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Comparison of the drying behavior of fermented cocoa (*Theobroma cacao* L.) beans dried in a cocoa house, greenhouse and mechanical oven.

Saheeda Mujaffar[a], Darin Sukha[b] and Aveena Ramroop[a]

[a]Food Science and Technology Unit, Department of Chemical Engineering, The University of the West Indies, St. Augustine, Trinidad and Tobago, West Indies. Tel.:+1 868 662 2002 Extension 82190. E-mail: saheeda.mujaffar@sta.uwi.edu
Corresponding author.
[b]Cocoa Research Centre, The University of the West Indies, St. Augustine, Trinidad and Tobago, West Indies.

ABSTRACT

The objective of this study was to compare the drying behavior of fermented cocoa (*Theobroma cacao* L.) beans dried in a traditional cocoa house replica and greenhouse-type dryer with that of beans dried in a mechanical cabinet oven at 40°C (drying for 8h with a rest period of 16h). Weight measurements were taken at the start of drying and at regular intervals during the drying process, and drying continued until there was no change in bean weight. Moisture content, water activity, pH and color attributes were measured at the start and at the end of drying. Sensory evaluation of the cocoa liquor was done on the dried samples. Initial moisture content of beans averaged 1.04 g H_2O/g DM (50.9% wb). Final (equilibrium) moisture values attained after 11.4 days of drying in the cocoa house and the greenhouse and after 9.3 days of drying in the oven averaged 0.60, 0.70 and 0.50 g H_2O/g DM (2.3-4.6 % wb), respectively. During the first 3 days of drying, the decline in moisture content was similar in oven-dried beans and beans dried in the cocoa house, while the decline in moisture in beans dried in the greenhouse was not as pronounced. The industry-accepted moisture of 6-8% (wb) was attained after 4.8, 6.3 and 4.3 days of drying for beans dried in the cocoa house, greenhouse and oven, respectively. Drying rate constants for the first day of drying in the cocoa house, greenhouse and oven averaged 0.1194, 0.0840 and 0.1124 1/h, respectively, and diffusivity values averaged 3.36, 2.37 and 3.17 x 10^{-10} m^2/s. Moisture ratio curves were successfully modelled using the Hii et al. model. With respect to quality attributes, the pH of the cotyledon and testa of fresh (undried) beans averaged 4.98 and 4.86, respectively. Cotyledon pH did not change significantly with drying method, but was highest at 5.22 in oven dried beans. The pH of the testa of beans dried in the greenhouse was significantly higher than for the other drying methods. Hue angle (°) was higher in dried beans compared with fresh beans, with no effect of drying method seen. The results of the sensory evaluation exercise revealed very little differences in bean acidity and astringency, with beans dried in the cocoa house obtaining a moderately higher score for cocoa flavor compared with beans dried in the greenhouse and in the oven.

1.0 INTRODUCTION

In the primary processing of cocoa beans, drying is a critical step that follows fermentation. After fermentation, beans are dried to reduce the moisture content from about 60% to 6-8% (wb) for safe storage and transportation, as well as to reduce the astringency and bitterness of the beans. Sun-drying of fermented cocoa beans is the most widely practiced method of drying. Beans are spread on raised mats or on concrete floors during periods of sunshine and allowed to dry (Lasisi, 2014). In the West Indies, drying takes place on wooden or concrete drying floors with moveable roofs (called cocoa houses) and beans are mixed regularly by walking through the layers or raked by using a wooden palette. Depending on weather conditions, beans are sun-dried anywhere from 7 to 22 days. Slow drying in thick beds can sometimes result in over-fermentation of the beans and in mold growth while too rapid drying can result in in acidic beans with shriveling and/or case hardening of the shells (Jinap and Thien, 1994; Bonaparte et al., 1997, Sukha, 2003; Lasisi, 2014; Fagunwa et al., 2009; Zahouli et al., 2010).

To offset the drawbacks associated with sun drying of cocoa beans, several researchers have investigated the use of solar dryers. From these works, it is evident that compared with open sun-drying of beans, use of solar drying can reduce the drying time during periods of poor weather conditions, but increase the drying times under good weather conditions. Bonaparte et al. (1997) found that under adverse weather conditions, beans dried in an indirect solar dryer showed the highest cut test score, and that beans dried in the solar dryer attained the desired moisture content of <8% (wb) in 6.5 days compared with sun-dried beans, which took 12.5 days. Sankat and Ramlochan (1997) reported a reduction in drying time in beans dried in a solar cabinet fermenter/dryer, with beans attaining the desired moisture value of 6-7% moisture content within 6 days. The study also revealed that an increase in drying load affects the drying behavior. Hii et al. (2006) also reported that loading density has an impact on the quality of beans dried in a direct solar. With respect to bean quality, no significant differences were reported for cocoa dried in a solar type dryer when compared to sun drying (McDonald 1981).

Artificial drying can increase moisture removal rate and save time, and so has been the focus of many drying studies on cocoa beans. Amongst these studies are wide variations in experimental variables, for example, drying temperatures, pre-treatment of beans, depth and loading density, rest intervals, bean mixing and the end-point of the drying process. Several researchers have reported that while drying is enhanced at higher temperatures, artificially dried beans, especially beans dried at higher temperatures of 55-60°C, are more acidic than sun-dried beans. Jinap and Thien (1994) found that sun-dried beans produced the lowest concentration of volatile fatty acids and were higher in pH (5.12) compared with the oven-dried (60°C) beans which had the lowest pH of 5.02 and highest titratable acidity. Irie et al. (2010) also showed that sun-dried samples were less acidic with a pH of 4.0 than oven drying at 60°C which produced a pH of 3.7. Oke and Omotayo (2011) showed that intermittent drying in an oven at 55°C produced highly acidic beans with a pH of 4.70 while the pH of sun-dried samples averaged 5.03.

The objective of this study was to compare the drying behavior of fermented cocoa (*Theobroma cacao* L.) beans dried using three methods, namely; a traditional cocoa house replica, a greenhouse-type dryer and a mechanical cabinet oven at 40°C. Drying rate constants and moisture diffusivities were determined and an assessment of the impact of drying method on selected quality attributes of the dried beans and cocoa liquors carried out.

2.0 MATERIALS AND METHODS

Fermented cocoa beans of mixed Trinitario varieties, were obtained from the Cocoa Research Centre of the University of the West Indies, St. Augustine Campus. Drying of fermented beans was carried out in a small cocoa house replica, a greenhouse-type dryer and a mechanical oven. The cocoa house was made of metal beams and a moveable roof made of galvanized sheets (Figure 1). The drying tray was made of wood with dimensions of L 2.13 x W 1.22 x D 0.10 m and elevated 0.09m above the ground. Each day the roof of the cocoa house was opened at 9am and closed at 5pm.

(a) **(b)**

Figure 1. Miniature Cocoa House used for drying beans
a) Opened roof, exposing the cocoa beans to the sun b) Cocoa house with roof closed

Beans were dried in a greenhouse (Figure 2) approximately L 5.5 x W 2.7 m. The beans were placed onto wooden tables with built-in trays L 0.81 x W 0.61 x D 0.05 m, elevated 0.84m off the ground.

(a) **(b)**

Figure 2. Greenhouse used for drying beans
a) Exterior view b) Interior view showing the drying tables on both sides

For oven drying, cocoa beans were dried at 40°C in a natural convection Unitemp Drying Cabinet (LTE Scientific Ltd., Greenfield, Oldham) with a glass door and metal shelves (Figure 3). Internal dimensions of the dryer were H 1.12 x W 0.79 x D 0.61 m.

(a) (b)

Figure 3. Oven drying of fermented cocoa beans

a) Cabinet oven b) Arrangement of cocoa beans on wire tray

For drying in the cocoa house and greenhouse, weight (g) and temperature measurements (°C) were taken three times a day, at 9am, 12pm and at 5pm, and drying continued until there was no change in weight. For oven drying, beans were spread in a single layer (500g) onto wire mesh trays (L 0.33 x W 0.22 x H 0.06 m). The loaded trays were placed into the oven and at regular intervals the trays were taken out, quickly weighed (0.01±0.005g) using an Ohaus Explorer Pro Balance, Model EP2102C (Ohaus Corporation, NJ, USA), and returned to the oven until there was no change in weight. To mimic the traditional sun-drying regime, beans were dried for 8 hours and at the end of each drying day, the beans were placed in re-sealable plastic bags and stored in a cool room (24°C) overnight, for 16 hours. At the start of the next day, the beans were re-loaded onto the trays and drying resumed.

The moisture content of fermented and dried beans was measured in triplicate using a Halogen Moisture Analyzer HB43-S (Mettler Toledo-AG, Zurich, Switzerland). Water activity (a_w) was measured using an Aqua Lab CX-2 1021 water activity meter (Aqualab, Pullman, Washington, USA). The pH of the bean testa and cotyledon (nib) was determined using a Model HI991002 pH Meter (Model HI 991002, Woonsocket RI, USA). The color of the cotyledon or cocoa nib (Hii et al, 2009a) was measured using a Konica Minolta CR-410 Choma Meter (Konica Minolta Sensing Americas, Inc., NJ, USA). Triplicate L^*, a^* and b^* readings were recorded for each sample. L^* represents lightness (0-black to 100-white), a^* represents red (+ve value) and green (-ve value) while b^* represents yellow (+ve value) and blue (-ve value). *Hue angle (°)* was calculated as given in Equation 1:

$$Hue = Arc\tan\left(\frac{b^*}{a^*}\right) \quad (1)$$

The sensory evaluation of the cocoa liquor from dried beans was carried out (in triplicate) according to methods outlined by CAOBISCO/ECA/FCC (2015) and Sukha et al. (2008). Major attributes assessed included Cocoa flavour, Total Acidity, Bitterness, Astringency, Total Fruity and Total Floral notes, rated in intensity from 0 (none) to 10 (maximum).

Drying curves, drying rates, moisture ratio (*MR*) values, drying rate constants (*k*) and effective diffusivity (D_{eff}) values were determined as outlined by Mujaffar and Sankat (2014). Using the approach reported by Mujaffar and Lee Loy (2016), the *MR* data was modelled using a new thin layer model proposed for cocoa bean drying by Hii et al. (2009b), as given in Equation 2.

$$MR = a\,exp(-kt^n) + c\,exp(-gt^n) \quad (2)$$

Drying and quality data was analysed using one-way ANOVA (Assaad, 2014; Rapid publication-ready MS-Word tables for one-way ANOVA) and drying data modelled Curve Expert Professional software, Version 2.3.0 (Hyams, 2016).

3.0 RESULTS AND DISCUSSION

3.1 Drying data analysis

The average air temperatures recorded in the cocoa house and greenhouse for the drying period are given in Table 1.

Table 1. Average air temperatures

	Air Temperature °C	
Time of day	**Cocoa house**	**Greenhouse**
9 am	33.0 ± 3.4	31.8 ± 3.0
12 pm	35.1 ± 3.8	34.9 ± 2.1
5 pm	30.9 ± 3.5	31.4 ± 2.1

The initial moisture content of fermented beans averaged 1.04 g H_2O/g DM (50.9% wb) with an initial water activity value of 0.958. The decline in moisture content is shown in Figure 3. As expected, the decline was more pronounced for beans dried in the cocoa house and greenhouse during the daytime. It was also noted that the beans did continue to lose weight during the evening time due to exposure to the air in the evening as well as in the early morning. The decline in moisture content, although stepwise for beans dried in the oven, was similar to that seen in beans dried in the cocoa house.

During the first three days (72h) of drying, the decline in moisture content was similar in oven-dried beans and beans dried in the cocoa house, while the decline in moisture in beans dried in the greenhouse was not as pronounced. This could have been due to the windy conditions and higher temperatures experienced at the cocoa house. Final (equilibrium) moisture values attained after 11.4 days (274h) of drying in the cocoa house and the greenhouse and after 9.4 days (224h) of drying in the oven averaged 0.0617, 0.0670 and 0.0464 g H_2O/g DM (2.3-4.6 % wb), respectively. Water activity values of the beans at the end of drying averaged 0.565, 0.600 and 0.518 for beans dried in the cocoa house, greenhouse and oven, respectively. The industry-accepted moisture of 6-8% (wb) was attained after 6.3 days (151h) for beans dried in the greenhouse, which was significantly ($p \leq 0.05$) longer than the 4.8 days (116h) taken by beans dried in the cocoa house. Oven-dried beans attained this moisture value in a shortest time of 4.25 days (102h).

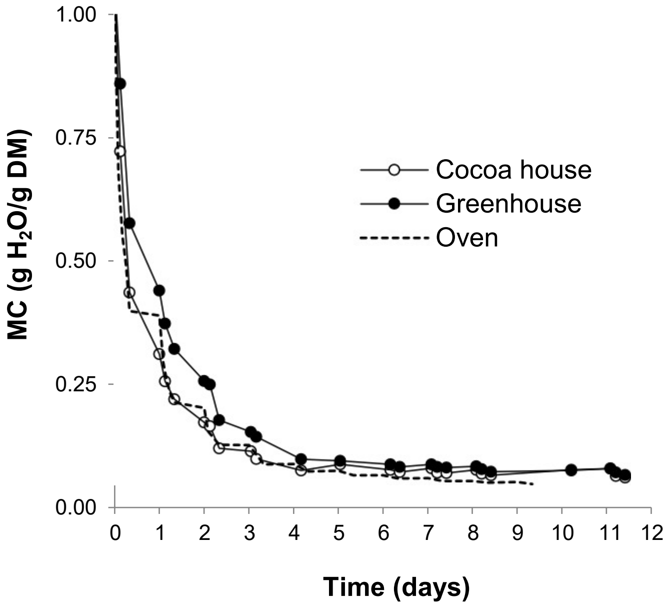

Figure 4. Drying curves for cocoa beans as a function of total drying time.

Drying rates calculated as the change in moisture content with respect to drying time revealed that initial drying rates were highest in oven dried beans (0.121 g H_2O/g DM/h) and lowest in beans dried in the greenhouse (0.068 g H_2O/g DM/h). For the duration of the drying period, rates were generally highest in beans dried in the oven at 40°C, followed by beans dried in the cocoa house. Drying rates were generally lowest in beans dried in the greenhouse.

Drying rate constants and diffusivity values were similar for beans dried in the cocoa house and in the oven, while these values were significantly ($p \leq 0.05$) lower in beans dried in the greenhouse. For the first day of drying in the cocoa house, greenhouse and oven, rate constants averaged 0.1194, 0.0840 and 0.1124 1/h, while diffusivity values averaged 3.36, 2.37 and 3.17 x 10^{-10} m^2/s. Drying rate constants of 0.009583 to 0.12666 1/h were reported by Chineye (2009) for the drying of beans three kernels deep in a heated batch cocoa bean dryer at three temperatures ranging from 55-81°C and three air velocity values ranging from 1.3 -3.7 m/s.

Moisture ratio (*MR*) data was successfully modelled using the thin layer model proposed by Hii et al. (2009b) given in Equation 2. As shown in Figure 5, there was good agreement between the Predicted and Experimental MR values (R^2 values of 0.9972 and 0.9923 for beans dried in the cocoa house and greenhouse, respectively). The *MR* data for oven dried beans was adequately modelled but with some deviation (R^2 value of 0.9811) due to the stepwise reduction on *MR* at the start of the drying process.

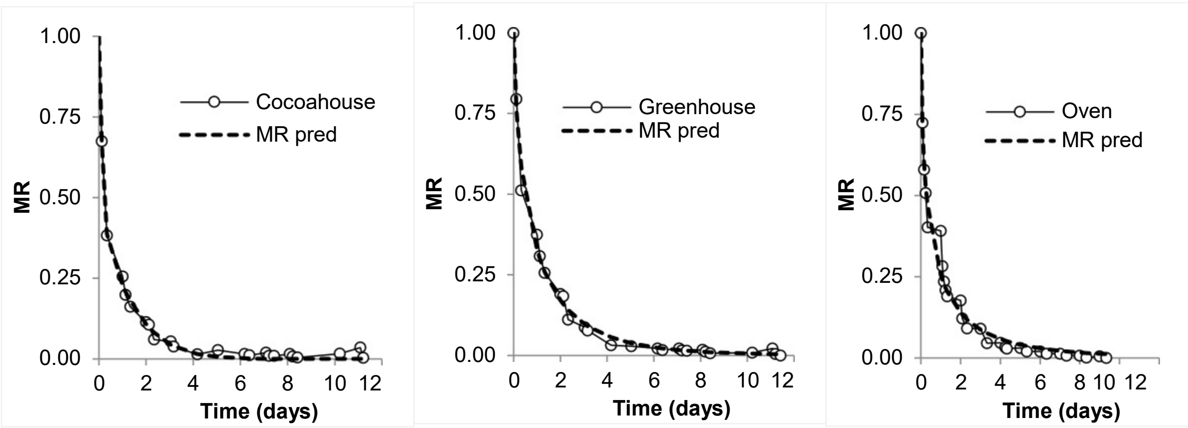

Figure 5. Predicted versus experimental Moisture Ratio (*MR*) values for beans.

3.2 Bean quality and liquor assessment

As shown in Figure 6, the pH of the testa of all dried beans was higher than for fresh beans (4.86), indicative of a decrease in acidity of beans as they dried. The pH of the testa of beans dried in the greenhouse was significantly higher than for the other drying methods, averaging 5.46. The pH of the testa of beans dried in the oven was the lowest at 4.97. Cotyledon pH averaged 4.98 in fresh beans and did not change significantly with drying method, but was highest at 5.22 in oven dried beans compared with 5.02 for beans dried in the cocoa house. Hii et al. (2006) reported pH values of 4.64 in fermented beans, which increased to 4.91 to 5.39 in beans dried in a solar dryer at different loading densities.

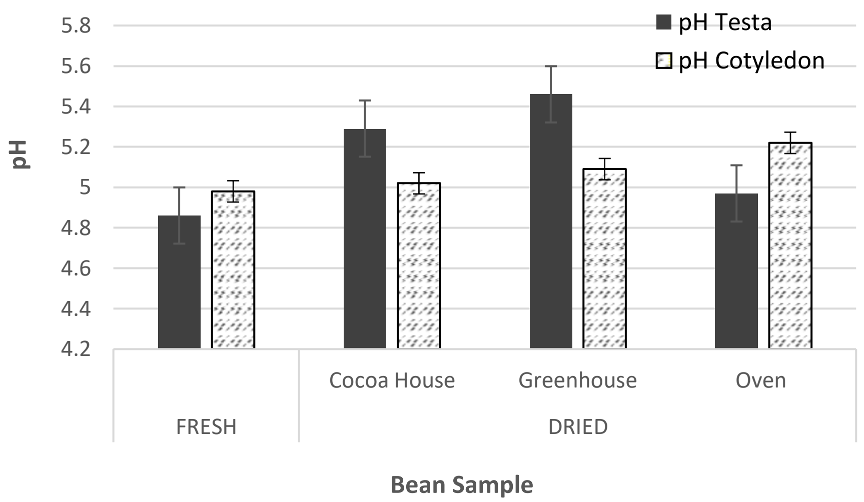

Figure 6. The pH values of fresh and dried beans

The Hunter *L**, *a** and *b** values for fresh and dried beans are given in Table 2. Drying method did not affect bean lightness (*L** values), but oven dried beans were found to be more brown/red (higher *a** value) and more yellow (higher *b** value) than beans dried using the sun's energy. Hue angle (°) was higher in dried beans compared with fresh beans, but no effect of drying method was seen.

Table 2. Colour attributes of fresh and dried cocoa beans.

		Dried Beans		
	Fresh Beans	**Cocoa house**	**Greenhouse**	**Oven**
*L**	27.0 ± 0.28	26.0 ± 1.34	25.9 ± 0.14	28.2 ± 0.14
*a**	11.6 ± 0.32^{a}	9.02 ± 0.12^{c}	8.48 ± 0.36^{c}	10.4 ± 0.06^{b}
*b**	6.59 ± 0.37^{ab}	5.8 ± 0.34^{b}	5.85 ± 0.41^{b}	7.74 ± 0.35^{a}
Hue (°)	29.5 ± 0.72^{b}	32.7 ± 1.70^{ab}	34.5 ± 1.10^{a}	36.6 ± 1.40^{a}

Values are means ± SEM, n = 3 per treatment group.
Means in a row without a common superscript letter differ ($P<0.05$) as analyzed by one-way ANOVA and the LSD test.

Bonaparte et al. (1997) found that the *L** values of cocoa nibs from beans dried in the sun and in an indirect solar dryer were slightly higher at 32.15 compared with the *L** values of 33.93 for beans dried in a hot plate assisted direct type solar dryer. Hii (2008a) studied the effect of drying on colour change of cocoa beans that were freeze dried, sun-dried and dried in an artificial hot air dryer 60-80°C. Hii et al (2009a) reported high *a** values for nibs of oven dried beans (7.96) at 60°C, indicative of more browning when compared with beans dried in the sun (7.06). While not statistically significant, beans dried in the oven were more yellow in colour (*b** value of 12.51) compared with sun-dried beans (*b** value of 10.40). In that study, Hue angle values were found to be higher in sun-dried beans compared with oven-dried beans.

While it is noted that the beans were dried to equilibrium moisture well below the 7% (wb) minimum moisture value that is the industry standard for storage, the results of the sensory evaluation exercise revealed very little differences in Bean Acidity, Astringency and Bitterness. Cocoa flavor was significantly ($p \leq 0.05$) higher in beans dried in the cocoa house (score of 5.0), compared with that of beans dried in the greenhouse (4.3) and oven (4.0), respectively. The acid-fruit score was lowest (0.9) in oven-dried beans and significantly higher in beans dried in the cocoa house (2.0) greenhouse (2.4). Total floral notes were present in oven-dried beans (score of 2.0) compared with significantly ($p \leq 0.05$) lower values for beans dried in the cocoa house and greenhouse (0.3-0.5).

4.0 CONCLUSIONS

The results show that fermented cocoa beans can be successfully dried in a greenhouse as well as a mechanical oven as an alternative to the traditional cocoa-house drying method. With respect to drying rates and drying time, drying can take up to 30% longer in a greenhouse-type dryer, while drying beans intermittently a mechanical oven set at 40°C can reduce drying time by approximately 10% compared with drying in a traditional cocoa-house. For both fresh and dried beans, pH was found to differ between the testa and the cotyledon (nib). Based on the pH values, the testa of the beans dried in the greenhouse, which was the slowest method of drying, was found to be the least acidic while the pH of the cotyledon of beans dried in the oven was the least acidic of the three treatments. The nibs of beans dried in the oven were found to be more red/brown and yellow than for beans dried in the cocoa house and greenhouse. There were detectable differences in the ratings for some sensory attributes of the liquors with regard to cocoa flavour, total floral and acid-fruit, however it is noted that these beans were dried to equilibrium moisture values of 4.6 to 6.3% (wb), well below the industry standard for safe storage of beans.

NOMENCLATURE

A	Drying constant
a_w	Water activity
D_{eff}	Effective diffusivity $D = k\ (4L^2/\pi^2)$ where L = 0.50 x 10^{-2} m
DM	Dry matter (g)
FW	Fresh weight (g)
k	Drying rate constant (1/h)
L	Half-thickness of sample (m)
L^*, a^*, b^*	Colour attributes of dried beans
M	Moisture content (g H_2O/g DM) at time = t
M_o	Moisture Content (g H_2O/g DM) at time = 0
M_e	Equilibrium Moisture Content (g H_2O/g DM)
MR	Moisture Ratio $MR = (M - M_e / M_o - M_e) = A\ e^{-kt}$
R^2	Coefficient of determination
t	Time (h)
wb	Wet basis (g H_2O/100g FW)

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