__Original Research Article__

DEVELOPMENT AND PERFORMANCE EVALUATION OF A BATCH-TYPE WASTE FIRED DRYER FOR COCOA

Abstract

The project work depicts the development and performance evaluation of a batch-type waste fired dryer for cocoa. Drying is an important step in the postharvest processing of cocoa beans. A batch type waste fired dryer was developed and it's evaluation was conducted at three different temperatures*viz*., 50℃, 60℃ and 70℃. The capacity of dryer was found to be 12 kg. The optimization of drying temperature was done based on the physico-chemical quality of the dried cocoa beans i.e. free fatty content. Based on the results, it was understood that the cocoa beans dried at 50°C was found to be superior among the other treatments. The combustion efficiency and energy requirement of dryer was found to be 24.61% and 83.68 MJ respectively.

Key words: Cocoa, dryer, biomass

Introduction

Plantation crops are high-value commercial crops which play a vital role in the agricultural economy and export trade of many developing and developed countries. Since the World Trade Organization (WTO) giving greater emphasis on agriculture, the commercial aspects of growing these crops assume considerable economic significance. Cocoa, (*Theobroma cacao L.)* a native of Amazon region of South America is an important plantation crop in the world which belongs to Malvaceae family.Cocoa beans, the seeds of the *Theobroma cacao* tree ~~(a native of Amazon region of South America),~~ are widely consumed all over the world (Beg *et al*., 2017). ~~In the world,~~It is estimated that more than fifty million people depend on cocoa for their livelihood (Tardzenyuy*et al*., 2020).

Most tropical nations harvest crops like cocoa throughout the year, and to decrease bulk losses and prevent spoiling, by drying right away after fermentation(Chinenye *et al*., 2010).Fermentation and drying constitute key unit operations in cocoa processing as they essentially determine the final quality of cocoa beans and subsequent products(Faborode, *et al*., 1995; Dzelagha*et al*., 2020; Ackah and Dompey, 2020). Drying is an important step in the postharvest processing of cocoa beans. It is a complex thermodynamic process in which unsteady heat and mass transfer occur simultaneously (Komolafe *et al*., 2021).The drying process through which apart from reducing moisture content of the bean is reduced, aids in the completion of the chemical reactions that were started during the fermentation process and in the development of the chocolate brown colour of well fermented beans (Wood and Lass, 1986). Drying of cocoa beans on most farms is carried out naturally by making use of the sun radiation while few large farms use artificial dryers to achieve the drying operations(Lasisi, 2014; Musa, 2012).

Open sun, solar, oven, microwave and freeze drying methods have been investigated at various levels in the drying of cocoa beans with objectives to improve the drying properties and final quality of cocoa beans. While an open sun dryer employs natural passive mechanisms, the solar drying methods can employ a combination of passive and active mechanisms. The oven, microwave, and freeze drying methods are fully active requiring electrical energy inputs (Dzelagha*et al*., 2020).The development of more energy-efficient drying processes would positively impact food availability and energy savings (Masud *et al*., 2020). However, limited studies have been reported on the use of firewood for cocoa drying (Komolafe *et al*., 2014). Biomass (including plants and animals) is a renewable energy resource that is relatively abundant on farms in rural areas (Komolafe *et al*., 2014).Biomass, in particular fuelwood, is a predominant form of renewable energy in rural areas (Murugan *et al*., 2021). Biomass contains a small amount of nitrogen and sulfur, so there is no harmful pollutants from biomass drying (Murugan *et al*., 2021).Considering the above facts, a study had been undertaken at KCAET, Tavanur on "Development and Performance Evaluation of a Batch-type Waste Fired Dryer for Cocoa".

Raw Materials

Cocoa (*Theobroma cacao* L.) fruits were procured from a progressive farmer at MeloorChalakudy, Thrissur district and Palachode, Malappuram district. Materials for the construction of machine were purchased from Coimbatore and Thrissur. Cocoa pods were broken and the beans were extracted using the cocoa pod breaker developed at KCAET, Tavanur. Beans having cracks and infections were rejected and only good quality beans were selected for this study. The selected cocoa beans were weighed and set for fermentation in a porous plastic sack for 5 days in a place with sufficient light and aeration. The sack was covered with a gunny bag and the beans were agitated manually for one minutesevery 2 days interval. After 5 days, fermented beans were taken out and subjected to other studies.

Determination of Engineering Properties of Fermented Cocoa Beans

The engineering properties of fermented cocoa beans *viz*., moisture content, size, mass, shape (sphericity), true density, bulk density, porosity, colour, coefficient of friction (stainless steel, aluminium, galvanized iron and plywood) and angle of repose were determined by standard methods.

Fermentation index

To determine the fermentation index (FI), a sample of 0.5 g of dry fermented cocoa beans (7% w/w) was obtained, macerated and then 50 ml of methanol: HCl solution (97:3) was added. Afterward, the sample was homogenized and left to rest at 8°C for 19 hours. Subsequently, the absorbance ratio at 460nm and 530nm was determined by spectrophotometry in a Thermo Scientific Helios Zeta UV-VIS spectrophotometer according to following equation.

$$FI = \frac{\text{Absorbance of value at 460 nm}}{\text{Absorbance of value at 530 nm}} \ldots\ldots\ldots\ldots\ldots (1)$$

The fermentation index is related to the colour changes in the cocoa beans, i.e. it has an intense violet colour at the beginning due to the polyphenols content that later turns to brown due to the condensation of anthocyanins that increases the absorbance value to 460 nm. Values above one (1) indicate well-fermented beans, meanwhile, values below 1 indicate an insufficient fermentation (Nazaruddin, *et al*., 2006).

Development of Cocoa Bean Dryer

A batch-type cocoa bean dryer was developed and fabricated atKelappaji College of Agricultural Engineering and Technology, Tavanur workshop.The main parts of the dryer are combustion chamber, drying chamber, fins, chimney, handle, feed inlet, product outlet, grate and frame.

Combustion chamber

Combustion chamber is one of the main components of the machine. The biomass or wood has been placed in a grate and is burnt inside this combustion chamber. It was made of 14 gauge galvanised plain sheet that was rolled into a cylinder of diameter 40cm and length 76.2cm. A semi perforated door with holes of 10mm diameter was provided to draw sufficient air from the atmosphere for combustion.

Fig. 1 Combustion Chamber

Fig. 2 Semi-perforated door of combustion chamber

Drying chamber

It is the main component of the dryer and is made of 16-gauge AISI (American Iron and Steel Institute) 304 stainless steel perforated sheet with 10 mm diameter holes rolled to form a cylinder of 30 cm diameter and 61 cm length. It was placed horizontally above the combustion chamber. The fermented cocoa beans are fed into this cylinder and are dried by hot air through natural convection. Spiral flights were welded at the inner circumference of the drying chamber. Spiral flights control the material handling and flow inside the dryer. It conveys the fermented cocoa beans from the inlet and spread uniformly in the drying chamber. Spiral flights are also helpful to collect the dried cocoa beans from the drying chamber at the end of drying process.

Fins

A total of 14 rectangular fins, each of size 17.78 cm x 7.62 cm made of 14 gauge galvanised plain sheet were welded both horizontally and vertically on the outer circumference of the combustion chamber that focused the drying chamber. The purpose of fixing fins is to enhance the heat transfer area thereby increase the heat transfer mechanism. The heat transfer is maximum in rectangular configuration compared to other design. Hence the rectangular fins were selected for the construction.

Chimney

An asbestos pipe of 10 cm diameter having length 189 cm was provided at the opposite side of the fuel inlet to release the exhaust flue gases to the atmosphere from the combustion chamber. Chimney prevents the entry of smoke into the drying chamber which results an increase in quality of dried cocoa beans.

Handle

A handle was provided to rotate the cocoa bean drying chamber which ensured uniform drying of the cocoa beans. It consists of a steel rod of length 91.4 cm and diameter 3.17 cm which was welded at the outlet side of the drying chamber.

Fig. 3 Drying chamber

Fig. 4 Chimney

Fig. 5 Handle

Feed inlet

It consists of a rectangular shaped feed hopper mounted on the top end of the cocoa bean drying chamber. It was made of 2 mm thick stainless steel sheet having 45° inclination and dimensions 21 cm × 15.8 cm × 5 cm. Fermented cocoa beans were fed into the drying chamber by rotating it in the anticlockwise direction using the handle.

Product outlet

It consists of a semi-circular shaped chute mounted at the bottom end of the drying chamber. It was made of 2mm thick stainless-steel sheet and it had a diameter of 30 cm. The products were collected by rotating the drying chamber in clock wise direction. The dried products could be collected from the product outlet by opening the lid using a handle.

Fig. 6 Feed inlet

Fig. 7 Product outlet

Grate

It consists of a rectangular shaped box of dimensions 61 cm × 28 cm × 15.2 cm that was made of mild steel rods to burn the fuel (fire wood) inside the combustion chamber.

Frame

The frame supports the entire machine to perform. It was fabricated using mild steel square pipes of sizes 3.8 cm and 1.9cm. The constituent units *viz*., combustion chamber, drying chamber, chimney etc. were mounted on the frame. The frame was covered by V board which is a kind of fibre cement board. The V board acts as an insulator that prevents the escape of the heat generated from the combustion chamber.

Fig. 8 Grate

Fig. 9 Front view

Fig. 10 Back view

Fig.11 Side view

Fig. 12 Top view

Operation of cocoa bean dryer

Dried biomass was selected for the study. Biomass was weighed and stacked inside the grate. The grate was then placed inside the combustion chamber and the biomass was ignited. The burning of the biomass was done inside the combustion chamber. The initial moisture content of the fermented cocoa beans was determined using an infrared moisture meter. The cocoa beans were fed into the drying chamber through the feed inlet. Simultaneously, the handle of the drying chamber was rotated in anti-clockwise direction to convey the cocoa beans inward the dying/drying chamber. The plenum chamber got heated due to the burning of controlled quantity of fuel in the furnace and drying air temperature was increased to the predetermined level. The dry and wet bulb temperature of the ambient air, heated air as well as exhaust air was measured using dry and wet bulb thermometer. The velocity of the heated air was controlled by altering the air suction valve. The average air velocity of 1.25 m/s was maintained throughout the experiment. It was measured with the help of a digital anemometer. The heated air entered the drying chamber through the perforations made on the drying chamber. While hot air passing through the moist cocoa beans, it absorbed moisture and came out through the exhaust port. The beans were mixed manually at specific intervals (4 anti-clockwise rotations every 10 minutes) by the handle that ensures uniform drying. The beans were dried to required moisture content, the dried cocoa beans had been collected through the product outlet by rotating the handle in clockwise direction.

Determination of chemical properties of dried cocoa beans

Free fatty acid

Fat from the cocoa bean samples dried at different temperatures were extracted by hexane using the Soxhlet extraction method (AOAC, 2005 method 963.15). FFA of the oils extracted was determined using the IOCCC method (1996).

Performance Evaluation of Cocoa Bean Dryer

The performance evaluation of cocoa bean batch-type dryer was carried out firstly by loading 12 kg of fermented cocoa beans of known moisture content is on the drying chamber with a known mass of wood in fixed volume inside the combustion chamber. The samples were then agitated for uniform drying at interval of 10 minutes and the moisture content of the samples were determined at every 30 minutes. Drying continued until the mass of the beans remain unchanged. According to Opeke (1987), drying should stop when the colour of the beans turned brown and a pressed handful of beans together give crack shells (testa) and a bean cut with knife gives separated cotyledons. The dryer was evaluated in terms of time required for drying, capacity, efficiency and energy requirement. Three drying temperatures *viz*., 50°C, 60°C and 70°C were selected in this study.

Determination of time required for drying

The cocoa beans were dried till 6-8 percent moisture content (db) was achieved and the time taken was recorded. Drying curve of drying/ A drying curve was plotted with moisture content in percent db along the y axis and time in minutes along x axis.

Determination of capacity of dryer

Capacity of dryer was decided by the amount and variety of beans to be dried per day or for a whole season. Sizes of dryers are expressed in terms of holding capacity or amount of beans to be dried per unit time or the amount of beans passing through the dryer per unit time (Chakraverty, 1995).

Combustion efficiency

Combustion efficiency is defined as the ratio of useful heat gain achieved by the drying material to the product of fuel consumption and its calorific value.

$$\eta_c = \frac{\left[m_{cocoa} \times C_{p_{cocoa}} \times (T_o - T_i)\right] + \left[m_w C_{p_w} (T_o - T_i)\right] + [m_{we}\, \lambda_w]}{\text{Fuel consumption} \times \text{Calorific value}}$$

Where, m_{cocoa} is the mass of the cocoa beans in kg

$C_{p_{cocoa}}$ is the specific heat of cocoa beans in kJ kg^{-1} $℃^{-1}$

T_o is the temperature inside the drying chamber in ℃

T_i is the ambient air temperature in ℃

m_w is the mass of initial water content in kg

C_{p_w} is the specific heat of water in kJ kg^{-1} $℃^{-1}$

m_{we} is the mass of the water to be removed in kg

λ_w is the latent heat of vaporisation of water in kJ kg^{-1}

Energy requirement

Energy requirement is the calorific value of the wood used per hour. The energy requirement of the dryer is calculated by the formula:

Energy consumption = Fuel consumption per hour × calorific value of fuel

RESULTS AND DISCUSSION

Engineering Properties

The results of physical properties viz., size, shape, mass, porosity, density, optical properties like colour and frictional properties like coefficient of friction, angle of repose etc. are presented and discussed in this section

Physical properties

Prior to the development of cocoa bean dryer, selected physical properties of fermented cocoa beans *viz*., moisture content, length, width, thickness, mass, sphericity, bulk density, true density and porosity were investigated. The average values of various physical properties of fermented cocoa beans are presented in Table 1. The average moisture content of fermented cocoa bean was 43.12 percent (wb) with a standard deviation (SD) of 1.80. The average length, width and thickness of cocoa beans were found to be 25.63±0.98, 14.63±0.65 and 8.47±0.83 mm, respectively. The average geometric mean diameter was 14.26±0.57 mm. The average mass of an individual cocoa bean was 2.24±0.67 g. The average sphericity was estimated as 0.56±0.01. The average true density and bulk density were 1009.54±10.31 and 621.27±16.38 kg/m^3, respectively. The average value of porosity was 38.31±0.7 percent.

Table 1. Physical properties of fermented cocoa beans

Sl. No	Physical property	Value	Standard deviation
1	Moisture content, % w.b.	43.12	±1.8
2	Length, mm	25.63	±0.98
3	Width, mm	14.63	±0.65

4	Thickness, mm	8.47	±0.83
5	Geometric mean diameter, mm	14.26	±0.57
6	Mass, g	2.24	±0.67
7	Sphericity	0.56	±0.01
8	Bulk density, kg/m^3	621.27	±16.38
9	True density, kg/m^3	1009.54	±10.31
10	Porosity, %	38.31	±0.70

Optical properties and frictional properties

The optical property of fermented cocoa beans *viz.*, colour and frictional properties such as angle of repose and coefficient of friction on four different surfaces were determined. The various optical and frictional properties of fermented cocoa beans are illustrated in Table 2. The colour of fermented cocoa bean was expressed in terms of L*, a* and b* values. Coefficient of friction of cocoa beans on four surfaces *viz.*, stainless steel, aluminium, GI and plywood were determined.

Table 2. Optical and frictional properties of fermented cocoa beans

Sl. No	Properties	Values	Standard deviation
1	Colour		
	L*	26.55	±0.01
	a*	8.54	±0.04
	b*	10.46	±0.01
2	Angle of repose	28.31	±0.13º
3	Coefficient of friction		
	Stainless steel	0.40	±0.002
	Galvanised Iron(GI)	0.47	±0.001
	Plywood	0.50	±0.002
	Aluminium	0.34	±0.001

The average L*, a* and b* values of fermented cocoa beans were 26.55±0.01, 8.54±0.04 and 10.46±0.0, respectively. The coefficient of friction of cocoa beans on stainless steel, GI, plywood andaluminium was 0.40±0.002, 0.47±0.001, 0.50±0.002 and 0.34±0.001 respectively. This information is useful in estimating the power losses due to friction so that provision can be made for such in computing the power requirement of the machine, and in choosing the appropriate materials for fabrication (Maduako and Hamman, 2004). The average angle of repose of fermented cocoa beans was found to be 28.31±0.13º.

Fermentation index

Fermentation Index is defined as the ratio of total free amino acids in fermented and non-fermented samples. The fermentation index value of cocoa beans is presented in Fig. 13. From the figure, it is observed that 73% of the cocoa beans were fully fermented, 23% were partially fermented and 4% were not fermented.

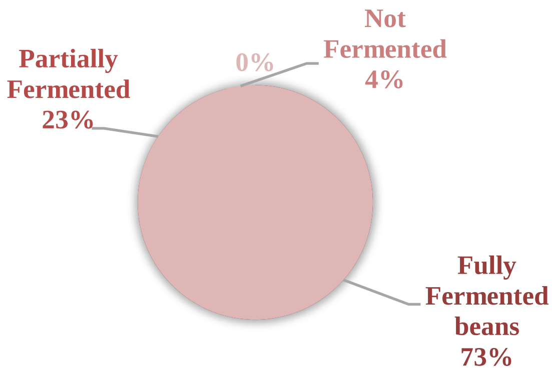

Fig.13 Fermentation index of the cocoa beans

Physical properties of dried cocoa beans

The physical properties of dried cocoa beans *viz.*, length, width and thickness were determined and presented in Fig. 14. The length, width and thickness of dried cocoa beans were 25.63±0.98, 14.63±0.65, 8.47±0.83 mm and 24.38±1.02, 13.41±0.31, 8.45±0.75 mm, respectively. The sphericity of dried beans was found to be 0.56±0.01 and 0.57±0.01, respectively. The cocoa beans undergo minute shrinkage during drying. The shrinkage caused during drying process was due to the removal of moisture from the beans (Koua *et al*., 2019). He reported that the shrinkage decreased linearly with decrease in moisture content. The seed coat and air moisture build up around the seed coat has obvious influence on the change in the shape of the entire heterogeneous structure of the cocoabean at the beginning of drying(Ndukwu,2012).

Chemical properties of fermented and dried cocoa beans

Free fatty acid

The effects of drying temperatures on free fatty acid content of cocoa beans are depicted in Fig. 15. From the figure, it is observed that the free fatty acid content of dried cocoa beans increased with increase in drying temperatures. Highest free fatty acid content was found in beans dried at 70ºC (1.85%) and lowest in beans dried at 50℃ (1.49%).

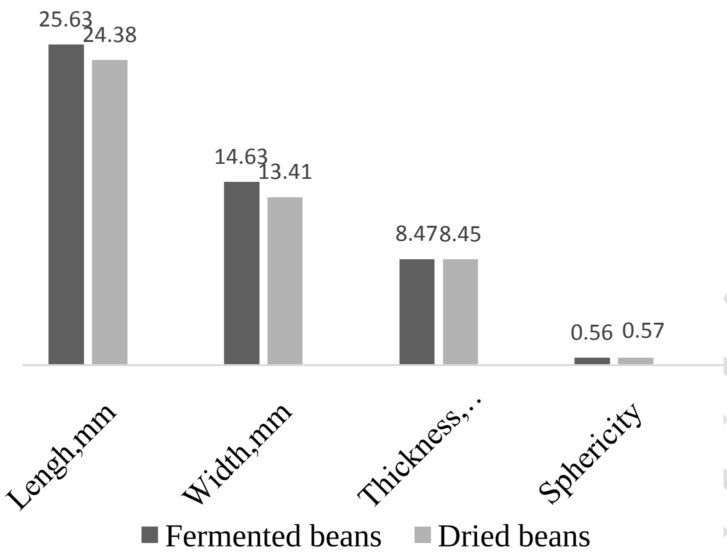

Fig. 14 Physical properties of the cocoa beans (fermented and dried cocoa beans)

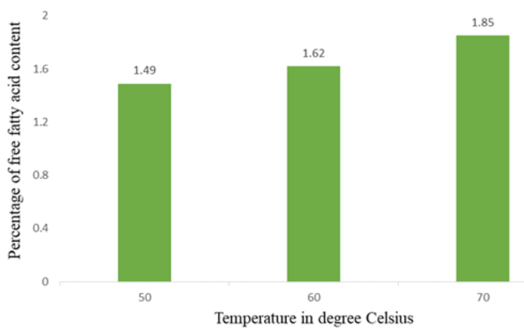

Fig. 15 Effect of drying temperature on free fatty acid of dried cocoa beans

The European parliament and European council directive 73/241/EEC limits the maximum FFAs content to 1.75% oleic acid equivalent in cocoa butter. To be able to meet the acceptable level, Dand (1997) reported that the FFAs levels should be less than 1% in fresh cocoa beans and less than 1.75% in dried cocoa beans. The high level of free fatty acid may be attributed to high drying rate which did not allow for the completion of the needed oxidative reaction and acid diffusion process.

Performance evaluation of waste fired dryer

Time required for drying

Time required for drying of cocoa beans at different drying temperatures is given in Table 3. From the table 3, it is clear that there is a significant change in drying time with drying temperature. The drying time required for drying fermented cocoa beans at drying temperatures 50°C, 60°C and 70°C were 8 hours, 6 hours and 5 hours respectively. The drying time was maximum and minimum at 50°C and 70°C, respectively.

Table 3. Effect of drying temperature on time required for drying

Sl.No	Temperature of drying(℃)	Drying time(hours)
1.	50	8
2.	60	6
3.	70	5

The moisture content decreased continuously with drying time showing a falling rate drying characteristics. There was no constant rate drying period. At the falling rate period the movement of moisture within the cocoa to the surface is governed by diffusion since the material is no longer saturated with water. The results obtained are in agreement with the observations of many researchers. Ndukwu*et al*. (2010) reported that the moisture ratio, moisture content and drying rate decreased continuously with drying time showing a falling rate drying characteristic. There was no constant rate drying period because most crops exhibit the constant rate drying characteristics at their critical moisture content therefore cocoa is not an exception.

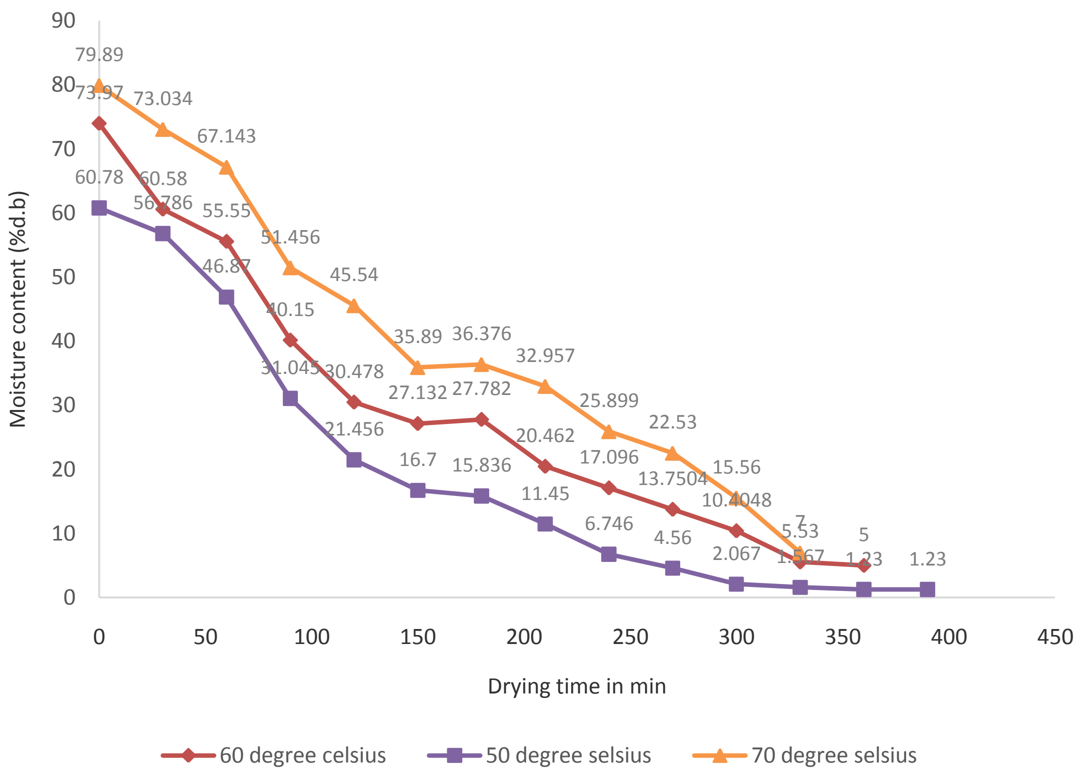

Fig.16 Drying curve of the cocoa beans dried by waste fired dryer

Capacity of batch-type cocoa bean dryer

The capacity of the developed dryer was found to be 12 kg per batch.

Combustion efficiency

The combustion efficiency primarily depends on the type and amount of waste used for firing, proper control of the drying temperature and optimum amount of fermented cocoa beans fed into the drying chamber for drying. As given in table 4 the combustion efficiencies at temperatures 50ºC, 60℃ and 70℃ were 24.61, 19.95 and 17.02 per cent, respectively**.** Highest efficiency was obtained when the beans were dried at 50ºC**.**

Table 4. Effect of drying temperatures in the combustion efficiency

S. No	**Drying temperature (℃)**	**Combustion efficiency (%)**
1.	50	24.61
2.	60	19.95
3.	70	17.02

Energy requirement

The total energy required for operating the drier having a capacity of 12 kg for one hour was found to be 83.68 MJ

Conclusion

Drying is an important step in the postharvest processing of cocoa beans. Cocoa beans are dried after fermentation in order to reduce the moisture content from about 40 per cent to about 6-7 per cent (db). At present drying of cocoa is done mostly by sun drying. Sun drying of cocoa beans has many disadvantages *viz*., it is weather dependent, exposure to dust, molds and pests, longer drying time etc. Artificial dryers, which are used at present produce low quality cocoa beans with high acidity. Electric dryers are found comparatively expensive with regard to consumption of electricity and brought very little profit to the farmers. The developed cocoa bean dryer is a compact as well as portable machine. It is found efficient in drying cocoa beans and will be benefitted to small and marginal cocoa growers.

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