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Development of low cost portable biomass fired dryer for cardamom drying in hilly areas

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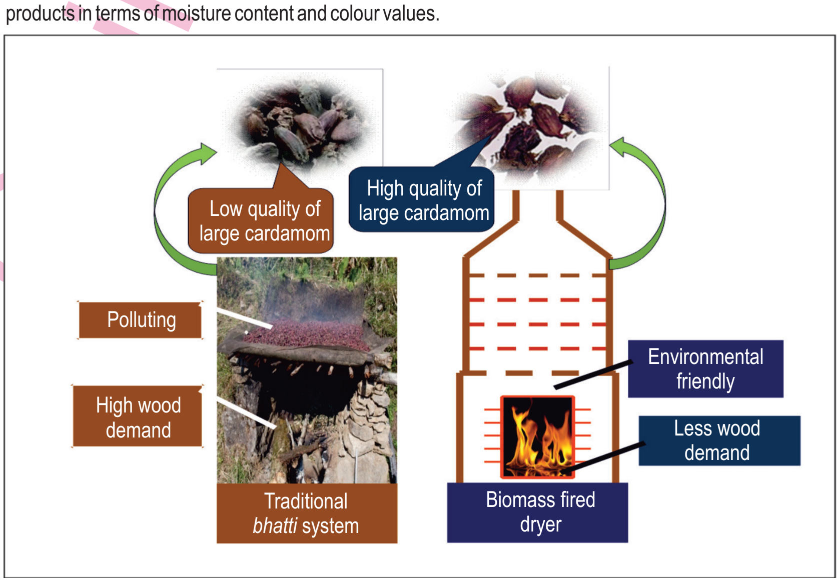
Abstract

Aim : The aim of the present study was to develop a low cost portable biomass fired dryer for cardamom (*Amomum subulatum* Roxburgh) drying in hilly areas.

Methodology : A low-cost and portable biomass fired dryer was designed and evaluated for its suitability for drying large cardamom. The dryer was made in two halves containing the drying trays in upper half and the biomass burner in lower half. The upper half and lower half weighed 22 and 16 kg, respectively, making it light weight and portable.

Results : It was observed that large cardamom was dried from about 80% initial moisture to 10% final moisture content in 14 hrs for 20 kg loading and 19 hrs for 30 kg loading. It was also found that for drying of 20 and 30 kg fresh cardamom, 14 and 19.5 kg biomass was burnt and moisture driven away was 14.07 kg and 20.8 kg, respectively. Thus, the average fuel requirement for drying of per kg large cardamom was 0.67 kg. The cost of the dryer was found to be Rs. 8300 (USD 127.66) and cost of drying 100 kg cardamom was Rs. 245 (US $ 3.81).

Interpretation : The developed cardamom dryer was found portable and low-cost. It consumed lesser fire wood than traditional *bhatti* system, required lesser drying time and delivered higher quality of dried products in terms of moisture content and colour values.



Introduction

Large cardamom (*Amomum subulatum* Roxburgh) is one of the major cash crops in India producing 53.3% of global production followed by Nepal (33.3%) and Bhutan (13.3%). In India, the state of Sikkim from North East produces 85% of total production in the country (Pathak, 2008). This crop is mostly grown in hilly region at an altitude of 1000 to 2000 m (Singh *et al.,* 1989; Rao *et al.,* 2001). For better aroma and storage quality, large cardamom is dried from an initial moisture content of 80% to less than 10% wet basis (w.b.) and this process is known as curing, which has to be done immediately after harvesting to avoid fungal infection (Mande *et al.,* 1999; Ducourtieux *et al.,* 2006). Farmers practice traditional method called *Bhatti* for curing which causes degradation in quality of the product fetching meagre remuneration (Chua and Chou, 2003). This process also produces huge amount of smoke degrading the quality of product and polluting the surrounding environment (Mandal *et al.,* 2014). Attempts have been made in the past to study the *Bhatti* system and to improve its design or to replace by gasifier based curing chambers which worked well. With a more advance attempt, a trolley type tray dryer of 600 kg per batch capacity was designed, developed and evaluated. It was equipped with a heat exchanger based on diesel fuel. It could dry the product at controlled temperature giving high grade quality of the dried product (Sharma *et al.,* 2009; Bhutia *et al.,* 2017).

However, all these modified dryers are stationary, operated by diesel fuel or electricity and require high initial investment. Small farmers are not financially sound to afford the bigger units and access to electricity in the remote areas is scarce. They have to carry their harvested materials to the drying station which is cumbersome and time consuming. To avoid this hard work, they go for the traditional *bhatti* system of drying. Hence, to encourage the growers, this study was undertaken to replace the *bhatti* system with a modified drier. Therefore, objectives of this study were to develop a portable and low-cost biomass fired drier for drying of large cardamom using locally available biomass and to evaluate its performance in terms of drying time, temperature profile and dried product quality.

Materials and Methods

Development of portable dryer : The dryer was fabricated in two halves to make it portable so that it can be moved by two persons. The upper half consisted of drying cabinet, four drying trays and the hood (Fig. 1). Drying trays with aluminum wire mesh base were of 1.2 m x 0.8 m size and spaced 150 mm apart. Thus, they provided total drying area of 3.84 m^2. Three walls and the hood of the drying cabinet were closed by 0.35 mm galvanized iron (GI) sheet and insulated using 5 mm plywood board. A square shape opening of 75 mm x 75 mm was provided at the top for escape of moist air. A damper was placed over the opening to reduce the speed of escaping hot air. Drying cabinet is accessible through two hinged doors provided in the front side of the dryer. Wooden sliding rollers were provided below the drying trays for easy loading, unloading and cleaning. The whole upper half weighed 22 kg which could be easily transported by two persons. The upper half was fitted above lower half and was air sealed by rubber strips.

Lower half consisted of a heating chamber which housed the biomass burner. The biomass burner can be accessed through a door at one side of the heating chamber. Concept of indirect heating was adopted so that product was not contaminated with flue gas. Fresh air was heated by the burner which flowed from outside through rectangular vents, provided at two sides at the bottom of the heating chamber. The opening area of vents could be adjusted by using rotating flaps. An opening was provided in the burner door in which a glass visor was fixed to inspect the biomass burning. An adjustable flap was fixed on one side of the burner to control the airflow for burning of biomass. To delay the movement of flue gas and to increase the heat transfer, a baffle was provided inside the burner as shown in Fig. 1. The burner walls were made of used vegetable oil containers (0.25 mm tin sheet) and insulated with 15 mm thick glass wool. Aluminum sheet of 200 mm x 40 mm size were riveted to each side of the burner surface at 25 mm spacing to increase heat transfer rate from burner to incoming fresh air. Weight of the lower half including burner was 16 kg making total weight of the dryer as 38 kg.

Operation of the dryer : In operation, the burner surface and vertically attached aluminum sheets were heated by the heat generated from burning biomass inside the burner. The flowing ambient air was heated by hot surfaces of fins and moved upside picking moisture from each tray on its path. The moist hot air went out of the burner through the rectangular outlet provided at the top. Continuous flow of air was maintained by natural convection (Koppejan and Loo, 2012). The temperature inside heating chamber was controlled by controlling the air flow with rotating flaps.

After loading fresh materials to the trays, burner was loaded with 500 g biomass (having <20% moisture) and a fire was started. A small fire was carefully maintained to keep the drying temperature as 65ºC at the bottom of first tray. To achieve this, very small quantity of biomass was fed every time to the burner as suggested by Bena and Fuller (2002). When the temperature was abruptly high, the flaps of heating chamber were fully opened to allow more air inside the chamber to reduce the temperature. Biomass feeding was stopped when moisture content of cardamom reached 10%. Remaining biomass and charcoal were taken out and weighed.

Properties of large cardamom : Dimensional properties of freshly harvested large cardamom such as length (L), width (W) and thickness (T) were measured using a digital vernier caliper having 0.01 mm accuracy. The geometric mean diameter (Dg) was calculated by the formula of Mohsenin (1978). Moisture content was determined by standard hot air oven method, keeping the cardamom for 48 hrs at 65°C temperature (Gupta and Das, 1997).

Drying of large cardamom : Freshly harvested large cardamoms were transported to ICAR RC NEH, Umiam, Meghalaya from ICAR Sikkim centre at Tadong, Gangtok and stored at 4°C temperature in sealed plastic bags. Before starting of drying experiment, large cardamoms were taken out and kept in ambient conditions for two hours to normalize the temperature. The dryer was tested for two capacities *viz.,* 20 and 30 kg. Each tray was loaded with 5 kg of cardamom while testing for 20 kg capacity and 7.5 kg for 30 kg capacity, respectively. Five temperature probes were installed over four trays inside heating chamber. Five small containers of 50 mm x 50 mm size were placed on each tray- one at the center and four at each four corners. A representative sample of 100 g cardamom was put inside these containers. After every one hour, weight of these containers were noted to record moisture loss. Trays were not interchanged throughout the drying period, but lower most tray was removed once the cardamom reached the equilibrium moisture content. Overall thermal efficiency of the dryer was calculated as the ratio of heat required to evaporate the moisture from the cardamom capsules and heat supplied by burnt biomass (Yahya *et al.,* 2017).

Quality evaluation of large cardamom : Quality evaluation of large cardamom was done based on the final moisture content and the change in visual colour after drying. Visual colour of large cardamom samples was determined before and after drying experiments using a tri-stimulus colorimeter which was calibrated using white and black standard ceramic tiles. The colour was expressed in terms of 'L' value [lightness, ranging from zero (black) to 100 (white)], 'a' value [ranging from +60 (red) to −60 (green)] and 'b' value [ranging from +60 (yellow) to −60 (blue)] which were measured using D-65 illuminant and 10° observer. The total colour difference (TCD), a combination of L, a and b values, was used to characterize the overall change in colour after drying (Kaleemullah and Kailappan, 2006; Cubero *et al.,* 2011; Saxena *et al.,* 2012; Yemmireddy *et al.,* 2013). There was non-uniformity in appearance on the fresh cardamom capsules. Therefore, colour values were taken only at the centre of the capsule surface where colour was uniform in almost all the capsules.

Results and Discussion

Average length, width and thickness of fresh large cardamom were found to be 22.29 ±1.30 mm, 17.93±0.86 mm and 14.66±0.66 mm, respectively. The geometric mean diameter was calculated as 18.02±0.75 mm. Fresh large cardamom capsules contained 78.71 ± 0.92% initial moisture (w.b.). Large cardamom was dried from about 80% initial moisture to 10% final moisture content. Total drying time was found to be 14 hrs for 20 kg loading and 19 hrs for 30 kg (Fig. 2) which was much lesser than the traditional *bhatti* system where it took 25-40 hrs as reported by Mande *et al.* (1999). However, the dryer took more

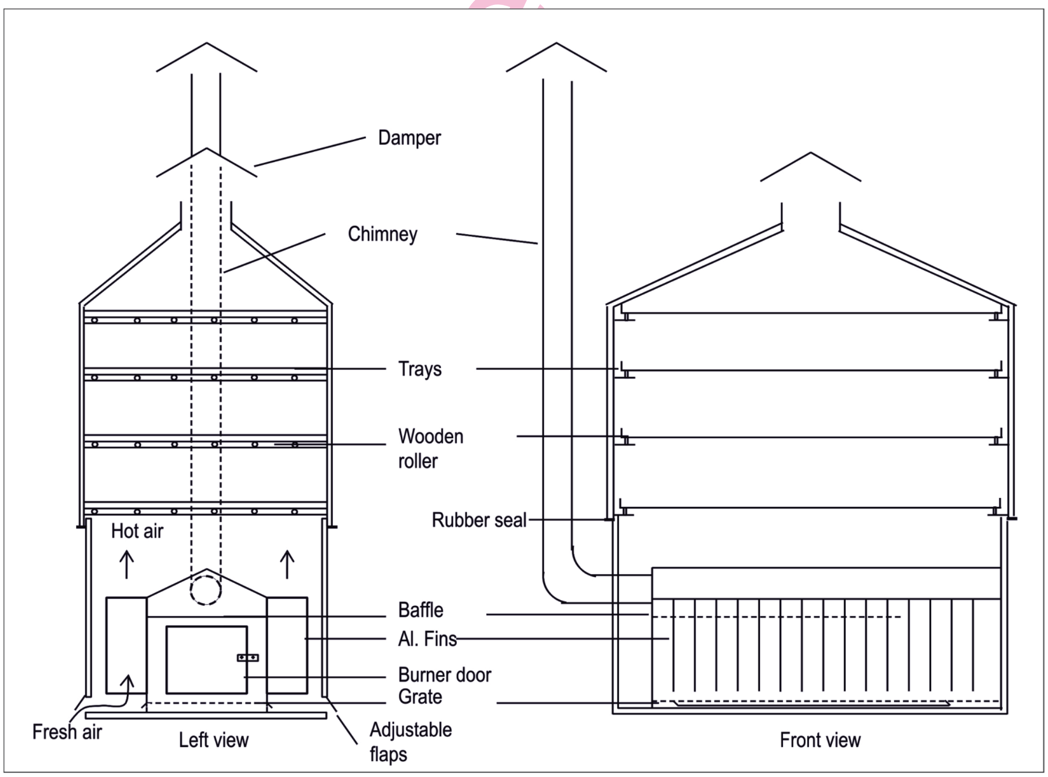


Fig. 1 : Low-cost portable large cardamom dryer.

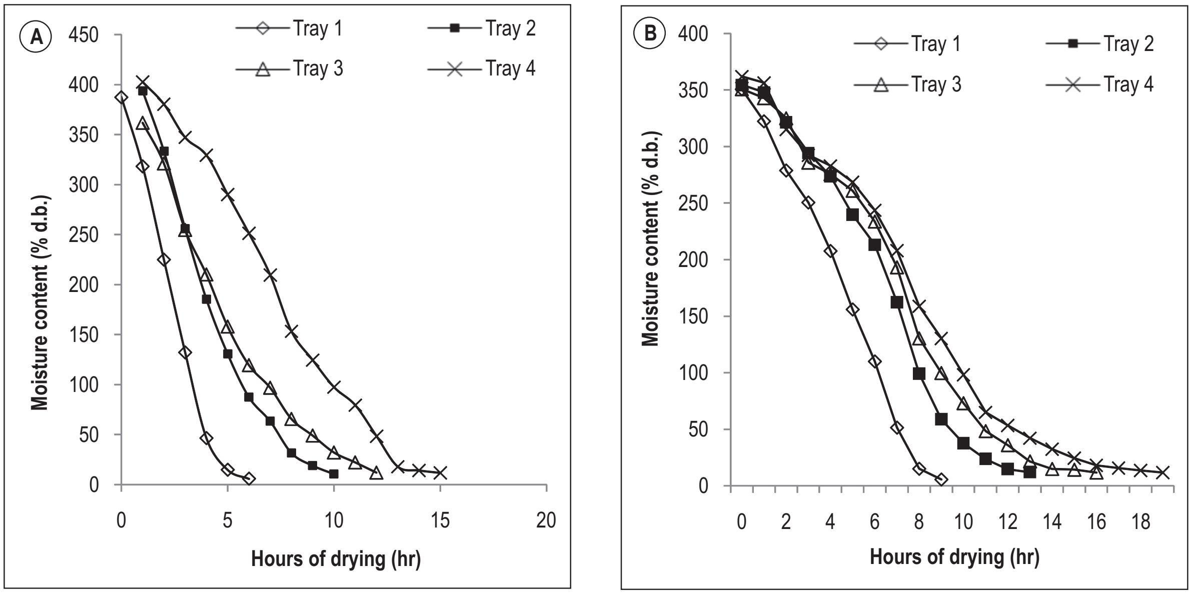


Fig. 2 : Moisture reduction curve of large cardamom at different tray levels: (A) 20 kg and (B) 30 kg loading.

time than the kiln dryer (9.5 – 13.0 hrs) reported by Balakrishnan *et al.* (2011). Thickness of material on the trays was 15 and 21 mm for 20 and 30 kg loading, respectively. The higher bed thickness took more time for 30 kg loading. Similar findings were reported by Ilis and Demir (2018). Higher variations in drying conditions in different tray levels were observed. The bottom tray dried very fast in both the cases which took 6 and 9 hrs for 20 and 30 kg loading, respectively. The top most tray took 14 and 19 hrs in the respective loading of 20 and 30 kg. Similar results were reported by Bena and Fuller (2002) for natural convection solar-biomass hybrid dryer.

Moisture loss gradually decreased from bottom tray to top tray with time (Fig. 3). The cardamom of bottom tray lost 88% moisture within the first four hours and followed by second and third trays from bottom which lost 67 and 56% moisture, respectively in case of 20 kg loading. This condition was reached

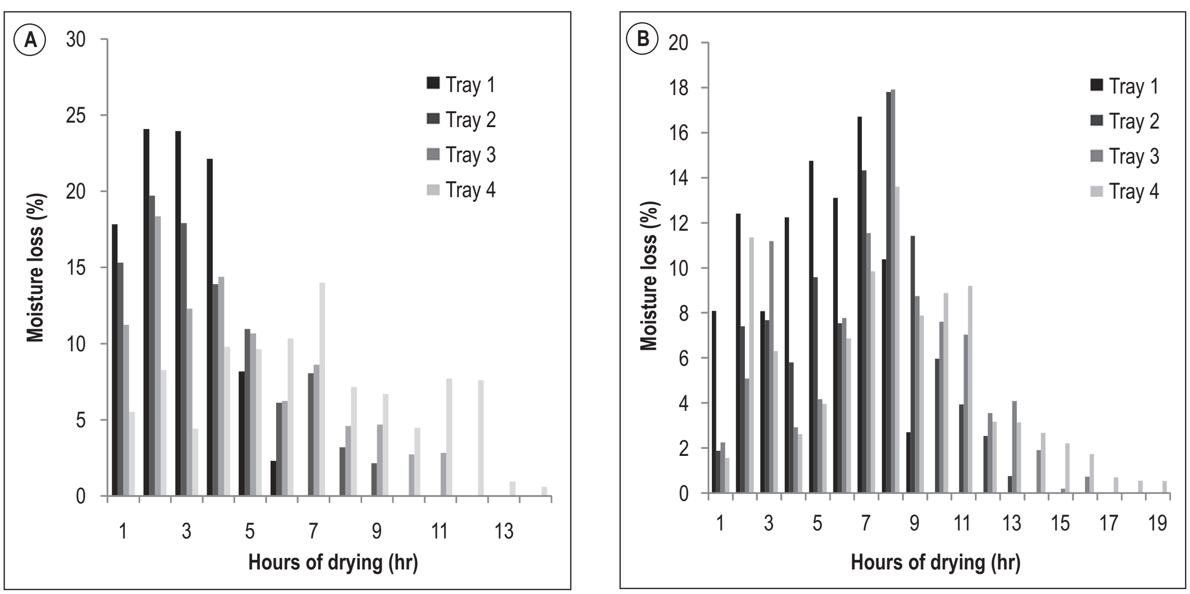


Fig. 3 : Moisture loss pattern of large cardamom at different tray levels: (A) 20 kg and (B) 30 kg loading.

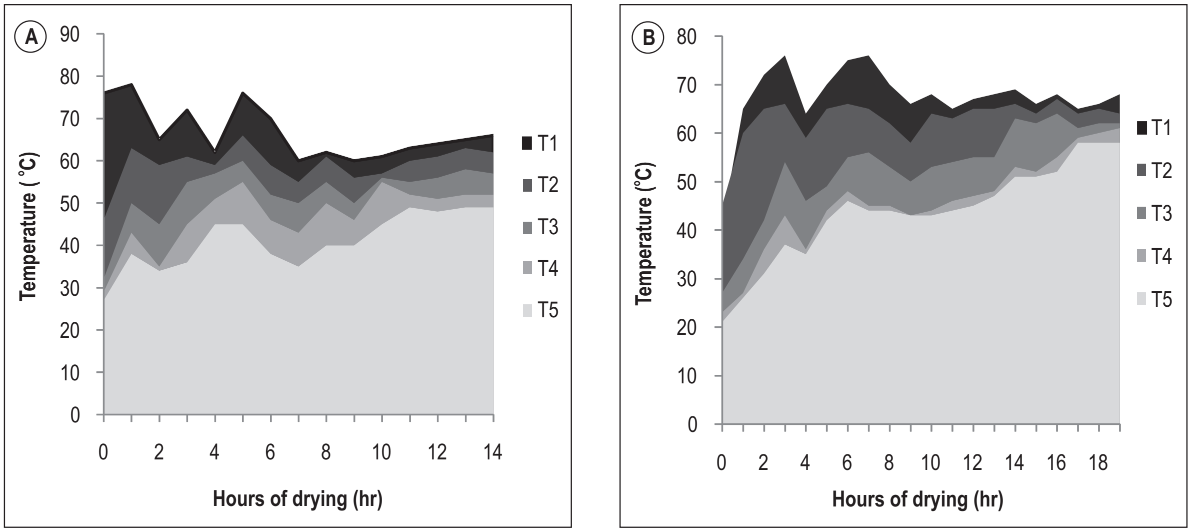


Fig. 4 : Temperature profile inside the dryer at different tray levels: (A) 20 kg and (B) 30 kg loading (T1 is the temperature below Tray 1 and T2 to T5 are the temperatures above Tray 1 to Tray 4, respectively).

after eight hours for 30 kg loading. The moisture loss pattern of large cardamom dried in this dryer may not be similar to the electrical dryer because temperature was not constant throughout the time and varied considerably.

The temperature was recorded at heating chamber (T1) and on top of each tray (T2 to T5). Maximum temperature in the heating chamber was recorded to be 76°C (Fig. 4) which was more than the recommended temperature for drying of biological materials *i.e.,* 65°C as reported by Mukhopadhyay and Siebenmorgen (2017). Therefore, the efforts were made to reduce the temperature of heating chamber to save the materials of the bottom tray. This was done by opening the doors of heating chamber and allowing more air to enter which reduced the temperature. The average temperature of heating chamber was found to be 67°C which was close to the recommended temperature. Average temperature of the subsequent trays (T2 to T5) reduced by 7, 9 and 6°C, respectively, as the heated air moved slowly upward after picking the moisture and loosing enthalpy.

Cardamoms in all the trays had attained a final moisture content of 10% dry basis (d.b.). This value of moisture content is safe for long term storage of spices as reported by Jin *et al.* (2017). Quality of large cardamom is best judged by the colour value because pinkish products fetch the maximum remuneration in the market. On drying, pinkish colour of fresh cardamom fades and turns brownish or blackish which reduces the selling cost of the product significantly (Bhutia *et al.,* 2017). After drying, considerable changes in Hunter colour coordinates, *L;a;b* were observed. After drying of large cardamom, average 'L' colour value of dried products was observed as 33.78 where it was 37.25 for fresh cardamom (Table 1). It was lowered further to 30.56 for those which dried at close vicinity to the burner at the bottom tray. There was more decrease in colour 'a' values which indicated decrease in red colour. The poor quality dried products registered colour 'a' value of 5.74 which was much lower than the fresh cardamom. Little change in 'b' colour value was observed in dried large cardamom. The brightness of dried large cardamom was highest in Tray 4 which was farthest from the burner. The change in colour 'a' was very high in cardamom of Tray 1. Increase in TCD was in the range of 6.58 to 9.78 indicating change in visual colour. Similar kinds of colour degradation patterns were reported for jackfruit (Saxena *et al.,* 2012) and kiwi fruit (Maskan, 2001) due to thermal treatment.

The cardamom of Tray 1 which was close to the burner dried faster due to high temperature and first exposure of incoming hot air with less humidity. High temperature caused higher TCD and higher proportion of poor quality product. The quality and proportion of good quality large cardamom increased in the trays with the distance from burner. Bena and Fuller (2002) experienced the same while drying pineapple slices using a hybrid dryer in burner mode at night. There was not much difference in quality of dried large cardamom at two loading rates. For drying of 20 and 30 kg fresh cardamom, 14 and 19.5 kg

Table 1 : Hunter colour values of fresh and dried large cardamom

Colour values	Fresh	Tray 1	Tray 2	Tray 3	Tray 4	Poor quality
L	37.25	32.68	33.30	33.59	35.58	30.56
a	18.72	10.49	12.01	12.11	12.40	5.74
b	6.79	4.14	6.59	7.21	7.57	5.31
TCD	-	9.78	7.79	7.56	6.58	14.67
% poor	-	14.56	5.25	5.21	3.15	-

biomass was burnt and moisture driven away was 14.07 kg and 20.8 kg, respectively. Thus, average fuel requirement for drying of per kg large cardamom was 0.67 kg, which was much lower than traditional methods which required 2.5 kg wood per kg of large cardamom (Rao *et al.,* 2001). Considering the calorific value of biomass as 14 MJ kg^{-1}, thermal efficiency of the dryer was found to be 18.28 and 19.39% for 20 and 30 kg loading, respectively. It indicated that higher loading reduced the fuel requirement for the dryer. When time is a constraint, with low loading, faster drying can be achieved. Similar findings were reported by Thanompongchar *et al.* (2017) in drying of glutinous rice crackers. The fins provided on two sides of the burner increased the heat exchange between air and the burner surface which increased the overall dryer efficiency.

The manufacturing cost of the dryer was calculated as Rs. 8300 (USD $ 127.66). The life expectancy of the dryer was assumed to be four years. If the dryer was used only for drying of large cardamom, the dryer will be used for 30-45 days every year which is the harvesting period of large cardamom reported by Sharma *et al.* (2000). So, 30 batches of large cardamom will be dried using the dryer which would dry 900 kg of large cardamom and consume 585 kg wood costing Rs. 638 to 1064 (USD 9.82 to 16.37). Thus, drying cost per 100 kg of large cardamom will be only Rs. 245 (USD 3.81). In an electric dryer of the same capacity, drying cost was calculated to be Rs. 303 (USD 4.66) per 100 kg. If the labour cost of transportation of raw large cardamom is considered in case of electric dryer, the total cost will be many folds higher than the dryer under study.

The biomass fired dryer developed for drying of large cardamom was found portable and low-cost. Drying of large cardamom can be achieved within shorter time period with low fuel consumption. Quality of dried products in terms of moisture content and colour values was found satisfactory.

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