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Development of a cocoa beans batch dryer

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ABSTRACT: *A cocoa beans batch dryer of 25kg wet capacity was designed, constructed and evaluated using wood as fuel material. It consists of four major parts namely; drying platform, drying chamber, heating duct (flue) and air holes. The heated air cocoa batch dryer used in the evaluation was successful in drying 5cm deep thin layer of cocoa beans from initial moisture content of 80.01% (db) to 7.49% (db) in 7 hours of continuous drying at drying temperature between 61.3^{0}C and 66.7 ^{0}C. The even drying efficiencies ranges between 72.3% to 92.9%. Drying efficiency were observed to increase with increase in batch mass . Hence, adopting the dryer will help in boosting cocoa production for agricultural advancement of the country.*

KEYWORDS: *Batch-dryer, Cocoa Beans, Moisture Content, Drying efficiency*

I. INTRODUCTION

Cocoa (Theobroma Cacao) is one of the most important cash crop in Nigeria and other countries such as Cote d'voire, Ghana, Indonesia, Cameroon, Brazil, Ecuador, Malaysia, Sierra-Leone and Republic of Benin. In Nigeria, the crop has recently gained government re-birth process after long dependence on petroleum. The Nigerian average annual production according to CRS [1] is about 170,000 tonnes. About 90-95 percent of cocoa production in Nigeria are from the Western part of the country and concentrated in Oyo and Ondo States Laryca, [2].

The end products from cocoa bean especially chocolate and beverages are considered among the basic food in many countries of the World and the quality of these end products is a function of how they are processed [3]. Also, economic importance of cocoa beans is indicated by its use in the manufacturing of wines, floor tiles, ceiling board and shoes polish among others. One of the most important post harvest processing of cocoa bean is drying before storage. Cocoa beans are dried traditionally or artificially. Traditionally, cocoa beans are dried by spreading the beans on concrete, raised platform, tarpaulin etc. in the sun for some days. Though, this method is the oldest and most widely used, it has disadvantages, such as beans damage by rodents, contamination by wind blown dust and dirt , inconsistency in the weather condition and frequent turning. All these therefore called for the use of artificial method. Artificially, solar and other conventional (heated air) driers are used. In conventional drying, the hot air in contact with the wet beans is used to supply heat and carry away the vapourised moisture. Musa-Makama [4] reported that hot-air drying of crops has been receiving much attention as an immediate alternative to sun-drying in developing countries. Biomass (including plant and animals) is a renewable energy resource which is relatively abundant on the farm in rural areas. ECN [5] presents that Nigeria need to work seriously toward incorporating renewable energy in the national energy mix and estimated a total biomass resources in the country to be about 9 x 10^{12} MJ. This offers a viable energy resource alternative to biofuels and petroleum in artificial dryers for drying crop.

Upon harvesting of ripe cocoa pods, fresh cocoa beans were fermented in wooden boxes for 5-7 days and dried until it reaches the safe moisture level of 7.5% [6]. According to Are and Gwynee-Jonnes [7] a loss of 55 to 64% in weight of cocoa beans occur during fermentation and drying of the beans.
In the humid tropics, slow drying with ambient air is not sufficiently attractive because the prevailing environmental condition of about 29-32^{0}C and relative humidity result in low drying potential Fagunwa et al [8].

Incidentally, harvest season of cocoa beans fall within the raining season, thus, the need of a weather dependent drying system.

In recent years, investigations have been undertaken and reported on drying of cocoa beans using solar and artificial drying methods in comparison with traditional/ open sun drying, Ndukwu et al [3], Hii et al[6], Fagunwa et al [8], Nicholas [9], Leopold et al [10], Akmel et al [11], Yeboah [12]. However, limited studies have been reported on the use of firewood for cocoa drying. Since the usage of solar and artificial dryers is invisible in the rural areas where boiling, cooking, frying and heating are done by firewood or charcoal. In Nigeria, it was observed that most people in cocoa business are peasant farmers and illiterates thus operating a costly and complex dryer will be difficult. Therefore, this paper present a report on the development of a natural heated air cocoa beans batch dryer which is cheap, simple to construct and operate, independent of weather, and capable of reducing problems associated with traditional/open sun-drying method.

II. MATERIALS AND METHODS

A developed conventional (heated air) natural heat transfer cocoa beans batch dryer was adopted for this study. The Cocoa beans used for the study were obtained from Cocoa Research Institute of Nigeria (CRIN), Ibadan and fermented for seven days Ndukwu [13] prior to the dryer evaluation. Locally available firewood were collected from the Farm of the Federal College of Agriculture, Ibadan on Lat. 7^0 22 ½ ^{1} N and Long 3^0 50 ½ ^{1} E where the study was carried out. Rainfall pattern is usually bimodal with a long and short rainy season separated by a short period of dryness.

The construction materials were obtained locally at Araromi , Agodi gate and Ogunpa markets both at Ibadan, Nigeria. These construction materials are galvanized metal sheet (2mm thick) for the heating duct and chimney, stainless steel (3mm thick) for the drying platform, Plywood (12.5mm thick) for the buffler and fired bricks. The flow of air into the drying chamber and heating duct is natural by the provision of air inlet holes and bufflers. The bufflers directs the natural air towards flue opening and air inlet holes respectively for proper combustion and convective heat transfer irrespective of the wind direction and speed.
The drying air temperature was measured at intervals with K-type thermocouple. At temperature above 60^0C (recommended drying temperature for cocoa) Hii et al [6] and Donald et al [14], a paddle made of metal head and wooden handle was used to draw out the firewood from the heating duct to prevent overheating.

2.1 Description of the batch dryer

The developed cocoa beans batch dryer and its general features are respectively shown on Plate 1 and Fig. 1. Below. It consists mainly of four major parts namely; drying platform, drying chamber, heating duct and air inlet holes. The drying platform (2) holds the beans during drying. It is made of stainless steel measuring 1900mm x 1000mm x 30mm . It has about 45% of its area perforated . The drying chamber (3) measuring 2340mm (length), 1340mm (width) and 920mm (depth) is made of mud brick walls which also help to reduce heat loss . The heating duct (flue) (4) enveloped by the drying chamber is where the fuel (wood) is burnt to heat the incoming air. One of its ends is opened for fuel loading, while the other end is connected to a chimney (1) through which the fumes is expelled. Also ashes from the burnt wood drops on the collection tray through perforated holes on the floor of the heating duct. Provision were made for adequate conventional heat transfer by the incorporation of two air inlet holes (6) of 150mm diameter each at the lower parts of the side. Bufflers and their slots (5) were also provided to properly direct the natural air towards the air inlet holes and the flue irrespective of the wind speed and direction. The thermometer/thermocouple holes (7) allow easy measurement of temperature in the drying chamber.

Plate 1: The Cocoa Beans Batch Dryer

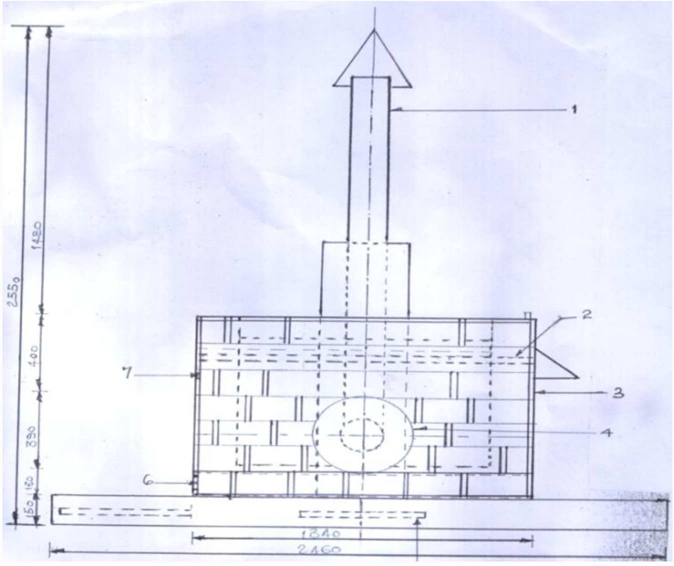

Fig. 1: Front view of the Cocoa Bean Batch Dryer

2.2 Design Equations

The design calculations for the construction of the dryer were based on the assumptions and criteria stated below.
The total energy required for drying of cocoa was calculated using equation presented by Seveda [15]

$$Q = M_d \times C_C \text{ X } (T_1 - T_2) + M \text{ x } Cp \text{ x } (T_1 - T_2) + Mw \text{ x } L \quad (1)$$

Where Q is the total energy required for drying of the beans(kJ), M_d is mass of bone dry beans in kg , c_c is the specific heat of beans in $kJkg^{-1}$ $^0C^{-1}$, T_2 is temperature inside the drying chamber in ^0C, T_1 is ambient air temperature in ^0C, M is the mass of initial water content in kg, C_p is specific heat water in kJ kg^{-1} $^0C^{-1}$, M_w is mass of water to be removed in kg and L is the latent heat of vapourization of water $kJkg^{-1}$.

Neglecting the effect of weather since the drying operation is expected to take place under a shed, the total amount of heat available for drying is that supplied by burnt wood and this was calculated from equation (2)

$$Q_T = M_{wt} \; S_p C_W \quad (2)$$

Where Q_T is total amount of heat in (J), M_{wt} is total mass of wood in kg and S_p C_w is the Specific Calorific value of wood in MJ/kg (18.5- 19MJ/kg, Valter and Eliseo [16]).
Heat required to evaluate the moisture and also keep the beans at the dryer temperature was calculated based principles of heat transfer using equation by Karlekar and Desmond[17]

$$E = m_c \; c_c d_T \; + M_W L \quad (3)$$

Where E is the heat required to evaporate the moisture, m_c is the mass of cocoa beans; c_c is specific heat of beans kJ kg^{-1} $^0C^{-1}$, M_w is mass of water to be removed in kg and L is the latent heat of vapourization of water $kJkg^{-1}$(2256kJ/kg, Liley[18]) and dT is change in temperature in ^0C.
While the total rate of heat transfer to the drying cocoa beans is a combination of conductive, convective and radiative which is similar to that of Okonkwo and Okoye [19].

$$q = q_c + q_r + q_k \quad (4)$$

Where q is the total rate of heat transfer in W, q_c is convective heat transfer in W, q_r is radiative heat transfer in W and q_k is conductive heat transfer, W
but

$$q_c = h_c \, (T - T_{ch}) \, A \quad (5)$$
$$q_r = h_r \, (T - T_{ch}) \, A \quad (6)$$
$$q_k = U_k \, (T - T_{ch}) \, A \quad (7)$$

where is h_c convective heat transfer coefficient w/m^{2}K, T is temperature of hot air coming from the heating duct ^{0}C, is T_{ch} temperature of chamber ^{0}C , h_r is radiative heat transfer coefficient, w/m.^{2}K and U_k is thermal conductivity of material in w/m^{2}K.

2.3 Evaluation

The performance evaluation of the cocoa batch dryer was carried out firstly by loading 20kg of fermented cocoa beans on the drying tray with a known mass of wood in fixed volume inside the flue. The drying samples were agitated for uniform drying at interval of 10 minutes and the moisture content of the samples on dry basis(db) were determined according to ASAE standard [20] at every one hour . Drying continued until the mass of the beans remain unchanged and also in accordance with Opeke [21] that drying should stop when the colour of the beans turned brown and a pressed handful of beans together gives crack shells (testa) and a bean cut with knife gives separated cotyledons.

Secondly, the dryer was evaluated for even drying efficiencies by drying varied masses (5kg, 10kg, 15kg and 20kg) and the dried products were separated manually into well dried, less dried and burnt beans and their weights were taken.
The even drying efficiencies were obtained from the relation as :

$$Z_e = \frac{M_{wd}}{M_{wd} + M_{ld} + M_b} \qquad (8)$$

Where Z_e is even drying efficiency in % , M_{wd} is mass of well dried beans in kg, M_{ld} is mass of less dried beans in kg and M_b is Mass of burnt beans in kg.

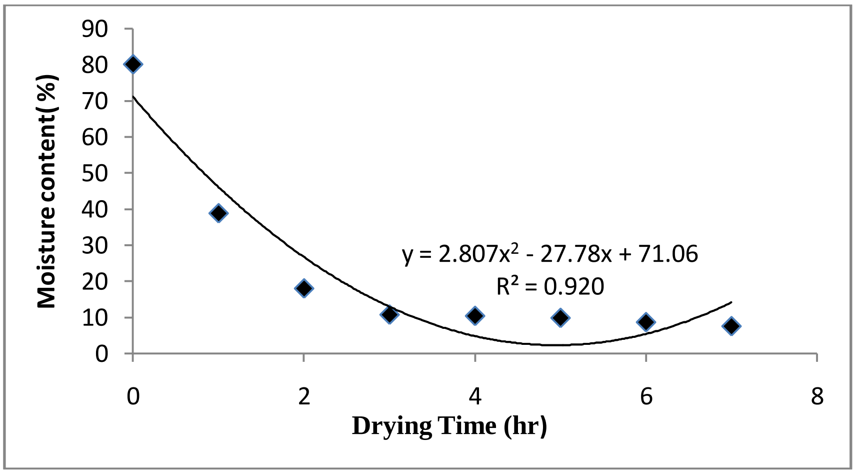

Fig.2 Drying rate of Cocoa beans batch dryer

TABLE 1: DRYING RATE OF COCOA BEANS DRYER

INITIAL MASS = 20.0kg
INITIAL MOISTURE CONTENT = 80.01% (db)

	REPLICATE 1			REPLICATE 2			REPLICATE 3			AVERAGE		
Drying Time (hr)	Mass (kg)	Temp. ^{0}C	Moisture Content (%)	Mass (kg)	Temp. ^{0}C	Moisture Content (%)	Mass (kg)	Temp. ^{0}C	Moisture Content (%)	Mass (kg)	Temp. ^{0}C	Moisture Content (%)
1	14.32	62.0	39.66	14.41	62.0	38.93	14.53	60.0	37.65	14.42	61.33	38.75
2	12.15	60.0	17.86	12.32	62.0	16.96	12.41	60.0	19.00	12.29	60.67	17.94
3	11.09	61.0	9.56	11.11	62.0	10.89	11.12	61.0	11.60	11.11	61.30	10.68
4	10.10	60.0	9.80	10.06	61.0	10.44	10.04	62.0	10.76	10.06	61.00	10.33
5	9.26	62.0	9.07	9.12	61.0	10.31	9.13	63.0	9.97	9.17	62.00	9.78
6	8.50	61.0	8.94	8.41	65.0	8.44	8.42	60.0	8.43	8.37	62.00	8.60
7	7.00	62.0	7.52	6.95	61.0	7.46	6.98	62.0	7.5	6.98	61.67	7.49

TABLE 2: COCOA BEAN BATCH DRYER PERFORMANCE ON MASS BASIS

S/N	Replicate	Initial Mass of Wet Beans (kg)	Time of drying (hr)	Mass of Wood used (kg)	Final Mass of Dried Beans (kg)	Mass of well dried beans (kg)	Mass of less dried (kg)	Mass of burnt beans (kg)	Even drying efficiency (%)
1	1	5.0	3.15	6.80	2.13	1.59	0.35	0.19	72.3
2	2		3.10	7.00	2.20	1.60	0.37	0.23	72.7
3	3		3.00	6.60	2.10	1.56	0.39	0.15	72.3
4	1	10.0	5.20	13.00	4.50	3.90	0.40	0.20	86.7
5	2		5.00	12.80	4.47	3.82	0.39	0.26	85.5
6	3		4.55	13.20	4.45	3.80	0.42	0.23	85.4
7	1	15.0	6.05	14.80	6.70	6.00	0.52	0.18	89.6
8	2		6.00	14.50	6.67	5.95	0.49	0.23	89.2
9	3		5.50	14.20	6.50	5.80	0.50	0.20	89.2
10	1	20.0	7.05	20.50	8.50	7.90	0.40	0.20	92.9
11	2		7.00	19.50	8.41	7.79	0.39	0.24	92.6
12.	3		6.50	20.00	8.40	7.80	0.42	0.18	92.9

III. RESULTS AND DISCUSSION

The result of the performance of cocoa batch dryer were as presented in Tables 1,2 and Figure 2. The result in Table 1 showed that the dryer dried 20kg of cocoa beans from initial moisture content of 80.01%(db) to 7.49%(db) in 7 hours in comparison with an open sun-drying of about 7days depending on weather condition. The average drying chamber temperature(61.4ºC) was found to be higher than that of open air (46^{0}C) obtained by Adejumo and Bamgboye [22] in the same environment . Fig. 2 showed falling rate drying similar to that obtained by Adejumo and Bamgboye [22] and Okonkwo and Okoye [19]. The dryer was found to have a high even drying efficiency of 72.3 to about 92.9% and increases as mass of cocoa beans increases. This suggests that the beans dried in bulk is evenly and thoroughly dried. The equation describing the relationship between moisture content and drying time is polynomial and it is given as $mc= 2.807dt^2 - 27.78dt + 71.06$, ($R^2$=0.920), where mc = moisture content (%) and dt = drying time (hr). The cocoa batch dryer can be expanded for community and commercial utilization. Biomass fuel such as wood, grass, animal residue e.t.c are easily obtained on the farm. Being operated under a shed, reduced the effect of rainfall and other environmental factors . The total cost of construction of about N5,200 is considered cheap and can be adopted by local communities in Cocoa producing areas for timely and effective drying of cocoa beans as an alternative to open sun- drying method.

IV. CONCLUSION

Development and performance evaluation of a Cocoa beans batch dryer were carried out. The results of the performance using locally available wood as heat source showed that the dryer dried 20kg of fermented cocoa beans from initial moisture content of 80.01% to 7.49% in 7hours. The average drying chamber temperature was 61.4^{0}C and over 90% even drying efficiency was obtained. The efficiency increases as the mass of cocoa beans increases per batch. The short period of drying cocoa beans suggests that this dryer is a good substitute for open sun-drying method especially when the insolation from sun is low because it does not depend on weather. No doubt, the dryer will help to boost cocoa production for agricultural advancement of the country.

REFERENCES

[1]. **CRS, "**Child Labour in West African Cocoa Production": Issues and U.S Policy Congressional Research Service (CRS) coordinated by Tiaji S: www.worldagroforestry.org/treesandmamalts/in aforesta/documents/cocoachildlabour w.africa. pp. 1-28 . 2005 accessed 7th June 2013.

[2]. **A.A. Laryca,** "Technology transfer to Cocoa farmer in West Africa". Proceeding of International Cocoa Research Conference Cortegena, Colombia. P. 584, 1982.

[3]. **M.C. Ndukwu, A.S. Ogunlowo, O.J. Olukunle, "** Cocoa Beans (Theobroma Cacao L.) Drying kinetics". Chilean Journal of Agricultural Research 70(4):633-639, 2010

[4]. **A.L. Musa-Makama,** "B- Carotene Retention in Sulphite Pretreotet –Air Dried Tomato Slices (Lycopersicum esulentum)". Proceeding of the West Africa Society for Agricultural Engineering and Nigeria Institution of Agricultural Engineers .Pp. 222-229. 2009..

[5]. **ECN , "**Potential for Renewable Energy Application in Nigeria". Energy Commission of Nigeria (ECN) Culspar Co. Ltd.; Lagos, Nigeria P. 2, 1997.

[6]. **C.L Hii, C.L. Law , M. Cloke, "**Modelling of thin layer drying kinetics of Cocoa beans during artificial and natural drying". Journal of Engineering Science and Technology, vol.3, No. 1.pp1-10, 2008

[7]. **L.A. Are and D.R.G Gwynee-Jones**. Cocoa in West Africa" Oxford University Press Ibadan, Nigeria. 1974.

[8]. **A.O Fagunwa, O.A Koya and M.O Faborode,** "Development of an Intermittent Solar Dryer for Cocoa Beans". Agricultural Engineering International: the CIGR Ejournal. Manuscript number 1292. Vol.XI, 2009.

[9]. **N.A. Musa, “**Drying Characteristics of Cocoa Beans using an Artificial Dryer”. Journal of Engineering and Applied Sciences, **7**(2): pp194-197, 2012.

[10]. **O.N. Leopold, A. Kamaruddin and W. Dyah.** “Study on Solar Dryer with Rotating Rack for Cocoa Beans”. Environmental Research Centre(PPLH- IPB) Working paper N0. 02

[11]. **D.C. Akmel, N.E. Assidjo , P. Kouame, K.B Yao, “**Mathematical Modelling of sun drying kinetics of thin layer Cocoa (Theobroma cacao) Beans”. Journal of applied sciences Research, **5**(9):pp1110-1116, (2009).

[12]. **I.K.Yeboah, “**Application of MATLAB- based Solar Dryer for Cocoa Drying”. Recent Researches in Applied Computers and computational Science. ISBN 978-1-61804-084-8

[13]. **M.C. Ndukwu,** “Effect of Drying Temperature and Drying Air Velocity on the drying rate and drying constant of Cocoa Bean”. Agricultural Engineering International; the CIGRE Journal Manuscript 1091. Vol. Xi .pp.1-14.April 2009.

[14]. **M.C. Donald, R.A. Lass, A.S.F.Lopez, “**Cocoa drying – A Review”. Cocoa Grower’s Bulletin 31, pp5-51, 1981.

[15]. **M.C. Seveda, “**Design and Development of Walk –In-Type Hemicylindrical Solar Tunnel Dryer for Industrial Use”. International Scholarly Research Network, ISRN Renewable Energy, vol 2012, Article ID 890820, 2012.

[16]. **Valter F, Eliseo A.** Wood Fuel Handbook (Production,Quality requirements and trading). Italy: AIEL- Italian Agriforestry Energy Association, Agripolis-viale dell’ Universita 141-35020 Legnaro(pd); 2008.

[17]. **B.V. Karlekar and R.M. Desmond,** “Engineering Heat Transfer”. West Publishing Company, USA, 1982.

[18]. **P.**E. Liley, Thermodynamic Properties of Substances. In: In Avallone EA, Baumeister T. editors. Mark’s Standard Handbook for Mechanical Engineers. III, 4: 31- 4:61. McGrawHill Books Co. 1997.

[19]. **W.I. Okonkwo and E.C. Okoye.** Integrated Pebble Bed Passive Solar Energy Storage Crop Dryer Proceedings of the Nigerian Institution of Agricultural Engineers (A division of the Nigerian Society of Engineers NSE).Vol. 26, pp. 417-423.2004.

[20]. **ASAE.** American Society of Agricultural Engineers (ASAE) Standards. 40^{th} Edition P. 449. 1993.

[21]. **L.K. Opeke.** Tropical Tree Crops. Ibadan: Spectrum Books Limited ; 1992.

[22]. **A.O.D. Adejumo, A.I. Bamgboye**. “Development and Evaluation of a Batch Solar Dryer Under Ibadan Climate”. Proceeding of Nigerian Institution of Agricultural Engineers. Vol. 26, pp. 412-416, 2004.