Investigating the effect of different loading densities on selected properties of dried coffee using a GHE dryer

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Abstract: Despite coffee being one of the leading cash crops in Uganda contributing 20%-30% of the total export earnings, it is mainly dried on bare earth surfaces hence its drastic decline in quality. A possible alternative solution is utilization of the greenhouse effect (GHE) solar dryer. This research was aimed at investigating the effect of different loading densities on selected properties of dried coffee using a GHE dryer that was designed and constructed at Makerere University Agricultural Research Institute Kabanyolo (MUARIK). The research involved determining the drying time for the loading densities of 5, 10 and 20 kg m^{-2} as well as analyzing the coffee quality at the end of the drying period. Three experimental runs were set up in the months of June and July which experienced average ambient temperature of 23.28 (±2.33)^{o}C and average dryer temperature of 35.68 (±13.85)^{o}C. The average drying time for the freshly harvested Robusta coffee at 61.3 (±1.36)% wb was 10 days for 5 kg m^{-2}, 11 days for 10 kg m^{-2} and 12 days for 20 kg m^{-2}. The loading of 20 kg m^{-2} resulted into an even roast with fair^{+} for body and flavour, while 5 and 10 kg m^{-2} loadings resulted into a silver skin roast with fair body and flavour. For this particular research, the loading density of 20 kg m^{-2} yielded the best results from the coffee quality analysis. The loading densities of 5 kg m^{-2} and 10 kg m^{-2} could not yield best results due to case hardening of the outer surfaces of the coffee beans which compromised the body and flavour of the coffee.

Keywords: greenhouse effect, solar dryer, loading densities, coffee quality, drying time

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1 Introduction

Uganda is one of the ten leading coffee growers in the world due to its climatic conditions that are favourable for the industry (U.S National Coffee Association, 2011). Presently two types of coffee are grown including Robusta coffee in the Central Buganda and South-Western regions and Arabica coffee from Eastern regions. The coffee produced contributes between 20%-30% of the foreign exchange earnings (UCDA, 2011). The quality of coffee directly affects the prices fetched by the coffee farmers in that when the quality of coffee is good, the coffee prices are also good and vice versa.

The drying operation is one of the most important steps in the coffee post harvest processing that influences the final quality of the coffee (Corrêa1 et al., 2006; IBERO, 2005). Drying can affect the physical appearance, the yield at hulling and the taste of the beverage (Aregba et al., 2006). According to Cirovelásquez, Abudcano and Pérezalegría (2009), drying is one part of the post harvest process that is responsible for the removal of excess moisture to a level that is safe for long time storage without any impact to aroma or taste of the final beverage. Several factors affect the coffee drying process including the drying method, drying air temperature, relative humidity, drying air velocity and the drying time (Corrêa1 et al., 2006).

Despite the economic importance of coffee in Uganda, proper drying mechanisms have not been prioritized by

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many rural coffee farmers in Uganda. The coffee is mainly dried by spreading on bare earth surfaces, where it is exposed to the sun's radiation (Alem, 2006). Although it is cheap and fairly effective, it has certain outstanding drawbacks such as increased cost of free land that restricts the sun drying floor area, high labour requirements, contamination from dust and dirt and exposure to erratic rains during the drying process. These drawbacks lead to high moisture of coffee, which is prone to attack by mould. Moreover, the coffee quality will decline drastically. This consequently results into low prices fetched by farmers (Lukwago et al., 1996; Singh, 1994; Nehemiah, 2008). Singh (1994) reported that because the use of the traditional open sun drying method made the drying rates slow, about 30% of crops were lost in the developing countries.

Several efforts have been made to address the drawbacks associated with open sun drying using bare earth surfaces. These include use of alternative drying surfaces such as tarpaulins, concrete surfaces, mats, black polythene sheets, raised tables or trays with wire mesh which keeps the coffee clean and free from contamination (Alem, 2006; IBERO, 2005). Others include use of natural circulation solar dryers which depend on solar radiation, ambient air temperature, relative humidity and wind velocity (Alem, 2006). According to Vanderhulst et al. (1990), the objective of solar drying is to supply the product with more heat than is available under ambient conditions, thereby increasing sufficiently the vapour pressure of the moisture held within the crop and decreasing significantly the relative humidity of the drying air. This consequently increases the moisture carrying capacity of drying air, which sufficiently lowers the equilibrium moisture content of the product being dried (Vanderhulst et al., 1990). Experiments conducted in many countries have clearly shown that solar energy can effectively be used to dry agricultural crops (Sarsavadia, 2007).

The drawbacks of open sun drying of coffee have been particularly addressed through the development of the greenhouse effect (GHE) solar dryer which in addition minimizes the need for labor to move the crop for safe storage at the end of the day (Alem, 2006). However, much as the GHE solar coffee dryer had been developed to address the above mentioned drawbacks, its performance had not been critically analyzed. There was therefore limited information on the utilization of the GHE solar dryer for coffee drying under the Ugandan conditions. This research was aimed at investigating the effect of different loading densities on selected properties of dried coffee using a GHE dryer that was designed and constructed at Makerere University Agricultural Research Institute Kabanyolo (MUARIK) by Alem (2006). The research involved determining the drying time of loading densities of 5, 10 and 20 kg m^{-2}, drying rate, absorber temperatures as well as analyzing the coffee quality at the end of the drying period. The research will benefit the coffee industry by finding the best suitable way of utilizing the GHE dryer with minimal effects on the quality of dried coffee.

2 Materials and methods

2.1 Description of the greenhouse effect (GHE) solar coffee dryer

The GHE solar dryer relies on the sun as a source of energy as does sun drying. However, it differs from open sun drying in that a structure often of a simple construction covered with a polythene sheet is used to enhance the effect of insolation. The dryer relies on natural circulation with the radiant energy from the sun heating the products directly through the absorption of solar radiation by the wet product. Figure 1 shows the GHE solar coffee dryer (dimensions 8 m × 5 m × 3 m) that was designed and constructed at MUARIK by Alem (2006).

Figure 1 GHE solar coffee dryer at MUARIK used for the experimental runs

The covering material envelops the air and creates a different environment from the ambient conditions. The GHE solar dryer allows accumulation of heat from the solar energy with short wave solar radiation from the sun passing through the polythene covering material and surfaces within the dryer absorbing it. The surfaces then re-radiate the absorbed solar radiation as long wave radiation that is unable to pass through the cabinet thus causing the air temperature in the dryer to rise. This increases the moisture holding capacity of air. The exhaust air exits via the chimney. The roof and drying chamber were covered with a UV stabilized transparent plastic sheet (UVA 205 per N polythene) with the following specifications:

- Thickness 0.2 mm
- Transmissivity 84%
- Weight per unit area 0.1862 kg m^{-2}

2.2 Experimental runs

Samples of red Robusta coffee cherries were collected from a farmer in Jinja district located in the Eastern part of Uganda. Three experimental runs were set up in the months of June and July starting from June 3 to July 17 2007. The treatments were loading densities of 5 kg m^{-2}, 10 kg m^{-2} and 20 kg m^{-2}. The coffee was dried in trays of size 1 m × 1 m with drying tray mesh fitted below the wooden box trays to allow air to pass through them and then through the product. The wooden box trays were supported by strong wooden stands of 400 mm height above the ground floor (Alem, 2006).

2.3 Temperature measurements

Ambient and dryer temperatures were determined using dry bulb thermometers on a three hours interval from 09:00 am to 15:00 pm and then a two hours interval to 17:00 pm. One thermometer was placed at the midpoint of the dryer just below the raised trays to determine the temperature of the air only excluding effects of direct radiation. The other thermometer was placed outside the dryer for measuring the ambient temperature.

2.4 Moisture content measurements

Three replications for each of the loading densities were set up to determine the average moisture content. Coffee cherries were then sampled from the drying trays to determine the moisture content using the oven drying method. The apparatus used included: vacuum oven, weighing balance, metal dishes with fitting covers and desiccators. The moisture content (% wb) was obtained by using Equation (1):

$$\textit{Moisture content wet basis } (w\ b) = \frac{W_2 - W_3}{W_2 - W_1} \times 100\% \qquad (1)$$

where, W_1 is the weight of both the metal dish and cover after being dried in an oven at 105°C; W_2 is the weight of the initial sample spread evenly over the bottom of the metal dish with cover fitted A metal dish is placed; W_3 is the weight of the sample after the initial sample has been dried to constant weight in an oven at 105°C and later cooled in a dessicator;

The drying time was obtained when constant moisture contents (% wb) were realized following analysis using the oven drying method. The drying process was stopped at this moisture content. For safe storage, coffee beans must be dried to 11-10% wb (Kamau, 1980).

2.5 Moisture Ratio (MR)

For thin layer drying, the moisture ratio (MR) was obtained by using Equation (2) (Buchinger and Weiss, 2001):

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

where, MR = dimensionless moisture content ratio; M = moisture content (% dry basis) at any level and at any time; M_0 = initial moisture content; M_e = equilibrium moisture content (% dry basis).

2.6 Drying Rate

The moisture readings for each of the loading densities were determined at 09:00 am in the morning and at 16:00 pm in the evening. The drying rate was then calculated by using Equation (3) (Buchinger and Weiss, 2001):

$$\textit{Drying rate} = \frac{\textit{initial weight} - \textit{final weight}}{\textit{time interval (day)}} \, [\text{kg m}^{-2} \text{ day}] \qquad (3)$$

2.7 Coffee quality analysis

According to UCDA (2009), coffee is rated of very good quality in terms of appearance, moisture content and in the cup. Samples from loading densities of 5, 10 and

20 kg m^{-2} were tested against quality parameters which included roast, body and flavour. The quality test was carried out at Uganda Coffee Development Authority (UCDA). The procedure that was followed during the quality test included:

- Hulling the dried coffee samples using a laboratory coffee huller (catador).
- Feeding the hulled coffee into a husk blower (cardon) to separate the coffee beans from its husks.
- Roasting of the beans in a roaster for about 10 minutes. Temperatures were not allowed to exceed 233^0C.
- The roasted beans were ground in a grinder to form a coffee paste.
- The coffee paste of each loading density was then used to prepare two cups, which were used in the cup taste.

3 Results and discussions

3.1 Ambient and dryer temperatures

The average ambient temperatures recorded during the drying period at 09:00 am, 12:00 noon, 15:00 pm and 17:00 pm were 21.84(±1.57)°C, 23.85(±1.57)°C, 24.13(±2.42)°C and 23.30(±2.80)°C, respectively. On the other hand, the average dryer temperatures recorded at 09:00 am, 12:00 noon, 15:00 pm and 17:00 pm were 32.85(±5.02)°C, 39.10(±4.78)°C, 36.95(±7.34)°C and 33.80(±5.07)°C, respectively. The GHE solar dryer therefore generates higher air temperatures and consequently lowers relative humidity that are both conducive to improve drying rates and lower final moisture content of the dried crop. Table 1 shows the recorded ambient and dryer temperatures for ten consecutive days.

Table 1 Daily ambient and dryer temperatures for 10 consecutive days

Day	09:00 am		12:00 noon		15:00 pm		17:00 pm	
	Ambient temp /°C	Dryer temp /°C	Ambient temp /°C	Dryer temp /°C	Ambient temp /°C	Dryer temp /°C	Ambient temp /°C	Dryer temp /°C
1	20.0	28.5	22.5	37.5	28.0	40.0	30.0	42.5
2	20.0	25.0	22.0	38.0	20.0	30.0	19.0	24.0
3	21.0	28.0	22.5	44.0	27.0	45.5	25.0	32.0
4	22.0	36.0	25.0	44.0	22.7	28.5	21.5	30.0
5	20.0	27.5	24.0	42.5	25.5	46.5	25.0	40.0
6	22.9	33.0	26.0	40.5	26.1	40.0	24.0	38.0
7	21.0	34.0	22.0	30.0	22.5	35.0	22.0	33.0
8	24.0	39.0	23.0	31.0	22.0	23.0	22.0	34.0
9	23.5	38.5	25.5	41.0	22.5	38.0	22.5	30.5
10	24.0	39.0	26.0	42.5	25.0	43.0	22.0	34.0

Figure 2 shows the variation of ambient and dryer temperatures at different times of the day during the drying period.

The ambient temperature varied between 19°C and 30°C with average ambient temperature recorded as 23.28(±2.33)°C while the dryer temperatures varied between 23°C and 46.5°C with average dryer temperature recorded as 35.68(±13.85)°C. Kamau (1980) reported that; good flavour of coffee grains is achieved when drying air temperatures are kept between 40-50°C. This temperature range was difficult to achieve due to variation in weather conditions and due to lack of a supplemental heat source for such conditions. The relatively low temperatures recorded were due to cloudy,

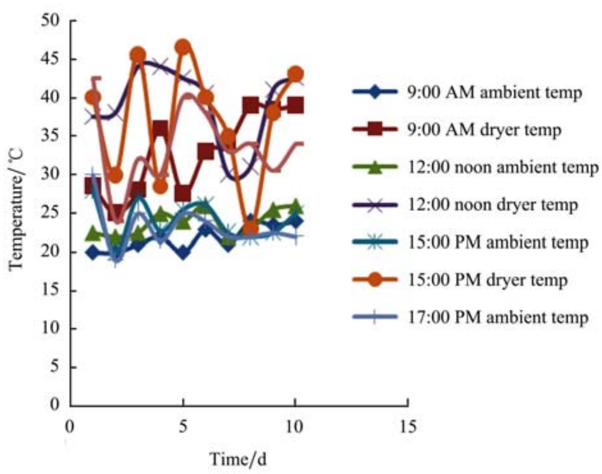

Figure 2 Variation of ambient and dryer temperatures

rainy and misty conditions characterised by limited sunshine during the drying period. This reduced the rate of moisture removal from the coffee. On the other hand, the higher temperatures were recorded at times of the day when the sky was clear with good solar radiation.

3.2 Moisture content variation

The average initial moisture content of the freshly harvested Robusta coffee was 61.3(±1.36)% wb while the average final moisture content obtained from the oven dry method was 11.65(±0.24)% wb. The initial moisture content lies within the range of 45 to 65% wb reported by Buchinger and Weiss (2001). On the other hand, the deviation from the final moisture content (i.e.11-10% wb) recommended by Kamau (1980) may be attributed to variation in weather conditions from one location to another; especially the relative humidity and drying air temperature that influence the equilibrium moisture content (Buchinger and Weiss, 2001). Additionally, it is not possible to dry to a product to a moisture content which is lower than the equilibrium moisture content (Buchinger and Weiss, 2001). Figure 3 shows the plot of moisture ratio against drying time for 5, 10 and 20 kg m^{-2} loading.

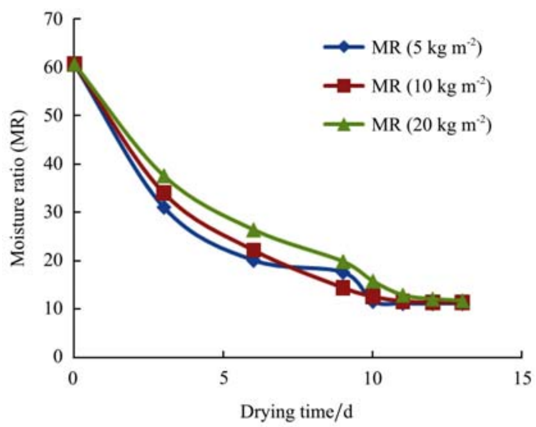

Figure 3 Plot of moisture ratio against drying time (days)

The drying curves show that the moisture ratio decreases with increase in drying time. The loading density of 20 kg m^{-2} was associated with higher moisture ratio followed by 10 kg m^{-2} and 5 kg m^{-2}.

3.3 Drying rate variation

In Figure 4 the drying curve of 5 kg m^{-2} was associated with a higher drying rate, followed by 10 kg m^{-2} and 20 kg m^{-2}. The variation in drying rates is attributed to the differences in the thickness of coffee in the drying trays. For all the three loading densities, the moisture content falls rapidly at first but as the coffee loses moisture the rate of drying slows. However on some days, the coffee was re-wetted due to condensation of moisture within the dryer. This was majorly attributed to the poor ventilation system meant to exhaust the drying air after it was saturated with moisture from the crop. In such cases, the drying process was affected.

Both the constant and falling drying rate periods were detected as shown in Figure 4. In the constant drying rate period, the surface of the food remains wet which exposes it to moulds and bacteria growth (Buchinger and Weiss, 2001). On the other hand, the surface is dry in the falling drying rate period. The risk of spoilage is therefore much smaller (Buchinger and Weiss, 2001). It is therefore advisable to dry to a weight that corresponds to the end of the constant rate period as quickly as possible to avoid spoilage (Buchinger and Weiss, 2001). However, this highly depends on the prevailing drying air conditions.

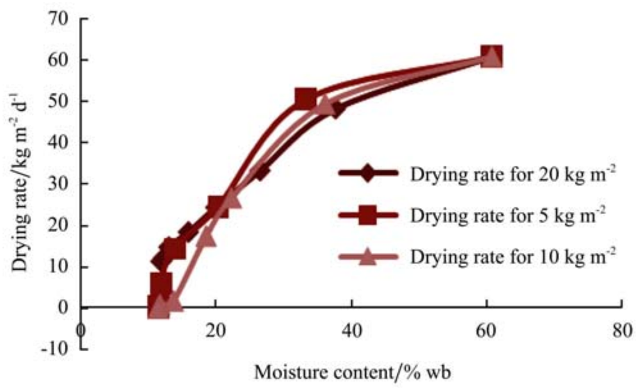

Figure 4 Drying rate curves for the loading densities of 5, 10 and 20 kg m^{-2}

The average drying time for the freshly harvested Robusta coffee at 61.3±1.36% wb was 10 days for 5 kg m^{-2}, 11 days for 10 kg m^{-2} and 12 days for 20 kg m^{-2}. According to Brooker et al. (1992), the total drying time for thin layer drying is less than that expected in thick layer drying for the similar product.

3.4 Coffee quality analysis

The thin layers of loading densities of 5 kg m^{-2} and 10 kg m^{-2} initially lost moisture at a generally high rate causing case hardening of the outer surface of the coffee beans. This compromised the body and flavour of the coffee. According to Van Arsdel (1973), high temperatures tend to damage the surface of the product thereby impending further moisture loss, a phenomenon known as case hardening. Drying should remove moisture from the coffee bean in a slow continuous process until the bean attains its final moisture content (Winston et al., 2005). However, this phenomenon was not easy to control in the GHE solar dryer since the drying process entirely depended on natural air circulation. The 20 kg m^{-2} had a slightly slower drying rate as seen from Figure 4 above.

The coffee quality analysis showed that 20 kg m^{-2} produces good quality coffee with an even roast while body and flavour of which are fair^{+} compared to 5 kg m^{-2} and 10 kg per m^2 that result into a silver skin roast with a fair body and flavour. For good flavour or cup taste of coffee grains, drying air temperatures should not exceed 40-50ºC (Kamau, 1980). This is a phenomenon that was not easy to control in a GHE solar dryer due to variation in weather conditions during the drying period. In addition, the thickness of the coffee in the drying trays influences the drying rate. Table 2 shows the results that were obtained from the coffee quality analysis that was conducted at UCDA.

Table 2 Average coffee quality test results

Loading density	Coffee quality test results		
	Roast	Body	Cup taste
5 kg/m^2	Silver skin	Fair	Fair
10 kg/m^2	Silver skin	Fair	Fair
20 kg/m^2	Evenly roasted	Fair^{+}	Fair^{+}

4 Conclusion

The drying process greatly affects the quality of coffee product in terms of appearance and flavor. When the drying process is done properly within the recommended conditions, a superior quality product can be obtained and vice versa. The thickness of coffee being dried also influences the drying rate hence the quality of coffee. For this particular research, the loading density of 20 kg m^{-2} yielded the best results from the coffee quality analysis. The loading densities of 5 kg m^{-2} and 10 kg m^{-2} could not yield best results due to case hardening of the outer surfaces of the coffee beans which compromised the body and flavour of the coffee. To improve the efficiency of the GHE dryer, there is need to investigate possible alternatives of energy storage which can be utilized when there is minimal amount of solar radiation.

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