Effect of Drying Temperature and Drying Air Velocity on the Drying Rate and Drying Constant of Cocoa Bean

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ABSTRACT

The effect of some drying parameters and drying conditions of cocoa bean were determined. Three levels of temperatures (55, 70 and 81 °C) and three air velocity levels (1.3, 2.51 and 3.7 m/s) were used in the presented study. The moisture content of the cocoa bean used was 79.6 % (db). The heated batch cocoa bean dryer used in the evaluation was successful in drying thin layer of cocoa bean 5 cm deep at initial moisture content of 79.6 % (db) to 6 % (db), in 4-6 h of continuous drying at the above mentioned temperature range. The drying constant ranged from 0.009583 h^{-1} to 0.12666 h^{-1} under the above drying conditions. Coefficient of determination of 84.8 % was obtained with relationship of temperature and drying constant but when air velocity was incorporated it decreased to 80.9 %. The drying rate increased with increase in temperature and air velocity but decreased with time. The dryer can remove an average of 4.66 kg of water per day at 55-81 °C and air velocity of 1.3 m/s while at 2.51 m/s it can remove an average of 5.3 kg of water per day under the same drying conditions.

Keywords: Drying constant, drying rate, drying air temperature, drying air velocity

1. INTRODUCTION

Cocoa (*Theobroma cacao*) is a perennial cash crop with three important varieties viz. Criollio, Forestero and Trinitario. The end product from cocoa bean especially chocolate and beverages is considered among the basic food in many countries of the world. It can also be used for livestock feeds, tea, wine, cream etc (Olayiwola, 1993). Cocoa is a perennial cash crop and its natural habitat is the humid tropics (Opeke, 1982). The yield varies between 1.0 to 1.5 tons of dry beans per year (Opeke, 1982).

Tropical countries are characterised by relative high ambient temperature, relative humidity and rainfall. In these countries agricultural products like cocoa is harvested all the year round and the beans must be dried immediately to reduce mass losses and prevent spoilage. These losses might occur as a result of microbial activities, especially mould. Drying of cocoa bean is done to retain chocolate flavour and for safe storage after fermentation from the moisture content of 60 % to 7 % dry basis or less for safe storage (Cunha, 1990). Drying can be achieved naturally by making use of the solar energy. This involves spreading of the cocoa bean on the concrete floor or on a raised platform under the sun. These beans are stirred manually to provide even drying of the bean. However, when the condition is not conducive, artificial drying is employed (Asiedu, 1989). Artificial drying system consists of mainly a motor, fan and heating element. The fan drives the heated or unheated drying air into the bed. When heat is added to the drying air, the rate of drying increases, depending on the selected drying temperature and air velocity (Jayas and Sohkansanj, 1989). Artificial drying of cocoa is brought about by the frequent raining, coupled with frequent turning which can be tiresome when the drying is done manually. However engineers are weary of the problem of over drying and quick drying of cocoa bean by heated dryers. Over drying reduces the dry matter and causes increase in energy cost (Arinze et al., 1996) while quick drying prevents the chemical processes started during fermentation to be completed. Therefore proper prediction of the drying time is very important. Knowledge of the drying rate and drying constant in relationship with the drying temperature and air velocity is very important to the scientists and engineers who are involved in the design of the dryers and other post harvest machines involved in cocoa processing.

The review of literature revealed some limited work on this area; however post-harvest machine designed with their data cannot function effectively because of the peculiar agro climatic conditions of a particular area (Ndirika and Oyeleke, 2006). Various studies on the drying of biomaterials indicated that drying constant and drying rate are important factors in predicting the drying time of biomaterials (Brooker et al., 1992). The importance of drying constant in relation to handling, processing and design of post harvest machine is justified.
The objective of this research was to determine

1. the drying constant of cocoa bean dryer.
2. the influence of temperature and air velocity on the drying constants of cocoa bean drying.
3. the influence of air temperature and air velocity on the drying rate of cocoa bean.

2. MATERIALS AND METHODS

2.1 Materials

Cocoa (Forestero varieties) was used for the experiment. Initially, heap fermentation technique was applied on 50 kg sample for seven days. After sorting stones, shell and other foreign material were removed. The sample was thoroughly mixed and stored in a bag (jute) at room temperature (25 °C) to allow uniform moisture distribution within the samples. The weight of cocoa bean that will form a three kernel layer on the drying trough was also determined. A heated batch cocoa bean dryer used for crops with high initial moisture content was used for the experiment.

2.2 Experimental Procedure

In order to obtain the evaluation factors used for the research, measurement of drying air temperature, ambient (surrounding) temperature, humidity, air velocity and moisture content were made. Dry and wet bulb temperature was measured with a type T thermocouple with a maximum error of 0.5 °C. To measure the wet bulb temperature, the thermocouple junction was covered in a wet wick, which protrudes out from a bottle filled with water. The measured temperature was used to obtain air humidity from the psychometric chart and psychometric relation. Drying time was determined with a stop watch.

Also to obtain the desired moisture content, the samples were conditioned by soaking them in a calculated quantity of water and mixing thoroughly. The mixed samples (1.378 kg each) were sealed in polyethylene bags at 5 °C in a refrigerator for 15 days to allow the moisture to distribute uniformly throughout the sample (Islam and Pederson, 1987). The quantity of 1.387 kg is the mass of the kernel that can completely form three kernel layer on the drying trough of the dryer. A moisture meter, which was previously calibrated with an oven method according to ASAE standard S358.2 (1983), was used to determine the moisture content dry basis.

The drying air temperature was controlled with the aid of a thermostat attached to the heating element of the dryer, which was previously calibrated to read its maximum at the drying air temperature and turn off heating if maximum threshold is exceeded. Drying air velocity is determined with a vane anemometer equipped with a multimeter. The drying parameters were as follows:

- Drying air temperature: 55, 70 and 81 °C
- Drying air velocity: 1.3, 2.51 and 3.7 m/s
- Initial moisture content: 79.6 % (db)
- Relative humidity: 80 % (ambient)
- Mass of each sample: 1.378 kg

2.3 Drying Test

The method adopted here is the thin layer drying method. 1.378 kg of cocoa bean at initial moisture content of 79.6% (db) was loaded into the bean basket and spread to form about three kernel layer on the tray. Drying air temperature was determined with a type T thermocouple fixed at the exhaust duct. The bean basket and the cocoa bean were removed every 30 min and weighed to record moisture loss data. This was done for every air velocity and temperature as stated above. The test was completed in triplicate and the average taken. The test was carried out until there was no change in mass. At that point, it was assumed that the moisture content has reached equilibrium with the surrounding. The drying time started immediately when drying process began. However, before the drying began a dummy basket was used to achieve the stable drying condition. The moisture ratio was calculated from the Equations 1-3.

$$MR = e^{-Kt} \tag{1}$$

$$MR = \frac{M - M_e}{M_i - M_e} = e^{-Kt} \tag{2}$$

$$K = -\frac{\ln MR}{t} \tag{3}$$

Where MR is moisture ratio, M_i is initial moisture content, M_e is equilibrium moisture content, M is moisture content at time t and K is drying constant.

The drying constant was calculated from the slope of the negative natural log of the moisture ratio against time. The drying rate was determined from change in mass with time.

3. RESULTS AND DISCUSSION

3.1 Effect of Drying Air Temperature and Air Velocity on the Drying Constant

The data obtained from the experiment was indicated in table 1 and table 2. The drying constant (K_1) was calculated from the slopes of drying curves as shown in figures 1, 2 and 3 plotted based on equation 3 for the different drying temperatures and drying air velocities and presented as K_1 in table 1. From the table 1 and figures 1-3, the drying constant showed a relationship with the drying temperature and drying air velocity. It increased with increase in drying temperature and drying air velocity. From table 1 a linear regression was run with the drying constant (K_1) as the dependent variable and drying temperature (T) as the independent variable. The best fitting equation was given as

$$K_2 = 4.882\times10^{-4}T - 1.82\times10^{-2} \tag{4}$$

The above equation has a coefficient of determination of 84.8 %. When air velocity (V) was incorporated into the above equation, the best fitting equation was given as K_3

$$K_3 = 4.882\times10^{-4}T + 1.506\times10^{-3}V - 2.23\times10^{-3} \tag{5}$$

The coefficient of determination was 80.9 % in this latter case. The standard error for the two equations were 5.22×10^{-3} and 4.22×10^{-3}. K_1, K_2 and K_3 are presented in table 1 below. In the equations 4 and 5, it can be concluded that the air velocity has a lesser effect on the drying constant while is a strong function of temperature. However, both correlate well with the drying constant. This agrees with the work of Jayas and Sokhansanj (1989) that temperature has the strongest effect on the drying constant of barley at low temperature.

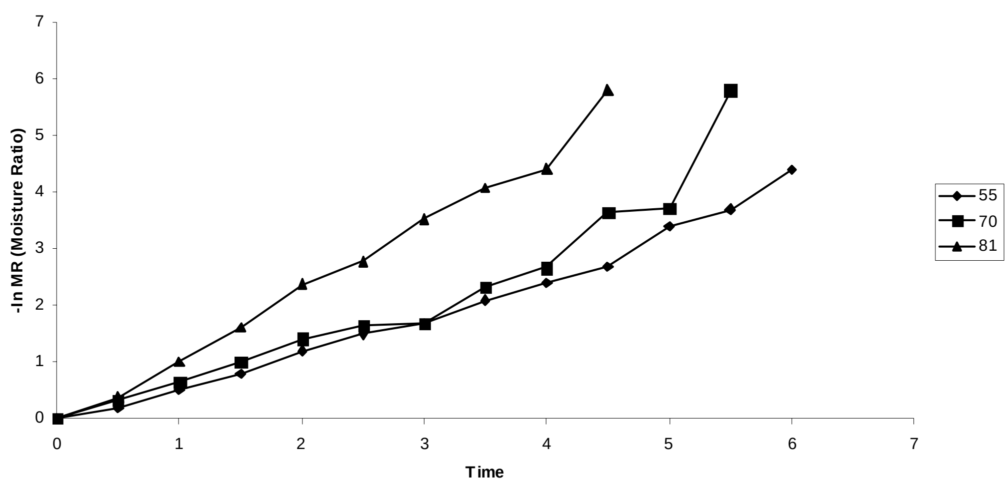

Figure 1. Drying curve of cocoa bean drier at 1.3 m/s at different temperature

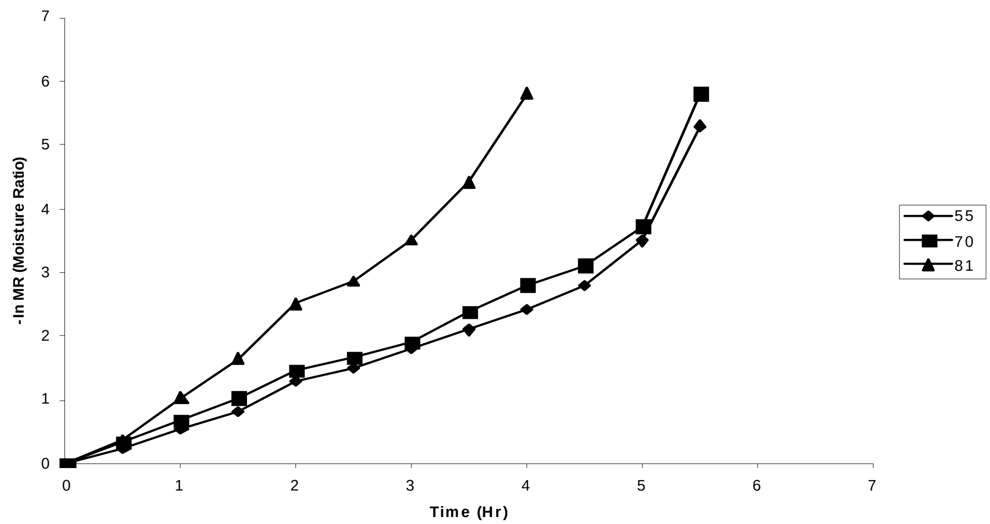

Figure 2. Drying curve for cocoa bean dried at 2.51 m/s at different temperature

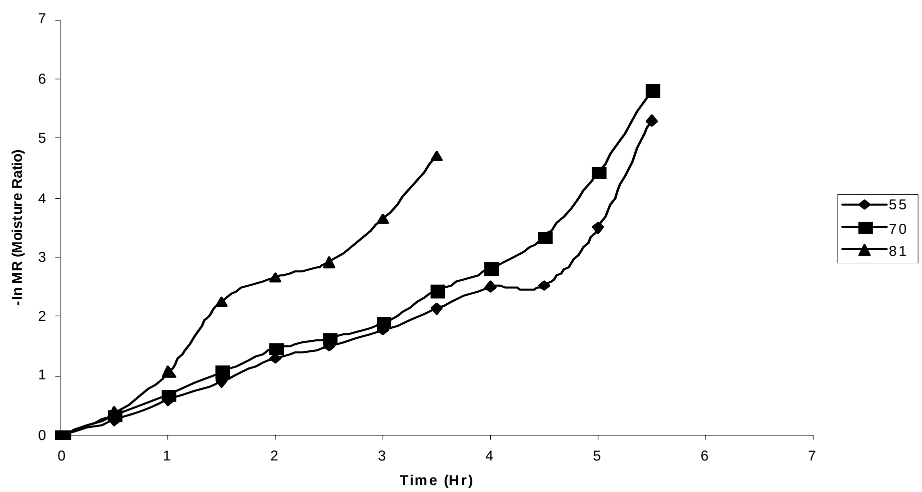

Figure 3. Drying curve of cocoa bean dried at 3.7 m/s at different temperature

Table 1. Drying constants of cocoa bean

Temperature, °C	Air velocity, m/s	K_1, min^{-1}	K_2, min^{-1}	K_3, min^{-1}
55	1.3	0.009583	0.008251	0.0064348
70	1.3	0.011123	0.15574	0.0137518
81	1.3	0.018291	0.020944	0.0184578
55	2.51	0.010083	0.008251	0.008257
70	2.51	0.011250	0.015574	0.0015574
81	2.51	0.012208	0.020949	0.020280
55	3.7	0.010459	0.018257	0.0100432
70	3.7	0.011708	0.015576	0.0173662
81	3.7	0.012666	0.020944	0.220722

3.2 Drying Rate and Moisture Content Variations

Table 2 shows the drying rate for the drier when the cocoa bean at 79.6 % (dry bases) initial moisture content is dried at the respective temperature of 55, 70 and 81 °C and air velocities of 1.3, 2.51 and 3.7 m/s. The cocoa bean exhibited a falling rate period just like most of other agriculture products. According to Baryeh (1985), cocoa exhibits critical moisture content at 100 % db but since the moisture content used is less, therefore it follows a falling rate period. The calculated average drying rates for the entire drying period, at 1.3 m/s, were 0.149 kg/h for 55 °C, 0.171 kg/h for 70 °C and 0.291 kg/h for 81 ^{o}C. This implies that the machine can remove an average of 3.576 - 6.984 kg of water a day with the above drying conditions. However, it increases at 2.5 m/s given an average of 3.912, 4.464 and 7.512 kg of water per day respectively at the drying air temperatures of 55, 70 and 81 °C. This shows that the drying rate is a strong function of temperature, air velocity and time. It is highest at the first one hour of continuous drying for all temperatures and decreases with time. This is a result of low internal resistance of moisture at the beginning of drying; therefore when energy is impacted moisture can easily move to surface, where evaporated. As the drying progressed, more energy was required to break the molecular bond of the moisture and since constant energy was supplied, it took longer time to break, therefore drying rate decreased. The drying is completed within 6 h of continuous drying on the thin layer.

Table 2. Calculated drying rates at different air velocity and drying air temperature (kg/h)

Time, h	V=1.3 m/s			V=2.51 m/s			V=3.7 m/s		
	55°C	70°C	81°C	55°C	70°C	81°C	55°C	70°C	81°C
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.50	0.60	0.75	0.81	0.65	0.78	0.81	0.66	0.79	0.83
1.00	0.38	0.40	0.60	0.40	0.50	0.63	0.44	0.61	0.65
1.50	0.21	0.23	0.035	0.24	0.32	0.40	0.27	0.32	0.44
2.00	0.15	0.17	0.19	0.16	0.20	0.20	0.18	0.25	0.31
2.50	0.10	0.11	0.14	0.10	0.15	0.16	0.12	0.19	0.19
3.00	0.08	0.09	0.10	0.09	0.12	0.14	0.10	0.13	0.14
3.50	0.04	0.05	0.08	0.04	0.07	0.09	0.09	0.09	0.10
4.00	0.03	0.03	0.06	0.04	0.04	0.08	0.05	0.07	0.10
4.50	0.02	0.02	0.06	0.023	0.02		0.025	0.03	
5.00	0.02	0.02		0.02	0.02		0.02	0.03	
5.50	0.01	0.01		0.01	0.015		0.01	0.02	
6.00	0.01	0.01		0.01					

4. CONCLUSIONS

From the study it can be concluded that the research has tried to widen the fundamental knowledge on cocoa bean drying. The result has shown that drying constant and drying rate has strong relationship with drying temperature and drying air velocity. The drying constant showed a linear relationship with temperature, with a coefficient of determination of 84.8 %, however it came down to 80.9 % when air velocity was added showing that air temperature has a greater effect. The drying constant ranged from 0.009583 h^{-1} to 0.12666 h^{-1} which may be adequate for engineering design. Generally, the drying rate increased with drying temperature and air velocity but decreased with time at the same drying temperature. This shows that cocoa bean drying follows a falling rate characteristic which is an important design consideration. The result of the study can also be adopted by other engineers and designers who are interested in processing similar crop. The optimum drying constant and drying rate, which will give the desired result, should be chosen based on the drying temperature and drying air velocity.

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