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EFFICIENT SOLAR HEATER BOX FOR CONTROL OF Tribolium castaneum (HERBST) (COLEOPTERA: TENEBRIONIDAE) ON COCOA BEANS

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By

GAMBO ABDULLAHI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

October 2017

DEDICATION

To my family members

Abstract of thesis presented to Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

EFFICIENT SOLAR HEATER BOX FOR CONTROL OF *Tribolium castaneum* (HERBST) (COLEOPTERA: TENEBRIONIDAE) ON COCOA BEANS

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October 2017

Chairman : Professor Rita Muhamad Awang, PhD
Faculty : Agriculture

Insect infestation is one of the factors that is normally considered during the grading of cocoa beans. *Tribolium castaneum* (Herbst) is one of the insect pests that has been consistently found attacking cocoa beans in Malaysia. Solar heater boxes of smaller sizes have been found to be effective in collection and retention of solar radiation as heat at levels lethal to stored product arthropod pest inside the box. The need to determine the damage potential of *T. castaneum* on cocoa beans and to develop solar heater box that could handle large amount of commodity lead to this study with the following objectives: (1) to determine the damage potential of *T. castaneum* on Malaysia cocoa beans (2) to construct a solar heater boxes of different sizes and assess their solar heat-trapping capacity as well as the effect of quantity of cocoa beans and exposure time on the heat trapping ability of the solar heater box (3) to evaluate the effect of solar heat trapped by best performing solar heater box on the life stages of *T. castaneum* (4) to examine the effect of solar heat treatment at different exposure times in cardboard solar heater box on the quality attributes of cocoa beans. Damage potentials of *T. castaneum* on cocoa beans were investigated under laboratory conditions by focusing on the effect of different initial population densities (0, 10, 20 and 30) at five post infestation storage times (30, 60, 90, 120 and 150 days) as well as their interactions on final adult population density, percentage of insect damaged cocoa beans, percentage of weight loss, and weight of insect feeding residues. Both factors and the associated interaction had a highly significant ($P<0.01$) effects on all the response variables assessed. The highest mean final population density of 129.67±4.60 was recorded in samples infested with 30 adults and stored for 150 d, while the least mean adult population density of 10.81±0.54 were recorded on samples infested with 10 adults and stored for 30 days. The highest percentage (50.97±1.21%) insect damaged cocoa beans were recorded in samples infested with 30 individuals, while the least mean percentage (16.88±1.26%) insect damaged cocoa beans were also recorded on samples infested with the lowest 10 adults and stored for 30 days. Similar trends of means were recorded for all the remaining other response variables. Correlations between variables were significant and positive.

Multiple and simple linear regressions analyses were significant ($P<0.01$) and all equations fitted the regression lines perfectly and hence adequately described the relationship between independent and dependent variables. On the overall, the result shows that *T. castaneum* can impact negatively on both the quantity and quality of stored cocoa within just 30 days of infestation, with the impact increasing with increasing population density and post infestation storage time. The effect of sizes of solar heater boxes on their heat-trapping efficiency was studied by exposing solar heater boxes of five different sizes to solar radiation for 5 h. The influence of the quantity of cocoa beans and length of exposure time on heat collection capabilities of the best performing solar heater box was evaluated using five different quantities of cocoa beans (9, 12, 15, 18 and 21 kg) for 30,60 90 and 120 min of an exposure period. The result for the effect of size on heat-trapping capacity shows that the size of solar heater box had a significant effect on the amount of heat trapped in the solar heater boxes. The largest solar heater box trapped the highest mean between and within cocoa beans temperatures (69.38±4.97 and 69.45±3.97°C respectively) over the 5h of exposure time. All bigger heater boxes trapped significantly higher mean temperatures that of the control solar heater box. Heat trapped in solar heater box were significantly affected by the quantity of cocoa beans and length of exposure time. Quantity was inversely related to trapped heat, while, exposure time was proportionally related to trapped heat. Interaction effects were also significant. The highest mean temperatures were obtained at 120 min exposure time using 9kg of cocoa beans for both between and within bean temperature (70.00±0.73 and 71.23±0.85^{0}C respectively), while the least mean temperatures between cocoa bean (43.03±1.92^{0}C) and within beans temperature (44.83±3.09^{0}C) were obtained when 21 kg of cocoa beans were exposed for 30 min. The effects of heat treatment in solar heater box on life stages of *T. castaneum* infested on cocoa beans were examined by artificially infesting 30 adults, larvae, eggs and pupae of *T. castaneum* on one (1) kg of cocoa beans in fabric bags and exposure to solar radiation in solar heater box for 30, 45, 60, 90 and 120 min. Adult and larval mortalities were assessed 24 h after exposure until 72 h. Eggs hatchability and pupal eclosions were also assessed daily for 9 and 7 days respectively after exposure. The results show that the solar heat treatment had a significant lethal effect on all the life stages. Therefore, regardless of exposure time, absolute mortalities were recorded in both the adult and larval population treated in the solar heater box. Similarly, both egg hatchability and adult emergence from pupal stages were effectively inhibited in a similar manner for all solar heater box treated groups. The effect of heat treatment in solar heater box on the proximate and mineral composition, pH levels of the sample of cocoa beans and free fatty acid content of the fats extracted from the treated cocoa beans were determined using standard procedures and protocol for same in cocoa beans. The result shows that solar heat treatment at temperatures lethal to insect pest did not affect any of the quality characteristics of the cocoa beans over the tested periods. On the overall, it was concluded that *T. castaneum* can cause substantial damage on infested cocoa beans. The bigger the solar heater box, the higher the trapped temperature and quantity of beans was inversely related to temperature. All treated life stages of *T. castaneum* suffered absolute mortality with no effect on cocoa beans quality parameters. Hence, the cardboard solar heater box used for this study is an efficient and reliable tool for heat sequestrations for the eco-friendly control of *T. castaneum* on cocoa beans.

Abstrak tesis yang dikemukakan kepada Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

CEKAP KOTAK PEMANAS SOLAR BAGI PENGAWALAN *Tribolium castaneum*(HERBST) (COLEOPTERA: TENEBRIONIDAE) PADA BIJI KOKO

Oleh

GAMBO ABDULLAHI

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Serangan serangga adalah salah satu faktor yang pada kebiasaannya diambilkira semasa penggredan biji koko. *Tribolium castaneum* (Herbst) adalah salah satu serangga perosak yang telah ditemui secara konsisten menyerang biji koko di Malaysia. Kotak-kotak pemanas solar yang bersaiz lebih kecil telah didapati berkesan dalam pengumpulan dan pengekalan radiasi solar sebagai haba pada tahap yang boleh membawa maut kepada penyimpanan produk serangga artropod di dalam kotak. Keperluan untuk menentukan potensi kerosakan *T. castaneum* pada biji koko dan untuk membangunkan kotak pemanas solar yang boleh mengendalikan jumlah komoditi yang besar telah menyebabkan kajian ini dijalankan dengan objektif-objektif seperti berikut: (1) Untuk menentukan potensi kerosakan *T. castaneum* terhadap biji koko Malaysia (2) Untuk membina kotak pemanas solar yang berbeza saiz dan menilai kapasiti memerangkap haba solar dan juga kesan kuantiti biji koko dan masa pendedahan terhadap kebolehan kotak pemanas solar memerangkap haba (3) Untuk menilai kesan haba solar yang diperangkap oleh kotak pemanas solar berprestasi terbaik pada peringkat-peringkat hidup *T. castaneum* (4) Untuk menguji kesan rawatan haba solar pada masa pendedahan yang berbeza dalam kotak pemanas solar kadbod terhadap kualiti sifat-sifat biji koko. Potensi kerosakan *T. castaneum* pada biji koko telah disiasat di makmal dengan menfokuskan pada kesan ketumpatan populasi awal yang berbeza (0, 10, 20 and 30) pada lima masa penyimpanan selepas serangan (30, 60, 90, 120 and 150 hari) dan juga interaksi pada ketumpatan populasi dewasa yang akhir, peratusan serangga yang telah merosakkan biji koko, peratusan kehilangan berat, dan berat makanan serangga. Kedua-dua faktor dan interaksi berkaitan mempunyai kesan signifikan yang tinggi ($P<0.01$) terhadap semua pembolehubah tindak balas yang diuji. Min ketumpatan populasi akhir yang paling tinggi adalah sebanyak 129.67±4.60 telah direkodkan dalam sampel yang dijangkiti dengan 30 dewasa dan disimpan selama 150 hari, sementara min ketumpatan populasi dewasa yang paling sedikit adalah sebanyak 10.81±0.54 telah direkodkan pada sampel yang dijangkiti dengan 10 dewasa dan disimpan selama 30 hari. Peratusan paling

tinggi (50.97±1.21%) serangga yang telah merosakkan biji koko telah direkodkan dalam sampel yang telah dijangkiti dengan 30 individu, sementara peratusan min paling sedikit (16.88±1.26%) serangga yang telah merosakkan biji koko juga telah direkodkan pada sampel yang dijangkiti dengan paling sedikit iaitu sebanyak 10 dewasa dan disimpan selama 30 hari. Trend min yang sama telah direkodkan untuk semua pembolehubah tindak balas yang lain. Korrelasi antara pembolehubah adalah signifikan dan positif. Analisis regresi linear pelbagai dan mudah adalah signifikan ($P < 0.01$) dan semua persamaan padan dengan garis regresi dengan sempurna dan sekali gus cukup untuk menggambarkan hubungan antara pembolehubah bergantung dan bebas. Secara keseluruhannya, keputusan menunjukkan bahawa *T. castaneum* boleh memberi kesan negatif kepada kedua-dua kuantiti dan kualiti koko yang disimpan dalam hanya 30 hari tempoh serangan, dengan kesan yang semakin meningkat berserta peningkatan kepadatan populasi dan masa penyimpanan selepas serangan. Kesan saiz-saiz kotak pemanas solar terhadap kecekapan setiap saiz kotak pemanas solar memerangkap haba telah dikaji dengan mendedahkan lima kotak pemanas solar yang berbeza saiz kepada radiasi solar untuk 5 jam. Pengaruh kuantiti biji koko dan tempoh masa pendedahan kepada keupayaan pengumpulan haba daripada kotak pemanas solar berprestasi terbaik telah dinilai menggunakan lima kuantiti biji koko yang berbeza (9, 12, 15, 18 dan 21 kg) selama 2 jam tempoh pendedahan. Keputusan bagi kesan saiz terhadap kapasiti memerangkap haba menunjukkan bahawa saiz kotak pemanas solar mempunyai kesan yang signifikan ke atas jumlah haba yang terperangkap dalam kotak pemanas solar. Kotak pemanas solar yang terbesar telah memerangkap min terbesar antara dan dalam suhu biji koko (masing-masing 69.38 ± 4.97 dan 69.45 ± 3.97^{o}C) selama 5 jam masa pendedahan. Kesemua kotak pemanas solar yang lebih besar telah memerangkap min suhu yang lebih tinggi dengan signifikannya berbanding kotak pemanas solar pemalar. Haba yang terperangkap dalam kotak pemanas solar dipengaruhi dengan signifikannya oleh kuantiti biji koko dan tempoh masa pendedahan. Kuantiti adalah berkait secara songsang terhadap haba yang terperangkap, sementara, masa pendedahan adalah berkadar terus terhadap haba yang terperangkap. Kesan interaksi juga adalah signifikan. Min suhu tertinggi telah diperolehi pada 120 minit masa pendedahan menggunakan 9kg biji koko untuk kedua-dua antara dan dalam suhu biji (masing-masing 70.00±0.73 and 71.23±0.85^{0}C), sementara min suhu terendah antara biji koko (43.03±1.92^{0}C) dan dalam suhu biji (44.83±3.09^{0}C) telah diperolehi apabila 21 kg biji koko didedahkan selama 30 minit. Kesan rawatan haba dalam kotak pemanas solar terhadap peringkat-peringkat hidup *T. castaneum* yang menyerang biji koko telah diperiksa dengan meletakkan 30 dewasa, larva, telur dan pupa *T. castaneum* pada satu (1) kg biji koko dalam beg fabrik dan pendedahan kepada radiasi solar dalam kotak pemanas solar selama 30, 45, 60, 90 dan 120 minit. Kematian larva dan dewasa telah diuji 24 jam selepas pendedahan sehingga 72 jam. Penetasan telur dan kemunculan dari pupa juga telah diuji setiap hari masing-masing selama tuju (7) hari selepas pendedahan. Keputusan menunjukkan bahawa rawatan haba solar mempunyai kesan yang membawa maut yang signifikan pada kesemua peringkat hidup. Oleh itu, tanpa menghiraukan masa pendedahan, kematian mutlak telah direkodkan dalam kedua-dua populasi larva dan dewasa yang dirawat dalam kotak pemanas solar. Begitu juga, kedua-dua penetasan telur dan kemunculan dewasa daripada peringkat pupa telah dihalang dengan berkesan dengan cara yang sama untuk semua kumpulan yang dirawat kotak pemanas solar. Kesan rawatan haba dalam kotak pemanas solar terhadap komposisi mineral dan proksimat, tahap pH bagi sampel biji koko dan kandungan asid lemak bebas daripada lemak yang diekstrak daripada biji koko yang dirawat telah ditentukan menggunakan protokol dan prosedur biasa begitu

juga dalam biji koko. Keputusan menunjukkan bahawa rawatan haba solar pada suhu yang boleh membawa maut kepada serangga perosak tidak menjejaskan mana-mana ciri-ciri kualiti biji koko sepanjang tempoh diuji. Secara keseluruhan, dapat dikonklusikan bahawa *T. castaneum* mampu menyebabkan kerosakan besar pada biji koko yang diserang. Semakin besar kotak pemanas solar, semakin tinggi suhu yang terperangkap dan kuantiti biji berkait secara songsang terhadap suhu. Semua peringkat hidup *T. castaneum* yang dirawat mengalami kematian mutlak tanpa sebarang kesan pada parameter kualiti biji koko. Oleh yang demikian, kotak pemanas solar kadbod yang digunakan dalam kajian ini adalah alat yang boleh dipercayai dan berkesan untuk penangkapan haba bagi kawalan *T. castaneum* terhadap biji koko yang mesra alam.

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I certify that a Thesis Examination Committee has met on 23 October 2017 to conduct the final examination of Gambo Abdullahi on his thesis entitled "Efficient Solar Heater Box for Control of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) on Cocoa Beans" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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Date: 30 November 2017

This Thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted in fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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%	percentage
^{0}C	degree Celsius
ANOVA	Analysis of variance
Ca	calcium
cm	centimetre
CRD	Completely Randomized Design
Cu	Copper
d	day
D	weight of damaged grains,
Fe	Iron
FFA	Free fatty acids
Fig	Figure
ft	feet
g	grams
h	hour
ha	hectare
K	Potassium
kg	kilogram
L	litre
M	molarity of acid or alkali
Mg	Magnesium
mg	Milligrams
mg/L	milligram/litre
min	minutes
mL	Millilitres
mm	millimetre
N	normality of acid or alkali

Na	Sodium
NaOH	Sodium hydroxide
Nd	Number of damaged grains
Nu	Number of undamaged grains,
P	phosphorus
p	Probability
PROC GLM	General Linear Model Procedure in SAS software
r	correlation coefficient
R^2	coefficient of determination
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis software
U	weight of undamaged grains,
v/v	Volume/Volume basis
w/w	on weight/ weight basis
Zn	zinc

CHAPTER 1

GENERAL INTRODUCTION

The production of cocoa in Malaysia is currently threatened by numerous factors. Prominent among which is the infestation by pests and diseases on the crop in the field and on the fermented and dried cocoa beans in the warehouse (Silvapragasam, 1990; Silvapragasam and Musa, 1990; Hamid and Lopez 2000; Asimah et al., 2014). Stored product insect pests known to infest cocoa beans in warehouses worldwide are in the order Coleoptera and Lepidoptera (Bateman, 2015). The red flour beetle, *Tribolium castaneum* is a cosmopolitan pest of stored products (Rees, 1996; Nenaah, 2014). It is one of the major insect pests attacking stored cocoa beans globally (Bateman, 2015) including Malaysia (Silvapragasam and Musa, 1990; Hamid and Lopez, 2000; Asimah et al., 2014). The attack of cocoa beans by *T. castaneum* causes damages with consequent loss in weight, as well as commercial and nutritional value (Dharmaputra et al., 1999; Tettey et al., 2014). Its infestation of cocoa beans is, therefore, of serious concern and a major problem that normally necessitate fumigation with insecticides (Ridner and Dias, 2007; Jonfia-Essien et al., 2010; Asimah et al., 2014). Numerous insecticide like deltamethrin, chlorpyriphos-methyl, pirimiphos-methyl, malathion (Daglish et al., 1992), phosphine (Qasim et al., 2013), and many others have been used with success against *T. castaneum.*

Although, fumigations with insecticides are extensively utilised for pest containment in all stored product protection including cocoa beans for the prevention of quantitative and qualitative losses instigated by arthropod pests (CA, 2013; Asimah et al. 2014), it is currently fraught with technical problems (Obeng-Ofori, 2010). For instance, phosphine, a popular disinfectant in stored products protection has the technical issue of widespread occurrences of resistance in most stored product insect pests (Qaisarani and Banks, 2000; UNEP, 2014).This has negatively impacted on its established popularity and preference as a reliable tool for fumigation in cocoa and other durable commodities (Savvidou et al., 2003; Navarro et al., 2007). Thus, limiting its suitability, sustainability and acceptability as a tool for pest control in stored products protection (Cao et al., 2003: Savvidou et al., 2003). Also, there is growing concern on the negative effects of pesticide residues in feed/food and the environment (Navarro, 2006; Dayan et al., 2007; Asimah et al., 2014). These have warranted the enforcement of strict regulations and restrictions on the use of insecticides on food and feeds stuff in most advanced societies (Navarro, 2006; Asimah et al., 2014; Anankware et al., 2014). Hence, there is a heightened demand for their substitution with unconventional/alternate control techniques (Qaisarani and Banks, 2000; Navarro, 2006; Jonfia-Essien et al., 2010; Obeng-Ofori, 2010; UNEP, 2014).

Non-chemical and ecologically friendly means of pest management in the post-harvest environment are becoming increasingly significant (Navarro, 2006; Jonfia-Essien et al., 2010). Consequent to the above, tremendous attention is universally being directed

towards alternative control techniques (Obeng-Ofori, 2010; Asimah, et al., 2014; Sha and Khan, 2014). This entails the development and adoption of suitable non-toxic substitutes such as microbial, botanicals, inert materials, biological control agents, controlled environment and physical control methods for pest control purposes (Jonfia-Essien et al., 2010; Sha and Khan, 2014).

Physical control method which include the use of elevated temperature, cold environment, other bio-generated atmosphere, and especially the utilisation of solar heat treatment at high temperature regimes has been established as an effective means of pest control since the beginning of the 1900s (Mahroof et al., 2005). But it is recently receiving much interest as substitute disinfestation method to synthetic pesticides in stored product protection (Philips and Throne, 2009). This is because it is economically cheap, rapid, easy to manipulate and uses the safest form of energy relative to other sources of heat (Yoshida and Gichuku, 1983; Ragaa et al., 2013).

Among the major challenges of utilisation solar thermal energy and other forms of high temperature in stored product protection is the lack of the needed instruments to accurately deliver the desired heat doses economically at the required targets (Burks et al., 2000). The above can be overcome by designing and developing local, cheap, efficient, and easy to construct grain disinfestation technologies (Qaisarani and Banks, 2000), especially those that can operate on solar energy which is abundant in the tropics. Mekasha et al., (2006a) developed a prototype grain disinfestation solar heater box using metal sheet, and was successfully used to disinfest *Callosobruchus maculatus* (Fab.) on adzuka beans (Mekasha et al., 2006b). But it was prohibitively expensive and too heavy to handle easily (Ragaa, 2011; Ragaa et al., 2017). A cost efficient model of Mekasha's solar heater box was produced by Ragaa, (2011) using cardboard, but it could only handle 7 kg of grains efficiently. This quantity is too small for practical purposes and may render the adoption of the technology unattractive even to small holder farmers.

It can, therefore, be deduced from the above that even though, *T. castaneum* is always associated with dried cocoa beans in Malaysia, recent information on quantitative figures of the extent of its damaging effects on cocoa beans is lacking in literature. Similarly, cardboard solar heater boxes of smaller sizes have been shown to successfully trap temperature at levels lethal to stored product insect pests and have demonstrated an effective disinfestation of *C. maculatus* on adzuka beans with negligible effects on seed viability. However, the potential of cardboard solar heater boxes of bigger dimensions to trap such insect lethal solar heat is uncertain. Likewise, the effect of such solar heat treatment on nutritional quality parameters of treated commodities is also unknown. Hence, there is the need to study the damage potential of *T. castaneum* on cocoa beans, develop bigger cardboard solar heater boxes and validate their potential to trap solar heat at regimes lethal to stored product arthropods, and assess its efficiency for the control of other stored product insect pests on other commodities. The main objective of this study, therefore, is to develop a solar heater box that can efficiently handle larger amount of grains, and effectively control *T. castaneum* infestation on cocoa beans.

The specific objectives are:

1) To determine the damage potential of *T. castaneum* on Malaysian cocoa beans.
2) To construct solar heater boxes of different sizes and assess their solar heat/energy trapping capacity.
3) To evaluate the effect of solar heat trapped by best performing solar heater box on the life stages of *T. castaneum.*
4) To examine the effect of solar heat treatment at different exposure times in cardboard solar heater box on the nutritional quality attributes of cocoa beans.

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