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Analysis of quality retentions in cocoa beans exposed to solar heat treatment in cardboard solar heater box

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Abstract: The use of heat treatment for the disinfestation of insect pests of stored products has been demonstrated to hold great potential as an ecofriendly alternative technique of choice in the feature grain storage systems. However, the success of this method depends on the application of heat on the commodity at levels that cause maximum mortality on the target population and insignificant effect on commodity quality deterioration. Experiments were conducted to assess the effect of heat treatment in solar heater box on the proximate and mineral composition of cocoa beans over series of exposure times. The result shows that solar heat treatment in cardboard solar heater box at temperatures lethal to stored-product insect pest did not affect any of the quality characteristics of the cocoa beans over the tested periods. The implication of this for the application of the cardboard solar heater box for the disinfestation of insect pests on cocoa beans was discussed.

Subjects: Zoology; Entomology; Food Additives & Ingredients; Power & Energy

Keywords: cocoa beans; heat treatment; quality characteristics; cardboard solar heater box; free fatty acids; pH

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PUBLIC INTEREST STATEMENT

Cocoa is a vital agricultural commodity in international trade. The presence of insect and their by-products, as well as insecticides residues on the beans are focal considerations during its purchase. Also, due to environmental and health concerns on the use of insecticides on food items, there is a heightened campaigns for the development and use of safer alternatives methods of pest control. Heat treatment of stored product has been shown to hold great potential in the disinfestations of durables from insect pests infestations with no residues on products. The cheapest source of heat for such disinfestation is the solar energy that is abundant in all cocoa producing regions worldwide. We developed a simple technology that can be used to trap solar energy at levels lethal to insect pests. We evaluated the effect of treating cocoa beans in the device at the insect lethal temperatures and found that is safe on all the quality parameters assessed.

1. Introduction

Cocoa beans rank high among agricultural commodities traded globally (Afoakwa, Quao, Takrama, Budu, & Saalia, 2013) and are mostly produced in developing nations of tropical rainforest climatic zones close to the Equator (Afoakwa et al., 2013; Bateman, 2015; Guehi, Zahouli, Ban-Koffi, Fae, & Nemlin, 2010). More than 90% of cocoa is produced by resource poor smallholder farmers (Bateman, 2015; Knudsen & Fold, 2011). It is a primary raw material in the production of chocolate (Adeyeye et al., 2010; Ardhana & Fleet, 2003; Joel, Pius, Deborah, & Chris, 2013) and are mostly traded with advance countries with high standards of regulations on the physical and chemical properties of the beans (Adeyeye et al., 2010; Bateman, 2015). This normally demands for the need for more aggressive inspections and/or disinfestation of the beans especially at the point of export. Hence, cocoa beans meant for export are expected to be of high quality and free from insect infestation, as well as pesticides residues, as one of the criteria for grading of cocoa beans consignment at purchase is the level of arthropods pest infestations (Malaysian Cocoa Board [MCB], 2017).

However, Sivapragasam (1990) noted that the immature stages of the major insect pests species affecting cocoa beans in Malaysia are hardly detected during inspection, but could serve as sources of cross infestations during shipment. He suggested that regardless of the numbers of adult insect, the beans for export must be fumigated. Fumigation is normally done with synthetic insecticides (Asimah et al., 2014; Sivapragasam & Musa, 1990). Such disinfestations normally eliminate apparent infestations, leaving some hidden infestations that may later lead to population rebounds during shipment (Sivapragasam & Musa, 1990). Similarly, it, in most of the cases, leaves traces of such disinfectants at levels above the maximum residues limits (MRL) set by importing countries (Asimah et al., 2014). Residues in food has been one the major concerns of stored-product specialist with respect to the use insecticides on stored product (cocoa beans inclusive) (Asimah et al., 2014; Obeng-Ofori, 2008). Strict regulation on MRL imposed by importing countries has triggered the need to explore other alternatives to the use insecticides for insect pest disinfestation on cocoa beans (Asimah et al., 2014).

Temperature extremes, especially elevated temperature (at or above 50°C), from diverse heat sources have been proven to be a good potential alternatives to fumigants for stored product disinfestation (Hansen, Johnson, & Winter, 2011). It has been utilised to manage insect pests of stored product for centuries (Downes et al., 2008; Fields, 1992). Solar energy is one of the heat source through which high temperature can be generated for utilisation in agriculture (Chikaire et al., 2010) for numerous uses, ranging from produce drying, livestock heating, soil and product heating for disease and pest management (Hansen et al., 2011).

The use of solar heat for the protection of grains from insect pests attack is one of the methods with enormous advantages of being fast in action, green, abundant and renewable in nature (Beckett, Fields, & Subramanyam, 2007; Ragaa, Awang, Omar, Sinniah, & Grozescu, 2017; Ragaa et al., 2013). Thus, it offers ample promise for the feature grain storage systems, especially for integration with other methods (Banks, 1998; Burks, Johnson, Maier, & Heaps, 2000), and as credible and rapid standalone alternative phytosanitary protocols/quarantine tool for durable stored product (Beckett et al., 2007; Subramanyam, Mahroof, & Brijwani, 2011).

Successful use of solar energy for pest management in stored products, however, requires the use of certain basics tools that will guarantee the application of the required doses of the solar heat without any noticeable effects on product quality (Neven, 2000, 2003). The cardboard solar heater box is an innovative modest technology that can guarantee easy collection and retention of solar radiation as heat at levels lethal to all stored product arthropod pest inside the box (Ragaa et al., 2013). It has been most recently proved to be efficient against *Tribolium castaneum* (Herbst) (Abdullahi, Muhamad, Dzolkhifli, & Sinniah, 2017), one of the major pest of cocoa beans in Malaysia (Asimah et al., 2014; Hamid & Lopez, 2000; Sivapragasam, 1990; Sivapragasam & Musa, 1990) and worldwide (Bateman, 2015). Earlier to this, the literature reported a significant thermal mortalities using solar heat trapped in solar heater boxes made from cardboard and other materials against some major insects pests of stored product like *Callosobruchus maculatus* (Fabricius, 1775) on adzuka beans (*Vigna angularis* Willd) without any effect on moisture content, seed viability and cooking time of the treated product (Fawki et al., 2014; Khaled et al., 2015; Mekasha, Dzolkifli, Yusuf, Rita, & Noorma, 2006; Ragaa et al., 2017).

Adoptability of the use of cardboard solar heater box for commodity disinfestation will largely depend on the extent of its confirmed assurance on the protection of quality parameter of the treated commodity in the face of maximum mortality in the pest species. Quality retention on any food stuff is critical, as consumers are increasingly becoming more anxious about the composition of all dietary components of the food items in their diet (Ieggli, Bohrer, Nascimento, & Carvalho, 2011; Joel et al., 2013). Hence food quality and safety have become one of the major concerns of consumers especially in technologically advanced societies (Guehi et al., 2010).

Nutritional quality of cocoa beans (*Theobroma cacao* L.) is said to be the function of the proximate composition of its powder, which in turn depends on their mineral elements, carbohydrates, proteins and lipids contents (Adeyeye et al., 2010; Afoakwa et al., 2013; De Muijnck, 2005; Joel et al., 2013; Lettieri-Barbato et al., 2012; Torres-Moreno, Torrescasana, Salas-Salvadó, & Blanch, 2015). Others quality determinants are fineness, pH, wettability, dispensability and solubility (De Muijnck, 2005; Joel et al., 2013). Likewise, the nutritional quality of cocoa beans largely determines same in the by-products produced from them (Adeyeye et al., 2010; Joel et al., 2013).

We studied the effect of heat treatments of cocoa bean at five different exposure times in cardboard solar heater box on its pH, free fatty acid (FFA), proximate and mineral elements compositions.

2. Materials and methods

2.1. Design, materials and construction of cardboard solar heater box

Cardboard solar heater box of truncated and inverted pyramid shape were constructed maintaining the obtuse-base-angle of 118° (Figure 1) reported of being more efficient in trapping more solar radiation (Fawki et al., 2014; Mekasha et al., 2006; Ragaa, 2011). The cardboard solar heater box with the topside of 100 cm, height of 112 cm, and base of 60 cm was constructed using, cardboard sheets (2 mm thickness), polystyrene (12 mm thickness), woods (5.08 × 5.08 cm^2 thickness), adhesive glues and nails. The wood served as the frame at each angle and the cardboard sheets were used as walling material for all the lateral sides of the box. The interior sides of cardboard walls were coated with black paint and glued from within with aluminium foil, while the polystyrene was used as an insulating material from the outside of the cardboard sheets. The adhesive glue and the nails were used for joining the components.

Figure 1. Showing sketch of the design of the solar heater box (A), the cardboard solar heater box (B), and the top side view of the solar heater box with the commodity in fabric bag (C).

2.2. Sample preparations, solar heat treatment and the experimental design
Standard Malaysian cocoa beans grade one (smc1) was purchased from Cocoa Research and Development Centre Hilir-Perak, Malaysia. The beans were sorted to remove the flat beans and other contaminants to obtain clean lot of beans. About 100 g of the clean cocoa beans in fabric bags were exposed to solar heat treatment in cardboard solar heater box for 30, 45, 60, 90 and 120 min. Each exposure time served as treatment and was replicated three times in a Randomized complete block design. Temperature achieved for each treatment was recorded using two types (1 and 5 mm diameter) of J-type thermocouple attached to an Intech Micro Scan 2100-16A data logger (Intech Instruments Ltd) using Microscan 2000 software version 4 connected to a PC. The 1 mm diameter thermocouple was inserted into a randomly selected cocoa bean via a hole drilled with hand held battery operated drill using 1 mm drill bit to record the within cocoa bean temperature. The 5 mm diameter thermocouple was placed between the beans lot to capture between beans temperature.

After each exposure time, the beans were removed and allowed to cool to room temperature before being sealed in plastic bag. For each replication in each treatment a control sample (beans not exposure to heat treatment in the cardboard solar heater box) was set aside. The cocoa beans from all the treatments and the controls were seperately grinded used a mechanical grinder (Retsch SK 100, standard GuBeisen, 2002, Retsch GMBH and Co., Germany) in the laboratory. The ground samples were stored at room conditions of temperature and relative humidity (29.45 ± 0.43°C and 66.43 ± 1.65%, respectively) until needed.

2.3. Determination of the effects of solar heat treatment in the cardboard solar heater box on the quality of cocoa beans
The ground samples were thoroughly pulverised and sieved through 0.21 mm diameter sieve to obtain a fine cocoa beans powder. The fine powders were separately placed in sealed plastic bags according to the treatments and were used for the analysis of their proximate, pH, FFA and the mineral element constituents to determine the effect of the treatment on same.

2.3.1. Proximate analysis
Proximate compositions of the samples were analysed using standards procedures and methods of AOAC (2005) for cocoa beans. The ash, crude fat, crude protein, moisture and crude fibres were determined using methods 972.15, 963.15, 970.22, 931.04 and 972.15, respectively. The “by difference method” was used for the determination of the carbohydrate. All analyses were done in triplicates.

2.3.2. pH and free fatty acids determination
The pH values for each sample were determined using AOAC (2005) official method 970.21 for cocoa beans. The percent FFA content of the cocoa butter extracted from the treated samples and that of the controls were determined following Cocoa and Sugar Confectionery Official Method 42-1993 (IOCCC, 1996) as modified by Guehi et al. (2008) and Afoakwa et al. (2014).

2.3.3. Mineral element analysis
Analyses of mineral element composition of the cocoa beans were done using AOAC (2005) methods with some minor modifications. Sample solutions for the determination of mineral composition were processed as follows. Approximately, 0.25 g of the ground sample of the cocoa beans was weighed into a digestion flask and was digested at 100°C using 10 mL of H_2SO_4 in the block digester (Gerhardt Kjeldertherm, Germany) until all the materials were completely digested (mixture turn near colourless). Then, 5 mL of H_2O_2 was added and the digestion process continued until an apparently colourless solution is obtained. All digestion was conducted in the fume hood following standard practices. After the digestion process was completed, the colourless solution was cooled and filtered into a 100 ml volumetric flask through a filter paper (Whatman No. 4). The volume of the solution was then made to the mark by adding deionized water.

2.3.4. Determination of Ca, Mg, Zn, Fe, Cu, Na, K and P
The amount of Ca, Mg, Zn, Fe, Na and K were determined using atomic absorption spectrophotometer (AAS PinA Acle, 900T-Perkin Elmer) (Anvoh et al., 2009). Aliquots of one (1) mL of the digest was used for each element to assess the Ca, Mg, Zn, Fe, Cu, Na and K content of the samples using standard procedure recommended by the manufacturer. The amount of P was determined using an aliquot of 2 ml of the digest in molybdovanadate solution following standard procedures (Afoakwa et al., 2013).

2.4. Data analysis
Data generated from this experiment was analysed by one-way ANOVA using PROC GLM procedure in SAS 9.4 (SAS institute Inc. 2012). Means were compared using Tukey HSD (p = 0.05) where ANOVA show that significant difference.

3. Results

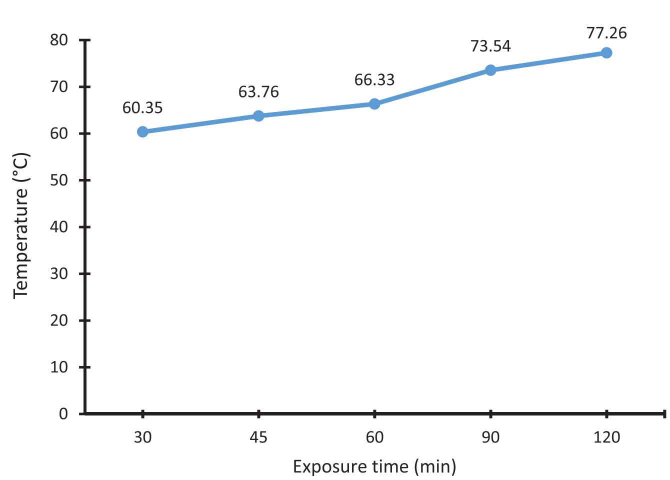
3.1. Temperature recorded in the solar heater box
The mean temperatures recorded during the experiment in the solar heater box were 60.35 ± 2.41, 63.76 ± 2.05, 66.33 ± 4.33, 73.54 ± 3.78 and 77.26 ± 5.08°C at 30, 45, 60, 90 and 120 min exposure time, respectively (Figure 2). The mean ambient temperature was 29.45 ± 0.43°C.

3.2. Effect of exposure in solar heater box on proximate composition
Proximate composition in food and feed analysis refers to the proportions of the six components of food or feed substrates namely: crude protein, moisture, crude fibre, crude fat (ether extract), total ash and the carbohydrate content expressed in percentages.

The results for effect of solar heat treatment on proximate composition of the cocoa beans treated in solar heater box are shown in Table 1. One-way ANOVA output for the effect of the heat treatment in solar heater box on the chemical composition show that treatments did not had any significant (Moisture content: F = 1.2, DF = 5, 12, p = 0.3679; Ash: F = 0.3, DF = 5, 12, p = 0.9063; Crude fat: F = 0.76, DF = 5, 12, p = 0.5985; Crude protein: F = 0.92 DF = 5, 12, p = 0.5034; Crude fibre: F = 1.2, DF = 5, 12, p = 0.6791; Carbohydrate: F = 0.97, DF = 5, 12, p = 0.9623) negative effect on any of the proximate components of the treated cocoa beans as compared to those of the untreated samples.

3.3. Effect of exposure in solar heater box on pH and percentage of free fatty acids
ANOVA output for pH show that a highly significant (F = 74.59; DF = 5, 12; p < .0001) difference exist among mean for pH values over the different exposure time. On the other hand, the ANOVA

Figure 2. Mean temperature recorded in solar heater box for each exposure time.



output for FFA composition of cocoa butter for all exposure times show that heat treatment had no detrimental effect (F = 1.37, DF = 5,12, p = 0.3032) on the percent FFA content of the fats extracted from the solar heat treated cocoa beans compared to those from the control samples.

The mean comparisons for the pH levels show that highest mean pH value (5.74 ± 0.01) was recorded at 30 min exposure time and was significantly higher than all other mean pH values from other exposure time except that at 45 min. The least mean pH value of 5.31 ± 0.03 was recorded at 120 min exposure time and was significantly lower than all other pH values for all exposure times except that at 60 min (Table 2). While the percentage of FFA of the butter fat ranged from 1.12 ± 0.05% to 1.18 ± 0.19%. The least percentage FFA (1.12%) was recorded in fats extracted from the control samples and the highest (1.18%) was obtained from samples exposed for 45 min in the solar heater box (Table 2). However, differences are not statistically significant.

3.4. Effect of exposure in solar heater box on mineral element composition

The results for the effect of heat treatment in solar heater box on the mineral element compositions of cocoa beans are presented in Table 3. The ANOVA output for the all the mineral elements indicate that, heat treatment in solar heater box did had any significant (Na: F = 0.85, DF = 5, 12, p = 0.5378; K: F = 0.93, DF = 5, 12, p = 0.4976; Mg: F = 1.63, DF = 5, 12, p = 0.2252; Ca: F = 0.63, DF = 5, 12, p = 0.6813; Zn: F = 0.4, DF = 5, 12, p = 0.8414; Cu: F = 1.76, DF = 5, 12, p = 0.1968; P: F = 1.13, DF = 5, 12, p = 0.3965) effect on the mineral element composition of the treated cocoa beans for all the exposure times at the recorded temperature levels (Figure 1). However, the ANOVA for Fe content showed that a highly significant (Fe: F = 6.83, DF = 5, 12, p = 0.0031) difference exist among the means of Fe element composition of the treated cocoa beans for some of the exposure times (Table 3).

The highest mean Fe content (1.38 ± 0.07 mg/L) was recorded in samples treated for 120 min in the solar heater box, while the least (0.86 ± 0.05 mg/L) was recorded with samples exposed for 45 min. However, the least mean value was only significantly lower than the highest value which was significantly higher than values from all other exposure times (Table 3).

4. Discussion

The results obtained from this study show that heat treatment in the solar heater box used for the study at all exposure time and temperatures regime attained did not affect any of the proximate compositions of the treated cocoa beans (Table 1). Similarly, except for Fe, solar heat treatment in the cardboard solar heater box did not affect the mineral element compositions of cocoa beans (Table 2). This implies that the solar heater box used for this study could guarantee the successful disinfestation of insect pests on cocoa beans and other commodities without any concerns for loss in quality. The non-negative effect of the solar heat in trapped in the solar heater box on any of the assessed quality parameters of cocoa beans seen in this study is expected because, exposure of

Table 1. Effect of heat treatment in solar heater box on proximate composition of cocoa beans (Means ± SE)

Exposure time (min)	Moisture (%)	Ash (%)	Crude fat (%)	Crude Protein (%)	Crude fibre (%)	Carbohydrate (%) bd
Control	5.33 ± 0.58[a]	5.13 ± 0.45[a]	41.22 ± 2.56[a]	12.30 ± 0.10[a]	9.78 ± 0.80[a]	26.76 ± 3.66[a]
30	5.33 ± 0.13[a]	4.83 ± 0.01[a]	45.67 ± 1.36[a]	11.67 ± 0.71[a]	10.89 ± 0.61[a]	21.61 ± 2.65[a]
45	5.08 ± 0.17[a]	4.83 ± 0.11[a]	42.34 ± 1.34[a]	11.57 ± 0.43[a]	11.55 ± 0.45[a]	24.37 ± 1.98[a]
60	4.81 ± 0.63[a]	4.97 ± 0.01[a]	39.00 ± 3.02[a]	12.38 ± 0.00[a]	10.66 ± 0.67[a]	28.72 ± 3.47[a]
90	4.71 ± 0.14[a]	4.98 ± 0.00[a]	39.80 ± 3.40[a]	12.28 ± 0.07[a]	10.67 ± 0.38[a]	27.11 ± 3.30[a]
120	4.26 ± 0.15[a]	4.99 ± 0.08[a]	40.33 ± 2.33[a]	11.83 ± 0.22[a]	9.33 ± 0.38[a]	28.74 ± 2.33[a]

Notes: Means ± SE in the same column followed by same letter(s) are not significantly different (p = 0.05).
bd = value arrived at using the by difference method of carbohydrate determination.

Table 2. Effect of heat treatment in solar heater box on pH levels of cocoa beans and free fatty acids composition of extracted cocoa butter fats (Means ± SE)

Exposure time (Min)	pH levels	Free fatty acids (%)
Control	5.42 ± 0.04[b]	1.12 ± 0.05[a]
30	5.74 ± 0.01[a]	1.15 ± 0.01[a]
45	5.66 ± 0.01[a]	1.18 ± 0.19[a]
60	5.37 ± 0.02[bc]	1.17 ± 0.02[a]
90	5.41 ± 0.01[b]	1.16 ± 0.07[a]
120	5.31 ± 0.03[c]	1.17 ± 0.05[a]

Note: Means ± SE followed with the same letter in the same column are not significantly different (p = 0.05).

commodities to solar heat treatment have been previously found not to adversely affect any quality characteristics of the so treated commodities and their by-products (Hansen et al., 2011). Furthermore, recent reports of the safe use of solar radiation collected in variable heaters without any detrimental effects on quality abound in literature. Ntoukam, Kitch, Shade, and Murdock (1997) reported that solar heating of cowpea (*Vigna unguiculata* (L.) Walp) seeds for the control of bruchids had no effect on its viability. Mekasha (2004) found that solar heat treatment of adzuka beans (*V. angularis*) in solar heater box made from metal sheets for one hour to control *C. maculatus* infestation did not have any significant effect on moisture content, and the viability of the treated seeds. Ragaa (2011) reported that solar heat treatment of the adzuka beans (*V. angularis*) seeds in cardboard solar heater box had no effects on its moisture content, germination percentage and other desirable seedlings parameters, such as shoot and root length.

Also, Al-Amri (2013) reported a safe use of solar radiation on sorghum (*Sorgum bicolar* (Linn.) Moench) grains at temperature >50°C for 2 h using different solar heaters made from tin cans without any undesirable consequence on seed viability, crude protein, total fat content and its acidity, and moisture content. He, however, found lower moisture content, hectoliter weight, and 1,000 kernel weight after solar heater treatment. Lower moisture content is desirable and beneficial for the stored product (Hill, 2002; Lale, 2002; Obeng-Ofori, 2008). Other past reports of the safe use of heat from solar radiation in solar heaters made from variable materials on the quality of treated products have been documented (see Kitch, Ntoukam, Shade, Wolfson, & Murdock, 1992; Lale & Ajayi, 2001; Murdock & Shade, 1991).

Similarly, reports of significant improvement in the quality of seeds after exposure to solar radiation have been shown by Chauhan and Ghaffar (2002). They reported an increase in seed germination percentage of pigeon pea (*Cajanus cajan* (Linn.) Huth) by 2% after solarisation at 65°C in polyethene bags. Likewise, advantageous uses of high temperature with respect to improvement of the quality of products have been found in some non-durables. For instance, Lara, García, and Vendrell (2006) reported that mild heat treatment of strawberry fruit (*Fragaria ananassa* Linn.) was beneficial for its quality when compared to the untreated. Das, Kumar, and Shah (2013) revealed that a careful microwave heat treatment of cashew (*Anacardium occodentale* Linn) nut helped to keep rancidity very low for six months post treatment. Similarly, hot water treatment of sweet potato (*Ipomoea batatas* Linn) was found to be helpful in lowering sprouting of the roots with insignificant effects on quality (Hu et al., 2011). All these literature citations and the result of this study strengthens the assertions that heat treatment is a viable alternative tool that could be adopted for stored product disinfestation without much concerns about the loss of product quality.

Though, significant differences were seen in the mean values for pH and Fe element composition, the pattern of the means differences, where the highest pH (4.74 ± 0.01) and the highest Fe content (1.38 ± 0.07), was recorded at 45 and 120 min of exposure time respectively is very unpredictable and appears to be a random rather than treatment dependent response. The random response is the situations where the observed difference in the measured response of experimental objects is so inconsistent and unpredictable. Such

Table 3. Effect of heat treatment in solar heater box at different exposure times on mineral element composition of cocoa beans

Exposure time (min)	Na	K	Mg	Ca	Fe	Zn	Cu	P
Control	2.01 ± 0.11^a	25.74 ± 1.66^a	3.65 ± 0.27^a	$1.19^{\pm}0.27^a$	1.07 ± 0.12^b	0.017 ± 0.014^a	0.014 ± 0.00^a	1.43 ± 0.67^a
30	1.76 ± 0.05^a	23.66 ± 0.59^a	3.97 ± 0.09^a	1.27 ± 0.11^a	0.89 ± 0.03^b	0.022 ± 0.00^a	0.031 ± 0.00^a	2.06 ± 0.15^a
45	1.75 ± 0.08^a	23.76 ± 0.05^a	4.89 ± 0.07^a	1.52 ± 0.12^a	0.86 ± 0.05^b	0.023 ± 0.00^a	0.037 ± 0.00	1.59 ± 0.14^a
60	1.80 ± 0.10^a	23.67 ± 1.24^a	4.76 ± 0.77^a	$1.49^{\pm}0.29^a$	0.87 ± 0.06^b	0.014 ± 0.06^a	0.038 ± 0.00^a	1.04 ± 0.51^a
90	1.78 ± 0.18^a	25.48 ± 0.64^a	4.81 ± 0.56^a	1.35 ± 0.23^a	1.04 ± 0.10^b	0.024 ± 0.002^a	0.04 ± 0.00^a	2.28 ± 0.41^a
120	1.77 ± 0.20^a	24.54 ± 0.84^a	4.10 ± 0.10^a	1.12 ± 0.2^a	1.38 ± 0.07^a	0.020 ± 0.01^a	0.038 ± 0.0^a	0.93 ± 0.78^a

Note: Means ± SE in the same column followed by same letter(s) are not significantly different (p = 0.05).

responses may be due to hidden variation in experimental conditions but not necessarily due treatment effect. The variability in Fe content of treated cocoa beans from this study is said to be a random response because there is no evidence in the literature that suggest that heat treatment enhances Fe element content of the cocoa product or that of its pH. This may imply that it is very difficult to specifically tell that such inconsistent pattern of variation of means is primarily due to the effect of the solar heat treatment. The random response of variable to treatments has been reported (Arthur, 2004; Golizadeh et al., 2016).

It is also important to note that processing of cocoa beans are normally done through the application of heat that is often higher than those recorded in all experiments with the solar heater box used in this study. For instance roasting, a vital step in cocoa beans processing for the production of chocolate and its products, is mostly done at 130–150°C for up to 45 min (Krysiak, 2011), or 250 ± 5°C for 5 min (Méndez-Albores, Campos-Agular, Moreno-Martínez, & Vázquez-Durán, 2013). These much of temperature regimes are quite above the maximum mean temperature of 77.26°C (Figure 2) recorded in the solar heater in this study over the exposure period of 2 h. It is, therefore, safe to argue that heat treatment in this solar heater box is safe and can be an ideal method for quick thermal disinfestation of cocoa beans from insect pests infestation especially at the point of export or local sales. Such treatment may even be advantageous as high temperature in treating cocoa beans during processing is believed to aid the attainment of required browning of the beans, a much desired physiochemical property in chocolate production (Krysiak, Adamski, & Żyżelewicz, 2013). It is also known to aid in producing the unique aroma of cocoa (Chokhonelidze, Forgor, & Brown-Acquaye, 2014; Krysiak, 2011). For this reason, it could be envisaged that heat treatment of cocoa beans in solar heater box may help to enhance its desired qualities as it can retard fungal growth or even kill them as well (Qaisarani & Banks, 2000). This will likely increase the acceptability of such treated beans at the point of sales, hence can attract better prices for the farmers. This, however, needs to be investigated in a separate study, especially relating to value addition along the cocoa beans supply chain.

5. Conclusion

We concluded that solar heat treatment of cocoa beans in the cardboard solar heater box had no effects on its chemical and mineral composition. The proximate and mineral elements compositions (except Fe), and the FFA compositions of the sample of cocoa beans treated in the cardboard solar heater box for the tested exposure times did not differ significantly with those of the untreated control samples.

Although a significant difference was recorded for pH levels of some samples, the difference was not ordered along temperature gradient and may not, therefore, be said to be due to the effect of the treatment. Hence, the cardboard solar heater box can be used as an efficient and modest technology for the disinfestation of insect pests on stored cocoa beans with no concern on quality deterioration.

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Competing interests
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