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Experimental study of drying characteristics of cocoa bean in a swirling fluidized bed dryer

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Abstract. Drying is a process to reduce the weight for easy transportation and enhance the shelf life of product without quality losses over an extended period of time. Cocoa bean is an agricultural product that contains high moisture. The drying process of cocoa bean was conducted by two methods which are conventional method and swirling fluidized bed dryer. The conventional method is by drying under the sunlight. By using swirling fluidized bed dryer, it can shorten the time where heater is used to supply heat in this experiment. This fluidized bed dryer functions by the addition of design of air distributor used in the experiment. The distributor installed to improve mixing inside the bed. Therefore, in order to minimize the cost of using high capacity blower as well as to reduce energy, viable design of air distributor which can contribute to low pressure drop and improved particulate mixing in fluidized bed is essential. A fluidized bed column of 108 mm in diameter with one slotted distributor with inclination angles of 45º is used in the experiment. We find the results by using 1kg sample for conventional method are 11 days drying time, 58.55% weight loss reduction, and 0.4145 moisture ratio. Meanwhile for swirling fluidized bed dryer the time required was 2 days, 59.16% weight loss reduction, and 0.4083 moisture ratio. Based on the results obtained, the drying by using swirling fluidized bed dryer is more efficient compare to conventional method.

1. Introduction

Cocoa (Theobroma cacao) is one of the economic tree crops grown in Malaysia. It is grown in tropical countries like Nigeria, Ghana, Ivory Coast, Brazil, Venezuela and Indonesia [1]. The cocoa pod which is botanically a berry, attains a height of 129 to 159 mm and diameter of 72 to 83 mm when fully ripe [2]. It normally contains 20 to 40 seeds surrounded by a mucilaginous pulp when the pod is ripe. By weight, cocoa pod is composed of about 74.4% husk, 22.5% wet beans and 3.1% placenta. Cocoa is a perennial cash crop with three important varieties viz. criollio, foresterio and trinitario. Cocoa beans is mainly consumed as chocolate and widely used in beverages, cosmetics, pharmaceuticals and health benefits such as anti-carcinogenic, antiulcer, anti-inflammatory, anti-microbial and analgesic [3,4].

Processing of cocoa beans involves the harvesting of cocoa pods, breaking of the harvested pods, fermentation of wet mass of cocoa beans obtained from broken pods, drying of fermented cocoa beans to moisture content of about 6 to 8% and storage of the dried beans till the time of use. Figure 1 shows a flow chart of the preparation processes. Out of these steps of processing cocoa pods into beans, the two major steps are fermentation and drying. Fermentation of cocoa beans involves keeping a mass of cocoa beans well insulated while at the same time air is allowed to pass through. This process is carried out to develop the chocolate flavour and aroma in the beans [5].

During fermentation, the pulp surrounding the bean is removed and the sugar in the pulp is converted into acetic acid. The different methods of fermentation are box, basket and heap and tray fermentation. The duration of fermentation varies from 4 to 7 days depending on the method of fermentation employed. Fermentation is the initial step needed in the development of various flavour precursors in the beans [6]. After fermentation, the moisture content of the beans is about 55% and this must be reduced to 6 to 8% for safe storage [7]. The drying process apart from reducing moisture content of the beans, 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 [8]. Drying of cocoa beans on most farms is carried out naturally by making use of the sun rays while few large farms use artificial dryers to achieve the drying operations [5]. Drying is essentially a process of simultaneous heat and mass transfer. In most drying operations, water is the liquid evaporated, and air is the drying medium. Heat, necessary for evaporation, is supplied to the particles of the material and moisture vapor, evaporated liquid, is removed from the material into the drying medium. Fluidized drying of granular products of solids can be either batch wise or continuous. Batch operation is preferred for small scale production and for heat sensitive materials. Fluidized bed dryers are widely used in a number of industry sectors to dry finely divided 50–5000lm particulate materials. Compared with other drying techniques, fluidized bed drying offers many advantages. High heat and mass transfer rates between the gas and the particles are possible because of good contact or large contact area between the particles and gas, good and rapid mixing of solids, nearly uniform moisture content distribution throughout the bed, closely controllable temperature in the bed, ease in transport and handling of particles, and simplicity in construction. On the other hand, the disadvantages include high pressure drop, attrition of the solids and erosion of the containing surfaces [9].

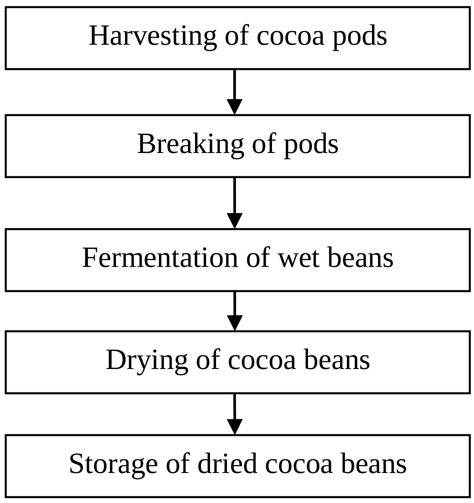

Figure 1. Preparation processes of cocoa bean.

2. Drying technology of cocoa bean

2.1. Sun drying

The natural way to dry the cocoa beans is in the sun on drying mats, which is a simple and cheap method. The mats are usually placed on a raised platform to protect the cocoa beans against animals and foreign matters. Sun drying can be carried out in a drying 'autobus', which is a shelter and ramps at different heights allowing trays to slide from the sun under the roof. Sliding roofs and immobile drying platforms are also developed [11].

The drying area should be located away from contaminant sources and should receive maximum sun exposure and air circulation during most times of the day, to speed up the drying process of cocoa beans. Thermometer was used to measure the peak temperature of drying [5]. Shady areas should be avoided. In rainy or wet regions, cocoa beans must be covered and re-spread once the drying surface has dried. Ensure that the drying surface is clean and located away from contaminants sources. The layer of drying cocoa beans should not exceed 6 cm thick to avoid slow or inadequate drying that may lead to mould growth. Beans must be turned several times each day to ensure uniformly dried beans. Rake over the cocoa bean layer frequently during the day time to allow faster drying and reduce the risk of fungal growth (5 - 10 times per day). Protect cocoa beans during drying from rain and dew. The cocoa beans should be heaped and covered at night or during rainy weather to avoid re-wetting. [10].

2.2. Plastic roof solar

The dryer has a width of 2.0 m, length of 5.0 m and height 2.2 m. The walls and roof are covered by a polyethylene film with 2.0 mm of thickness and supported by corrugated rods (diameter 0.9525 cm) separated 1.0 m. A platform (rack), which contained the product to be dried, was installed inside the dryer. The platform has a width of 1.0 m, length of 5.0 m and height 0.9 m. The main purpose of the plastic roof solar dryers is to make the solar radiation incident more efficient and to provide protection from rain and insects [12].

2.3. Artificial drying

Artificial drying is necessary in weather conditions that are cold and rainy or at plantations that are so big that sun drying would take too much space. Ovens are simple dryers that use heat to dry the cocoa beans. They can be heated either by the base of the oven, or by hot air from an external fire. The beans are spread in trays, allowing the air to permeate through a ladder system.

Using this method, the cocoa beans are not contaminated with smoke from the fire since dry beans easily absorb flavours and aromas from the environment. To avoid this, it must be ensured that the smoke ducts are impermeable. This method is also used in family plantations. Mechanical dryers are occasionally used in larger plantations, where big volumes of cocoa beans are to be dried.

The cocoa beans are placed on rotating platforms that circulate in a tunnel through which hot air is blown [11, 13, 14]. Heat was generated by the heater integrated into the side walls of the oven and the hot air flowed through the samples [15]. This method takes 10 – 20 hours, depending on the initial moisture-content of the cocoa bean. And the beans were left to rest at room temperature overnight. The tempering step is a common routine in cocoa drying, and the purpose is to redistribute the internal moisture to the outer beans layer after each drying cycle [15]. This is to reduce bean breakage associated with drying without tempering [16].

2.4. Swirling fluidized bed dryer

Fluidized bed dryers have been widely used for drying various agricultural products such as apple [17], olive pom ace [18], canola [19], soybeans [20], castor oil seeds [21], bird’s eye chilli, red bell pepper, carrots, black tea, baker’s yeast, coconut and hazelnut. Fluidized bed drying, a technique that was originally adapted for catalytic cracking of crude oil, offers several advantages over other types of drying such as solar drying, freeze drying, osmotic dehydration, spray drying, and vacuum drying. The main advantage is the thorough mixing of solids in this drying process which results in efficient mass and heat transfer, thus leading to rapid and economic drying [22].

Furthermore, inherent characteristics such as temperature uniformity and ease of control make fluidized bed dryers highly suitable for drying heat-sensitive products [23][24]. Also, fluidized bed dryers allow for easy handling and transport of the dried products which makes them appropriate for industrial purposes [25]. The main limitations of fluidized bed drying include loss of product qualities such as colour, texture, flavour, and nutrients [26]. However, such drawbacks can be avoided by using appropriate drying conditions [27].

2.5. Drying parameter

The drying parameter that used to calculate the drying result is moisture content and moisture ratio. It is important to calculate the moisture content reduction loss to get the result of the experiment. Drying curves obtained under controlled conditions provide important information regarding the water transportation mechanisms, and it used in the determination of the effective diffusion coefficient. The moisture content (M) at any time of drying (%), was calculated according to equation (1).

$$M = \frac{W_i - W_d}{W_i} \times 100\% \quad (1)$$

The reduction of moisture ratio with drying time was used to analyze the experimental drying data. Moisture ratio (MR) represents the amount of moisture remaining in the samples reported to the initial moisture content. It was calculated using equation (2).

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (2)$$

The equilibrium moisture content (M_e) were determined by drying until no further change in weight was observed for the samples in each treatment and drying conditions [11].

3. Experimental set up and procedure

3.1. Conventional sun drying experiment

The conventional drying under direct sunlight was conducted at Kampung Beruas, Kuala Pahang. The cocoa pods were selected according to their ripeness and maturity levels. There were 13 pods spread on the net and dried under direct sunlight for periods of 11 days (12 March - 22 March) from 10 am to 5 pm. The range of ambient temperature is at Kuala Pahang around 28 °C (minimum) to 34 °C (maximum). The ambient temperature was recorded using Temperature Data Logger. The temperature data logger used was a 4 channel K Type thermocouple with SD card data logger.

The sun drying experimental set up is shown in figure 2. The spreaded cocoa bean is covered with net to minimize the insect damages, dirt, dust and other pollutants. The purpose of using the net and using basket as their base is to smoothen the air ventilation. The weights of the cocoa bean were recorded every day after 5 pm within 11 days to do the analysis of the weight losses and the moisture ratio.

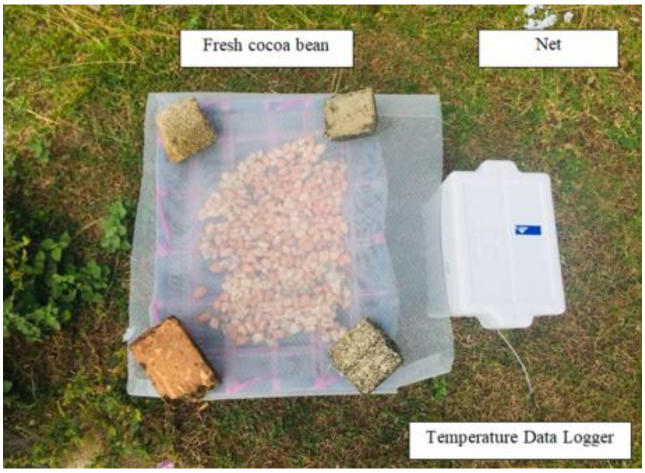

Figure 2. Conventional sun drying experimental set up.

3.2. Swirling fluidized bed dryer experimental set up

The fluidized bed apparatus is located at Energy and Sustainability Focus Group laboratory, Universiti Malaysia Pahang. In order to scientifically investigate the performance of the distributor configurations and its effect to the bed material, the following requirements are specified such as fluidized bed system that allows interchangeability of the distributor, clear silica glass cylinder to enable visualization of studies, pressure drop measurement and the velocity of the air flow. The fluidization column consists of transparent cylindrical silica glass which has 108 mm internal diameter, 5 mm thickness and 310 mm length as shown in figure 3 and figure 4. An acrylic plate that has the same diameter with the glass column's flange was mounted at the bottom. The air flow was controlled by the controller that controls the speed of the blower between 0 and 50 Hz speed range. Fluidization air was generated from a blower and it was heated to a desirable temperature using an electrical heater. The temperature and humidity sensor was installed at the outlet of the bed to measure the temperature and relatively humidity of the exhaust air.

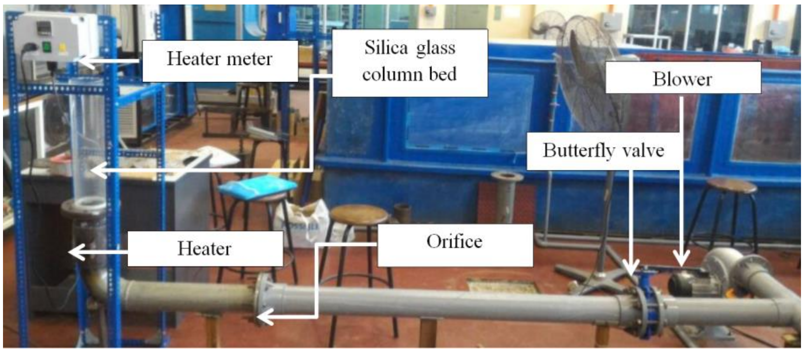

Figure 3. Swirling Fluidized Bed Dryer Set Up.

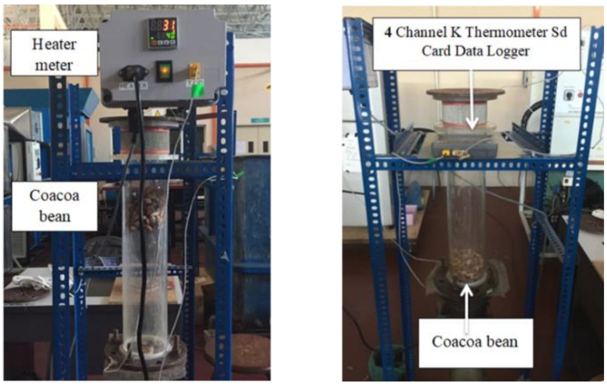

Figure 4. Initial set up before the experiment started.

3.3. Distributor

A design of air distributor made of aluminium with 115 mm diameter and 8 mm thickness was tested in the experiments. The distributor geometry was modified to introduce novel swirling distributor by making the edge opening with 45 inclined air intakes as shown in figure 5.

Figure 5. The 45° distributor that were used in the fluidized bed dryer.

4. Results and discussion

4.1. Conventional drying

The sample of 1.023 kilogram of cocoa bean was dried under direct sunlight within 11 days starting from day 1 to day 11. Based on figure 6 for moisture ratio versus time, the average ambient temperature for 11 days of drying is around 29 to 32 °C. The time taken for cocoa bean to dry completely is until the value of moisture ratio is constant. Table 1 also shows the weight of cocoa bean before and after the drying and the moisture ratio of the cocoa bean in 11 days.

Table 1. The data for conventional drying under direct sunlight for cocoa bean.

Time (Day)	Weight before (g)	Weight after (g)	Moisture ratio
1	1023	667	0.6520
2	667	560	0.5474
3	560	500	0.4888
4	500	497	0.4858
5	497	483	0.4721
6	482	464	0.4536
7	464	451	0.4409
8	451	441	0.4311
9	441	432	0.4223
10	432	424	0.4145
11	424	424	0.4145

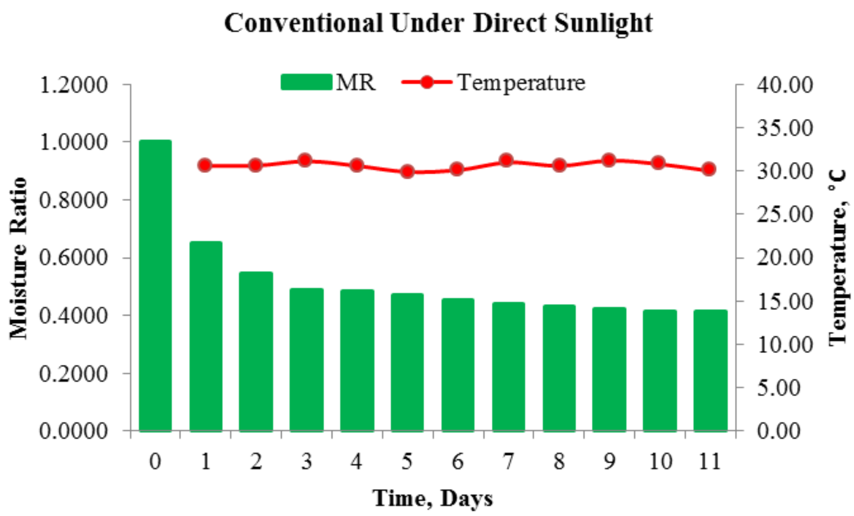

Figure 6. Graph for moisture ratio and temperature versus time (days) of the cocoa bean.

4.2. Swirling fluidized bed drying

A sample of 0.502 kilogram of cocoa bean was dried using Swirling fluidized bed dryer within 2 days. Table 2 tabulates the average temperature for 2 days using the heater of drying is around 34 to 35 °C. Meanwhile, moisture ratio and temperature versus time (days) of the cocoa bean is shown in figure 7. Based on data in figure 7, it shows that the percent of weight loss for swirling fluidized bed in day 1 and day 2 is 42.34% and 59.16%. While using conventional method in day 1 and day 2, the percent of weight loss is 34.8% and 45.26%. It shows that the drying performance by using swirling fluidized bed is better than conventional method. In addition the final moisture ratio for swirling fluidized bed dryer is lower than conventional method which is 0.4083 and 0.4145.

Table 2. The data by using swirling fluidized bed dryer for cocoa bean.

Time (Day)	Weight before (g)	Weight after (g)	Moisture ratio
1	502	290	0.5777
2	290	210	0.4083

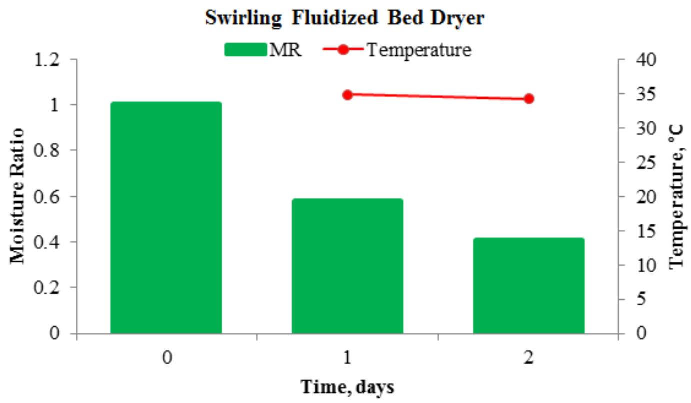

Figure 7. Graph for moisture ratio and temperature versus time (days) of the cocoa bean.

The drying characteristics of cocoa bean have been experimentally studied both by conventional drying method and by swirling fluidized bed dryer. It can be concluded that for conventional method, the drying time red required to dry cocoa bean took too much time which 11 days for it to fully dried because the factor of weather need to be considered in order to conduct this experiment as. However, drying by using fluidized bed dryer only took 2 days to evaporate the moisture content of the cocoa bean. It shows that fluidized bed dryer could save more time compared to conventional method.

This result shown that the performance of fluidized bed dryer in drying the cocoa bean was more efficient compared to conventional method. Furthermore, the visual characteristic of cocoa bean can be observed by using both methods. In short, it is proved that the performance of swirling fluidized bed dryer is more efficient in terms of save time, percentage of moisture content reduced and the quality is maintained compared to conventional method. Hence, the objectives for this project were achieved.

4.3. The comparison between conventional drying and swirling FBD

Figure 8 shows the comparison of moisture ratio by using conventional method and swirling fluidized bed. From the graph, table 1 and table 2, the moisture ratio by using swirling fluidized bed dryer is lower compared to conventional method which is the final moisture ratio by using swirling fluidized bed dryer is 0.4083 and for conventional method the final moisture ratio is 0.4145. The difference of weight loss between these methods within day 1 and day 2 is 7.2% and 12.7% respectively.

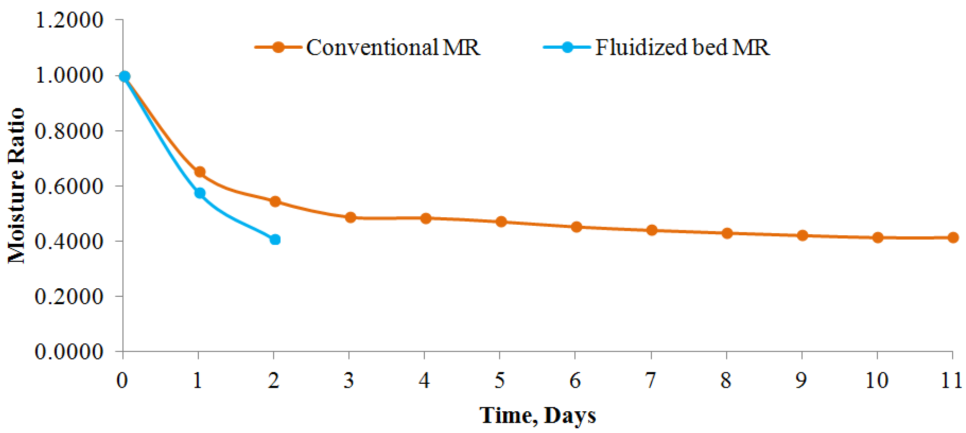

Figure 8. Comparison of moisture ratio by using conventional method and swirling fluidized bed.

5. Conclusion

As conclusion, we find the results by using 1kg sample for conventional method are 11 days drying time, 58.55% weight loss reduction, and 0.4145 moisture ratio. Meanwhile for swirling fluidized bed dryer the time required was 2 days, 59.16% weight loss reduction, and 0.4083 moisture ratio. Swirling fluidized bed drying is proven experimentally to be more efficient than conventional drying for cocoa bean. From the study, it has resulted that the characteristics of cocoa bean by swirling fluidized bed drying is better than the conventional drying. The study can be improved by introducing different design of air distributors which can contribute to low pressure drop and improved particulate mixing in fluidized bed dryer. This swirling fluidized bed drying also can be extended to other agricultural products such as black pepper, etc. which the has characteristics of low in moisture and feasible shape to be tested in the swirling fluidized bed dryer.

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