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Research Article

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Impact Analysis of Solar Heater Box with Linear Actuator on Characteristics of Chickpea Seeds

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Abstract

Food security is one of the major concerns of humankind in the present era and a lot of work has been done to ensure the availability of food to the growing population. Post-harvest technology is one of the key components to store the seeds for long duration for consumption as food or grow as seed. The disinfection of seeds during storage from insect pests is one of the major problems that need to be addressed. In this study, an efficient solar box is designed which is operated through renewable solar energy. For this purpose, the solar heater box was prepared of an acrylic sheet (2mm thickness), Lasani sheet (2mm thickness) and hardboard sheet (12mm thickness) which were an octagon in shape with 135ºC at the base. A 12v linear actuator was installed in the solar box along with hardwood log (saw tooth-like comb) to equally distribute the heat in the seed place for experiment. The highest thermal performance was generated by an acrylic solar heater box 87.40 ℃ compared to hardboard and Lasani box. However, the material used for assembling acrylic boxes was too costly. A hardboard box was too heavy and the temperature was generated 69.69℃ which was relatively significant to the temperature recorded in Lasani solar heater box (70.19℃) at after 6 hour of an observation. Concerning the financial aspect, the price of each of the three solar heater boxes was estimated based on the cost of the materials used to construct the boxes and the additional labour costs, with the assistance of carpenters during assembly. These costs show how much cheaper the Lasani box is compared to the other prototypes. The temperature at a depth of 6 cm was noted 67.42℃ among Chickpea seeds, whereas the temperature recorded within seeds was 69.61℃. Furthermore, the experiment conducted in RCBD revealed that germination percentage of seeds at a depth of 6cm was observed to be 97% after treatment. The overall conclusion of the study is that the solar box with linear actuator is more efficient as compared to traditional drying method.

Keywords: Solar heater box, linear actuator, heat treatment, Chickpea grains.

Introduction

Food consumption is continuously increasing globally, whereas food prices drastically increasing due to inflation which cause a great threat to food security, particularly in underdeveloped countries (Hussain *et al*., 2020). By 2050, the world population is projected to reach near about 9 billion, demanding a 60% increase in food production (Bradford *et al*., 2018). Most of this population growth is anticipated due to emerging nations, many of which have hunger and food insecurity problems. Concerns about food demand are growing due to factors such as increased urbanization, climate change and land exploitation for the cultivation of non-food crops (Zhang *et al*., 2021). In recent decades, most countries have prioritized improving agricultural production, land use and population control to meet this growing food demand. In recent year, food loss is a serious concern that does not receive the attention it deserves and less than 5% of research funds have been devoted to this issue (Deepak & Prasanta, 2017). The post harvesting techniques are often used to preserve the food for long period of time or store the seeds for next season. The most ancient method is open or solar drying that is still popular in rural regions for drying several crops such as fruits, vegetables, and medicinal plants (Deng *et al*., 2021). Most crops have high moisture levels and can quickly deteriorate and even spoil if not kept in temperature-controlled storage facilities. Agricultural crops with a high moisture level rise to advancement of bacteria and fungi. Drying reduces the moisture level, which prevents the growth of bacteria and fungi (Saka *et al*., 2022). Seed unsuitability at the time of harvest is naturally high for safe storage and may cause contamination or spoilage. As a result, it is critical to correctly estimate the moisture content and dry the crops to appropriate levels. Grain needs to be dried to 13% for long-term storage and 15% for short-term storage to be stored safely (Trabelsi *et al*., 2019). The reason behind adopting this practice is that there are significant chances of losses in terms of quality and quantity. According to literature, approximately twenty thousand (20,000) species are identified as pests of stored products (Sidauruk *et al*., 2022; Lijun Zhu *et al*., 2022) and estimated to destroy 1/3 of the global production of food that is worthy of more than 100 billion dollars (Kale PR *et al*., 2021; Singh *et al*., 2021). Quantity losses happen when the grain is consumed, whereas quality losses show up as a reduced economic value of the crops or a decreased market worth of the product (Morrisonn *et al*., 2019; Elhadi *et al*., 2019). This results in decreased nutritional value, decreased seed germination, increased moisture, free fatty acid levels, decreased pH, and protein contents in food grain, which (Marinez *et al*., 1997) describe as losses in quantity. Additionally, they could be carriers of bacteria and other harmful protozoa that cause dysentery and typhoid. In order to accommodate the world's expanding population, agricultural fields are being turned into residential and commercial sectors, which reduces the amount of land available for crop cultivation. Methyl bromide fumigation has been widely employed to treat stored grains for phytosanitary reasons, however the US Environmental Protection Agency (USEPA) has acknowledged that it has significant consequences on ozone depletion. Accordingly, alternatives to methyl bromide are therefore required for all postharvest applications (Kumar *et al*., 2017). Insect resistance to phosphine and market demands for residue-free grain has once more increased the importance of heat disinfestations Qaisrani & Banks, (2000). Open sun drying is a slow technique of drying crops that increases the danger of contamination, the deterioration of nutritional quality, and the creation of mycotoxin, which affects an estimated 4 billion people in underdeveloped countries and is the cause of more than 40% of the worldwide illness burden (Watson *et al*., 2022). Traditionally, agricultural commodities like grains, fruits, and vegetables are left to dry out in the sun on surfaces like compacted dirt, mats, concrete floors, and roadways. Applying this technique results in successful drying but exposes the agricultural products to contamination from dirt, dust, insect infestation, and loss from birds and other animals (Oni *et al*., 2021). Moreover, there is a risk that cereal grains and other products will be contaminated with aflatoxin (Watson *et al*., 2022). To avoid the contamination of various bio agents, numerous studies have been undertaken and published on the natural convection solar drying of agricultural products (Babar *et al*., 2021; Komolafe *et al*., 2022; Pinto *et al*., 2022). Solarization is one of the most reliable practices for seed disinfection for various noxious store grain insect pests. Such management of store grain pests is more successful, particularly in tropical and sub-tropical nations where there is lot of sunshine all the year (Gambo *et al*., 2018). The aim of this study is to capture and retain solar thermal in our newly built solar heater box with the required lethal level (i.e.,>50-60ºC) (Field, 1992; chauhan & Ghaffar, 2002) of heat in a small exposure time to disinfect the stored grain products from store grain insect pests without damaging grains quality. Furthermore, the effect of solar drying on the characteristics of Chickpea seed was also determined.

Material and Methods

Design and structure of an octagonal solar heater boxes: Earlier, solar heater boxes were made with a reverse pyramid shape and an obtuse base angle of 118º which had proved to be more efficient at capturing more solar energy (Fawki *et al*., 2014; Gambo *et al*., 2018; Abdullahi *et al*., 2019). In this study, a slight modification has been made to the overall design, which consist of an acrylic sheet (2mm thickness), a lasani sheet (2mm thickness) and hardboard sheet (12mm thickness). The solar boxes are designed with an octagon shape having 135º at the base to trap the heat inside as shown in Fig. 1. The inner and outer shaped view of solar heater box is shown in Figure. 2.

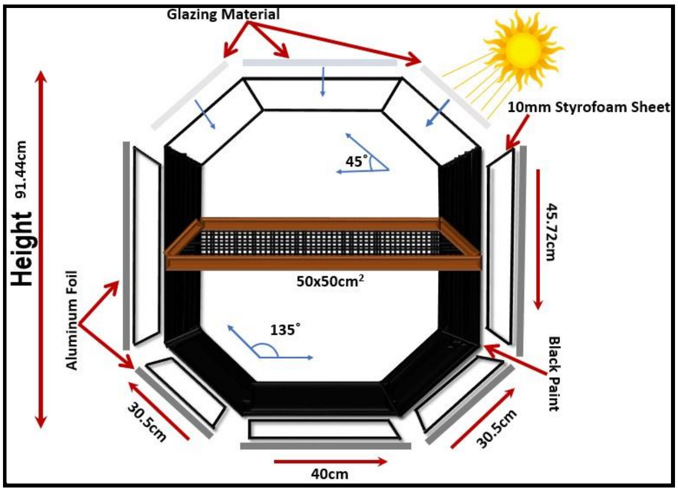

Figure. 1: Design and construction of Octagonal solar heater box showing all the measurements.

Figure. 2: Inner and outer shaped view of solar heater boxes used for experiment.

According to the longitude and latitude of an experiment for capturing the most solar radiation, the angle N-S for the upper side of the boxes is kept at 45°. The total height of solar heater box is 92 cm, and the top face and base measure 40×40 cm^2 in size. For maximum heat absorption, the walls of the boxes were painted with black paint on both the inside and the outside. A 10mm Styrofoam sheet was mounted on the outside of the boxes as it is an insulator that contains air-filled bubbles that reduce heat loss from the solar boxes by conduction and convection. An aluminum foil was then adhered to the outside of the solar box with glue to maximize the reflection of solar radiation. For heat penetration and retention inside the solar box, the sides and half of the arms of the boxes were covered with glass. The inner and outer shape of solar heater boxes are shown in Fig. 2. In the first experiment, the temperature and humidity of the empty boxes were recorded using a digital data logger placed on a tray (50 × 50 cm^2) containing holes that allowed the temperature to penetrate in all directions. To allow heat to enter from all sides, the tray was fixed at the center of each box at a perpendicular height.

Temperature and moisture of seed in solar heater box: The temperature and the seed moisture in solar heater box were recorded by using mini portable digital data logger (16000 points recoding capacity, 40°C~+85°C Model: Elitech RC-4HC; China) assembled with external thermal sensor (thermocouples) as shown in Fig. 3. The data after recording was exported in MS-excel via data management software in hp laptop for further review and analyzation. A sharp pointed sensor needle was inserted inside the seeds to know the penetration of temperature and moisture in solar heater box as shown in Fig. 4. The thermocouple sensor was positioned between the seeds at random depths to record the temperature and moisture using data loggers (Memon *et al*, 2013). The different seed dimensions such as 2cm, 4cm, and 6cm were placed inside the solar heater box. The temperature readings were set to be automatically taken every 15 mins during each time interval. The ambient temperature was also recorded with digital thermometer (℃) (HTC-1). The experiment lasted for 6 hours, starting at 9:00 a.m. and ending at 3:00 p.m. To increase the grains quantity inside the solar heater box, the efficiency of the solar heater box was improved by installing a 12v linear actuator assembled with a hardwood log (saw tooth-like comb) placed in the solar heater box, as shown in Fig. 5. The temperature in the solar heater box would be kept constant at different grain volumes by rotating the seeds inside the box using a 12v linear actuator. The linear actuator's direction and speed were controlled by the H-bridge motor driver. A linear actuator's stroke will automatically stop after 10 mins of extending and retracting using an Arduino UNO microcontroller and C++ programming.

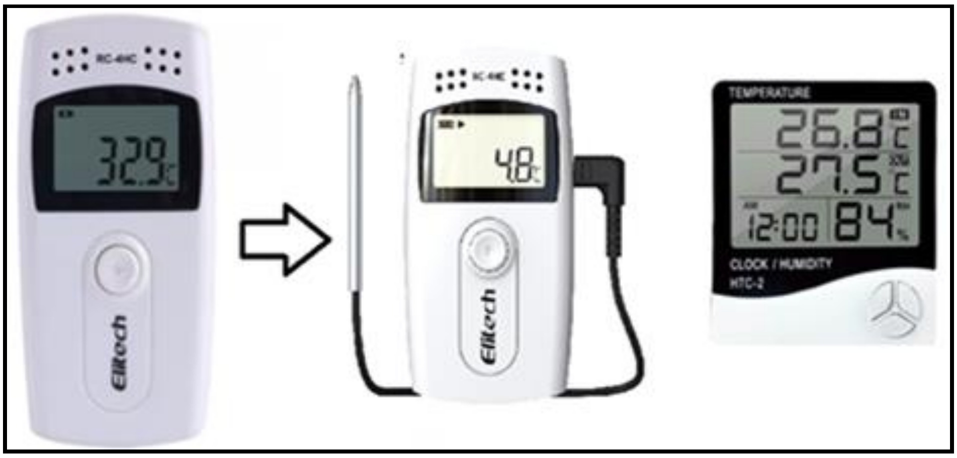

Figure. 3. Digital data logger and thermometer for recording temperature and humidity

Figure. 4. Temperature recording and seed moisture at different depths using pointed sensor needle.

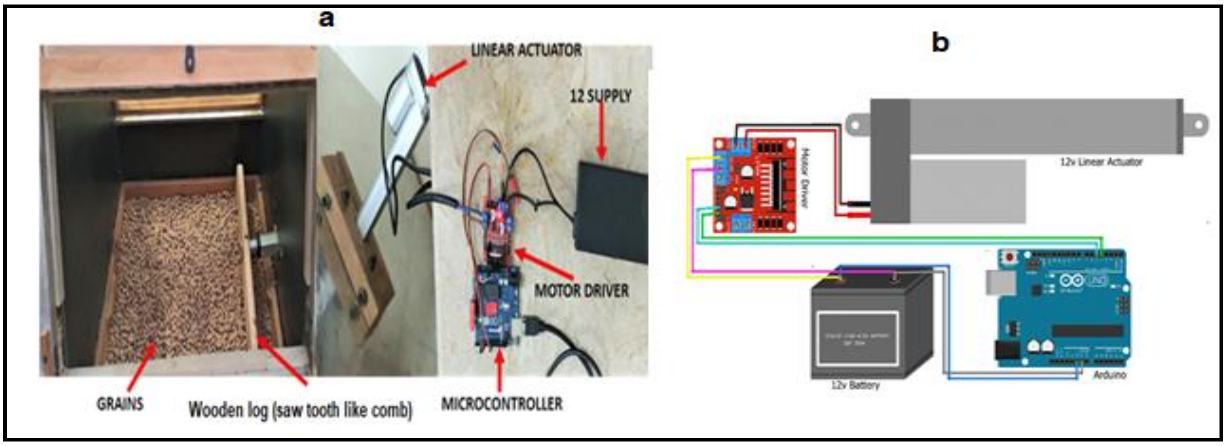

Figure. 5. Prototype (a) and circuit diagram (b) showing linear actuator assembled with wooden log for better retention of temperature and reduce moisture between grains inside solar heater box.

Effect of solar heater box treatments on characteristics of chickpea seed: In this experiment, the solarization effects on seed characteristics including moisture content (%), seed germination (%) and seed vigor tests were performed on the treated chickpea seed soon after exposure. The random samples of seeds were taken from each treatment (after seed solarization) after mixing homogeneously and compared with untreated seeds. The seeds were allowed to cool for 1 hr and then shifted from solar heater box to small plastic jars Petri dishes and all parameters were calculated before and after heat treatment. The moisture of seeds was measured with moisture meter after 6 hours of experiment and a sample of 10 seeds after one, two, and three-days intervals were taken to observe vigor index (V.I) of seed. To check V.I, all the treated seeds were grown on jute moisture bed in Petri dishes (10 x 15mm) inside laboratory conditions for to observe germination. Continuous watering of the seeds was done with distilled water from a wash bottle. After seven days, seeds were germinated and the seed germination (%) was calculated.

Germination percentage (GP) = seeds germinated/total seeds x 100 ... Equation (1)

Furthermore, the seed vigor index of the chickpea seedling by measuring their roots and shoots lengths (cm) by ruler. The vigor index of seed was calculated using equation number which is a formula as given by Abdul-Baki and Anderson, (1973).

Vigor index (V. I) = germination percentage x root length (cm) ……. Equation (2)

Data Analysis: Temperatures were recorded in the solar thermal box for each 60 mins exposure time assessed by method (RCBD) using analysis of variance (ANOVA) in statistical analysis software (Statistics 8.1). The data logger and thermocouple were configured to collect temperature data and the relationship between the temperature measurements taken over a 15 mins period in the solar thermal box and the exposure times were tested using regression analysis and correlation of the coefficients. Temperature trend data were transformed prior to regression analysis. ANOVA with RCBD was used to analyze the data on the effect of seeding rate on optimal solar-heated boxes, while a student t-test was used to compare seed moisture content inside. Solar heater boxes with and without linear actuators were used. LSD (P = 0.05) was used to demonstrate the heat retention capacity of individual solar heater boxes.

Results

Temperature and humidity of various solar heater boxes: The results shown in Table. 1 demonstrate the temperature trapped inside the solar heater boxes was significantly different (P=0.05). The results showed the maximum temperature 87.4±0.84℃ was observed in solar heater box composed from acrylic sheets and minimum 69.69±1.02℃ from hardboard sheets. The Lasani sheets produced 70.19±1.00ºC that was not statistically different from the temperature produced inside the Hardboard shee

Table.1. Trapped temperatures in solar heater boxes for exposure time of 60 to 360 mins

Solar Heater Boxes	Exposure time (min)/ Mean±SE trapped temperature (˚C)					
	60	120	180	240	300	360
Acrylic	47.35±0.89[a]	67.13±1.11[a]	81±1.30[a]	83.2±±1.53[a]	84.72±1.67[a]	87.40±0.84[a]
Hardboard	39.95±0.66[c]	53.23±0.52[c]	62.52±0.49[b]	66.78±0.55[b]	69.53±0.80[b]	69.69±1.02[b]
Lasani	41.9±0.63[b]	56.8±0.88[b]	63.61±0.88[b]	67.37±1.07[b]	69.9±1.05[b]	70.19±1.00[b]
Ambient Temperature (℃)	29.48±0.32[d]	31.65± 0.44[d]	33.32± 0.48[c]	34.48± 0.49[c]	35.4± 0.55[c]	36.33± 0.68[c]

Note: Means followed by same letters in the same column are not significantly different p=0.05 (LSD)

The variation in trapped temperature could be due to the materials used in this experiment. The most important findings of these results were that the temperature trapped in all the solar heater boxes was entirely different from the ambient temperature. Thus, all these materials successfully trapped the enough temperature inside the box in comparison to the ambient temperature (36.33±0.68ºC). The trapped humidity in solar heater boxes was significantly different (P=0.05) shown in Table. 2. The findings revealed that the humidity recorded in hardboard solar box was the highest 36.14% and the lowest in Lasani (Lamination sheet) 13.91%. The humidity generated by the acrylic sheets was 15.25%, which was not statistically different from the humidity generated by the Lasani (lamination sheet).

Table. 2. Humidity in solar heater boxes for exposure time of 60 to 360 mins

Solar Heater Boxes	Exposure time in (min)/ Mean±SE trapped humidity %					
	60	120	180	240	300	360
Acrylic	30.43±2.55[d]	19.27±2.75[d]	15.77±2.55[c]	14.86±2.77[b]	13.94±2.66[b]	15.25±3.78[b]
Hardboard	45.89±1.56[b]	38.75±2.10[b]	36.18±2.00[b]	35.64±2.09[a]	35.73±2.08[a]	36.14±2.18[a]
Lasani	39.74±1.97[c]	27.34±1.90[c]	20.55±2.10[c]	17.2±1.95[b]	15.15±2.00[b]	13.91±1.82[b]
Relative Humidity %	62.32±0.6[a]	54.42±1.11[a]	46.53±1.95[a]	42.00±1.81[a]	38.14±1.62[a]	35.67±1.22[a]

Note: Means followed by same letters in the same column are not significantly different p=0.05 (LSD)

Temperature in the solar heater box and ambient temperature was linearly related, with an essential coefficient of determination (r^2) falling between 0.79 and 0.96. It is also demonstrated that there is not a significantly different ($P<0.05$) but moderate ($r^2=0.60$) linear relationship between seed moisture in solar heater box without linear actuator with respect to time. Only 60% of the seed moisture variation depended on time, according to the moderate coefficient of determination (r^2) value for seed moisture in solar heater box without linear actuator as shown in Figure. 6.

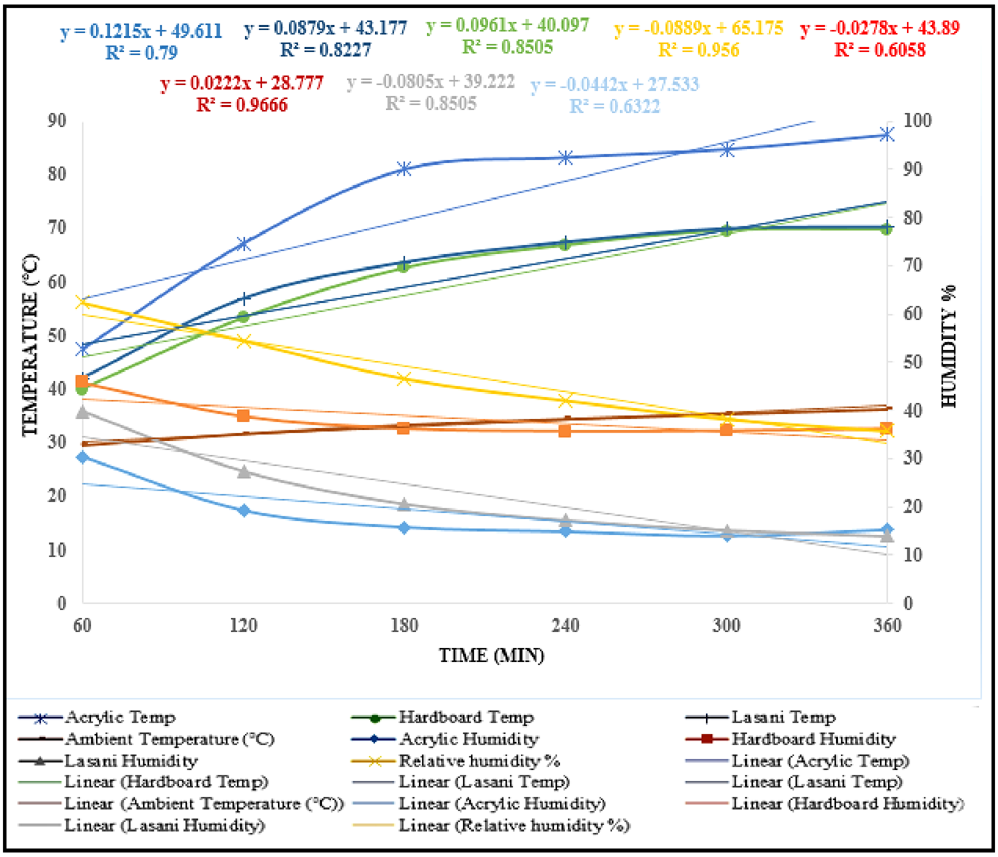

Figure. 6. Relationship between temperature and humidity of ambient in solar heater box

Table. 3. Record of temperature between grains with and without linear actuator in solar heater box.

Time (minutes)	Temperature (°C) of solar heater box						Ambient Temperature (°C)
	without Linear Actuator			with Linear Actuator			
	Seed Depth						
	2cm	4cm	6cm	2cm	4cm	6cm	
60	37.76±0.60[a]	31.97±0.39[b]	30.82±0.32[b]	43.29±0.55[a]	40.11±0.51[b]	40.19±0.33[b]	31.55± 0.72[d]
120	50.69±0.96[a]	38.58±0.63[b]	36.07±0.33[c]	57.16±0.34[a]	52.17±0.99[b]	48.18±0.26[c]	34.21±0.78[d]
180	58.07±0.50[a]	45.16±0.52[b]	42.03±0.36[c]	63.33±1.09[a]	59.46±0.58[b]	57.66±0.58[c]	36.48± 0.76[d]
240	65.92±1.05[a]	52.88±0.88[b]	47.78±0.30[c]	68.61±0.92[a]	65.13±1.55[b]	63.17±1.22[c]	38.12±0.75[d]
300	68.78±0.94[a]	57.63±0.66[b]	53.02±0.48[c]	72.13±1.15[a]	68.22±1.23[c]	63.98±1.56[c]	39.28±0.68[d]
360	67.84±1.08[a]	59.76±0.59[b]	56.46±0.36[c]	75.21±1.23[a]	70.91±1.35[c]	67.42±1.92[c]	40.17± 0.68[d]

Temperature at various depth between seeds with and without Linear actuator: Later, the temperature with different quantity of grains (that was placed at different seed bed thickness in Lasani solar heater box) at different intervals were recorded. The results indicated that without linear actuator the maximum quantity of seeds with higher seed bed thickness statistically ($P<0.05$) affect the penetration of heat between grains in solar heater box but still it was enough in comparison to ambient temperature as presented in Table. 3

The temperature was successfully trapped above 50 °C in both solar heater boxes with different quantity of seeds at the end of experimental period. However, the maximum temperature of 75.21±1.23 °C was recorded at seed bed width of 2cm seeds in linear actuator solar heater box, whereas the ambient temperature was 40.17 °C after 360 mints. Similarly, like temperature the moisture between the seeds were also recorded significantly different at different volume of seeds ($P<0.05$) in initial period of experiment (60 mins) but interestingly no significant different ($P>0.05$) in moisture (12.21 to 14.97 %) was found in different volume of seeds at the end of experiment (360 mins) with linear actuator as shown in Table. 4. As time passed, the seed moisture started to decline in reciprocal to temperature. Meanwhile, the higher seed moisture of 40.91 % at 60 mins of exposure was recorded at maximum seed thickness (6cm) in linear actuator solar heater box and on the same time the seed moisture was the highest in the environment (60.00±4.10 %).

Table. 4. Record of moisture between seeds in solar heater boxes over 6 hours exposure time.

Time (minutes)	Grains moisture in solar heater box						Seed moisture (%) in control
	without Linear Actuator			with Linear Actuator			
	Seed Depth						
	2cm	4cm	6cm	2cm	4cm	6cm	
60	38.77±2.48[b]	39.68±2.06[b]	40.25±2.37[b]	39.56±0.63[b]	40.73±0.51[b]	40.91±0.33[b]	60.00±4.10[d]
120	26.61±2.26[b]	35.81±2.23[b]	32.35±1.74[b]	30.11±0.40[a]	33.39±0.99[b]	34.28±0.51[b]	51.32±3.41[d]
180	22.40±3.00[b]	31.98±1.86[b]	27.74±1.43[b]	21.02±1.12[a]	27.31±0.82[b]	26.83±0.58[b]	45.35±3.17[d]
240	11.07±3.25[b]	27.68±2.35[b]	26.59±1.87[b]	17.37±0.81[a]	18.92±1.55[b]	20.26±1.33[c]	39.63±2.29[d]
300	19.03±3.12[b]	22.68±2.29[b]	23.68±1.70[b]	15.08±1.05[a]	16.22±1.32[b]	18.51±1.56[c]	35.35±1.83[d]
360	19.30±2.67[b]	19.90±2.00[b]	21.78±2.10[b]	12.21±1.22[a]	12.68±1.45[b]	14.97±1.72[c]	32.67±1.19[d]

Temperature within grains at different volume with and without Linear actuator: Subsequently, the record of temperature in Lasani solar heater box after between seeds later within seeds was persuaded in similar different quantity of seeds at various intervals. The details are shown in Table. 5. In initial recorded time interval, the trapped temperature (36.20±0.71°C) within the seeds at 2cm was significantly different ($P<0.05$) from the temperatures at 4cm (34.04±0.85°C) and at 6cm (31.78±0.40°C) in solar heater box without linear actuator. The trend of maximum temperature with minimum volume of seeds remained same as it was found maximum (77.11±1.22°C) at the end of experimental time (360 mins) in linear actuator solar heater box. However, the increased volume of seeds inside solar heater box at maximum limits of 21 kg still got better results (58.44±2.39°C) to trapping the temperature as compared to ambient temperature (40.14±0.66°C). Overall, the result showed that the temperature within seeds was much better as compared to temperature trapped between seeds.

Table. 5: Record of temperature within seeds in solar heater boxes over 6 hours of exposure time.

Time (mins)	Temperature (°C) within seeds of solar heater box						
	without Linear Actuator			with Linear Actuator			Ambient Temperature (°C)
	Seed Depth						
	2cm	4cm	6cm	2cm	4cm	6cm	
60	36.20±0.71a	34.04±0.85b	31.78±0.40[c]	38.51±0.63[a]	35.28±0.51[b]	30.36±0.33[c]	32.45±0.47[d]
120	47.49±1.92[a]	42.17±1.42[b]	36.86±1.17[c]	44.76±0.40[a]	41.40±0.99[b]	39.07±0.51[c]	35.16±0.51[d]
180	57.96±3.00[a]	50.78±2.02[b]	42.40±1.65[c]	58.12±1.12[a]	53.82±0.82[b]	50.15±0.58[c]	37.32±0.65[d]
240	62.50±2.74[a]	57.42±2.04[a]	47.96±2.08[b]	69.66±0.81[a]	65.08±1.55[b]	57.41±1.33[c]	39.13±0.55[d]
300	67.31±2.06[a]	61.88±1.90[a]	53.96±2.35[b]	73.02±1.05[a]	68.13±1.32[b]	64.59±1.56[c]	40.01±0.57[d]
360	69.74±2.05[a]	64.89±2.11[a]	58.44±2.39[b]	77.11±1.22[a]	72.77±1.45[b]	69.61±1.72[c]	40.41±0.66[d]

Fig. 7: Seed germination process of Chickpea seeds

Seed Germination: Seed germination is the biological process by which a dormant seed transforms into a new seedling and begins its growth journey as shown in Fig. 7. Germination in seeds starts when water intake causes the seed tissues to rehydrate, which activates enzyme activities that break down protein, lipid, and carbohydrate reserves that have been stored inside the cotyledons.

Moisture content, germination percentage and root length: The results in Table 6 indicate that after solar treatment of seeds at different depth inside solar heater box, the moisture content of seeds was reduced within 6 hours. The final moisture of seeds was 12.21%, 12.68% and 14.97% at different depth at 2, 4 and 6cm in solar heater box respectfully. Exposure to solar heat for 6 hours caused 52.79% loss in moisture content of seeds in solar heater box at 2 cm depth. When depth of seed was extended to 4cm, the moisture reduced to 52.32% was recorded. A reduction of moisture 50.03% was recorded when seeds were exposed to solar heat at 6cm depth in solar heater box. The final moisture in control method 32.67% was observed respectively. The germination percentage was 90% recorded at 2cm depth and the recorded temperature at this depth between seeds temperature was 61.33±0.88^{0}C with relative humidity 21.26±0.63% inside the solar heater box. In comparison, when seed beds were increased to 2 and 4cm thickness, the seed germination percentage found increased 93.33% and 100.0%, respectively the temperature (58.2±0.64^{0}C; 56.13±0.61^{0}C) and relative humidity (23.9±0.45%; 19.56±0.38%) were observed in solar heater. However, in control treatment at 27.13±0.46 ^{0}C with relative humidity of 57.00±1.52%, seed germination was 86.67% found after 7 days. The results indicated that exposure to the sun for 6 hours raised maximum temperatures of 61.33°C in solar heater boxes at 2 cm depth, but this did not affect seed viability as a high percentage of germination like untreated seeds were obtained. Whereas exposure to heat at 6cm resulted in a high germination rate that was recorded 100% as compared to 2 and 4cm depth because minimum temperature was recorded in solar heater box on 6cm. results of this study showed that there was no adverse effect of solar radiation on seeds germination. The effect of solar heater boxes on root lengths of grains are presented in Table 6. When grains were exposed to solar radiation for 6 hours the root length higher were measured at 4 cm 2.771± 0.31 cm and lowest 3.263±0.06 cm at 6 cm and 2.413±0.35 cm at 2 cm depth of seed. When the root length in un-treated seed was 2.270±0.10 cm, respectively. The results were not significantly different from the untreated control. However, exposure for up to 6 hours in solar heater boxes have; t shown any significant changes on root lengths of chickpea seed.

Table. 6: Effect of solarization on moisture, germination, root length and seed vigor index of seeds.

Treatment	Seed depth	Initial moisture%	Final moisture%	Loss of moisture%	Germination%	Root length (cm)	Vigor Index
Solarized seeds	2cm	65	12.21	52.79	90.00	2.413±0.35^{bc}	225.17
	4cm	65	12.68	52.32	93.33	2.771± 0.31^{ab}	277.00
	6cm	65	14.97	50.03	100.0	3.263±0.06^{a}	326.33
(Control)	Initial moisture	65	32.67	32.33	86.67	2.270±0.10^{bc}	196.74

Discussion

The construction of solar heater boxes with an inverted pyramid form and an obtuse base angle of 118˚ was more effective in capturing more solar energy (Mekasha *et al*., 2006; Ragga, 2011; Fawki *et al*., 2014; Gambo *et al*., 2018; Abdullahi *et al*., 2019). In this work, the overall design of the solar heater box has been slightly modified. The top face of the solar heater box has been constructed at a 45˚ angle to provide maximum collecting heat (thermal) operation and can be used to increase total solar energy during sunny periods. (Mathur *et al*., 2006) created a solar-powered mixed dryer fitted with a solar chimney tilted at a 45˚ angle. In a study conducted by Samimi and Arabhosseini, 2018; revealed that the drying performance of tomato slices during drying and built a laboratory-scale PV-assisted solar drying system equipped with a solar monitor. All drought tests were conducted in East Azerbaijan at 45.8° longitude and 37.4° latitude. Later, the heat transfer coefficient for free convection between the surface and the moving air was also calculated (Kayiem and Yassen, 2015). The current study was carried out after designing an octagonal solar heater box to achieve the best results for capturing the maximum amount of solar energy that can be damaging to pest control of stored grains, as temperatures above 60°C with a retention time of one hour are quite lethal for all stages of store grain pests (Field, 2012). The significance of creating heat energy in a solar heater box having outstanding heat retention for a longer period of time. The use of an actuator increased the efficacy of a solar heater box in trapping extreme heat because heat penetrated more easily in seeds without being blocked. As a result, the temperature trapped inside the solar heater box were significantly improved with the use of a linear actuator. The intensity of temperature between the seeds was maximum (67.42±1.92°C) at 6cm depth in the solar heater box with a linear actuator, compared to seed temperature (56.46±0.36°C) in the solar heater box without a linear actuator. Thus, after 6 hours of an experimental period, the solar heater box with linear actuator successfully trapped enough seed temperature inside the box as compared to ambient temperature. Previous research has shown that the temperature must be kept above 50°C for at least 24 hours (Beckett *et al*., 2007). Controlling arthropod pests by disinfecting items and/or structures at high temperatures (over 50°C) is an environmentally beneficial way to preserve stored products (Hansen *et al*., 2011; Field *et al*., 2012; Gambo *et al*., 2018). Temperature was also observed to impact seed moisture with the specified study at different intervals in difference to seed moisture preserved in open sunshine. Initially, seed moisture (%) was at the highest level 65%, but after one hour of solarization, it decreased and was recorded at about 60% (in control conditions). In contrast, seed moisture observed in the solar heater box without a linear actuator was (38.77%) and (39.56%) with a linear actuator, which demonstrated the precise difference between solarization with and without a linear actuator. At the end of the day, seed moisture decreased in all treatments, although it was the lowest in the solar heater box with linear actuator (12.21%) in the 2cm depth and without linear actuator (19.30%). When compared to previous treatments, the use of a linear actuator successfully lowered the maximum percentage of seed moisture. According to Gambo *et al*. (2018), controlling stored-product pests with high temperatures (above 50°C) is an environmentally friendly method because it not only makes the majority of store-grain pests live in an aerobic environment but also helps to reduce seed moisture which make difficulties in further biological activities of an insect pests. In other studies, increasing the volume of seeds reduced the temperature within the solar heater box without a linear actuator. However, increasing the amount of seeds inside the linear actuator solar heater box to 6cm produced better results. Meanwhile, the best results were obtained in 2cm of seeds volume with a linear actuator, indicating that the use of a more powerful motor for linear actuators got better results in terms of seed moisture and heat-trapping for solar heater boxes. Temperature (>45°C) is the heat-lethal zone for most storage pests (Beckett *et al*., 2007), however, temperatures as high as 50°C may exist at specific points in the product disinfection system (Beckett *et al*., 2007; Beckett 2011). Others, such as (Mahroof *et al*., 2003) and (Dosland *et al*., 2006) individually detailed a temperature range of 50-60°C for product disinfection on preserved arthropods. Results from previous studies support the hypothesis that lasani solar heater box with maximum average temperature detection can disinfect more products when used for pest control of stored product.

Conclusion

An acrylic solar heater box generated incredibly high thermal performance compared to hardboard and Lasani box, However, the material used in this box was very expensive. Comparatively, the thermal performance of hardboard and Lasani box was good, and they are inexpensive compared to acrylic box, but hardboard box was too heavy due to material thickness. Concerning the financial issue, the price of each of the three solar heater boxes were estimated based on the expense of the materials that made up the boxes and the additional labor costs, with the assistance of carpenters during assembly. These expenses demonstrate how much less expensive the Lasani box is than the other prototypes. Each solar heater box is a relatively safe and environmentally acceptable management technique for producing enough heat to disinfest store grain pests. Furthermore, the use of a linear actuator improved the effectiveness of the solar heater box to enhance the quantity of seed inside it. As a result, solar heater boxes with higher powerful motors are advised for future operations.

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