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Kinetics, mass transport characteristics, and structural changes during air-drying of purple yam *(Dioscorea Alata L.)* at different process conditions

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Abstract. This experiment was designed to follow the 2^k factorial design to study the effects of the three drying parameters on the drying characteristics and effective moisture diffusivity and to fit each run performed on the best thin-layer drying kinetics model. Raw purple yam samples were pre-treated and undergone the designed drying procedures at which the weight of the samples were recorded every minute until such time that the sample weights become constant. Scanning Electron Microscopy (SEM) is utilized for qualitative analysis of the dried samples. The number of pores per unit area and the overall aesthetics of the surface of the dried samples were compared also using SEM. Considering the qualitative analysis conducted on the samples from the images of SEM, dried samples from run 2 has the most desirable conditions such as high temperature and low air velocity for drying because the samples from this run have large pore diameters with minimal cell breakages.

1 Introduction

Drying refers to the removal of relatively trace amounts of liquid (generally water) from a material. The use of heat to expel liquids recognizes drying from mechanical dewatering techniques like filtration, decantation or sedimentation, and centrifugation, in which no adjustment in stage from liquid to vapor occurs [5]. In the food industry, drying is being used as a preservation technique. Since microorganisms in food require water for growth and reproduction; and enzymes, which cause chemical alterations in food and biological materials, cannot function in the absence of water, removal of water results in reduced rate of spoilage and prevention of chemical changes in food. For microorganisms to be inactive, water content of the food must be reduced below 10 wt % while it is desirable to reduce the water content below 5 wt % for nutrient and flavor preservation [3]. Drying in food industry is usually the final processing step before packaging because drying promotes increased shelf-life of food and preservation of food characteristics. It is used to dry meats, garlics and onions, edible mushrooms, fruits, vegetables, and other starchy foods.

In this study, purple yam was dried to serve as a potential source of starch. Starch is commonly produced by isolating it from the food source through drying. Starch is the term applied to a white, powdery or granular, odorless and tasteless complex carbohydrate $(C_6H_{10}O_5)x$, which is commonly derived from the seeds of cereal plants, and in bulbs, roots and tubers. Starch consists of 20-30% amylose and 70-80% amylopectin. It can be utilized as a significant raw material in the food, pharmaceutical, cosmetic, chemical and oil industries, and is commonly extracted from the source material in aqueous medium. This material is usually packaged and supplied in granular or powdery form making the drying process a fundamental unit operation in starch production. The extraction of starch commonly involves dry milling, wet milling or the combination of both. Some of the commonly used raw materials as the natural source of starch are yams. Yams are from the genus Dioscorea of the family Dioscoreaceae; which has around 600 species, one of which is the Dioscorea. alata L. [1]. D. alata L., generally known as purple yam, is a vital tuber crop and purple pigmented elite cultivar has recently become popular due to its associated health benefits. It provides protein three times more superior than cassava and sweet potato [2]. Purple yam begun in the Asian tropics and is a boss commodity in some tropical countries (Fang et al., 211). In a previous study, it was reported purple yam's moisture content of 82.91±.41% (wet basis). To gain control of the high perishability because of high moisture content, purple yams are typically subjected to drying. It is necessary to extend the duration of storage of purple yam for its supply throughout the entire time of its off-season without losing healthful abilities [6].

There are literatures about drying of different food products but until now, characterization of drying and

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drying kinetics of purple yam specifically using tray dryer, is not yet completely established for there is still limited information on the said topic. A study claimed that dehydration of fruits, vegetables, and crops deal challenging problems involving complex drying conditions that involve many interconnected and opposing phenomenon associated with material's complex nature of drying. Another problem specifically upon drying of purple yam is the determination of the desired temperature that should be utilized during the process. If the temperature is too high, the food matrix ruptures which results to reduction of the sizes of pores. Large pores sizes are desirable for good rehydration of the dried product [4].

The major objective of this study is to determine the drying kinetics of purple yam. The specific objectives include 1) to study the effects of different process conditions on the drying behavior of purple yam slices; 2) to determine the most efficient process condition for purple yam through scanning electron microscopy; 3) to generate drying curves for purple yam; and.

This study will help establish drying protocol for purple yams. The protocol will include the appropriate drying air temperature with the corresponding air velocity and thickness as well as the proper pretreatments for the purple yam upon using tray dryers. Additionally, this study will lead to the equation that fits the drying phenomena of purple yam. The experimental data that will be obtained from this study may be of good considerations upon the design of future dryers.

The drying process will be conducted at temperatures 50ºC and 60 ºC with air velocities 1 and 1.3 m/s and sample thickness of 1 and 2 mm. The tray dryer that will be used is the model UOP8MkII computer controlled tray dryer of Armfield. Characterization of the samples will be done through scanning electron microscopy.

2 Material and methods

2.1 Preparation of purple yam

The purple yam samples (*Discorea alata L.*) were purchased from Balintawak Market and were stored at a room temperature not exceeding 30ºC prior to usage. A sample was brought to the Bureau of Plant Industry for species authentication. Yams were washed and manually sliced using mandolin slicer. Uniform disk shaped was maintained for all samples through a round shape cookie cutter having a 55 mm. In this way disk-shaped samples having uniform area and thickness were prepared. The slices were steam blanched for 7 min at 98±2ºC as adapted from Hsu [7]. The purpose of blanching is to deactivate enzymes responsible for deterioration of samples. Subsequently, the samples were then soaked in sodium sulfite solution at 45°C for 10 minutes to avoid discoloration and browning. The soaked yam slices were drained and laid on paper towels to remove any adhering dirt and excess water and weighed on an analytical balance.

2.2 Initial moisture content (IMC) determination

The Initial moisture content was determined in triplicate by drying known weight of samples prepared at a temperature of 105ºC until constant weight is achieved. Samples were then cooled in a desiccator for about 5 to 10 minutes. The difference between the initial weight and final weight of the samples is considered as the *IMC*.

$$IMC_{wb} = \frac{W_i - W_f}{W_i} x100 \tag{1}$$

2.3 Tray dryer

The tray dryer that was used is the model UOP8MkII computer controlled tray dryer of Armfield. This small-scale bench top tray drier dries solids by passing a stream of hot air over trays of wet material. The tray dryers specifications are as follows: i) a compact desktop tray dryer for laboratory use, ii) computer control of temperature and air flow rate, with sophisticated data logging and analysis software, iii) capacity up to 2.1 kg of wet material, iv) flow rates, 0.4-3.0 m/s over trays, v) temperature up to 80 ºC at 0.4 m/s (less at higher flows), vi) integrated electronic weight measurement to determine drying rate, vii) electronic measurement of temperature and humidity before and after the drying trays, viii) electronic measurement of air flow, and ix) Stainless steel construction. The dimensions of the tray dryer are 0.325x1.160x 0.345 m in height, length and depth.

2.4 Drying

The sliced samples were spread evenly across the customized stainless wire mesh trays. Trays were placed inside the tray dryer at different drying conditions. Sixteen pieces of samples per tray and three rays per trial were utilized during the drying process. Table 1 shows the design matrix at different varying parameters such as temperature, air velocity, and thickness. Table 1 displays the drying conditions to be used in relation with the symbols used in the 2^3 factorial designs.

Table 1. Drying Conditions to be Designated in the 24 Factorial Designs.

Drying Conditions	+	-
Temperature (°C)	60	50
Air Velocity (m/s)	1.3	1.0
Thickness (mm)	3.02 ± 0.024	2.00 ± 0.042

2.5 Experimental design

Three drying parameters, namely drying air temperature, drying air velocity and slice thickness, were considered during the drying process. High and low values for the said parameters were utilized and so an experimental design of 2^3 factorial was followed. Thus, there are 8 treatment combinations or 8 runs and there were three trials for each combination. Table 2 presents the design matrix was used during the drying process.

Table 2. Design Matrix with factors Temperature, Velocity and Thickness.

Run	Temperature	Air Velocity	Thickness	Label
1	-	-	-	(1)
2	+	-	-	A
3	-	+	-	B
4	+	+	-	AB
5	-	-	+	C
6	+	-	+	AC
7	-	+	+	BC
8	+	+	+	ABC

2.6 Drying-time curve and drying-rate curve

The drying time curves were generated by the computer which controls the dryer. Drying time curves are plots of weight of the sample as the ordinate with elapsed time as the abscissa. The drying-rate curves were generated based on the slopes of the drying-time curve, which were placed in the vertical axis and the corresponding moisture content in the horizontal axis. The equations used for the drying curves determination were obtained [3]. The moisture content is being defined as:

$$M_t = \frac{W_i - W_f}{W_i} x100 \qquad (2)$$

Where M_t is the moisture loss at t time, W_i is the initial weight of the sample and W_f is the weight of the dried sample.

2.7 Determination of drying time curves and drying rate curves

The drying time curves were determined for each run by plotting the Moisture Ratio (MR) vs. time (min) data. The drying rate curves were determined for each run by plotting the Drying Rate vs. Free Moisture content data.

2.8 Drying shrinkage and pore Size

The shrinkage of the dried samples were determined by comparing the thickness of the purple yam slices, before and after drying using a Vernier caliper [8]. The value percentage shrinkage must be minimal to consider the drying procedure to be successful and also represents a good rehydration quality of the dried product.

The pore sizes of dried samples were obtained through scanning electron microscope (JEOL JSM-5310, Japan). Samples were preserved in ziplock plastic bags prior to testing. The samples were coated with gold by electron beam evaporation in a fine coater (EOL KFC-1200, Japan) and were then placed in the SEM. Micrographs were be generated for each sample.

2.9 Statistical analysis of data

All results were reported as mean of 3 trials and standard deviation. One-way analysis of variance was conducted to determine if there are significant differences between means. Post hoc analysis was be performed to study further significantly different means and minitab software was used for all statistical analysis.

3 Results and discussions

3.1 Initial moisture content

The plot for the percent decrease in weight of fresh samples vs. time was presented in Figure 1. Based on the plot, the percentage decrease in weight of the fresh samples were 82.24% and 80.18% for thick fresh samples and thin fresh samples respectively. The average percentage decrease in weight for the fresh samples is 81.21%. It is assumed that the decrease in weight of the fresh samples is mainly composed of evaporated water from the fresh samples due to the exposure of the fresh samples in the high drying temperature catered by the oven drier. Thus, the average initial moisture content of the fresh samples is 81.21%. Based on a previous study, the initial moisture content for *D. alata* is 82.91±0.41% [6].

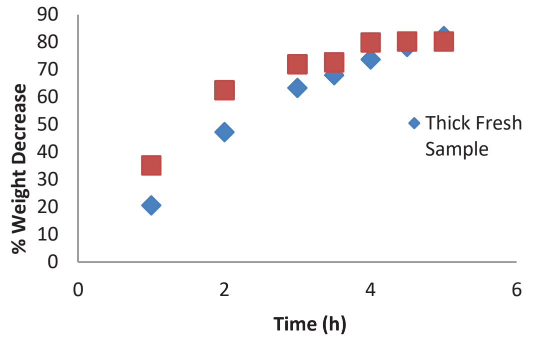

Fig. 1. Percentage Weight Decrease of Fresh Samples Vs. Time (h)

3.2 Scanning electron microscopy (SEM)

In this study, scanning electron microscopy is used to conduct a qualitative analysis to determine the most efficient condition among the generated conditions from the 2^3 factorial design. Figures 2 to 3 show the micrographs generated for thin dried purple yam samples.

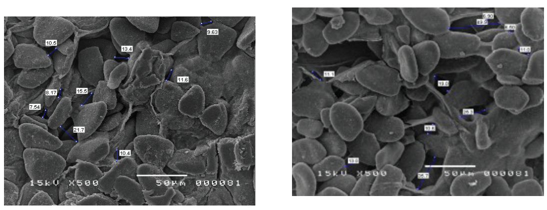

Fig. 2. Micrographs of Dried Purple Yam for Run 1 and Run 2

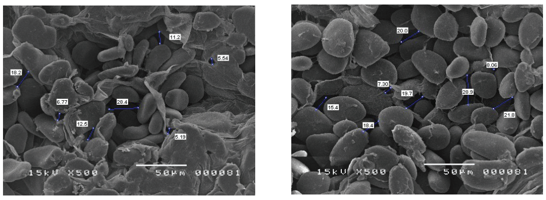

Fig. 3. Micrographs of Dried Purple Yam for Run 3 and Run 4

Based on the micrographs presented for thin dried purple yam samples, desirable qualities of dried purple yam are obtained from Run 2. High temperature and low air velocity were able to present large pores sizes which are being desired for good rehydration of the dried product. It can also be observed through that condition that the sample was able to maintain its food matrix which means that minimal cell breakages occurred or rupturing of the food structure have been avoided. Figures 4 to 5 present the micrographs generated for thick dried purple yam samples.

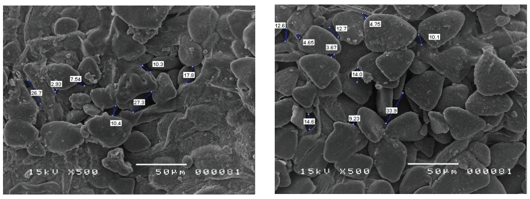

Fig. 4. Micrographs of Dried Purple Yam for Run 5 and Run 6

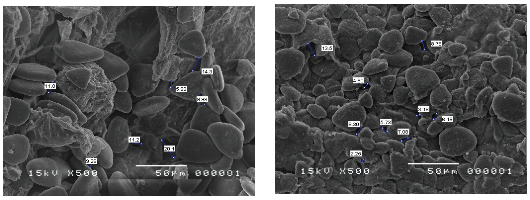

Fig. 5. Micrographs of Dried Purple Yam for Run 7 and Run 8

Same observations as to that of thin dried samples were observed for thick dried samples. High temperature and low air velocity under Run 6 give the desirable qualities of thick dried purple yam samples. Large pores sizes as well as intact cell structure were maintained. According to [9], low air velocity contributed to a lower pressure in the food product tissues resulting to a nearly intact cellular structure despite of the high temperature applied to the samples. Both for thin and thick slices, the desired qualities of dried product were observed for high temperature and low air velocity however as to comparing Run 2 with Run 6, smoother surfaces were observed under Run 2 and so Run 2 has the better drying condition.

3.3 Drying characteristics

In analyzing the pore size distribution in each sample, one-way analysis of variance using Minitab 17 was performed to determine if there is a significant difference between the means of the runs which are of different drying conditions. The null hypothesis which states that all means are equal was rejected after having a P-value of 0.044 which is smaller than the α-value equal to 0.05. This means that varying drying conditions would give significant effect on the pore size distribution of the dried samples. As presented in Figure 6, runs with high temperature give higher pore sizes than runs with lower temperature. Increasing the air velocity from the chosen low to high value has almost negligible effect. Runs with low thickness give higher pore sizes than those with high thickness

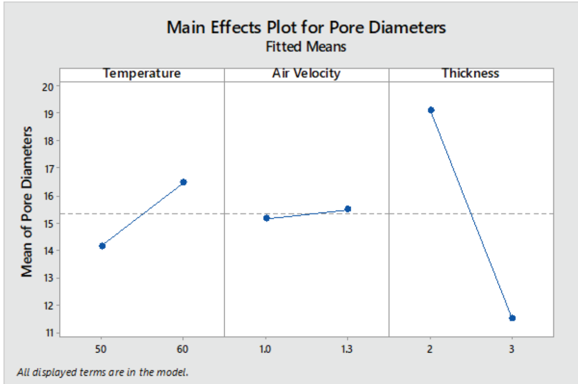

Fig. 6. Effect of Temperature, Air velocity and Thickness on Pore Diameters

As can be seen from Figure 7, thickness and the interaction of temperature and thickness are of equal magnitude therefore are of same effect. Both having the highest magnitude which and so both greatly affects the pore size distribution of the dried samples. The chart shows that thickness affects the effective moisture diffusion coefficient most as compared to temperature and air velocity as well as the combinations of the said factors. It also shows that air velocity has the least effect among the given factors. And so to have high diffusion coefficient, thickness is potentially the most important factor to consider while air velocity is the least one

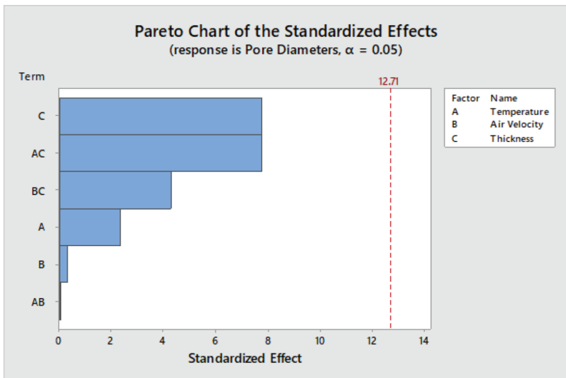

Fig. 7. Pareto Chart on Standardized Effects of Temperature, Air velocity and Thickness on Pore Size Distribution of Dried Samples

3.4 Drying curves

Figure 8 displays the change in the moisture content of the dried samples as the drying time progressed. It can be seen that each run decreased their moisture content during drying which corresponds to the decrease in weight of the samples. It can be observed that runs having higher drying temperature and air velocity have much lower drying time compared to runs of lower drying temperature and air velocity. Based on an analysis of factorial design using Minitab 17, the thickness of the sample has the highest effect on the drying time as compared to the other varying parameters. On the other hand, air velocity has the next major effect on drying time while the temperature has the least effect on the drying time.

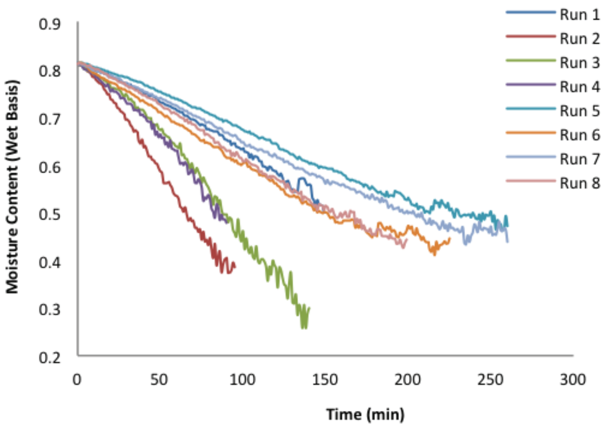

Fig. 8. Moisture Content of Samples in Wet Basis vs. Drying Time (min)

4 Conclusion

In this study, the drying characteristics of purple yam *(Dioscorea Alata L.)* were assessed by subjecting the purple yam samples into different drying conditions at which eight runs were generated using 2^3 factorial design. The three varying drying parameters considered were temperature,, air velocity and thickness. After drying, the tabulated values generated were treated to obtain the drying curves for each run. Based on the generated drying curves, it was determined that the drying rate decreases as the moisture content of the sample decreases. Considering the individual effects of each drying parameters on the drying process itself, it was found that the thickness of the samples directly affect the drying time. Thicker samples took much longer to achieve their corresponding equilibrium moisture content. The drying air temperature is responsible in determining the equilibrium moisture content that can be achieved on each sample regardless of the thickness. It was found that samples dried on higher temperature achieved much lower equilibrium moisture content as compared with the thinner samples. The last drying parameter, air velocity directly affects the drying time to achieve the equilibrium moisture. Samples dried at higher air velocity approached the equilibrium moisture content much faster than samples dried at lower air velocity. The three varying drying parameters also affected the shrinkage of the dried samples and the effective moisture diffusivity. It was found that the thicker samples have the highest shrinkage of around 21.69% as compared to the 14.42% shrinkage of thinner samples. It was also found that the effective moisture diffusion coefficient is higher at higher drying temperature. it was found that run 2, high temperature-low air velocity, yielded the most desirable quality of the dried samples. Samples from run 2 have large pore diameters but with minimal cell breakages, thus allowing optimal rehydration

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