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Optimization of Direct Passive Solar Dryer and Raised Drying Platform for Cassava Drying

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ABSTRACT

Cassava (*Manihot esculenta, Crantz*) is one the most important root crops in the world, providing energy to consumers due to the large amount of carbohydrates. However, farmers face the challenge of post-harvest losses of the crop. In order to avoid post-harvest losses, farmers have been engaged in traditional processing through peeling and drying chips to make flour and other products. Sun drying on a raised drying platform and direct passive solar dryers as the most used drying methods face the challenge of poor-quality dried cassava due to factors like inappropriate cassava chip size, poor drying layer depth, and long drying time. This study therefore sought to optimize these two cassava drying methods so as to improve the quality of dried cassava chips and the subsequent products. Randomized complete block design experiments were conducted and the measurements considered were drying time, moisture content, and microbial contamination in terms of Total plate count (TPC), Total coliforms (TC), and Yeast and moulds (YM). Models to predict moisture content for cassava chip size and drying layer depth were also generated. Results show that for all cassava chip sizes, there was no significant difference in drying time for drying layer depths of 3cm and 5.5cm. The optimal cassava chip sizes were 5cm arc length and 2 cm arc length for the raised drying platform and passive solar dryer respectively. Samples of drying layer depth of 3cm were least contaminated by coliforms and total plate count. Statistical analysis showed that for both drying technologies, individual factors of chip size and drying layer depth did not significantly affect the TPC ($p>0.05$). Samples from a 3cm drying layer depth were least mouldy and could therefore be stored for a longer time yet samples dried in a solar dryer had higher counts of yeast and moulds compared to those dried on a raised platform.

Keywords: drying layer depth; cassava chip size; drying area

INTRODUCTION

Cassava (*Manihot esculenta, Crantz*) is one the most important root crops in the world, providing energy to consumers due to the large amount of carbohydrates (Shittu et al., 2016). Africa's consolidated production of cassava was estimated at 53% of the world production. Nigeria, the Democratic Republic of Congo, Angola, Ghana, Mozambique, and Uganda being the largest producers in the continent (Kilimo Trust, 2012). In order to avoid post-harvest losses, farmers have been engaged in traditional processing through peeling and drying chips to make flour and other products (Mukasa, 2015). Drying is a major unit operation in cassava processing. According to Kajuna et al., (2001), the most common drying method is direct sun-drying of peeled roots for days into a storable product. In Uganda, over 88% of Cassava farmers dry their products by open sun drying (Buyinza & Kitinoja, 2018). However, other methods are also used and these include solar dryers and fermentation depending on the desired final product of cassava.

Sun drying on a raised drying platform and direct passive solar dryer as the mostly used drying methods face a challenge of poor-quality dried cassava due to factors like inappropriate cassava chip size, poor drying layer depth and long drying time. This study therefore sought to optimize these two cassava drying methods so as to improve the quality of dried cassava chips and the subsequent products.

MATERIALS

The materials and equipment used for the investigation are the raised drying platform and direct passive solar dryer for all the drying experiments. Freshly harvested cassava tubers of the NASE 14 variety obtained from the farmer's field were used. All other experiments were carried out in the laboratories of the school of Food Technology, Nutrition and Bio-Engineering, Makerere University.

METHODS

(1) Sample preparation

Fresh roots were harvested, peeled, washed using portable water, and sliced using hand knives. Four cassava chip sizes (Figure 1) were studied; size 1 was 9 cm arch length obtained after first slicing of an average tuber of 6 cm diameter, size 2 was a whole tuber of 3 cm thick diameter, size 3 was 5 cm arch length obtained after second slicing, and size 4 was 2 cm arch length obtained after third slicing of the average tuber.

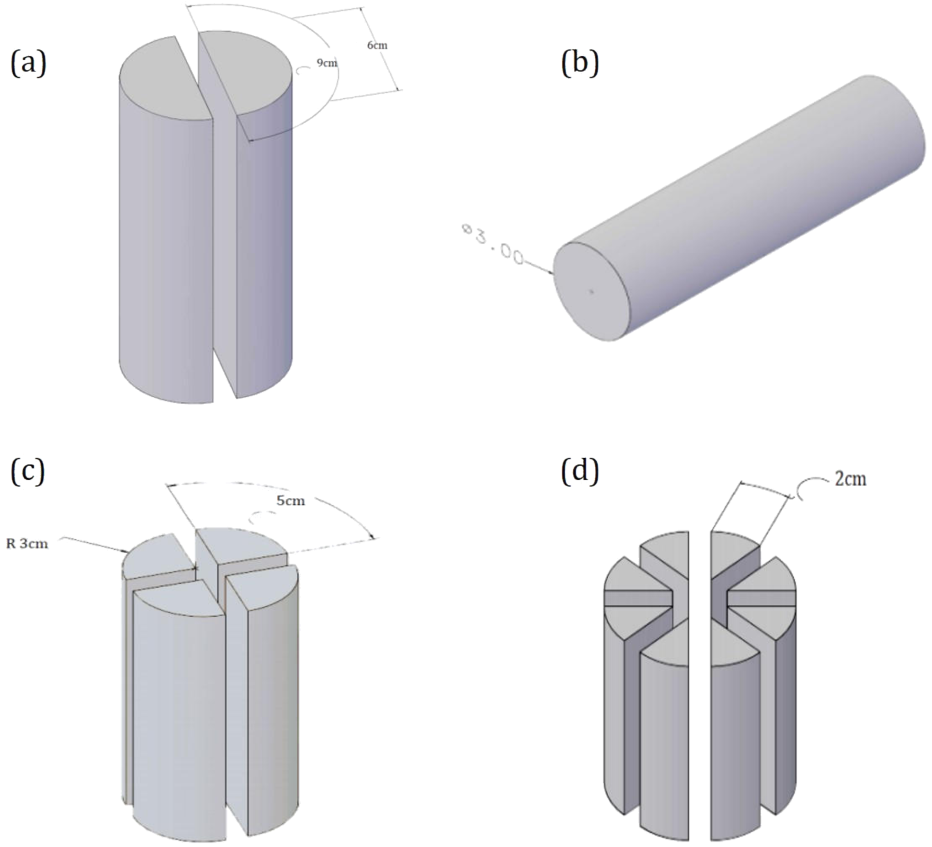


FIGURE 1: Illustration of cassava chip sizes: (a) size 1 of 9cm arc length (b) size 2 of 3cm diameter (c) size 3 of 5cm arc length (d) size 4 of 2cm arc length.

(2) Experimental setup

For both direct passive solar dryer and raised drying platform, a Randomized Complete Block Design (RCBD) experiment based on chip size and drying layer depth was set up at the farmer's field (Figure 2). For each cassava chip size, 3kg were weighed and spread in three different layer depths of 3cm, 5.5cm, and 8.5cm. The occupied area for all cassava chip sizes and drying layer depths were measured and recorded. Each cassava chip size and drying layer depth combination was replicated twice for two experimental runs. Drying time, moisture content, pH, microbial load, starch content, final viscosity, and pasting temperature for all cassava chip size and drying layer depth were determined and results analyzed.

(a) (b)

FIGURE 2: (a) drying in the solar dryer (b) drying on a raised platform.

(3) Analysis of chemical and functional properties of cassava chips

The moisture content of dried Cassava chips and flour was determined according to the procedure described by (Gacheru, 2015). The moisture content (wet basis) was reported as a percentage as given in Equation 1.

$$= \frac{(Dish\ weight + Moist\ sample\ weight) - (Dish\ weight + Dried\ sample\ weight)}{Moist\ Sample\ weight} \times 100 \text{ ....Equation 1}$$

pH was determined using a pH meter (Jenway 3330, UK). Starch content was determined by the method of (Åman et al., 1994) and Equation 2.

$$\%\ starch\ (dry\ matter) = \frac{(glucose) \times 25.15 \times 0.9 \times 25}{Sample\ weight\ (mg, DM)} \text{ ....Equation 2}$$

The pasting properties of cassava flours upon heating and subsequent cooling were determined using a Rapid Visco-Analyzer (RVA). A total running time of 13 min was used and the viscosity values were recorded as the temperature increased from 50ºC to 95ºC before cooling to 50ºC again. Rotation speed was set to 960 rpm for the first 10 sec and to 160 rpm until the end.

(4) Determination of microbial load

Microbial content was determined using laboratory methods and procedures as described by Harrigan and McCance, (1976). The plate count technique was used to enumerate total viable microorganisms (Total plate Count, TPC) whereby a known amount of the product is mixed with a culture medium in a petri dish, incubated, and the numbers of developed colonies counted, and the viable count of the microorganisms (per gram) calculated. Yeasts and moulds (YM) were enumerated using Potato dextrose agar (PDA) and Total Coliforms (TC) were determined using Violet Red Bile Agar (VRBA).

(5) Model fitting

From experimental data, models to predict moisture content, for different drying layer depths and cassava chip size combinations were generated using Matlab R2016b. Moisture content was the response (dependent) variable and time in days as the predictor (independent) variable.

(5.1) Model Selection Based on Goodness of Fit Statistics

In this study the goodness of fit statistics considered was R2. A better fit is indicated by a high value of R2 (value close to 1) (Das et al., 2014). Therefore, the best models were chosen based on the highest R2.

(5.2) Model validation

Established models for solar dryers and raised drying platforms were validated to determine the extent to which they can predict new cases.

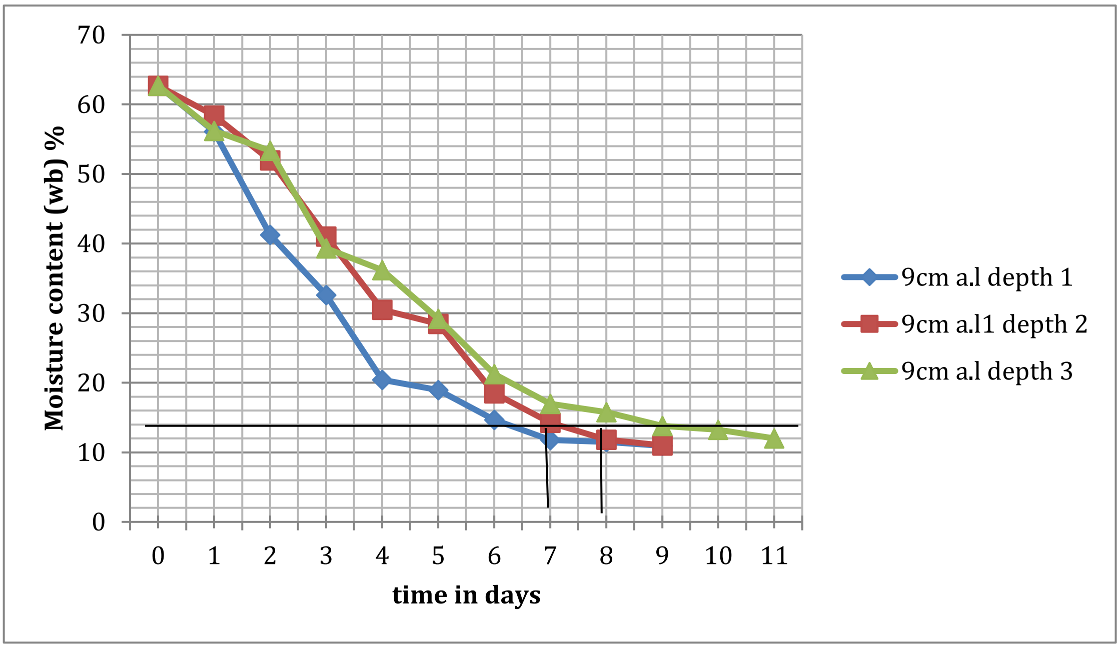
Cassava chip samples for all four sizes were prepared as described in section (1) and dried on the raised drying platform and solar dryer for drying layer depths of 3cm and 5.5cm. Initial and daily moisture contents for all chip sizes and depths were measured and recorded as experimental values. Predicted moisture content values per day were also determined from the established models. Predicted moisture content curves and experimental moisture content curves were fitted on the same graph to demonstrate the correlations between the predicted values and experimental values and also show the extent to which the models can predict new cases.

(6) Statistical Analysis

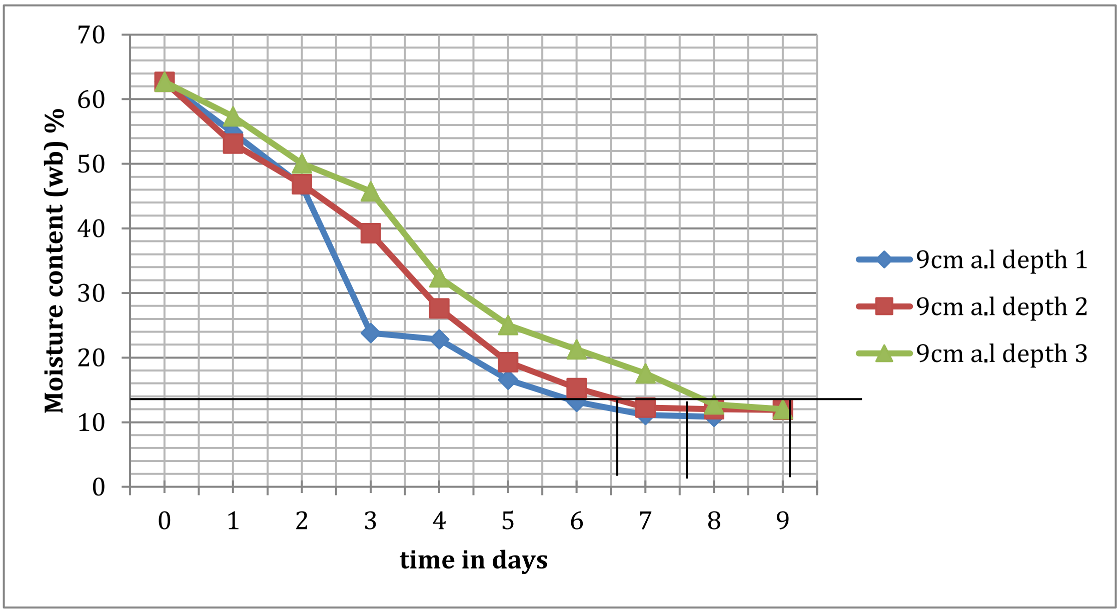
Data was recorded and subjected to analysis of variance (ANOVA) to test of significance of experimental factors and interaction. The analysis of variance for each factor was done using MATLAB R2016b. A significance level ($p < 0.05$) was used for all analyses. Relationships for drying rates between the dryer and the raised platform were determined using graph analysis.

RESULTS AND DISCUSSION

The average moisture content of freshly harvested tubers was 62.7% wet basis. This value is within the ranges reported by previous studies of 63% wet basis (Bradbury & Holloway, 1988) and 60.7% wet basis (Weiss & Lebel, 2009). From Figure 3, it is observed that samples dried in drying layer depth of 3cm had the shortest drying time followed by those in drying layer depth 5.5cm and 8.5cm. It was also found that samples of 3cm diameter on the raised platform and samples of 5cm arc length in the solar dryer had the same drying time of seven days for both drying layer depth of 3cm and 5.5cm. Findings therefore show that drying time for drying layer depth of 3cm and 5.5cm are generally not much different.



(a)

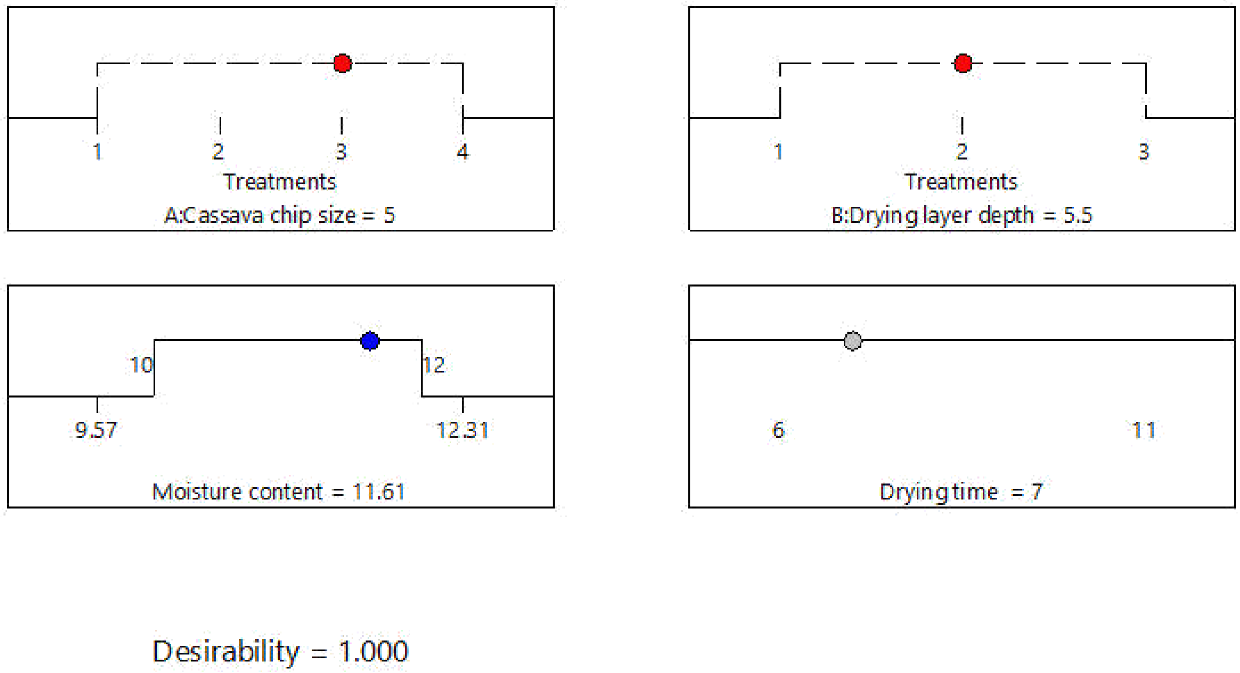


(b)

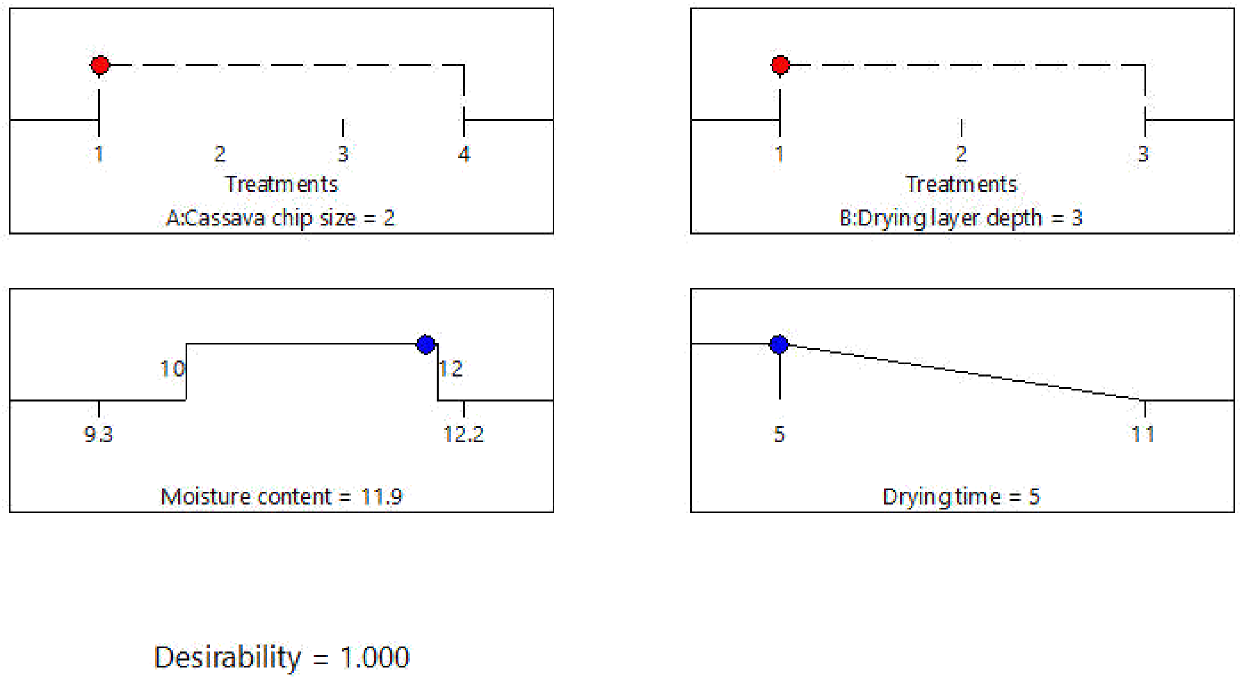
FIGURE 3: Cassava chip size and drying layer depth drying curves:
(a) 9cm arc length for the solar dryer (b) 9cm arc length for the raised platform.

From Figure 4 (a), the optimal cassava chip size was a 5cm arc length at a drying layer depth of 5.5 cm with a drying time of seven (7) days and a final moisture content of 11.61% wet basis.

Also, Figure 4 (b), shows that for the solar dryer, the optimal cassava chip size was 2 cm arc length at a drying layer depth of 3cm with a drying time of five (5) days and a final moisture content of 11.9 % wet basis.



(a)



(b)

FIGURE 4: Response surface methodology output for optimal chip size and drying layer depth: (a)Raised platform (b) solar dryer.

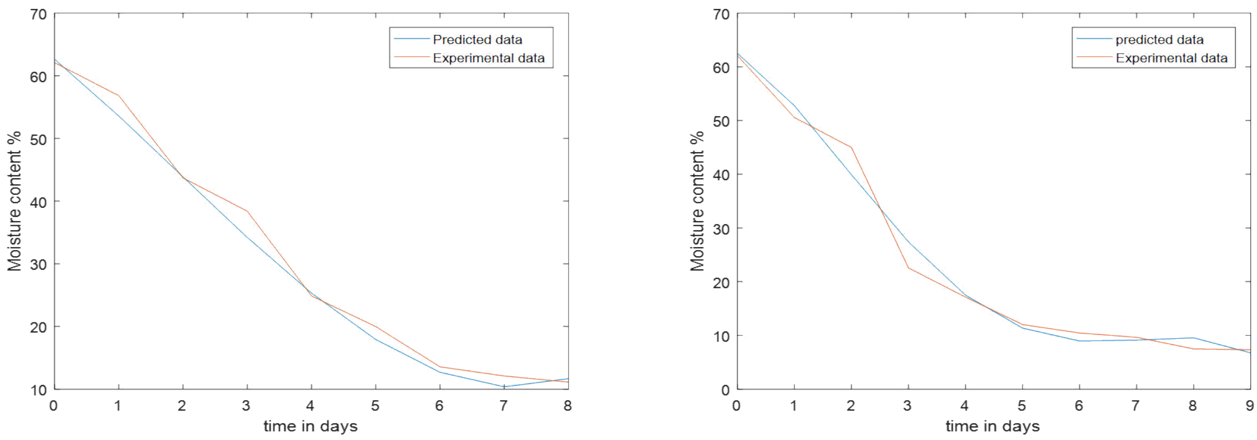
Models to predict moisture content for the optimal chip size and drying layer depths are presented in Table 1.

Both models have high values of R2 close to 1 which is an indicator of good models for predicting future cases.

TABLE 1: Models for optimal cassava chip size and drying layer depth for the raised drying platform and solar dryer.

Raised drying platform			
Model name	**Model expression**	**Coefficients with 95% confidence bounds**	$\mathbf{R^2}$
Size 5cm a.l depth 5.5cm	$f(x) = P_1x^3 + P_2x^2 + P_3x + P_4$	$P_1 = 0.1184$, $P_2 = -0.6804$, $P_3 = -8.505$, $P_4 = 62.65$	0.998
Solar dryer			
Model name	**Model expression**	**Coefficients with 95% confidence bounds**	$\mathbf{R^2}$
Size 2cm a.l depth 3cm	$f(x) = P_1x^4 + P_2x^3 + P_3x^2 + P_4x + P_5$	$P_1 = -0.04801$, $P_2 = 0.8614$, $P_3 = -3.801$, $P_4 = -6.758$, $P_5 = 62.52$	0.982

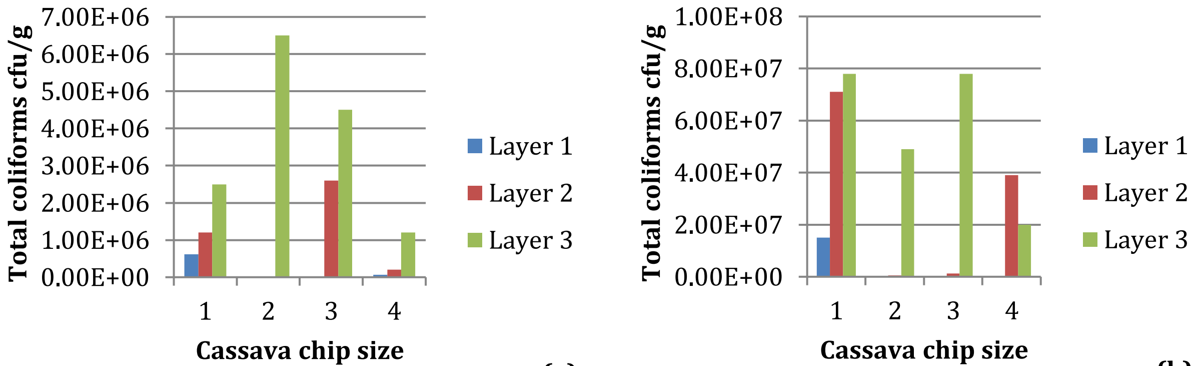
Established models were validated and provided satisfactorily a good conformity between experimental and predicted moisture content. From Figure 5, predicted data generally fitted well on the experimental drying curves which showed the suitability of these models in describing the drying behaviour of cassava chips using both technologies.



(a) (b)

FIGURE 5: Model validation graphs: (a) Raised platform; 5cm arc length 5.5 cm depth (b) Solar dryer; 2cm arc length 3cm depth.

Figure 6 shows the effect of cassava chip size and drying layer depth on Total coliforms for samples dried in the solar dryer and raised drying platform. It is observed that for all cassava chip sizes, samples of drying layer depth 3cm were least contaminated by Total coliforms. Additionally, a sample of drying layer depth 8.5 is not safe for human consumption since they had the highest Total Coliform counts. For samples dried in the solar dryer, there was a significant difference in Total coliforms among cassava chip sizes ($p < 0.05$).



(a) (b)

FIGURE 6: Effect of cassava chip size and drying layer depth on Total coliforms: (a) for raised drying platform (b) for solar dryer.

It is observed from Figure 7 that for all cassava chip sizes dried by both solar dryers and raised drying platforms, samples from a drying layer depth of 3cm were the least mouldy. This suggests that these samples have a longer shelf life than those dried in drying layer depths of 5.5cm and 8.5cm. It is also observed from the same figure that samples dried on a raised drying platform had low counts of yeast and moulds compared to those dried in a solar dryer. This implies that a raised drying platform is a safer method of drying cassava chips for human consumption compared to the use of a direct passive solar dryer. Unlike samples dried in the raised drying platform, there was no significant difference ($p > 0.05$) in yeast and moulds among drying layer depths for samples dried in the passive solar dryer. This implies that other factors besides drying layer depth affected the growth of yeast and moulds on samples dried in a solar dryer.

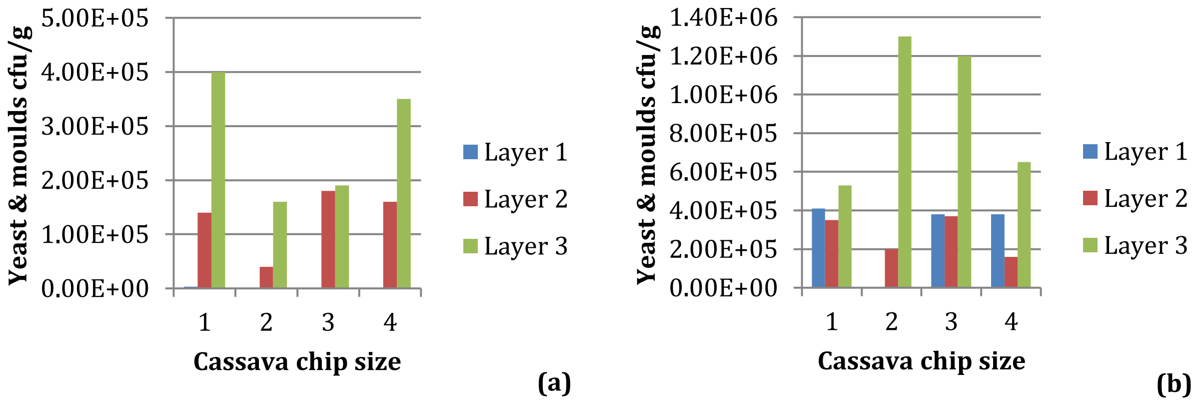


FIGURE 7: Effect of cassava chip size and drying layer depth on yeast and moulds: (a) for raised drying platform (b) for solar dryer.

Figure 8 shows the effect of cassava chip size and drying layer depth on the Total plate count for samples dried in the solar dryer and raised drying platform. Samples of drying layer depth of 3cm are the least contaminated followed by those in drying layer depth of 5.5cm.

Statistical analysis showed that for both drying technologies, individual factors of chip size and drying layer depth did not significantly affect total plate count ($p>0.05$). This implies that other factors besides chip size and drying layer depth affected contamination levels in the samples and these could be the personal hygiene of the processors and general sanitation of the processing area.

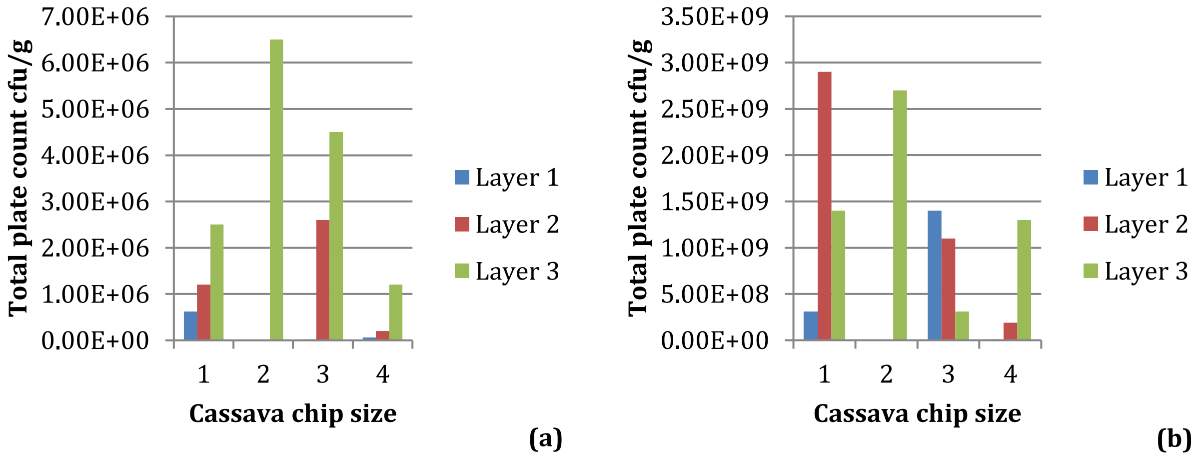


FIGURE 8: Effect of cassava chip size and drying layer depth on Total Plate Count: (a) for raised drying platform (b) for solar dryer.

CONCLUSIONS

Although samples dried in a drying layer depth of 3cm had the shortest drying time, it was not significantly different from that of a 5.5cm drying layer depth. Fitted models accounted for a greater proportion of variance which indicates that they are useful for prediction. Optimal chip sizes were 5cm arc length and 2cm arc length for raised platform and solar dryer respectively and the optimal drying layer depth was 3cm for both cassava drying methods. Cassava dried on the raised platform showed superior quality in terms of microbial contamination compared to that from the solar dryer. Good hygiene practices and sanitary rules should be practiced during the entire cassava drying operation.

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