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SHORT COMMUNICATION

DEVELOPMENT OF EFFICIENT SOLAR HEATERS FOR STORAGE INSECT PEST MANAGEMENT

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ABSTRACT

Two designs of solar heaters, obtuse-base-angle box and square box, were evaluated for solar energy trapping efficiency using adzuki bean as test crop. The angle box had three base-angles and glued with either copper shim or aluminium foil from inside. The latter had three box heights with black painting either from inside or outside. Then adzuki bean seed, infested with *Callosobruchus maculatus,* was heat treated at 1, 2, 3, and 4 cm seed layer thickness in 118° base-angle aluminium foil glued box heater. Maximum within-seed temperature of 80.7°C was obtained in the aluminium foil glued heaters; the 118° base-angle heater having high performance. For the square box heaters, the maximum within-seed temperature of 73.5°C was evident in those painted black from inside with better performance of boxes with 10 cm height. Square boxes painted black from outside were not as efficient. Heating of up to 3 cm adzuki bean seed layer resulted in complete *C. maculatus* control. Thus, obtuse-base-angle box heater glued with aluminium foil from inside could be a potential solar heater for storage pest control by optimising base angle and size of the box.

Key Words: Adzuki bean, aluminium, *Callosobruchus maculatus,* copper foil

RÉSUMÉ

Deux conceptions de fours solaires, boîte avec base en angle obtus et boîte carrée étaient évaluées pour leur efficacité dans la capture d'énergie solaire en utilisant le grain Adzuki comme culture d'essai. La boite à angle avait trois angles de base et était collée avec soit un revêtement de cuivre ou de l'emballage aluminium, de l'intérieur. Ce dernier avait trois fois la hauteur de la boite avec peinture noire soit de l'extérieur ou à l'intérieur. La semence de grain d'Adzuki, alors infestée par *Callosobruchus maculatus* était traité à la chaleur à une épaisseur de la couche de semence de 1, 2, 3 et 4 cm par 118o dans un four à boîte à angle de base et emballage d'aluminium collé. La température maximale au sein de la semence de 80.7° C était obtenue dans les fours aluminium collé, étant donné que le four à angle de base à 118o présente une performance élevée. Concernant les fours à boîte carrée, la température maximale au sein de la semence de 73.5° C était évidente dans ceux qui étaient peint en noir de l'intérieur, avec la meilleure performance provenant de boîtes de 10 cm de haut. Les boîtes carrées peintes en noir de l'extérieur n'étaient pas aussi efficaces. Le chauffage jusqu'à 3 cm d'épaisseur de la couche de semence de grain d'Adzuki a produit une élimination complète de *C. maculatus*. Ainsi le four à boîte avec base en angle obtus et revêtement d'aluminium collé de l'intérieur pourrait etre un four solaire potentiel en vue de l'élimination de parasite de stokage par optimisation de l'ange de base et des dimensions de la boîte.

Mots Clés: Grain d'Adzuki, aluminium, *Callosobruchus maculatus*, revêtement de cuivre

INTRODUCTION

Heat energy collected from solar radiation has multiple uses in agriculture. Drying of grains and other agricultural produce such as vegetables, fruits and fish using solar energy has been an important practice of preservation since early civilisation (CEC, 1986; Brenndorfer *et al.*, 1987; Chuaham and Ghaffar, 2002). Solar energy is also used to sterilise soil and cooking food. Solar heating of grains in solar heaters was found to effectively control storage pests in a number of studies (Nakayama *et al.*, 1983; Murdock and Shade, 1991; Kitch *et al.*, 1992; Chinwada and Giga, 1996; Ntoukama *et al.*, 1997; Lale, 1998; Mohammed *et al.*, 2001; Chuaham and Ghaffar, 2002). However, most of these studies were based on experimental findings of small quantities of seeds treated at a time and recommended further investigation on refinement of the technology for practical application.

Using solar heater constructed from black polyethylene sheet as an under-layer and transparent polyethylene sheet as an over-layer, Murdock and Shade (1991) reported that exposure of cowpea seeds to solar heat for one hour and more raised the temperature inside the heater in excess of 60° C and killed all stages of *Callosobruchus maculatus*. Their results also revealed that solar treatments had no significant effect on cooking time, seed moisture content and seed germination. A relatively large capacity solar heater made of similar material (50 kg capacity) was demonstrated by Kitch *et al.* (1992) to be effective and fairly suitable for low resource farmers to control cowpea weevil, *C. maculatus*, with special emphasis on the cultural and material setting of northern Cameroon.

In general, earlier investigations revealed the potential of solar energy in the integrated management of storage insect pests. Utilisation of solar energy for post-harvest insect pest control is a safe technology. Moreover, the energy is free for everyone except the initial cost of solar heater construction. To make use of this safe and free energy development of solar heater with better capacity and solar energy trapping efficiency is worth investigating. This study, therefore, was envisaged to develop solar heater(s) of larger capacity with better solar energy trapping ability.

MATERIALS AND METHODS

Two solar heater designs, an obtuse-base-angle boxes and square boxes, were evaluated in separate experiments.

Obtuse-base-angle heaters. Obtuse-base-angle box heaters (see prototype, Fig. 1) were constructed with 1.2 mm thick metal sheet. The upper open side of the boxes was 0.5 m x 0.5 m, width by length and the perpendicular height was 0.5 m. The interior sides of the box heaters that faced the sun were glued with 0.127 mm thick copper shim (treatments 1-3) and those of treatments 4-6 were glued with aluminium foil for solar radiation absorption. The box under respective treatment for the copper shim and aluminium foil glued heaters had 106°, 112° and 118° base-angle. Hence, six designs contrasting different base-angles and solar radiation absorption materials were compared with standard check. The exterior sides and bases of the box heaters were insulated by fixing a 1 cm thick polystyrene sheet to minimise conduction and convection heat losses.

A mesh tray was fixed at the middle of the height of each box. In order to determine whether the heat generated was sufficient to control storage insect pests, adzuki bean, *Vigna angularis*, seed was used as a test crop. On the mesh tray 1 kg adzuki bean seed in a fabric bag was placed to allow heating from all direction. The boxes were covered with 0.15 mm thick clear plastic sheet as a glazing material. The plastic cover was fixed tightly using an angled-iron frame tied with rubbers band to hooks on opposite sides of the boxes.

A solar heater demonstrated by Kitch *et al.* (1992) was used as a standard check (Treatment 7) with a reduced size of 0.5 m x 0.5 m as follows. A dried grass mattress of ca 5 cm thickness was spread on the ground as an insulating material to reduce heat loss to the ground. A black polyethylene sheet was laid on the grass mattress on which 1 kg of adzuki beans was evenly spread roughly in a single layer. The seeds were then covered with 0.15 mm thick clear plastic sheet. The edges of both black and clear plastic sheets were folded under and small stones were placed at the folded edges to secure air tightness.

Each heater constituted a block in randomised complete block design in four replications. The treatments were applied for two hours, 11:00 am to 1:00 pm. The experiment was repeated twice and pooled data were used for analysis. Temperature records at 10 minute intervals were used to examine the trend in temperature increment.

Square box heater. Square box heaters were constructed with a 1.2 mm thick metal sheet. The boxes were 0.5 m x 0.5 m, width by length. Box heaters under treatments 1-3 were square; top-end-open boxes of 10, 15 and 20 cm height, respectively, whose interior sides, that faced the sun, were painted black. The exterior sides and bases of these heaters were insulated by fixing 1 cm thick polystyrene sheet to minimize conduction and convection loss of heat. One kilogramme adzuki bean in fabric bag was placed in the boxes. The boxes were covered with a 0.15 mm thick clear plastic sheet that was fixed tightly to the box by fitting an angled-iron frame tied with rubber band on the back of the box.

Box heaters under treatments 4-6 were square, bottom-end-open boxes, of 10, 15 and 20 cm height, respectively, exterior sides of which facing the sun were painted black. Two centimeter thick polystyrene sheet was laid on the ground as an insulator to minimise heat loss to the ground. One kilogramme adzuki beans in a fabric bag was placed on the polystyrene insulator and covered by the boxes. A standard check, similar to that described in the first experiment was included (Treatment 7).

This experiment was conducted in randomised complete block design with four replications where each heater constituted a block. It was repeated twice and pooled data were used for analysis. The treatments were applied for two hours (11:00 am to 1:00 pm) and temperature, again temperature records were summarised as described in the first experiment.

Effect of heating on *C. maculatus*. Adzuki beans infested with *C. maculatus* were subjected to heat at 1, 2, 3 and 4 cm-seed layer thickness until the within-seed temperature reached 60°C, to investigate the effect of seed layer thickness on the control *C. maculatus* by heat treatment. This temperature was found to kill all stages of most storage insect pests (Fields, 1992). Untreated

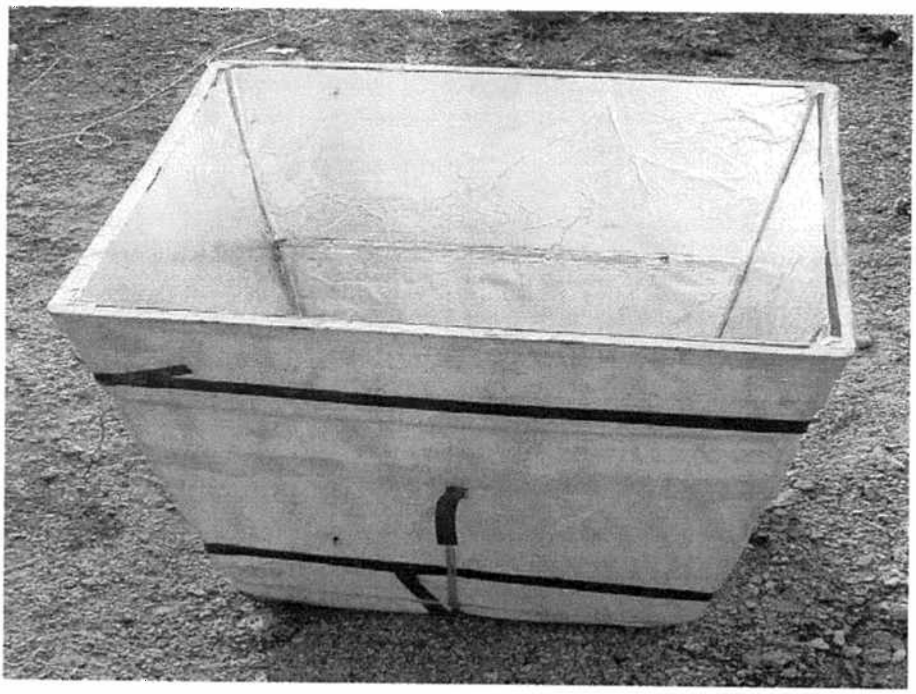


Figure 1. Obtuse-base-angle box heater glued from inside with aluminium foil.

seed was included as check. A 118° obtuse-base-angle box heater glued from inside with aluminium foil was used. Within-seed temperatures were measured at the middle of each seed layer thickness. Samples of 100 g seed from each treatment were evaluated. Dead and live adults *C. maculatus* were counted 24 hours after treatment and removed thereafter to asses the effect of heating on adult mortality. Adults that emerged later were counted after two weeks to evaluate the effect of heating on immature stages.

Temperature measurement. Temperatures (between-and within-seed, and ambient) were recorded at two minutes interval with 'Type J' thermocouples fitted to 'Intech Micro 2100 16A' data logger using 'Microscan 2000 version 4' software, to assess the trend of temperature increment in each solar heater design. A 5 mm diameter thermocouple was placed in the seed lot in between the seeds to sense the temperature between the seeds (between-seed temperature) that affects adults and eggs outside the seed. The within-seed temperature that affects larvae and pupae was sensed by a 1 mm diameter thermocouple inserted into seed, drilled with battery operated Standard PBC drill of 1mm diameter drill bit (14, 500 rpm). The hole around the thermocouple was sealed with instant filler to exclude external air from entering seed cavity along the thermocouple wire. Air temperature was sensed using thermocouples of 1 mm and 5 mm diameter placed at about 30 cm above the ground; the average value was considered.

Statistical analysis. Statistical Analysis Software (SAS) was used for data analysis using analysis of variance (ANOVA) procedure. Thereafter, each treatment in the first two experiments were subjected to linear regression analysis. For the third experiment, Tukey's Studentized Range Test was used for mean separation.

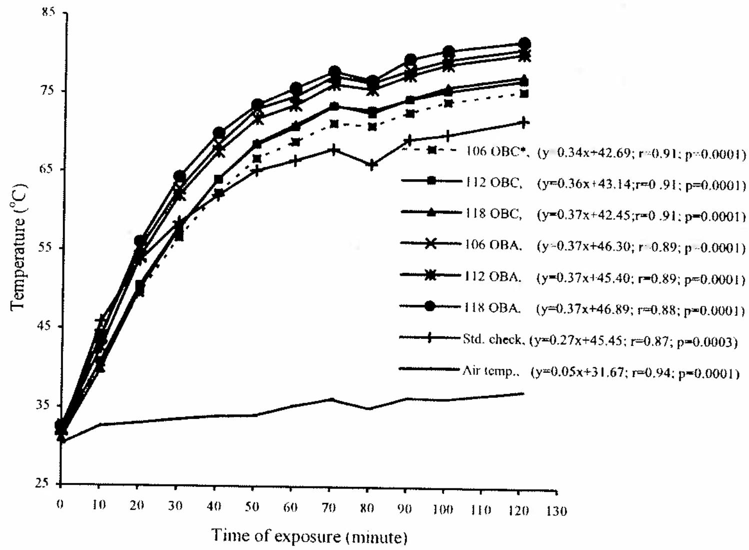
RESULTS

The average annual solar insolation (10 years average) around Kuala Lumpur was 4.7 KW h m^{-2} day^{-1}, which is characterised as moderate level according to NASA Surface Meteorology and Solar Energy Data Set (Focus Solar, 2001).

Between-seed temperatures were almost similar for all treatments of obtuse-base-angle box heaters at the start of solar exposure, ranging between 31.0 and 32.8°C (Fig. 2). The temperature in the standard check increased faster at the beginning of exposure to the solar radiation (between 10 to 20 minutes) but the increment slowed in later exposure periods compared to the box heaters. On the other hand, obtuse-base-angle box heaters had slower temperature acceleration at the start of solar exposure but increased faster in later exposure periods. Between-seed temperature in obtuse-base-angle box heaters glued with aluminium foil (OBA) and copper shim (OBC) from inside exceeded that of the standard check in about 20 and 40 minutes of solar exposure, respectively. Within-seed temperatures at the start of solar exposure were also similar for all the treatments, ranging between 30.8 and 31.8°C (Fig. 3). Within-seed temperatures in the obtuse-base-angle box heaters glued from inside with aluminium foil and copper shim also exceeded that of the standard check in about 30 and 40 minutes of solar exposure, respectively.

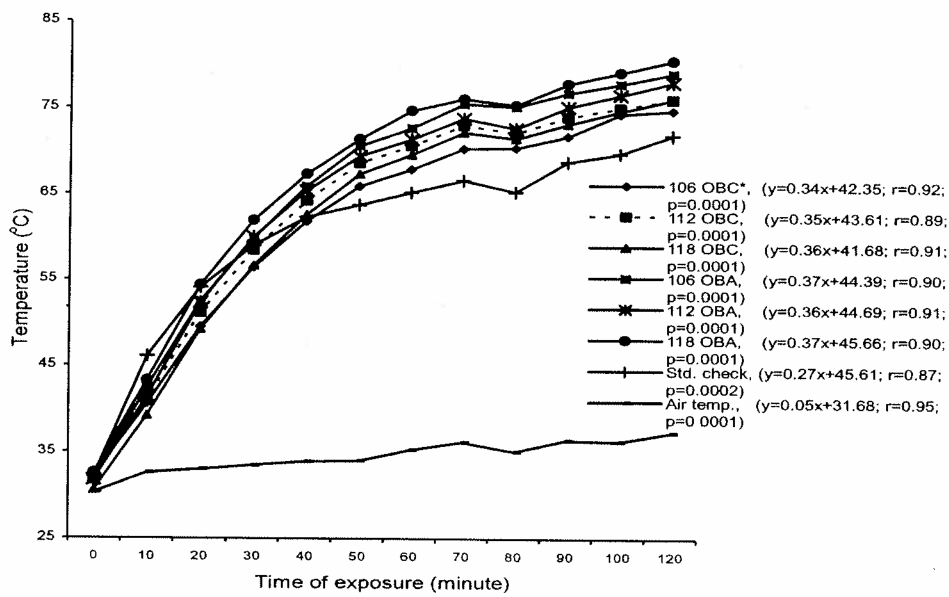
Both types of the obtuse-base-angle box heaters trapped more solar energy compared to the standard check. However, greater efficiency in trapping solar energy was obtained from the OBAs. Maximum between-seed temperature of 81.9°C was recorded in OBAs, while maximum of 78.1 and 74.9°C were recorded in OBCs and the standard check, respectively, in two hour's solar exposure. On the other hand, maximum within-seed temperature of 80.7°C was obtained in OBAs, while 77.1 and 71.9°C were recorded in OBCs and standard check treatments, respectively. The drops in temperatures at some points during the exposure period were due to intermittent cloud cover that prevailed. Ambient temperature during the study period ranged between 30.3 and 37.3°C with a mean of 34.5°C.

At all solar exposure periods, more solar energy was trapped in OBAs, where significantly higher between-seed temperatures were recorded in 118° base-angle OBA than the standard check. Between-seed temperatures in the OBCs were not significantly different from standard check, though relatively higher solar energy was trapped by these box heaters. At thirty minutes of solar exposure, were between treatments with respect



*Values preceding abbreviations refer to box base angle; OBC = Obtuse-base-angle box heater glued from inside with copper shim; OBA = Obtuse-base angle box heater glued from inside with aluminium foil; Std. check = Standard check; Air temp. = Air temperature; Values in parenthesis refer to regression equation.

Figure 2. Trend in between-seed temperature increment in obtuse-base-angle box heaters glued from inside with copper shim or aluminium foil due to exposure to sun light.



*Values preceding abbreviations refer to box base angle; OBC = Obtuse-base-angle box heater glued from inside with copper shim; OBA = Obtuse-base angle box heater glued from inside with aluminium foil; Std. check = Standard check; Air temp. = Air temperature; Values in parenthesis refer to regression equation.

Figure 3. Trend in within-seed temperature increment in obtuse-base-angle box heaters glued from inside with copper shim or aluminium foil due to exposure to sun light.

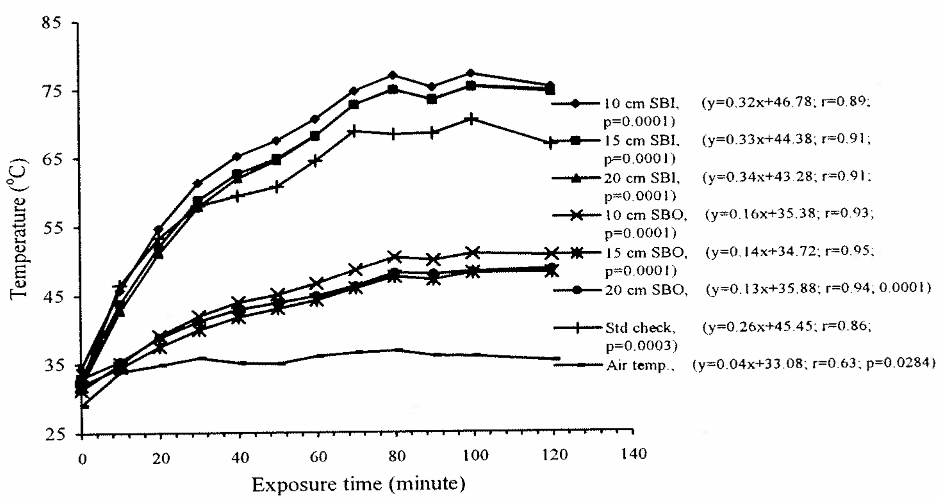
to within-seed temperatures were not statistically significant (P<0.05). However, within-seed temperature in 118°OBA was significantly higher than the standard check throughout later exposure periods. In general, OBAs trapped higher solar energy than the OBCs, though the differences were not statistically significant.

Square box heaters painted black from inside (SBI) trapped higher solar energy than the standard check and square box heaters painted black from outside (SBO). Both between-seed (Fig. 4) and within-seed temperatures (Fig. 5) in the standard check increased faster than the square box heaters for the first 10 minutes of solar exposure whereas in later periods the increment became slow and exceeded by the SBIs. On the other hand, SBOs were inferior in trapping solar energy to the standard check. Though significant variation was not observed between heights of the boxes, those with shortest height (10 cm) resulted in relatively higher temperature under both types of square box heaters.

Maximum between-seed temperature of 75.1°C was recorded in SBIs, while 50.6 and 66.7°C were obtained in SBOs and standard check, respectively in the two hours exposure. Maximum within-seed temperature of 73.5°C was evident in the SBIs, while 49.7 and 64.8°C were recorded in SBOs and standard check, respectively. Mean air temperature of 35.0°C that ranged from 29.0 to 36.8°C was recorded during the study period.

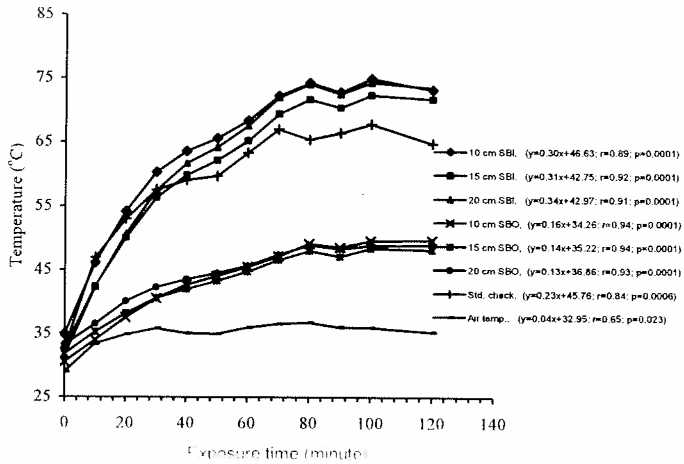
Under all exposure time, SBOs resulted in significantly lower between-seed and within-seed temperatures than the SBIs. During early exposure times of up to one and half hour between-seed and within-seed temperatures in the SBIs were not significantly different from the standard check. However, at two hours exposure significantly higher temperatures were recorded in those box heaters than in the standard check. Square box heaters painted black from outside were not capable of trapping much solar energy as the temperatures in these heaters could not reach a level lethal (Fields, 1992) in the two hour exposure period. On the other hand, the temperatures in SBIs and the standard check reached lethal level as early as about half an hour of solar exposure.

Within-seed temperature of ca 60°C, lethal temperature to most stored product insect pests, was attained at 30, 50, 64 and 70 minutes of exposure for 1, 2, 3 and 4 cm seed layer thickness treatments, respectively (Fig. 6). Adult bruchids



*Values preceding abbreviations refer to box height; SBI = Square box heater painted black from inside; SBO = Square box heater painted black from outside; Std. check = Standard check; Air temp. = Air temperature; Values in parenthesis refer to regression equation.

Figure 4. Trend in between-seed temperature increment in square box heaters of different box height painted black from inside or from outside due to exposure.



*Values preceding abbreviations refer to box height; SBI = Square box heater painted black from inside; SBO = Square box heater painted black from outside; Std. check = Standard check; Air temp. = Air temperature; Values in parenthesis refer to regression equation.

Figure 5. Trend in within-seed temperature increment in square box heaters of different box height painted black from inside or from outside due to exposure to sun light.

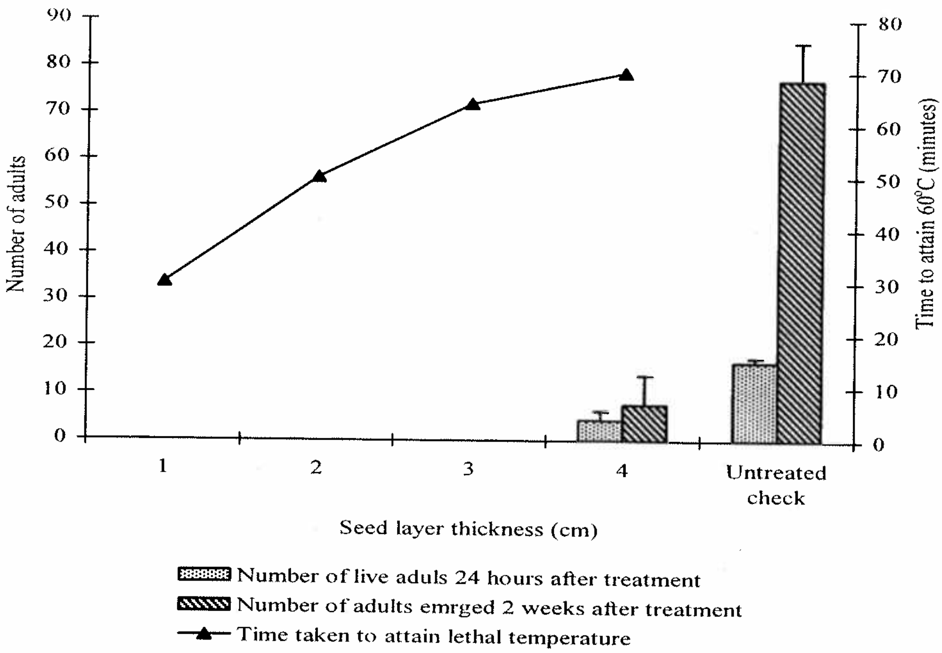


Figure 6. Effect of adzuki bean, *V. angularis*, seed layer thickness on the control of *C. maculatus* by heating (± standard error).

treated with the seeds under 1, 2 and 3 cm seed layer did not survive heat treatment, while a significantly high number of adults, 21.3, was found alive in the untreated check. Though not significantly different from the other seed layer thicknesses, 4.3 adults survived in the 4 cm seed layer treatment.

The number of adults emerged in two weeks time after heat treatment revealed that heating of infested adzuki beans at various seed layer thickness also affected immature stages of the pest that reside within the seed. No adult had emerged from the seeds treated at 1-3 cm thickness in the aforementioned duration while 6.7 adults were evident from seeds treated at 4 cm seed layer. On the other hand, significantly high number of adults (77) had emerged from the untreated check.

DISCUSSION

Though copper has higher thermal conductivity (385 W/m-K) than aluminium (210 W/m-K) (OSA, 1995), it trapped less solar energy in this study. This is largely due to the reflection of light by aluminium to the center, of the heaters where the seeds were laid. Aluminium is known to possess higher reflectance (reflection coefficient of 0.9) than copper (reflection coefficient of 0.63) (OSA, 1995). Thus, solar heaters glued with aluminium foil concentrated the solar radiation to the seeds and generated more heat compared to the copper shim glued box heaters.

The low solar energy trapping capacity of the SBOs could be attributed to the condition that large proportion of the solar radiation that reached the absorber surface were emitted back and lost. On the other hand, in the heaters painted black from inside, the proportion of radiation that was emitted was trapped by the glazing plastic and absorbed back by the absorber surface, hence, they were able to trap more energy.

In the SBIs, seeds to be heat treated were spread on the bottom floor of the heater. Thus, it is necessary to leave some space uncovered by the seed for solar radiation absorption. Moreover, the sides of the boxes failed to face the sun, even at noon, due to their perpendicular orientation to the bottom surface, hence, contributing less to the absorption of solar energy. This situation, therefore, would not allow treating large amounts of seed at a time.

It has already been discussed that aluminium foil glued box heater performed best due to the high reflectance property of aluminium. The sides of the boxes are in a position to receive sunlight, especially around noon, due to their obtuse orientation. This orientation helped to concentrate the reflected light energy to the center of the boxes where the seeds were laid. Besides, in these heaters seeds are spread on mesh tray fixed at the middle of the perpendicular height of the heaters. This would allow much more surface area on the sides of the boxes, above the seed layer, for solar energy absorption. Moreover, the seeds could be heated from all directions through convection by the heated air. This would enable this solar heater to treat large amounts of seed at a time. The solar heaters evaluated or demonstrated so far, however, could treat only sparsely spread single layer of grain.

The result of heating various seed layer thicknesses revealed that solar heating of adzuki beans of up to 3 cm seed layer thickness in obtuse-base-angle heater glued from inside with aluminium foil, for about an hour around noon would result in maximum control of *C. maculatus*. A 1 cm thick adzuki bean seed in a 0.5 m x 0.5 m box weighed 7.6 kg. Hence, it could be extrapolated to that in an obtuse-base-angle box heater having 1.5 m x 1.5 m seed spreading surface, 68.4, 136.8 and 205.2 kg adzuki bean seed could be treated at a time in 1, 2 and 3 cm of seed layer thicknesses, respectively. Though this area is only one quarter of the surface area of a 50 kg capacity solar heater demonstrated by Kitch *et al.* (1992), up to 1.4, 2.7 and 4.1 fold seed can be treated at a time with an obtuse-base-angle heater at 1, 2 and 3 cm seed layer thickness.

From the result of this study, it could be concluded that obtuse-base-angle box heaters glued with aluminium foil from inside are potential solar heaters for use in storage pest management. However, further refinement efforts should be made to optimise base-angle of the box heater that could trap high solar energy in shorter exposure period. This must also be accompanied with determination of the largest manageable box size that could be applicable to farmers.

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REFERENCES

Brenndorfer, B., Kennedy, L., Bateman, C.O.O., Trim, D.S., Mrema, G.C. and WerkoBrobby. 1987. Solar dryers - their role in post-harvest processing. Commonwealth Science Council. London, U.K. 298pp.

Commission of the European Community (CEC). 1986. Solar energy in agriculture and industry: Potential of solar heat in European agriculture, an assessment. In: *Solar Energy R&D in the European Community*. Schepens, G., Mahy, D., Buis, H. and Palz, W. (Eds.), pp. 198. Series H. D. Reidel Publishing Company, Netherlands.

Chinwada, P. and Giga, D. P. 1996. Sunning as a technique for disinfesting stored adzuki beans. *Postharvest Biol. Techn.*, 9:335-342.

Chuaham, Y. S. and Ghaffar, M. A. 2002. Solar heating of seeds - a low cost method to control bruchid (*Callosobruchus* spp.) attack durimg storage of pigeonpea. *J. Stored Prod. Res.* 38:87-91.

Fields, P. G. 1992. The control of stored product insects and mites with extreme temperatures. *J. Stored Prod. Res.* 28:89-118.

Focus solar. 2001. Solar insolation levels. http://www.focus solar.com/insolation.htm. Accessed on September 2003.

Kitch, L. W., Ktoukam, G., Shade, R. E., Wolfson, J. L. and Murdock, L. L. 1992. A solar heater for disinfesting stored cow peas on subsistence farms. *J. Stored Prod Res.* 28:261-267.

Lale, N. E. S. 1998. Preliminary studies on the effect of solar heat on oviposition, development and adult mortality of the cowpea bruchid, *Callosobruchus maculatus* (F.) in the Nigerian savanna. *J. Arid Envir.*40:157-162.

Mohammed, D. E., Yadav, T. D., Singh, V. S. and Siddiqui, K. H. 2001. Disinfesting maize grain from *Sitophilus oryzae* and its variant with solar heat. *Indian J. Entomol.* 63:413-420.

Murdock, L. L. and Shade, R. E. 1991. Eradication of cowpea weevil (Coleoptera: Bruchidae) in cowpea by solar heating. *American Entomologist* 37: 228-231

Nakayama, T., Allen, J., Cummins, S. and Wang, Y. 1983. Disinfestation of dried food by focused solar energy. *J. Food Proc.* 7:1-8.

Ntoukama, G. , Kitch, L. W., Shade, R. E. and Murdock, L. L. 1997. A novel method for conserving cow pea germplasm and breeding stocks using solar disinfestation. *J. Stored Prod. Res.*33:175-179.