55 min	30.0±2.0a	4.0±0.4e	85.0±8.1a	1.5±0.4c	90.0±4.1a
Control	22.6±0.3c	24.3±0.7a	2.6±1.3e	12.7±3.6a	40.0±8.1c
LSD _{0.05}	1.7	4.2	16.7	5.9	18.3
At 40°C					
4h	24.6±0.3a	18.0±1.4b	29.0±5.8c	9.9±0.5ab	52.5±2.0c
8h	25.0±0.0a	16.0±1.8b	33.0 ±7.4c	8.8±1.4ab	57.5±2.0bc
12h	25.3±0.3a	13.0±2.0b	48±8.0c	8.2±0.1ab	75.2±2.0ab
16h	26.0±0.0a	8.0±1.7c	68±6.9b	6.8±1.0b	78.0±6.1a
20h	0.0±0.0	0.0±d	100± 0.0a	0.0±c	88.0±2.0a
Control	22.6±0.3a	24.3±0.7a	2.6±1.3d	12.7±3.6a	40.0±8.1c
LSD _{0.05}	-	4.4	17.9	5.1	19.0

Data of Table (3) shows exposing the cowpea seeds containing the pupal stage at 60°C revealed significant differences among the test parameters. Mean developmental period (MDP) was 23.0 days after exposure 10.0 min while it was longer and reached to 29.3 days after exposure for 25.0 min. F₁ progeny was 24.0 adults after exposure for 10.0 min and decreased to 2.0 adults after 25.0 min exposure period at 60C°. Pupal stage mortality was 4.0% after 10 min of exposure and reached to 93.0% after 25.0 min of exposure period. Weight loss (%) was reduced to 0.5% after 25.0 min while it was 8.3% after 10.0 min. Germination (%) ranged from 53.0 to 87.0% in the test treatments, after 10 and 25 min respectively, compared with control (40.0 %). At 50°C, the mean developmental period (MDP) was 23.0 days after exposure 45.0 and 50.0 min while reached to 25.0

days after exposure to 60.0 min. The F₁ progeny was 24.0 adults after exposure for 45.0 min and reduced to 9.0 adults after 60.0 min. Pupal stage mortality was 4.0% after 45 min and reached to 63.0% after 60 min. Weight loss (%) was 7.7% after 45.0 min and reached 3.1% after 60.0 min. Germination (%) was ranged from 75.0 and 93.0% after 45.0 and 60.0 min compared with the control (40.0 %). At 40°C, the mean developmental period (MDP) was lengthed to 24.0 days after 25 h of exposure period. F₁ progeny was 13.0 adults after 25.0 h, while it was 24.0 adults after 5 h. Pupal stage mortality was 4.0% after 5 h of exposure and increased to 48.0% after 25 h of exposure period. Weight loss (%) was reduced with increasing the exposure period. It was 7.2% after 5 h and reached 4.9% after 25.0 h. Germination (%) was between 55.0 – 80.0% after 5 h and 25

h of exposure respectively, compared with the control (40.0 %). Many others mentioned that increasing either the temperature or the exposure period or both affected on the different biological insect parameters. For example at 60°C, a complete adult mortality (100%) was achieved after 20 min compared to 83% at 40 °C, after exposure period for 30 h. The developmental period (MPD) was increased with increasing exposure periods and at higher temperature compared to low temperature. The same trend was observed with the other biological parameters. The higher temperature with longer exposure periods increased the seed

dryness degree of the infested seeds and makes the insect feeding very difficult. F₁ progeny was 115.0 adults at 60°C for 10 min, was 63.0 adults at 50 °C for 35 min and it was 85 at 40 °C for 4 h exposure periods. Our results showed that the cowpea beetle could be physically controlled when the infested seeds with larvae and adults are exposed to 60°C for 20 min, while in case pupal stage was controlled after 25 min. This temperature (60°C) had no affects the biochemical composition as protein, fat and moisture content as mentioned Asmhan and Kassab (2002).

Table 3: Effect of high temperatures on the pupal stage of *C. maculatus* on cowpea seeds.

At 60°C					
Exposure periods	MDP (days)	Total progeny number	Pupal mortality (%)	Weight loss (%)	Seed germination (%)
10 min	23.0±0.0c	24.0±0.5a	4.0±2.3c	8.3±1.6ab	53.0±2.0bc
15min	24.3±0.3bc	22.0±2.3a	15±8.1c	7.8±4.2ab	55.0±4.1bc
20 min	26.0±0.5b	13.0±4.0b	49.3±16.3b	4.7±1.4ab	70.0±4.1bc
25 min	29.3±0.8a	2.0±0.6c	93.3±2.6a	0.5±0.1c	87.0±2.2a
Control	22.6±0.3c	24.3±0.7a	2.6±1.3c	12.7±3.6a	40±8.1c
LSD _{0.05}	1.8	6.7	26.3	6.6	20.7
At 50°C					
45min	23.0±0.0b	24.0±0.6a	6.0±2.3b	7.7±0.4ab	75.0±4.1a
50 min	23.0±0.0b	22.0±2.5a	12±10.1b	7.2±0.6ab	88.5±2.0a
55 min	23.6±0.3ab	17.0±1.9b	28±10.5b	5.2±0.4b	90.0±0.0a
60 min	25.0±0.3a	9.0±1.7c	63.0±7.1a	3.1±0.9b	93.5±2.0a
Control	22.6±0.3b	24.3±0.7a	2.6±1.3b	12.7±3.6a	40±8.1b
LSD _{0.05}	1.2	5.1	25.8	5.4	19.1
At 40°C					
5h	22.3±0.3c	24.0±0.7ab	4.0±3.0d	7.2±0.6a	55.0±4.1bc
10h	22.6±0.6bc	22.0±0.3ab	11.0±1.3cd	6.4±1.2a	60.0±4.1ab
15h	23.0±0.0abc	19.0±1.8bc	23.0±7.1bc	5.6±0.1a	63.0±2.1abc
20h	23.6±0.3abc	16.0±1.3cd	30.0±2.3b	5.3±0.5 a	75.0±4.1ab
25h	24.0±0.0ab	13.0±2.1d	48.0±8.3a	4.9±1.3a	80.0±4.1a
Control	22.6±0.3bc	24.3±0.7a	2.6±1.3d	12.7±3.6a	40.0± 8.1c
LSD _{0.05}	1.3	3.9	14.5	-	20.1

The data in Table (4) shows the calculated lethal time values (LT₅₀ and LT₉₀) at the different three high temperatures. The LT₅₀ value of required the adult stage was 16.1, 60.0 and 1566 while the corresponding value at 60, 50 and 40°C, respectively, (LT₉₀) was 18.1, 87.2 and 5154 min, at 60 °C, 50 °C and 40°C, respectively. The LT₅₀ of the larval stage was 11.4, 44.9 and 543.6 min respectively, and their corresponding LT₉₀ values were 22.7, 60.4 and 1728.1 min, at 60 °C, 50 °C and 40°C, respectively. The pupal stage of *C. maculatus* was the most heat-resistant stage, since their calculated sub-lethal values (LT₅₀) were 18.6, 58.0 and

1754.8 respectively, while the highest lethal time of 90% was 28.0, 69.0 and 5767.1, at 60, 50 and 40°C respectively. The pupal stage was the most resistant stage while the larval stage was the most susceptible stage to the tested high temperatures, also with increasing high temperatures, the lethal time period decrease of any of the three stage. The insect mortality due to exposure to higher temperatures depend on many factors as insect type, its stage the test temperatures and exposure periods as it was explained by many workers as by Loganathan and (2011) Ahmady *et al.*, (2016)^[1], Sanaa *et al.*, (2018).

Table 4: The sub-lethal times (LT₅₀ and LT₉₀) of three high temperatures in killing of the different stages of *Callosobruchus maculatus* (F.)

Tested temperature	Stages of insects	Lethal time (mins)		Slope (b)	Probability Level (0.05%)
		LT ₅₀	LT ₉₀		
60°C	Adult	16.1	18.1	21.1	0.3
	Larvae	11.4	22.7	4.2	0.0
	pupa	18.6	28.0	7.2	0.0
50°C	Adult	60.0	87.2	7.9	0.5
	Larvae	44.9	60.4	9.9	0.4
	pupa	58.0	69.0	17.3	0.2
40°C	Adult	1566	5154	2.4	0.0
	Larvae	543.6	1798.1	2.5	0.2
	pupa	1754.8	5767.1	2.5	0.5

Table 5: Germination percent of cowpea seeds exposed to the high temperature (60°C) after 20 min of exposure time.

Tested temperature	Germination (%)
60°C	92.0±3.5 a
control	96.0±2.3 a
LSD _{0.05}	-

Data of Table (5) shows non-significant differences on the cowpea seeds germination treated the highest temperature (60°C) and the control.

Discussion

Our results agree with those mentioned by Loganathan *et al.*, (2011) who found that the pupal stage of *C. maculatus* was the most heat tolerant than the larval and adult stage when reared on chickpea seeds at temperature ranged from 42-45 °C and exposed for 6, 12, 24, 36, 48, 60, 72, 84, 96 and 108 h. At 50 °C for 150, 300, 325, 350, 400min and at 55°C for 24, 27, 30, 33, 36, 39, 42, 45 min, 60°C for 9, 10, 11, 12, 13, 14, 15 and 16 min. Also the values of the lethal time (LT50) of the pupal and adult stages were 79.7 and 71.1 h, respectively at 40 °C, followed by larval stage which was the least tolerant. The lethal time (LT) for the pupal stage was investigated also at various temperatures. The LT50 values were 4907, 4262, 336, 36 and 13 mins at the cowpea seeds temperatures of 42, 45, 50, 55 and 60°C, respectively. The pupal and adult stage were the most heat tolerant stage but it was slightly different than mentioned by Murdock and Shade (1991) who found that the larval stage was the most tolerant at the higher temperatures. Unlike our study, adults of *C. maculatus* was the least tolerant stage (Table 1, 2 and 3). Our study was in agreement with those of Maharjan *et al.*, (2017) who proved that the developmental time and the total progeny number decreased with increasing the test temperature of *C. chinensis* on cowpea seeds.

To get a complete control of *C. maculatus* pupae, we recommend the following temperature-exposure times regime of 40 °C for 25 h, 50 °C for 1 h, 60 °C for 25 min. The temperature-exposure time combinations required for controlling *C. maculatus* in cowpea are different than the previous studies (Murdock and Shade, 1991, Johnson and Valero, 2003). This work was conducted at constant temperatures. In commercial storage facilities with large seed bulks, it is difficult to uniformly heat and cool the pulses. Mathematical models could be developed to predict mortality of the larval stage at 50 and 60 °C for 24h (Boina *et al.*, 2008). Further study is needed to determine whether these lethal temperatures are detrimental to the quality of cowpea seeds other than germination (%). It is mentioned before, the tested larvae of *C. maculatus* seems to be more susceptible compared with the pupal and adult stages. Our results agree with Upadhyay and Ahamed (2011), Longanatha (2011) and Sanaa *et al.*, (2018) but was different than Murdock and Shade (1991), who found that the larval stage was the most heat tolerant.

These results agree with previous research which has shown that the susceptibility of stored product insects to heat varied among species temperature, exposure period and among the life stages of a species. (Murdock and Shade (1991), Longanathan, 2011 and Sanaa *et al.*, (2018). These factors are responsible for the differences in stage specific tolerance of heat. The differences in the mortality of the selected insect stages could be due to the loss of the body water and death due to dryness. Insects die by exposing to high temperature

degrees, because of their limited physiological capacity to thermo regulate. Higher temperature presumably increases the respiratory and metabolic rates of exposed insects and thus caused more rapid mortality from increased stress due to low oxygen Ahmady *et al.*, (2016) [1]. The high temperature make the seeds loss more moisture and thus become very dry and this represent a difficulty of the feeding first immature stages of the insects. In this study, high temperature has a marked effect on the different stages of *C. maculatus* and the high temperature (60°C) with a longer exposure period of *C. maculatus* affected the mortality of the tested stages with which LT₉₀ of larvae, pupae and adults were 4.2, 7.2 and 18.1 min.

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