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Disinfestation of cocoa beans infested with life stages of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) using solar heat trapped in a cardboard solar heater box

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Abstract

Experiments were conducted to study the effects of solar heat treatment in a solar heater box on all the life stages, namely adult, larvae, eggs and pupa of *T. castaneum* infested on cocoa beans. Thirty (30) adults, larvae, eggs and pupae of *T. castaneum* were infested on cocoa beans and exposed to solar radiation in the solar heater box for 30, 45, 60, 90 and 120 min. Mortalities were assessed in the treated adults and larval stages 24 h after exposure for 3 days. Eggs hatchability and pupal eclosions were also assessed daily until 9 and 7 days after treatment respectively. The results show that adult and larval mortalities in the solar heater box treated populations were significant and ranged from 96.66-100%. Similarly, both egg hatchability and pupal eclosion were absolutely inhibited. It was concluded that the solar heater box can be used as a reliable tool for heat sequestrations for the eco-friendly control of *T. castaneum* on cocoa beans.

Keywords: Cocoa beans; *Tribolium castaneum*; Heat treatment; cardboard solar heater box; life stages of *T. castaneum*

Introduction

Cocoa is an important export crop in cocoa producing countries and a major import agricultural commodity in consuming countries [3, 4, 52]. Successful storage of cocoa beans and other stored product is being hampered by the infestation of insect pests [40, 50]. *Tribolium castaneum* is one of the cosmopolitan insect pest causing tremendous damage to stored foodstuffs and their by-product worldwide [14, 37]. It has maintained an extensive link with a widespread kind of agricultural produce including cocoa beans [13, 14, 50]. It is reported to be among the major pests of cocoa beans in Malaysia [48, 24, 9] and elsewhere [50].

The control of *T. castaneum* and other insect pests of stored products has for long greatly depended on the use of synthetic insecticides and fumigants. These chemicals have multitudes of problems such as residues in products, incidences of resistance in numerous species to insecticides, public and environmental health concerns among others, thereby limiting their use on stored food commodities [41, 3]. Moreover, customers, these days stress on safe and organic foodstuff and products [46], which are free from chemical residues [40]. This necessitates research into frontiers that explores alternatives techniques for pest control [35, 36, 40] especially on stored product commodities like cocoa beans [9]. Heat treatment of stored product commodities is one the control methods devoid of the drawbacks of synthetic insecticides [16]. It is currently receiving tremendous attention as an alternate tool for the management of arthropods pests in stored product environment [10, 25].

Methods of heating foodstuffs for the control of stored products arthropod pest are diverse and include the use of heat from microwave [16], solar radiation [15, 30], solar heat trapped in a solar heater box [34, 43, 18, 29] among others. Every method adopted for commodity heating must, however, raise the product temperature to between 50- 60 °C [27] or 60-65 °C for rapid killing (within seconds) of all life stages of all stored products arthropod pests [20, 17]. Similarly, it is pertinent to strike a delicate balance between target lethal temperature, product exposure or holding time, and the assurance against product quality deterioration during such disinfestation [38, 39, 42].

Solar heater box is a potential tool for the efficient collection of solar radiation as heat at levels that can maximise the control of insect pest on stored product [33, 44], with no noticeable effect on product quality [43]. It has been used to successfully control *Callosobruchus maculatus* Fab. infestations on adzuka beans [33, 43, 18]. The excellent result obtained from the above cited studies with solar heater boxes makes it expedient to assess the effectiveness of similar solar heater boxes for the control of other stored product insect pests on other commodities.

This study was therefore conducted to evaluate the effect of heat treatment in a solar heater box on the life stages of *T. castaneum* artificially infested on cocoa beans, to have an insight into the potentials of the solar heater box as a worthy alternative to the use of insecticides on cocoa beans.

2 Material and Methods

2.1 Insect culture

Tribolium castaneum used for the culture was obtained from a laboratory culture in the Entomology Laboratory of the Department of Plant Protection, Universiti Putra Malaysia. The insects were reared for this study in plastic containers on an artificial diet made from wheat bran and baker yeast (19:1 w/w) under laboratory conditions of $29.45 \pm 0.43^{\circ}\text{C}$, $66.43 \pm 1.65\%$ Relative humidity, and 12 L:12 D photoperiod. The wheat bran was sterilised by freezing in a refrigerator for three (3) weeks to disinfest it from probable residual infestations by other arthropods [5].

2.2 Source and sterilisation of cocoa beans

Standard Malaysian cocoa bean grade 1 (SMC1) used for this experiment was obtained from Malaysia Cocoa Board Research Centre, Hilir in Perak-Malaysia. The beans were sieved to remove dust and dirt, wrapped in papers, and sterilised at 60°C for 10 h in a ventilated oven (Memmet Model-D-91126 GmbH +CO.KG, Germany) to disinfest it from any residual infestation [49]. The sterilised beans were left in their wraps to acclimatise to room temperature before being used for insect life stages bioassay.

2.3 Solar heater box, data logger and temperature measurement

The solar heater box of truncated and inverted pyramid shape was constructed using cardboard sheets (2mm thickness) painted internally with black paint. The interior of the box was entirely glued from within with aluminium foil. Polystyrene (12 mm thickness) was used as an insulating material from the outside of the cardboard sheets. The top open sides of the box and the base were 100 x 100 and 60 x 60 cm, length by width respectively, and the height of each lateral side walls was 112 cm. it has an obtuse-base- angle of 118° reported to be more efficient in trapping solar radiation [33, 43, 18].

The above structural materials were chosen based on the previous reports of their use for the same purpose by Ragaa, [43]. The aluminium foil is known to provide a good reflective surface to create long wavelength radiation as reflected radiation argument the sun rays [1]. The black paint enhanced heat absorbance and retention within the solar heater box [47, 18]. Perforated squared shaped trays made from flat woods were placed at the middle of the box to serve as the platform for keeping the cocoa beans [43]. The top side of the box was covered with thin transparent plastic films (0.15mm thickness) to generate the needed greenhouse effect inside the box [1] and was overlaid by a square wooden frame to keep it

firm to solar heater box [18].

Data logger (Intech Micro 2100-16A, Intech Instruments Ltd) was used to record the temperature attained in the solar heater box. Temperature regimes were detected by J-type thermocouple sensors. All readings from the thermocouple were recorded into a personal computer (PC) via Microscan 2000 software version 4 [33, 43].

2.5 Bioassay for the effect of solar heat treatment in solar heater boxes on Adult *T. castaneum* mortality

Thirty (30) unsexed adult aged 1-3 weeks [32, 7] were collected from the colony and infested on one (1) kg of sterilized cocoa beans in fabric bags and exposed to solar radiation in solar heater boxes for 30, 45, 60, 90 and 120 minutes. After each exposure time, the treated sample was remove and allowed to cool to room temperature [42]. Then, the exposed insects were immediately separated from the beans by sieving through a 3mm mesh and were then transferred onto 100 clean cocoa beans in a ventilated aquarium and arranged in CRD in the laboratory under the prevailing conditions [43]. Each exposure time was replicated four times. The numbers of dead insects were assessed and recorded after 24 h following solar heat treatment. Dead insects are motionless and lay in reverses on their backs and do not respond to prodding on the abdomen [7, 54, 8]. Any treated insect that remained in this condition for 72 h is considered and recorded as dead. The percentage of adult mortality was computed based on the number of dead and initial live insect. Control treatments were included for each replication.

2.6 Bioassay for the effect of solar heat treatment in solar heater boxes on larval mortality

About 500 matured adults were introduced into aquarium tanks (91 x 160 x 92 mm) containing 100 g of pre-sieved wheat flour to lay eggs for 48 hours. The lid of the aquarium was covered with muslin clothes. The introduced adults were removed by sieving using a #25 and #75 mesh to separate both the eggs and the adult insect from the wheat flour. The eggs were kept in petri dishes to hatch. Hatchability was observed under a Dino-lite digital microscope (Model AM-7013MZZT, ANMO Electronics Corporation, Taiwan). The newly hatched larvae were then collected with a fine soft moistened camel brush and introduced onto sterilised wheat flour to continue feeding for growth until the seventh larval instar is attained at 18-21 days [21, 32]. Thirty (30) individuals of seventh larval instar were then introduced into a one (1) kg cocoa beans in fabric cloth bags and subjected to solar radiation in the solar heater box as described for the previous experiments. Larval mortality was assessed after 24 h. Dead larvae are immobile, darkened and shrunken [7]. Any larvae that remained in this condition for 72 h is considered as scored as dead. Percent larval mortality was calculated based on the initial number of live larvae inoculated. Control treatments were included for each replication.

2.7 Bioassay for the effect of solar heat treatment in solar heater boxes on *T. castaneum* egg hatchability

Matured adult (500) were introduced into aquarium tanks (91 x 160 x 92 mm) containing wheat flour and covered with a muslin cloth to oviposit for 48 hours. These adults were separated by sieving through a #25 and #75mm mesh from both the flour and the eggs. Thirty (30) eggs [32] were carefully collected and introduced into a one (1) kg of sterilised cocoa beans in fabrics bags. Then, placed on the wooden platform in the middle of the solar heater box and

exposed to solar radiation for 30, 45, 60, 90 and 120 minutes as in the previous experiments. After each exposure time, the solar heat treated eggs were kept in the laboratory in Completely Randomised Design (CRD) experimental layout under prevailing conditions of temperature and Relative humidity for 9 days. Control treatments were included for each replication. Daily checks for egg hatching was done under a Dino-lite digital microscope (Model AM-7013MZT, ANMO Electronics Corporation, Taiwan) for both treated and control groups. Percent hatchability was assessed by counting the number of hatched eggs out of the total egg for each replication.

2.8 Bioassay for the effect of solar heat treatment in solar heat box on pupal stages of *T. castaneum*

Eggs and larvae for pupal rearing were obtained as described for previous experiment above. Larvae were collected after 18-22 days incubation for pupation. Pupae were sieved out of the wheat flour at 26 days after larval incubation [32]. For each sample, 30 pupae were picked with a fine camel brush and transferred on to a one (1) kg clean and sterilised cocoa beans as in the previous experiment and exposed to solar radiation in the solar box for 30, 45, 60, 90, and 120 minutes as described for the previous experiment. After each treatment period, the treated pupae were kept in clean petri dishes and observed for eclosion for 7 days. Daily checks for emerged adults were conducted by observing under a Dino-lite digital microscope [43]. Control treatments were included for each experimental replication. Dead pupae appear darkened and desiccated [7]. Total emergence was recorded and the percent pupal mortality was computed based on the initial number used for the bioassay.

2.9 Statistical analysis

Data generated from this experiment were analysed using PROC TTEST procedure for two sample t-test in SAS version 9.4 [49] to compare mean mortalities and inhibitions in the treated and the control groups ($P=0.05$). Prior to analysis Abbott formular [2] was used to correct for control mortalities where mortality was recorded in the control group. Within and between cocoa beans temperatures were pooled to give

the average temperature inside the solar heater box.

3. Results

3.1 Effect of solar heat treatment in solar heater boxes on Adult *T. castaneum* mortality

The result for effect of solar heat treatment in solar heater boxes on Adult *T. castaneum* mortality is shown in Fig 1. The results for the two sample t-test analysis show adult mortality was significantly ($P<0.0001$) affected by solar heat treatment of adult in solar heater box compared to those of control for all exposure times (30 min: $t(6)=76.12$, $p<0.0001$; 45 min: $t(6)=83.90$, $P<0.0001$; 60 min: $t(6)=71.56$, $P<0.0001$; 90 min: $t(6)=61.16$, $P<0.0001$; 120 min: $t(6)=119.12$, $P<0.0001$).

At 30 min exposure time, the mean temperature in the solar heater box raised to $59.58\pm1.74^{\circ}\text{C}$ and has produced mean percentage mortality of $99.17\pm0.84\%$ in the treated group. The percentage mortality ranged from 96.66-100%. The mean percentage mortality in the control group was $0.83\pm0.13\%$. The control group percentage mortality range from 0-3.33%.

The mean temperature of $60.80\pm4.03^{\circ}\text{C}$ was equally captured in solar heater box at 45 min of exposure time. Mortality in the treated group was 100%, while the control group recorded no mortality. Furthermore, mean temperature of $62.14\pm2.69^{\circ}\text{C}$ was recorded in the solar heater box at 60 min of exposure time. This much of temperature as expected caused 100% mortality in the treated adult *T. castaneum*. No mortality was recorded in the control populations. Similarly, mean temperatures of $64.75\pm1.95^{\circ}\text{C}$, and $70.73\pm1.98^{\circ}\text{C}$ were recorded in the solar heater box at 90 and 120 min of exposure to solar radiation respectively. Corresponding mortalities of 100% were recorded in the solar heater box treated adults for both exposure times.

On the other hand, the mean control mortalities in the control groups were 2.49 ± 0.59 , and the mortalities ranged from 0-6.66% at the 90 min exposure time, while the control mortalities at 120 min exposure time range from 0-3.33% with a mean percentage mortality of $0.825\pm0.25\%$ (Fig 1). Ambient temperatures were 34.70 ± 0.31 , 33.18 ± 0.46 , 32.00 ± 1.47 , 31.80 ± 0.84 and $30.55\pm0.40^{\circ}\text{C}$ at 30, 45, 60, 90 and 120 min exposure times experiments respectively (Fig 1).

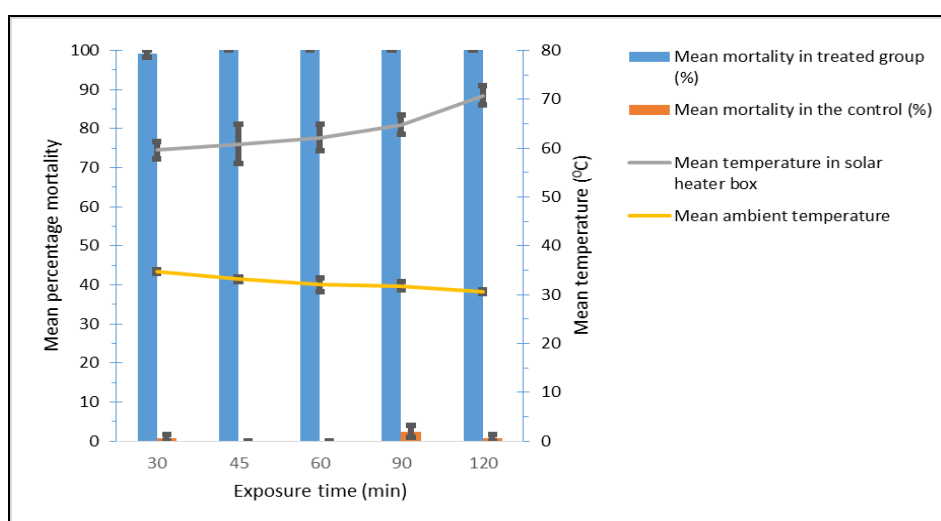


Fig 1: Percentage of mortalities of *T. castaneum* adults and temperatures recorded in both the solar heater box and the ambient environment over 2h exposure time

3.2 Effect of solar heat treatment in solar heater boxes larval mortality

The result of two sample t-test analysis for the effect of solar

heat treatment in solar heater box on larval stages show that heat treatment of the larvae had a highly significant (30 min: $t(6)=102.30$, $P<0.0001$; 45min: $t(6)=119.12$, $P<0.0001$; 60 min:

$t(6)=119.12$, $P<.0001$; 90 min: $t(6)=61.08$, $P<.0001$; 120min: $t(6)=118.13$, $P<.0001$) effect on the mean percentage larval mortality recorded in the solar heater box treated group compared those in the control group.

The solar heater box has recorded some lethal mean temperatures of 70.38 ± 6.29 , 72.05 ± 2.65 , 71.43 ± 1.61 , 68.40 ± 1.43 , and $71.34\pm0.86^\circ\text{C}$ at 30, 45, 60, 90 and 120 min of exposure time respectively. These temperature regimes caused absolute lethal effects (100%) on the treated larvae at

all the exposure times (Fig 2). Mean (range) of control mortalities over the same exposure time were 1.66 ± 0.96 (0-3.33%) at 30 min, and 0.83 ± 0.23 (0-3.33%) at 45, 60 and 120 min of exposure time. The mean mortality in the control group at 90 min exposure was $2.50\pm0.59\%$ and ranged from 0-6.66%. Likewise, the corresponding ambient temperatures of 32.00 ± 0.55 , 32.08 ± 0.38 , 28.58 ± 0.39 , 30.8 ± 0.31 , and $32.70.23^\circ\text{C}$ were recorded during the same exposure times stated above (Fig 2).

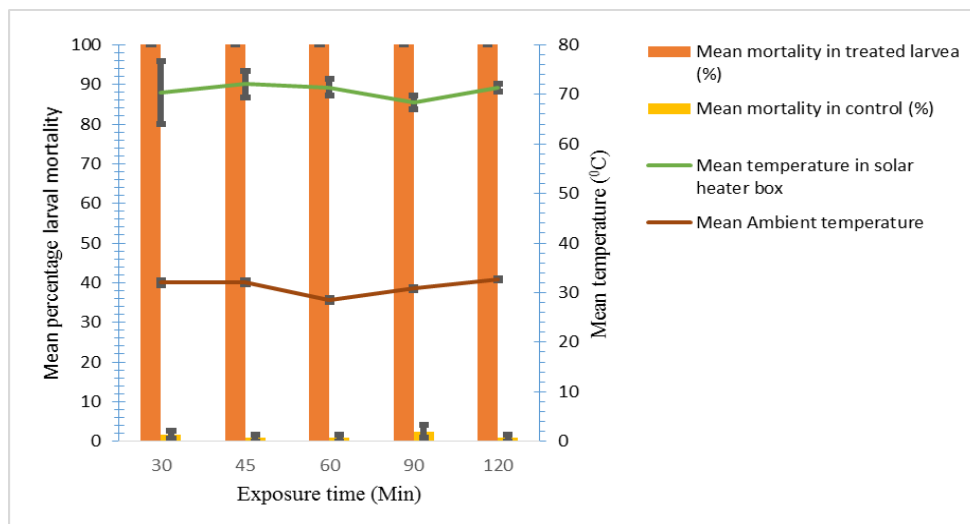


Fig 2: Percentage of *T. castaneum* larval mortality and temperatures recorded in both the solar heater box and the ambient environment over 2h exposure time

3.3 Effect of solar heat treatment in solar heater boxes on *T. castaneum* egg hatchability

Results for the effect of heat treatment in solar heater box on eggs of *T. castaneum* hatchability is shown in Fig 3. The results for two sample t-test show that a highly significantly (30 and 45min: $t(6)=71.00$, $P<.0001$; 60min: $t(6)=102.30$, $P<.0001$, 90min: $t(6)=119.12$, $P<.0001$, 120min: $t(6)=58.97$, $P<.0001$) effect of heat treatment on egg hatch of the solar heater box treated egg compared to those in the control populations.

Mean temperatures of 59.85 ± 3.86 , 67.14 ± 0.96 , 68.95 ± 0.98 , 58.16 ± 2.79 and $64.30\pm0.92^\circ\text{C}$ were recorded in the solar box at 30, 45, 60, 90 and 120 min of exposure time respectively. All temperature means are at level lethal to the life stages of stored product insect pests. Hence, absolute mortalities (100%) were recorded in all treated population for all the

exposure times (Fig 3)

Similarly, ambient temperatures of 30.55 ± 0.50 , 32.57 ± 0.15 , 32.00 ± 0.21 , 31.71 ± 0.35 , and $31.6\pm0.19^\circ\text{C}$ were recorded over the exposure times (Fig 3) and are within optimum range for *T. castaneum*. Therefore, means of egg hatchability in the control populations were very high. Mean percentage of hatched eggs in the control groups of the population treated for 30 min were 96.67 ± 2.72 , and hatchability ranged from 93.33-100%.

Mean percentage hatchability in the control groups for the eggs treated for 60 min in solar heater box was $96.66\pm0.89\%$. Mean percentage hatchability of 98.34 ± 0.96 and 98.33 ± 1.66 were recorded in the control populations of the groups treated for 60 and 120 min respectively. The highest mean hatched eggs of $99.17\pm0.83\%$ were recorded in the controls for the 90 min exposure time experiments (Fig 3)

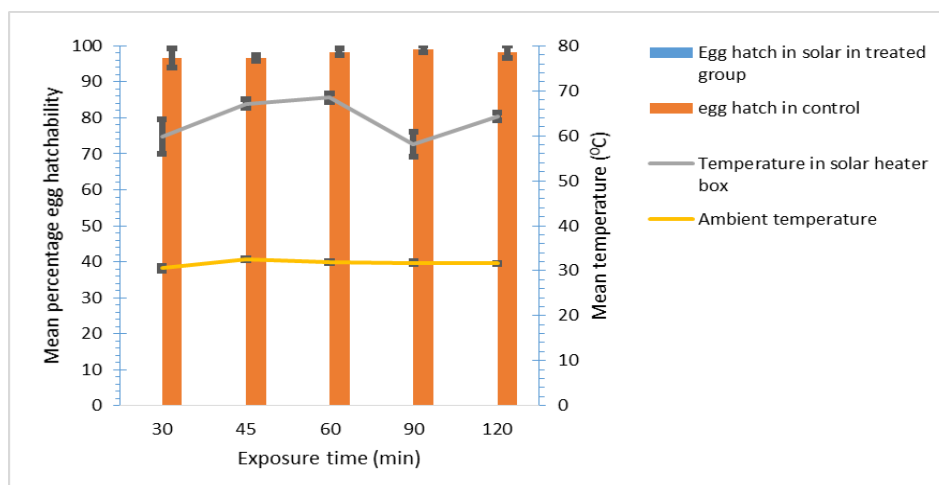


Fig 3: Percentage of *T. castaneum* eggs hatchability and temperatures recorded in both the solar heater box and the ambient environment over 2h exposure time

3.4 Effect of solar heat treatment in solar heat box on adult emergence from pupal stages of *T. castaneum*

The results for the effect of solar heat treatment in solar heat box on pupal stages of *T. castaneum* is as shown in Fig 4. Statistical analysis using student t-test showed that solar heat treatment in solar heater box had a highly significant (30 min: $t(6)=102.30$, $P<0.0001$; 45min: $t(6)=119.12$, $P<0.0001$; 60 min: $t(6)=58.97$, $P<0.0001$; 90 min: $t(6)=118.76$, $P<0.0001$; 120min: $t(6)=58.97$, $p<0.0001$) effect on adult emergence from treated pupae compared to those of the control group. Temperature means recorded in the solar heater box were 55.18 ± 1.52 , 55.77 ± 0.36 , 62.78 ± 3.28 , 59.28 ± 4.97 , and 62.52 ± 2.78 °C for 30, 45, 60, 90 and 120min of exposure times respectively. These temperature regimes are at levels lethal to the life stages of *T. castaneum* including the pupae.

Therefore, 100% pupal mortality (no adult emergence) was recorded in solar heater box treated populations as compared to the high mean adult emergence in the controls (Figure 4). The mean ambient temperatures of 31.80 ± 0.26 , 32.20 ± 0.36 , 30.80 ± 0.23 , 30.55 ± 0.35 , and 30.95 ± 0.27 °C were recorded over the same exposure times (Fig 5.8). Mean percentage adults that emerged from the control group were significantly ($P<0.0001$) higher than those in the solar heater box treated group. Mean adult emergence in the control groups for the 30 min exposure time was $98.33\pm0.96\%$ and the adult emergence ranged from 96.67-100%. Similarly, adult emergence ranged from 93.33-100, and 97.33-100% for the control groups at 90 and 120 min exposure times respectively. Mean emergence in the control populations for 90 min exposure time experiment was $99.17\pm0.63\%$ and ranged from 97.6-100%.

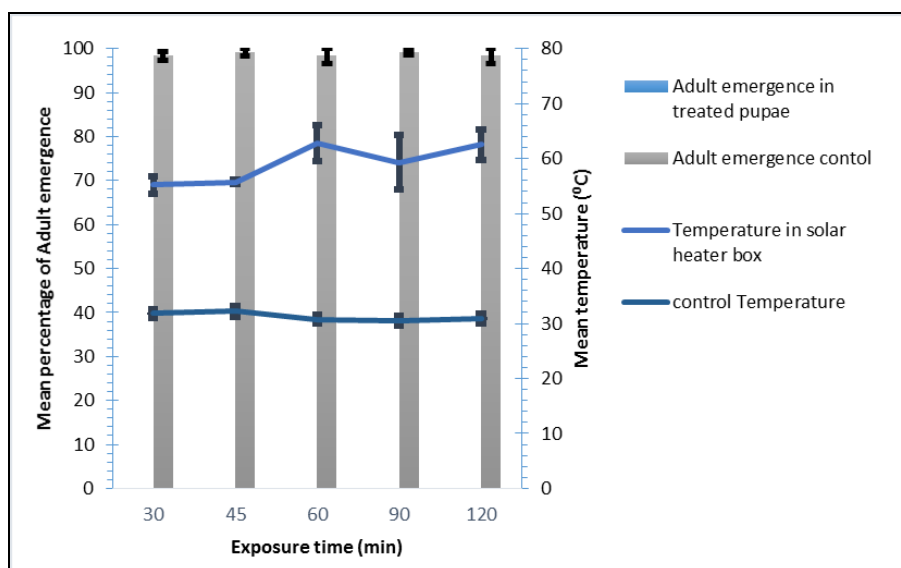


Fig 4: Percentage of *T. castaneum* adult emergence from pupae and temperatures recorded in both the solar heater box and the ambient environment over 2h exposure time

4. Discussion

Results from this study show that solar heat treatment of the life stages of *T. castaneum* in the solar heater box had caused significant mortality to the exposed individuals. All the mean temperatures recorded in the solar heater box were beyond the physiological upper limit of 50 °C for most stored product insect species [32, 19, 20]. Hence, absolute mortalities were achieved in all the life stages of *T. castaneum* tested in this study. Severe mortality in heat treated life stages of *T. castaneum* at temperatures $\geq 50^{\circ}\text{C}$ was documented by [32]. They reported an increased susceptibility of all life stages of this species at temperatures above 58-60°C when studying the time-mortality relationship of its life stages exposed to elevated temperature during heat treatment of flour mills. In another study, [28] while developing a radio frequency treatment using the heat block system, studied the thermal death kinetics in *T. castaneum*, and found the older larvae to be the most heat tolerant life stage, but fixed the temperature of 50-52 °C to be very efficient for the control of all life stage of *T. castaneum*. They recorded a mortality rate in the range of 92.9-100% for all life stages at 52 °C within the maximum of 2 min exposure in the heat block system, with difference among life stage being none significant. In a related study, [6] reported solar heat of 45°C as a lethal temperature for *T. castaneum*, *Trogoderma granarium*, and *R. dominica* and has caused significant mortalities in all life stages of all these species. In a study earlier to this, [11] studied the susceptibility of *T. castaneum* life stages exposed to elevated temperatures

during heat treatment of pilot flour mill. They found that the adult stages are the most resistant stages. They also reported 50-60 °C as the effective maximum temperature which must be held for 10-14 h. Generally, the time required for lethal effect to manifest in insect population is a function of the attained or applied temperature, species involved and the target life stage [16]. Literature information generally indicates that the higher the temperature, the faster the rate of death; and the higher the exposure time the more severe the mortality in the test group [20, 22].

This present study found almost 100% mortality in all life stages of *T. castaneum* after 30 min of exposure time to solar radiation in the cardboard solar heater box used. This implies that the solar heater box used for this present study is very efficient in the collection of solar heat that caused absolute mortality in *T. castaneum* life stages. It can then be said to be a good and an economical technology for control of this pest and other insect pests on cocoa beans and other stored products. This is obviously a remarkable additional improvement with respect to the efficacy of this technique over the other methods of heat treatment reported in the literature; aside the source of heat being free, green and renewable [53, 44].

The low mortality rate ($0.83\pm0.23\%$) in the control population obtained from this study is close to ($0.7\pm0.4\%$) recorded by [28], which they attributed to the effect of handling on the insect life stages rather than mortality due unforeseen circumstances, the same is also assumed for this study.

Similarly, [7] found negligible mortality in untreated control for all life stages, while studying the effect of exposure to variable temperature on delayed and initial mortalities in life stages *T. castaneum* and *T. confusum*.

Information on mortality in the life stages of other insects exposed to solar radiation are found in the literature. For instance, [47] studied the effect of solarisation of eggs and larvae of *Callosobruchus chinensis* (L.) infesting green gram in polythene bags of different colours. They reported a complete mortality of the larvae treated in black polythene bags and of eggs in poly bags of other colours after 24 h of exposure to the sun. Similarly, 100% mortality of eggs and larvae of *C. maculatus* and *C. subinnotatus* infesting seeds of *Vigna subterranean* L. (Verdcourt) after some 24 h exposure to sunlight was reported by [31]. Likewise, [34] and [43] in separate studies using solar heater boxes made from locally sourced materials achieved absolute control of all life stages of *C. maculatus* infested on adzuka beans seeds at a series of exposure periods ranging from 45-120min to solar radiation. They both separately reported that such treatment had no detectable effect on the quality parameters of the treated seeds. Also, [26] studied thermal death kinetic in *Conogethes punctiferalis* using a heat block system and reported 100% mortality in all its life stages at the least exposure time of 55, 12, 6, and 3 min at 44, 46, 48, and 50 °C, respectively. Similarly, [51] used electric heating system and five commercial propane to assess the effectiveness of thermal treatment of empty grain storage bins infested with *Sitophilus oryzae* L. *T. castaneum* and *R. dominica* and reported 100% mortality in all species at exposure periods ranging from 2-40 h. Additionally, mortalities and inhibitions recorded in this study due to extreme temperature are expected as the solar heater box has accumulated temperature regimes in the range of 54-70 °C. These are at levels $\geq 50^{\circ}\text{C}$ reported to be supra-optimal to insect pests and are acutely lethal to stored product insect pests [20, 12]. However, the short duration of exposure time recorded in the solar heater box used in this study is another point that emphasises its improved efficiency compared to most of the techniques reported in the literature. For instance, [32] reported the use temperature $\geq 50^{\circ}\text{C}$ for the thermal elimination of all life stages of *T. castaneum*. However, their study found the needed exposure time to be 0.9, 1.1, 1.5, 1.8 and 7.2 h for adult, old larvae, pupae, eggs and young larvae respectively. Based on the above result, they recommended that use of temperature $\geq 50^{\circ}\text{C}$ for 7.2 h as a bench mark for the control of *T. castaneum*. Similarly, [7] suggested exposure at 54 °C for 270 min as the needed exposure time needed for efficient mortality *T. castaneum*. This study, on the contrary, proved that exposure for just 30-120 min can eliminate all life stages of *T. castaneum* on cocoa beans and by extension on other related commodities that are hosts to this pest in Malaysia and related ecologies. These exposure times is less than half the time recommendation by [7] and [33], even at its highest exposure time (120 min).

5. Conclusion

It could be concluded that exposure in solar heater box for 30-120 min attained temperatures that are adequate to get rid of cocoa beans from the infestation of all life stages of *T. castaneum*. Temperatures of $59.59 \pm 1.74^{\circ}\text{C}$ - $70.73 \pm 1.98^{\circ}\text{C}$ were recorded during the experiments with adult stages of *T. castaneum* and have caused mortalities of 99.17-100% in the exposed adults. Temperatures regime of 68.40 ± 1.43 - $72.05 \pm 2.65^{\circ}\text{C}$ were recorded during experiments on larval stages and a corresponding 100% mortalities in all treated

larvae. Temperature regimes in the range of $58.16 \pm 64.30 \pm 0.92^{\circ}\text{C}$ were recorded in the solar heater during experiments with egg stages. These levels have caused 100% egg hatch inhibition. The experiment with pupal stage recorded temperature regimes in the range of 55.18 ± 1.52 - $62.78 \pm 3.28^{\circ}\text{C}$ and had caused 100% mortality of the pupal staged for all exposure times. These temperature regimes and their corresponding mortalities indicate that the solar heater box could be used efficiently in eliminating all life stage of *T. castaneum* on cocoa beans. This technology may, therefore, be used as a viable option to chemical disinfestation which is not only expensive but facing ever increasing challenges due to concerns about residues in feeds and food stuff and the issue of resistance to numerous insecticides recorded in many species. It could be found handy in place of methyl bromide, which has been banned and withdrawn for use on stored commodities.

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