International Journal of Multidisciplinary Studies and Innovative Research

ISSN: 2737-7172 (O), ISSN: 2737-7180 (P)
Volume 12, Number 01, pp. 1750-1762
DOI: 10.53075/Ijmsirq/0984573535552

Construction of Prototype Fire-Wood Clay Oven for Drying Cocoa Beans in Ghana

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How to Cite
Kofi Asante-Kyei, Caleb Nii Darku Dodoo, Ludwig Hesse Martei (2024). Construction of Prototype Fire-Wood Clay Oven for Drying Cocoa Beans in Ghana. *International Journal of Multidisciplinary Studies and Innovative Research*, 12(1), 1750-1762. DOI: DOI: 10.53075/Ijmsirq/0984573535552

Abstract: Despite several attempts made by various studies in trying to reduce the drying period, the period is still high. The main objective of the study was to compose insulating bricks to construct portable clay oven fueled by fire-wood for drying cocoa beans in order to minimize the prolong and hectic periods that Ghanaian cocoa farmers go through to get cocoa beans dried. The study sought to construct cocoa drying oven using Abonko clay, Atuobo red sand and sawdust as the main materials for the manufacturing of insulation bricks. Various proportions of the materials were experimented to arrive at the successful outcome of **test 5 (**6 parts of Abonko clay: 2 parts of sand: 2 parts of sawdust) and fired at 1200 ^{0}C, Therefore, the study adopted t**est**$_5$ as the body for making the insulating bricks to construct the clay oven Mild steel barrel was used as the main frame for holding the clay oven. The bricks were carefully cut to size and shape, arranged and fixed in the oven. Two (2) kilograms of fermented cocoa beans were placed and heated in the clay oven to determine its moisture content at different temperatures. It was realized that the prototype clay oven was able to dry the cocoa beans and reduced the moisture content from 75.9% to 6.4.0% in 4 hours and 30 mins at the temperature of 130 ^{0}C. The study recommended among others that; the Cocoa Research Institute of Ghana could do further research to find out the quality of the cocoa beans dried using the clay oven method. in terms of nutritional values, moisture content level, abnormal odours and insect pest and mould contamination

Keywords: Cocoa beans**,** Clay, Drying, Oven, Sawdust, Sand**,**

1. INRODUCTION

Ghana is among the largest cocoa producing countries in the world, accounting for 25% of global cocoa production. In West Africa, Ghana and Cote d'Ivoire are the most prominent countries that deliver majority of the world's cocoa supply. Despite the critical role Ghana plays in providing the beans, the production curve has been experiencing downward trends (Twum-Barima, 2023). A survey conducted nationwide among the cocoa growing communities showed that the Ghana Cocoa Marketing Board (CMB) has intensified campaign and supporting farmers with new technologies so as to increase cocoa production in the country. This is as a result of significant loss of forest vegetation hitherto earmarked for cocoa growing but now being destroyed as a result of illegal mining popularly known as "galamsey". Beside the "galamsey", loss of major soil nutrients due to change in climatic conditions has also affected Ghana's cocoa production (Afoakwa et al, 2013; Twum-Barima, 2023).

Cocoa beans constitute a global raw material for the chocolate industry, beverages, cosmetics, pharmaceuticals and toiletry products (Taubert et al, 2007;). Over fifty million people depend on cocoa for their livelihood with a global production capacity of 68% from Africa, 17% from Asia and 15% by the Americas. In Africa, the largest cocoa- production countries by volume are Ivory Coast (1900 million tons), Ghana (850 million tons) and Cameroon with 250 million tons of global supply in the cocoa market (Puello-Mendez et al, 2017; Tosom and Njimanted, 2013). The chemistry of cocoa beans is very complex and changes throughout its life span depending on the processing method and geographical origin. Cocoa beans of commercial grade should conform to specific criteria which include proper fermentation, dried to proper moisture level, free from abnormal odours and mould contamination (Guda et al, 2017). The quality of cocoa is significantly influenced by the drying process it undergoes after harvesting. Traditionally, cocoa farmers have relied on open-air sun drying, a method susceptible to weather conditions, pests and uneven drying rates leading to variations in cocoa quality. Cocoa beans are considered dry and suitable for marketing if the moisture content has been reduced from 60% to between 7% or less wet base for storage (Cunha, 1990; Marina et al, 2011). According to Guda et al (2017), cocoa processing has two main steps namely: (i) fermentation, which could last for 5 to 7 days and responsible for development of different flavour precursors in the beans and (ii) drying, involving the removal of moisture from the cocoa beans so as to store for longer period of time. In Ghana, the most common way of drying cocoa beans is sun-drying and the length of time depends on the farmers' location and climatic conditions. According to Ndukwu (2009), artificial drying of cocoa came into being as a result of frequent raining which can be tedious when the drying is done manually. To resolve this problem, artificial heat must be added to dry air to facilitate the drying of cocoa beans. A study conducted by Guda et al (2017) on different methods of drying cocoa beans showed that the time taken for the complete drying in (a) open sun drying was 30 hours, (b) solar cabinet was 16 hours and (c) try dryer was 8 hours. It is the lengthy drying period of cocoa beans that this study sought to reduce by composing refractory bricks to construct fire-wood clay oven for drying cocoa beans.

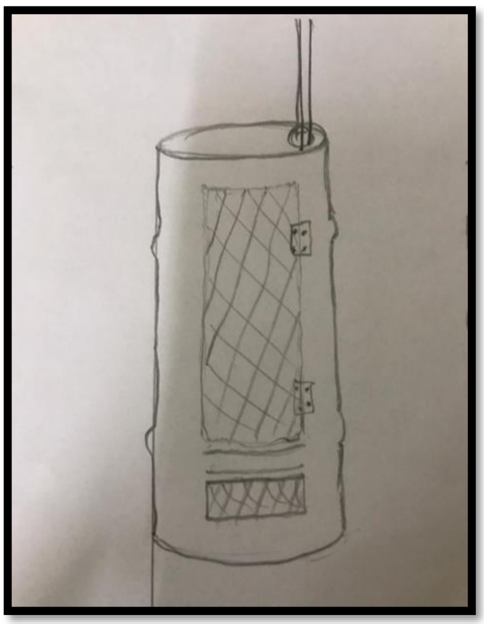
Refractory bricks are made from clay refractory and other non-clay refractory materials. Refractories and for that matter insulation bricks are noted to be physically and chemically stable, retain their shapes, strength and are not distorted at high temperatures (Atanda and Imasogie, 2009). These unique properties of refractories make them conducive for the production of high temperature devices and equipment such as furnaces, ovens, insulations and others where high resistant to high temperature is required. (Shuab-Babata et al, 2018).

In Ghana, the geographical location of clay minerals present special physico-chemical properties which finally determines the type of material produced and its application (Yaya et al, 2018). Hence, the choice of Abonko clay as a material for making the refractory bricks due to its unique characteristics. Refractory has been utilized to improve energy efficiency in heat plants systems and clay oven is no exception. According to Shuab-Babata et al (2018), insulating bricks are most common forms of refractory materials and are used widely in pottery kilns, cement industry, as well as steel and iron industry. In considering sawdust as a material, Phonphuak and Chindaprasirt (2014) posited that a fired clay and for that matter insulating bricks should possess high quantity of pores to result in lighter weight and have low heat conductivity. Therefore, in body composition, materials to create these pores are needful. Hence, several studies had been conducted into the use of other waste materials like rice husks, sawdust, charcoal and coconut husks to produce fired clay bricks (Kazmi et al, 2016).

The successful outcome of this study would lead to a cost-effective (low cost of producing the clay oven), less time consuming, environmentally friendly and locally adaptable cocoa drying solution and could significantly impact the livelihoods of cocoa farmers contributing to the production of high-quality cocoa and fostering sustainable practices within the cocoa industry. The main objective of the study was to research into clay and other non-ceramic materials that could be used to compose insulation bricks, integrate a firewood-based heating system into the construction of a portable fire-wood cocoa drying oven and creating a solution that is both technologically and economically viable for cocoa-producing communities. This study was limited to the use of local clay, sand and sawdust to construct cocoa beans drying oven

2. MATERIALS AND METHODS

2.1 Preliminary Sketches



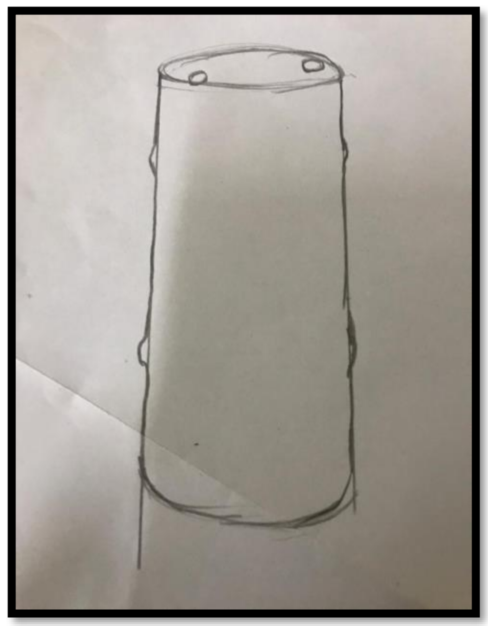


Fig.1: Sample of initial sketches   Fig.2: Sample of working sketches

Preliminary sketches were developed to achieve a final design which was very selectable for the construction of the cocoa bean drying oven. Samples of initial and working sketches are shown in figures 1 and 2.

Various parts of the proposed prototype clay oven have been incorporated into the design and shown in figure 3 with the descriptions as followed: i) Frame - the structural support that holds and reinforces the overall structure of the oven; ii)) Body - the whole structure of the oven enclosing or containing other components; iii) Door - a movable or hinged barrier which will be used to close and open allowing access to the interior of the oven.; iv) Chimney:- a vertical pipe or flue that conducts smoke and combustion gases away from a heating device to the outside. It is designed to ensure proper ventilation; v) Shelves - flat, horizontal surfaces designed for placing cocoa beans for heating; vi) Firebox**:** a chamber within the oven where fire is lit; and vii) Wheels**: -** these are knobs fixed under the oven to make it movable.

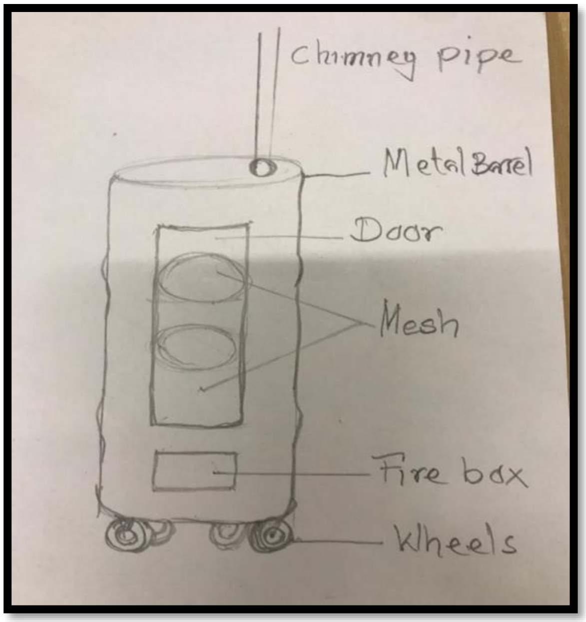


Fig.3: Sample of final sketch

2.2 Preparation of Clay Body for the Insulation Bricks

The materials used in composing refractory bricks for the fire-wood cocoa drying oven were Abonko clay, Atuobo red sand and sawdust. The justification for selecting these materials had been summarized in table 1.

Table 1: Justification for Material Selection

Materials	**Description** /Justification for selection	**Image**
Abonko clay	Abonko clay was employed for this study due to its unique properties such as cohesion, viscosity, plasticity and fired strength.	

Atuobo red Sand	This sand has tiny particles and when compacted together, create thermal mass which retains heat energy quite over time. It was incorporated into the clay body to control shrinkage, enhance clay texture and strength as well as workability and to prevent cracking during drying and firing processes.	
Sawdust	Sawdust is a byproduct of woodwork created by cutting, grinding, or sanding of wood. It was used in this study as pore-former to achieve insulating properties of bricks. It was also the most cost-effective insulating material available.	

2.3.1 Formulation of the Clay Body for Pre-Testing

Five (5) test compositions were formulated comprising **test 1** (5 parts of Abonko clay: 3 parts of sand: 2 parts of sawdust), **test 2** (5 parts of Abonko clay: 4 parts of sand: 1 part of sawdust), **test 3** (5 parts of Abonko clay: 2 parts of sand: 3 parts of sawdust), **test 4** (5 parts of Abonko clay: 2.5 parts of sand: 2.5 parts of sawdust), and t**est 5** (6 parts of Abonko clay: 2 parts of sand: 2 parts of sawdust). The materials were mixed and blended in a powdery form before adding water and thoroughly mixed to achieve a homogeneous consistency to facilitate creation of the brickettes. The dry mixing processes had been demonstrated in figures 4 and 5 respectively.

Fig. 4: Mixing of the powdered mixture

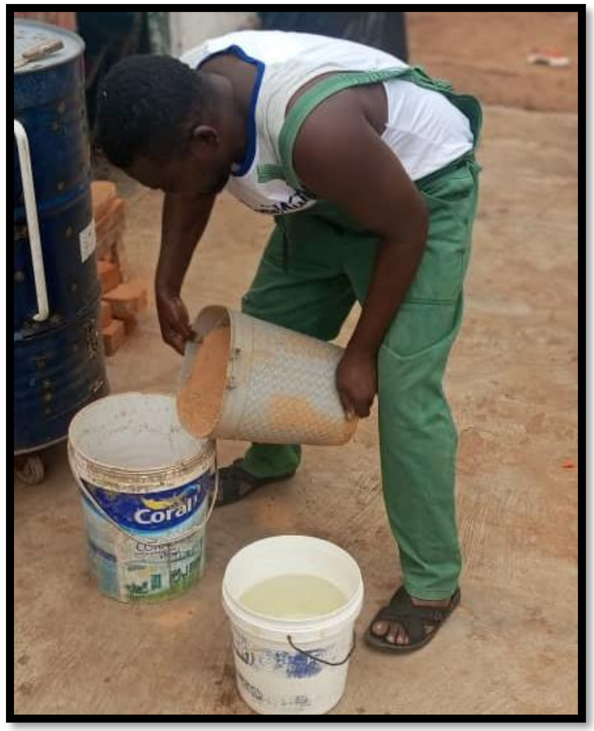


Fig 5: Pouring of the powdered mixture

Test pieces in the form of brickettes were made from the various compositions (test I to test 5), allowed to dry and then fired at 1200^{0}C in a test kiln to determine the suitability or otherwise of the materials as shown in table 2.

Table 2: Formulation of clay body for making brickettes

Sample	**Temperature** (^{0}C)	**Abonko clay**	**Atuobo sand**	**Sawdust**	**Outcome**
Test I	1200	5	3	2	Unsuccessful (flaked brickette)
Test 2	1200	5	4	1	Unsuccessful (flaked brickette)
Test 3	1200	5	2	3	Unsuccessful (flaked brickette)
Test 4	1200	5	2.5	2.5	Unsuccessful (flaked brickette)
Test 5	1200	6	2	2	Successful (unflaked brickette)

Fig,6: Sample of the unflaked brickette

Fig.7: Samples of the flaked brickette

Form table 2, only **test 5** (6 parts of Abonko clay: 2 parts of sand: 2 parts of sawdust) was successful since it did not flake as seen in figure 6 while the rest of the test pieces (test I – test 4) flaked as seen in figure 7 and as such were declared as unsuccessful for making insulating bricks. The material composition of the **test 5** showed that the clay insulation bricks could be predominantly clay-based and therefore making it an ideal for moderate-temperature applications like oven for heating of cocoa beans.

2. 3.2 Insulation Brick Making Processes

Form table 2, the outcome of only **test 5** (6 parts of Abonko clay: 2 parts of sand: 2 parts of sawdust) was successful and therefore adopted as the recipe for making the insulating bricks to construct the clay oven. In making the bricks, various materials were weighed according to the recipe developed and the bricks manufactured by using wooden mould as seen in figure 8. The mold box was dipped into water and some amount of clay body was fed into the mold box. Straight edge tools were used to scrape off the excess clay body and then the mold was turned upside down to remove the brick gently from the mold as captured in figure 9.

Fig. 8: Molding of the brick

Fig, 9: Molded brick

After the molding, the bricks were dried under shed, often turned to ensure uniformity in drying and also reduced warpage as seen in figure 10. The dried bricks were packed into firewood kiln for firing as seen in figure 11. Pre-heating lasted for about four hours. This was to ensure that all the atmospheric moisture had evaporated to avoid cracking. The firing temperature for the kiln was progressively increased for twenty-four hours until different tones of colours ranging of ordinary burnt brick insulation of red, buff, brown etc. were achieved through monitoring by viewing the spyhole as seen in figure 12. All these varied colours might be primarily attributed to amount of iron present in the Abonko clay in addition to it component element and manufacturing process. The kiln was left to cool down for two days before the insulating bricks were removed as seen in figure 13.

Fig. 10: Drying of the bricks

Fig. 11: firing of the bricks

Fig. 12: monitoring of bricks via the spyhole

Fig. 13: Samples of fired insulating bricks

Generally, a potential insulation brick must be hard, well-burnt to the required temperature through sound, texture and colour Therefore, basic tests for insulating bricks like compressive strength, firing shrinkage, porosity and bulk density were carried out to ascertain the qualities and properties of insulating bricks before using them to construct the oven.

2.4 Construction of the Oven

The frame was made of a cylindrical mild steel metal with height of 88cm and width of 58 cm (88cm x 58cm). The various parts were measured, cut with hacksaw blade and joined together by using electrode to form the structure of the oven. The shelves were made of metal iron mesh to serve as platforms for drying the cocoa beans. A hole was created on top of structure and fixed with fibre pipe to serve as chimney through which excess heat and smoke would exit the oven. Knobs were also fixed under the frame to serve as wheels to make the clay oven movable. The complete frame of the oven is seen in figure 14.

Fig.14: Complete skeletal structure of the oven

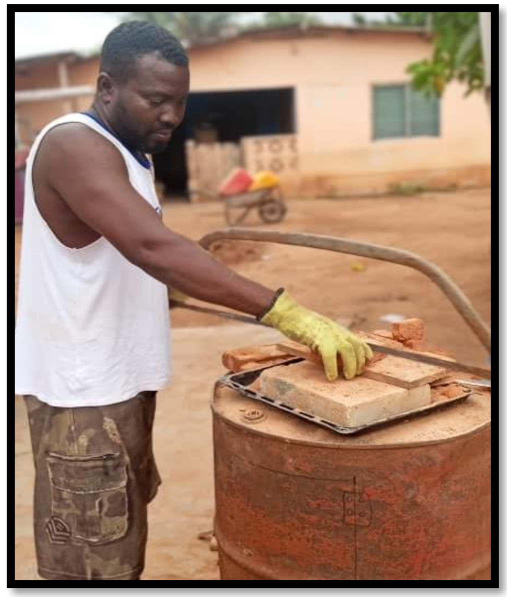


Fig. 15: Sizing of the brick by cutting

In lining the oven, heat resistant coating was applied inside the frame to prevent heat loss before the insulating bricks were cut with hacksaw blade as seen in figure 15. The rough edges were smoothened with sandpaper, white glue and sodium silicate mixed together as adhesive and used to join the bricks. The insulation bricks were systematically interlocked by applying the bricklaying method to fix the interior part of the oven as demonstrated in figures 16 and 17 respectively.

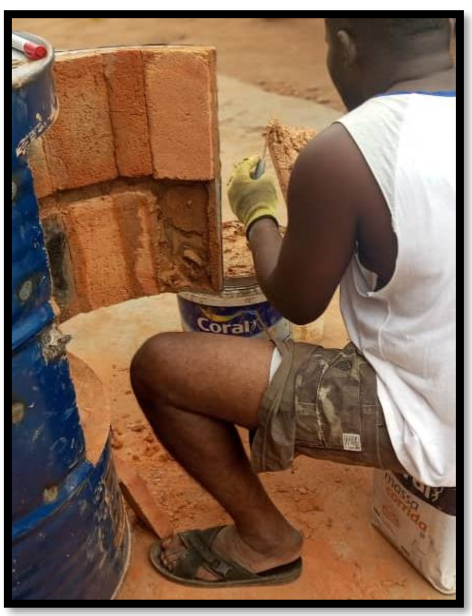


Fig. 16: Laying of the inside brick

Fig.17: Laying of the brick at the door

The main purpose of lining the interior part with insulation bricks was to contain heat and to prevent heat from escaping through the outermost part of the oven made of mild steel. The firewood box was also laid with insulation bricks as seen in figure 18 to serve as fire chamber to give flame for heating the cocoa beans. The completed oven has been showcased in figure 19 awaiting testing of the oven for heating of the cocoa beans.

Fig 18: Laying of the firewood box bricks

Fig. 19: Final display of the oven

3. RESULTS AND DISCUSSION

3.1 Testing of the Oven

Finally, two (2) kilograms of fermented cocoa beans obtained from Brofoyeduru, a growing cocoa community in the Wassa East District of Western Region were tested by heating in the constructed oven as seen in figures 20 and 21 to determine its efficiency and efficacy. In testing the oven, the study considered half an hour (30 mins) heating intervals for the recording of temperature to determine the intensity of heat in the oven as well as for the calculation of the moisture content. The half an hour interval was considered to be appropriate and to have been given ample time for the heating process to take place. It was also to prevent over-heating of the cocoa beans because the flame of firewood when not properly monitored could excessively affect the drying system.

Fig. 20: Placing cocoa beans for heating in the oven.

Fig. 21: Heating of cocoa beans in the oven

In terms of cost implications, the study revealed that the cost of producing the clay oven was relatively cheaper. This was because most of the materials such as clay, sawdust, sand and firewood were obtained free of charge and were also abundant in Ghana. Hence, it was a cost-effective project and its usage would be very simple that any cocoa farmer could adopt to facilitate drying of cocoa beans as compared to the open drying which takes longer days and weeks.

3.2 Experimental methods Adopted

In order to ascertain the efficacy of the oven, the drying condition (involving heat energy which causes water to evaporate from the cocoa beans) adopted for the study was to determine the moisture content of the cocoa beans which had initial content of 75.9%. The temperature was determined by using thermocouple (a sensor connected to a thermometer used for measuring temperature) and recorded after every half an hour (30mins) as shown in table 3.

Table 3: Test Results of Heated Cocoa Beans in the Prototype Clay Oven

Name of Sample of Batch Cocoa Beans	Initial Moisture Content	Recorded Temperature (^{0}C)	Duration (heating time in hours)	Outcome (moisture content -weight of beans in %)
Sample B	75.9%	0	0	75.9
		50	30mins	50.5
		60	1 hour	33.1
		70	1h.30mins	22.8
		80	2.hours	18.1
		90	2h:30mins	13.2
		100	3 hours	8.7
		110	3h:30mins	7.3
		120	4 hours	6.7
		130	4h:30mins	6.4

The heated batch cocoa clay oven used in the experiment was able to dry the cocoa beans from 75.9% to 6.4.0% in 4 hours and 30mins at the temperature of 130 ^{0}C. Thus, the drying rate increased with increase in temperature as indicated in table 3: 0 ^{0}C→ 75.9%, 50^{0}C→ 50.5%, 60^{0}C→ 33.1%, 70 ^{0}C→ 22.8%. 80 ^{0}C→ 18.1%, 90 ^{0}C→ 13.2%, 100^{0}C→ 8.7%, 110 ^{0}C→ 7.3%, 120 ^{0}C→ 6.7%, and 130 ^{0}C→ 6.4%.

4. CONCLUSION

The research made significant strides in enhancing the drying process of cocoa beans by employing a heating technique, revealing a notable direct proportionality between the drying rate and the applied heat temperature. Impressively, the study demonstrated the capability of reducing the moisture content of the cocoa beans from an initial 75.9% to a mere 6.4% within a span of 4 hours and 30 minutes, achieved at a controlled temperature of 130°C. This breakthrough is particularly encouraging as it aligns with the previous findings of esteemed researchers like Cunha (1990) and Marina et al. (2011). These pioneers in the field established that for cocoa beans to be considered adequately dry for market and storage purposes, their moisture levels must be brought down from 60% to a threshold of 7% or even less on a wet basis. Building on these promising results, the study puts forth a practical recommendation for the cocoa farming communities. It advocates for the construction of larger, more efficient ovens which can facilitate this enhanced drying method, thereby offering a robust solution to farmers keen on adopting this technique. Such an initiative could significantly streamline the post-harvest process, ensuring that the beans are promptly and effectively dried, ready for the market or storage with minimal quality degradation. Moreover, the study acknowledges the necessity for further research in this domain and suggests a targeted approach for future investigations. It specifically calls upon the Cocoa Research Institutes in

Ghana to spearhead these efforts, emphasizing the need to evaluate the quality of cocoa beans that have undergone drying using the clay oven method. This proposed research is vital, not just for validating the effectiveness of the new drying technique but also for ensuring that the quality of the cocoa beans meets the high standards required for market acceptance and consumer satisfaction. Through such comprehensive and continued research efforts, the cocoa industry can look forward to more innovative and efficient practices that bolster both the quality and sustainability of cocoa bean production.

ACKNOELEDGEMENT

The authors are grateful to the entire staff and students of the Department of Ceramic Technology, Takoradi Technical University (TTU) for supporting this novel project.

REFERENCES

Afoakwa, F. O., Jennifer, Q., Jemmy, T., Agnes, S. B, and Firibu, K. S. (2013). Chemical composition and physical quality characteristics of Ghanaian cocoa beans as affected by pulp pre-conditioning and fermentation. *Journal of Food Science Technology*, 50(6), 1097 – 1105.

Atanda, P. O. and Imasogie, B. I. (2009). Development of an integrated salt bath isothermal heat furnace unit for austempering of ductile iron. PhD Thesis. Department of Material Science and Engineering. Obafemi Awolowo University (OAU). Ile-Ife. Nigeria.

Cunha, J.D, (1990). Performance of Buraira 3*3n dryer for cocoa. *Agrotropica,* 2 (3), 157-160. Guda, P., Shruthi, G. and Jakkula, S. (2017). Drying of cocoa beans by using different techniques. *International Journal of Agriculture Innovations and Research (IJAIR).,* 859 -865.

Kazmi, S. M. S., Abass, S., Seleem, M. A., Munir, M. J., and Khitab, A. (2016). Utilization of waste sugarcane, bagasse and rice husk ashes. *Construction Building Materials,* 120, 29-41.

Marina, V. C., Beatriz, T. I., Jens, C. F., Jose, L.P., and Marta, H. T. (2011). Mycobiata cocoa: from farm to chocolate. *Food Microbiology,* 28 (8), 1499 – 1504.

Ndukwu, M. C. (2009). Effect of drying temperature and drying air velocity on the drying rate and drying constant of cocoa bean. *Agricultural Engineering International: the CIGR Ejournal. Manuscript* 1091. Vol. XI.

Phonphuak, N, and Chindaprasirt, P. (2014). Types of waste, properties and durability of pore forming waste- based fired masonry bricks. 1st End. Woodhead Publishing., 103-127.

Puello-Mendez, J., Castellar, P.M., and Ocana, L., C. (2017), "Comparative study of solar drying of cocoa beans: two methods used in Colombian rural areas" *Chemical Engineering Transactions.* Vol. 57, . 1711–1716.

Shuab-Babata, Y. L., Yaro, S. S., Abdulkareem, S., Busari, Y. O., Ambal, L. O., Ajao, K. S., and Mohammed, G. A. (2018). characterization of Baruten local government area of Kwara state (Nigeria) fireclays as suitable refractory materials. *Nigeria Journal of Technology (NIHOTECH).* Vol.12. No 2., 374-386. Retrieved from: www.nijotech.com [Accessed Date: 23/12/2023]

Taubert, D., Roesen, R and Schomig, E, (2007). effect of cocoa and tea intake on blood pressure: a meta-analysis *Arch Intern. Med.* 167(7): 626-634.

Tosom, J., and Njimanted, G. (2013). An analysis of the socio-economic determination of cocoa production in Meme Division, Cameroon. *Greener Journal of Business and Management Studies* 3(6)., 298-308.

Twum-Barima, A. (2023). Ghana's cocoa production in perspective from 2013 to 2023. CEO, Private Cocoa Buyer Ltd. [Interviewer: Kofi Asante-Kyei. Date of Conducting the Interview: 20/07/2023]

Yaya A, Asamoah, R.B., Nyankson, E., Annan, E., Agyei-Tuffour, B., Efavi, J. K., Kan-Dapaah, K., Apalangya, V. A., Damoah, L. N. W., Dodoo-Arhin, D., Tiburu, E. K., Kwofie, E.K., and Onwona-Agyeman, B. (2018). Industrial applications of clay minerals from Ghana (a review). *Oriental Journal of Chemistry*. Retrieved from: www.orientjchem.org . [Accessed Date: 29/12/2023]