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Comparative Study of Solar Drying of Cocoa Beans: Two Methods Used in Colombian Rural Areas

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In Colombia, the production of cocoa beans is an important export business classified as “fine cocoa” type by the International Cocoa Organization (ICCO). Drying for agricultural products is one of the most cost-effective applications of solar energy and the drying methods for cocoa beans are traditional and vary with geographical locality. Cocoa beans are dried after fermentation in order to reduce the moisture content, being the open-air solar drying (direct solar dryer) and the greenhouse drying (plastic roof solar dryer) two methods used in colombian rural areas. However, in the Caribbean region of Colombia is widely used, by rural farmers, the open-air solar drying. This method is economic but susceptible to contamination with foreign materials, insects and rodents, affecting the quality of the beans.
This work presents the construction of a plastic roof solar dryer for drying cocoa beans in a farm that use direct solar dryer. The moisture content of the cocoa beans were determined using a MB 45 Halogen Ohaus moisture analyzer. The moisture content was reduced from 58 % to 7 % in 6 d for the open-air solar drying (drying constant, k = 0.76 d^{-1}), while the greenhouse drying took only 4 d (drying constant, k = 1.68 d^{-1}) and produced better quality cocoa beans, protected from direct solar radiation, environmental pollution and animal contact. Technical and economical results indicate that greenhouse drying is feasible for rural farmers in the Caribbean region of Colombia.

1. Introduction

In 2016, Colombia produced 56,785 t of cacao beans by about 38,000 farmers families in rural areas (Fedecacao, 2017) that uses naturals sun drying methods. In solar drying of agricultural products, the moisture within the product is removed by vapourisation and it is subsequent evaporation (Jairaj et al., 2009). The percentage of moisture content in different agricultural products varies and the drying method can improve the quality. In dried cocoa beans the moisture content of good quality cocoa is about 7 % (Kumar et al., 2016). Open sun drying is a popular and economical method used for drying in Colombia and several types of solar dryers have been developed. The direct solar dryer consists of a wood tray that uses solar radiation to heat directly cocoa beans. However, long direct exposure to sun radiation result in quallity deterioration of the cocoa beans. The plastic roof solar dryer consists of a framework with plastic film of semi-transparent polyethylene (Belessiotis and Delyannis, 2011). 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.
Many researchers have investigated on solar drying of agricultural products. Rathore and Panwar (2010) developed a grapes drying through solar tunnel dryer in India. This dryer consisted of a hemi cylindrical metallic frame structure covered with semi-transparent polyethylene. The drying test was conducted seven days found that moisture content was reduced from 84.4 % to 16.2 %. In open sun drying it takes more than 11 d to dry.
Seveda (2012) used a solar tunnel dryer for drying Aonla (Embilica officinalis). The dryer consisted of a drying chamber (polyethylene sheet covered) with a solar collector combined in one unit. The solar tunnel dryer reduced the moisture content to a 10.08 % final value in 16 h while in open sun drying 40 h. Aritestya and Wulandania (2014) found that to dry wild ginger in a rack type-greenhouse solar dryer at 80 % to final

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moisture content 8 % - 11 % required drying time for 27.5 h and 30 h respectively. The dryer was a transparent building with 144 trays, four blowers, burner and cross-flow heat exchanger. ELkhadraoui et al. (2015) used a solar greenhouse dryer (a novel mixed mode) with forced convection for drying of red peppers and grapes. The system essentially consisted of a solar collector, centrifugal fans and a greenhouse with plexiglass cover on walls and roof. The red peppers were dried in the greenhouse solar drying within 17 h while in the open-sun drying within 24 h. The grapes were dried in the greenhouse solar dryer within 50 h while in the open-sun were dried within 67 h. Prakash et al. (2016) used a modified greenhouse dryer (transparent polycarbonate covered), operating under active mode (forced convection) and passive mode (natural convection) for dry potatoes, capsicums and tomatoes. Experimental results reveals that modified greenhouse dryer under active mode is better than modified greenhouse dryer under passive mode and open sun drying to dry the products. Experiments inside a forced convection solar dryer (indirect-type) were conducted by Castillo-Téllez et al. (2017) to study the red chilly drying. The experimental dryer was formed of a horizontal tunnel, a solar air heater and a centrifuge-flow fan. The final moisture content varied between 5.76 % and 9.9 %, for an initial average moisture content of 80.0 % and 21 h of drying.
The present paper is a contribution to the knowledge of the solar dryers in the Caribbean region of Colombia.

2. Description of the system

2.1 Dryer construction and material

The plastic roof solar dryer was installed in a farm called "El Rastro" (San Jacinto – Bolivar), in the Caribbean region of Colombia. 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 (Agrolene ®) 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 schematic diagram of the plastic roof solar dryer is shown in Figure 1.

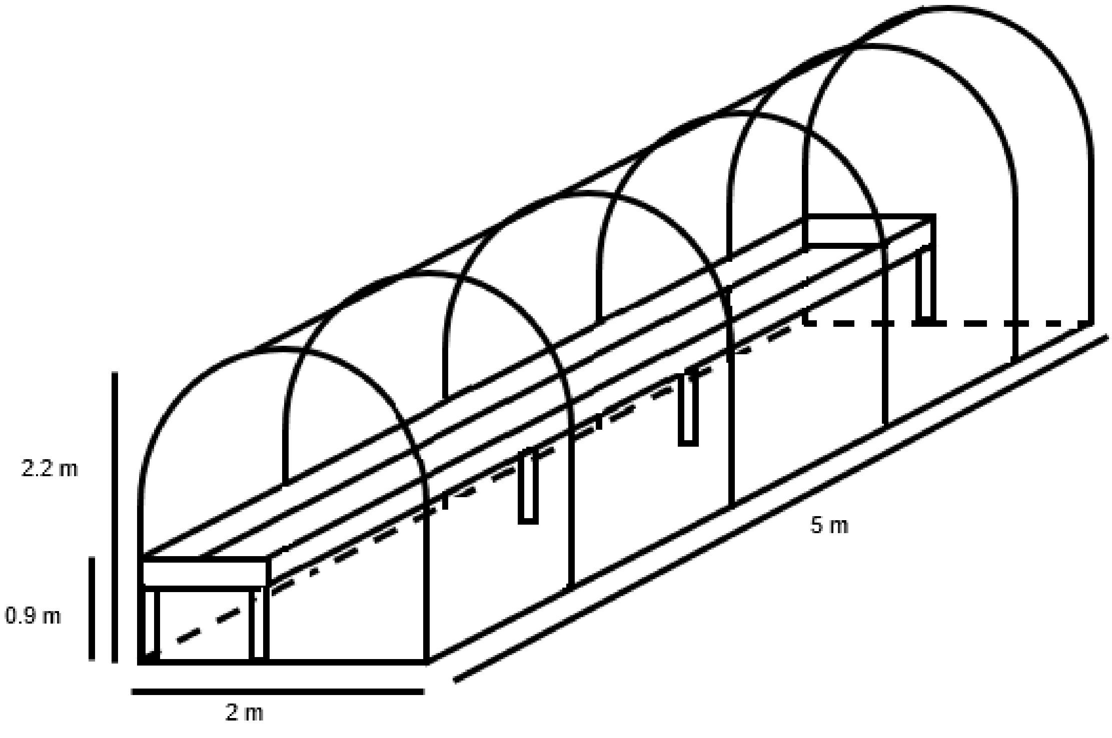

Figure 1: Schematic of plastic roof solar dryer.

Direct solar dryer, used by rural farmers, is a tray constructed with local wood and has a width of 0.8 m, length of 2.4 m and height 0.05 m. Figure 2 shown both dryers installations.

(a) (b)

Figure 2: Solar dryers: (a) plastic roof solar dryer; (b) direct solar dryer.

2.2 Experimental procedure

In the drying experiments, 2 kg cocoa beans (after fermentation) were placed on single level raised platform (rack) inside plastic roof solar dryer (Figure 3) and 2 kg inside direct solar dryer, from September 12 to September 19 (7 days).

Figure 3: Platform inside plastic roof solar dryer.

The cocoa beans were placed inside the two dryers in the middle of the trays in a single layer (thickness 1 cm) and were turned by hand every 24 h to ensure uniformity. For the tests, the samples were took from the top of the layer to obtain the data for moisture content. The moisture contents of the products inside the dryers were determined daily using a MB 45 Halogen Ohaus moisture analyser with cocoa beans samples about 10 g (took from the middle of the trays previously turned by hand), in 60 min intervals and 105 ºC. Every test started between 10:00 a.m. and 11:00 a.m.

3. Results and discussion

The experimental results showed that the moisture content was reduced of 58.0 ± 0.3 % to 7.0 ± 0.2 % (Figure 4). Traditional direct solar dryer taken 6 d to dry the cocoa beans while plastic roof solar dryer took only 4 d and produced better quality of produce because was completely protected from rain, animals and insects. The plastic roof solar dryer practically shortens the drying time of cocoa beans by two days. Similar behaviors using plastic roof solar dryer (greenhouse solar drying system) for banana, chilly and coffee are reported by Janjai et al. (2011).

The moisture content inside the open sun dryer and the greenhouse dryer rapidly decreased in the first and second day, then slowly decreased for the following days and the drying rate decreased with an increase in the drying time. A similar trend was reported by ELkhadraoui et al. (2015) for red pepper and grapes. Similar behaviour is reported by Morad et al. (2017) for drying of peppermint, founding that to the beginning of drying, moisture was easily evaporated from outer surface and as the drying progressed, diffusion of moisture from the interior of solid to the surface was more difficult and less evaporation took place and therefore drying rate decreased.

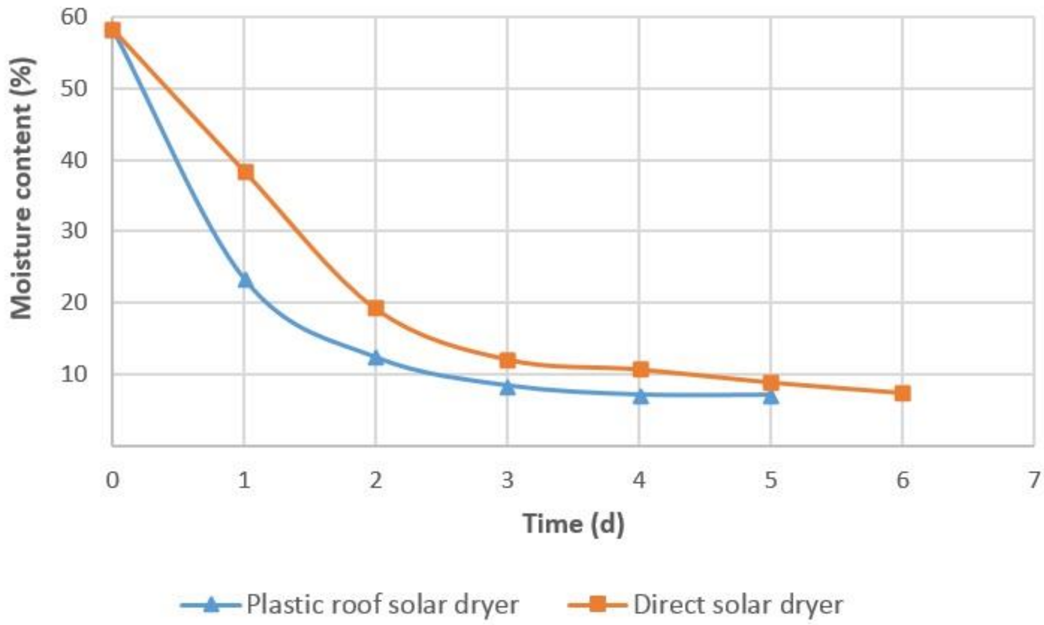

Figure 4: Drying curves: comparison of the moisture contents of cocoa beans.

A statistical analysis was performed using STATGRAPHICS Centurion XVI. The analysis of variance (ANOVA) for the experimental factors time (d) and type of dryer (direct and plastic roof), showed p-values 0.0002 and 0.0091 respectively, indicating that they are significantly different from zero at the 95 % confidence level and affected significantly the moisture content (%) of dried samples. Figure 5 show the response surface for moisture content (%) of the cocoa beans samples.

In Figure 5 is evident that the change in moisture content through time is quite faster in the plastic roof solar dryer. The change in moisture content is due to the rise in greenhouse room air temperature (Tiwari et al., 2016).This is a favourable drying condition for cocoa beans. Based in the climatic conditions in San Jacinto (ambient temperature: 28 ºC and relative humidity: 76 %), the plastic roof solar dryer can be used all the year for drying cocoa beans. The faster drying of cocoa beans inside the plastic roof solar dryer is due to the fact that the cocoa beans in this dryer received energy both from the air inside the greenhouse and from incident solar radiation, while the cocoa beans inside the direct solar dryer received energy only from incident radiation. Hossain and Bala (2007) found that during the drying of chilli, the air temperature inside the greenhouse dryer rise with the increase in solar radiation and this temperature was higher than the ambient temperature and relative humidity was lower than the ambient relative humidity.

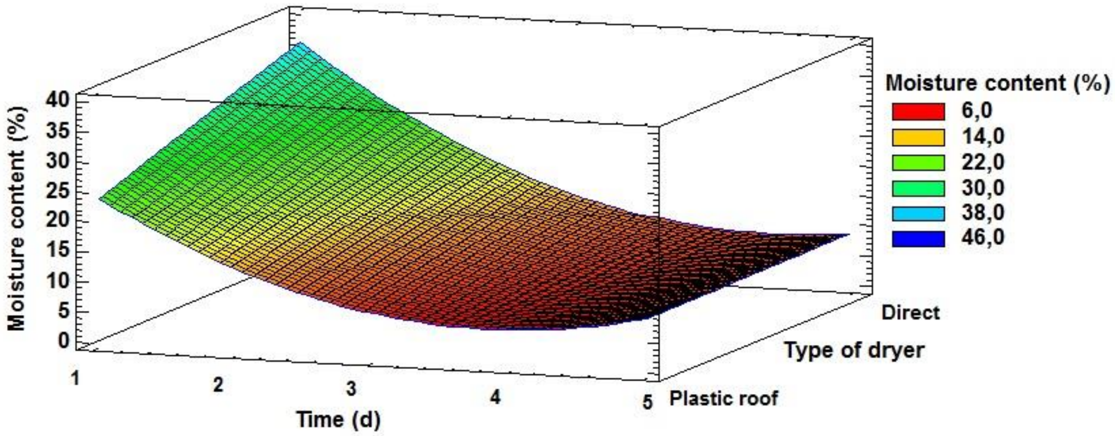

Figure 5: Response surface for moisture content as a function of time and type of dryer..

The experimental data were tested by fitting and the moisture content data obtained were converted to the moisture ratio (MR) and then the curve-fitting procedure was performed for Lewis, Henderson and Parbis model (MacManus et al., 2010) from the Eq(1):

$$MR = \frac{M - M_e}{M_i - M_e} = Ae^{-kt} \qquad (1)$$

Where MR is moisture ratio, M_i is initial moisture content, M_e is equilibrium moisture content (7.00 %), M is moisture content at any time, k is the drying constant (d^{-1}), t is the time (d), A is a coefficient. The data obtained from the experiment was indicated in Table 1:

Table 1: Values of drying constants and coefficients.

Solar Dryer	k (d^{-1})	A	R^2
Direct (open-air solar drying)	0.76	1.15	0.97
Plastic roof (greenhouse drying)	1.68	1.66	0.96

The equilibrium moisture content (M_e), that represent moisture equilibrium between the sample and air under dryer conditions, was the less value obtained in the tests (final moisture). This value, between 6 % and 8 %, maintain the quality of the cocoa beans during long storage. If the moisture content is less than 6 %, cocoa beans become brittle, while moisture content greater than 8% makes the beans susceptible to mold damage (Beckett et al., 2017). The result shows that drying constant has strong relationship with the drying method. The greenhouse drying (plastic roof) took less time to reach the final moisture content (M_e, equilibrium moisture content) due to the faster drying rate associated to the rise in air temperature inside the dryer (Rabha et al., 2017). The heat collected inside the dryer was utilized for removing the moisture from the cocoa beans; therefore, the cocoa beans absorbed heat from the heated air and also from the direct solar radiation.

The capital cost for construction and installation (initial investment) of the plastic roof solar dryer is 50 USD with capacity of 150 kg cocoa beans. Based on the local farmers production scales (12 kg by farmer/month) and price of the dried products (1.5 USD per kg), the payback period of the plastic roof solar dryer is about 3 months, Eq(2).

$$Payback\ period = \frac{Initial\ Investment}{Cash\ Inflow\ per\ month} = \frac{50\ USD}{(12x1.5)\ USD} = 2.8\ months \qquad (2)$$

4. Conclusions

In this comparative study of two solar dryers: plastic roof solar dryer and direct solar dryer, were tested in order to determine the moisture content of cocoa beans. The drying curves showed that solar drying in the plastic roof solar dryer resulted in considerable reductions in drying time as compared with the direct solar dryer. The increased temperature inside the plastic roof solar dryer permitted the faster moisture removal rate (drying constant, k = 1.68 d^{-1}), and high quality dried products. The estimated payback period of the plastic roof solar dryer is about 3 months. Due to its economic performance this type of dryer can be used by rural farmers in the Caribbean region of Colombia.

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