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Preparation and Quality of Dried Yam Chip Snack Coated with Ascorbic Acid Cocrystallized Sucrose

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Abstract The specific objectives of this study were to dry yam chips using microwave vacuum drying, freeze drying and hot air drying, then to coat the dried yam chips with ascorbic acid cocrystallized sucrose, and finally to compare the quality of yam chip snack foods with respect to drying and coating characteristics. The microwave vacuum dried sample showed the highest drying rates and much less surface damage than the hot air dried one did. The shape and color of the microwave vacuum dried/coated sample were allocated between those of the freeze dried/coated sample and the hot air dried/coated sample. The freeze dried/coated sample scored excessively low in organoleptic hardness and chewiness to be suitable as a snack. The hot air dried/coated sample was too deep in color, wrinkled, excessively high in organoleptic hardness and chewiness, and excessively low in mouthfeeling. Therefore, the microwave vacuum dried/coated sample presented the best overall attributes as a snack, with respect to organoleptic characteristics, shape, color, and drying rates.

Keywords: yam, microwave vacuum dying, cocrystallized sucrose, organoleptic characteristics, freeze drying, hot air drying

Introduction

The world production of yam was estimated at 28.1 million tons, 96% of which came from West Africa (1). Yams are important staple foods in tropical countries and have also been used as health foods and herbal medicinal ingredients in Asian countries, including Korea, Chin, and Japan (2). Health benefits recently reported in the literature include antioxidant activities (2,3,4), lowering of serum lipid levels (4) and immunological activities (5) of yam. Although the demand for functional foods with health benefits has motivated the production of various yam products (6,7), there have been few attempts to develop a functional, high quality, dried yam chip snack.

As it is difficult to store fresh yam tubers due to their high moisture content, they have usually been peeled, sliced, blanched, dried, and then milled into flour (2, 8-11). Several research works have been focused on the various blanching and drying methods. Blanching techniques have included steam blanching (2, 8) and hot water blanching (9, 10), while drying techniques have included hot air drying (2, 8, 9, 11) and freeze drying (2, 9, 10). Freeze drying produces dried foods substantially unaffected with respect to the physical and chemical structures; however, it is a time-consuming, energy-intensive, and expensive process. Although hot air drying is much cheaper than freeze drying for dried foods, the product is generally considered poorer in quality than the freeze dried one. On the contrary, microwave vacuum drying is an attractive process with respect to both quality and cost. Especially, the estimated cost of the process is only one third to one quarter that of conventional freeze drying (12). Microwave vacuum drying has successfully been applied to orange juice (12), mushroom, asparagus, and medicine (13), yogurt (14), and germinated brown rice (15). However, there has been no report on the drying of yam by microwave vacuum drying.

In general, yam has a small amount of free sugars (2-3% for cultivated yams in Korea), and a relatively bitter taste due to its saponin and phenolic compounds (16,17). In addition, a barrier layer against contact with oxygen or air may be beneficial for preventing the browning of dried yam. Therefore, coating of the yam surface with sugar is desirable to improve the sensory acceptability and to decrease the browning of yam snack foods. Especially, ascorbic acid cocrystallized sucrose (18-20) is a more desirable coating material, since ascorbic acid in fresh yam tubers (13-25 mg/100 g) (21) may be destroyed during the processing of yam to yam chip snacks.

The specific objectives of this study were to dry yam chips using microwave vacuum drying, freeze drying and hot air drying, then to coat the dried yam chips with ascorbic acid cocrystallized sucrose, and finally to compare the quality of yam chip snack foods with respect to drying and coating characteristics.

Materials and Methods

Materials Yam tubers (*Dioscorea aimadoimo*) and sucrose were purchased at a local market in Seoul, Korea. Corn zein was obtained from Showa Sangyo Inc. (Tokyo, Japan). L-ascorbic acid and 95% ethanol were purchased from Sigma Chemicals.

Dehydration of yam using three methods Washed yams were manually peeled, sliced (5 mm thick), and cut into rectangular pieces (30 mm × 30 mm). The rectangular slices were then dried using microwave vacuum drying, hot air drying, and freeze drying. Microwave vacuum drying and hot air drying were done in the form of isothermal drying at a constant sample temperature, whereas in freeze drying the sample temperature was not kept constant. The drying experiments for triplicate

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samples were run at least three times. All the dried samples were sealed in foil-laminated pouches and kept at 4°C until used.

Microwave vacuum drying was carried out in the laboratory microwave vacuum drier (model MVD-1, 2,450 MHz and 800 W, The Catholic University of Korea, Korea) shown in Fig. 1. Samples were placed on a circular teflon dish (100 mm diameter and 5 mm depth) and dried at a pressure of 1 kPa (10 mmHg) and a sample temperature of 40°C for three hours. Pressure was monitored with a pressure transducer and the desired product temperature was monitored with a K-type thermocouple probe and maintained with an on-off controller. Samples were taken and weighed at 5 to 10 min intervals during drying.

For hot air drying, yam samples were dried for three to four hours in a forced-convection, hot air drier (Yamato Constant Temperature Oven, model DN-61, Japan). Sample temperature was monitored with a K-type thermocouple probe and maintained at 40°C with an on-off controller. Samples were taken and weighed at 5 to 10 min intervals during drying.

Before freeze drying, yam samples were frozen at -20°C for 24 hours. The frozen samples were then dried in a laboratory freeze drier (Labconco Freeze Drier 5, Labconco Corp., Kansas City, MO, USA) at ambient temperature with a condenser temperature of -50°C and a pressure of 100 μm Hg for 14 hours.

Determination of moisture content and drying characteristics Triplicate samples were dried at 105°C for 3 hours to determine the moisture content. Drying characteristics were analyzed with respect to time vs. moisture content and moisture content vs. drying rate.

Cocrystallization of sucrose with L-ascorbic acid The sucrose syrup, supersaturated to a concentration of 92% and a temperature of 120-125°C, was cocrystallized with L-ascorbic acid (0.9 mg per 1 g sucrose) according the procedure in Fig. 2. The agitation speed of the mixer (Kitchen Aid 5K-5SS, St. Joseph, Michigan, USA) was adjusted to level 6 at the initial stage showing supersaturated liquid state, to level 4 at the mid stage showing little fluidity, and to level 4 at the final stage showing wet crystals (19-20).

The cocrystallized samples were vacuum dried at 100 mmHg and 40°C for six hours, ground in a mortar, screened with a 30-mesh sieve, and sealed in foil-laminated pouches until used.

Coating of yam with ascorbic acid cocrystallized sucrose Four grams of corn zein was dissolved in 100 mL 95% ethanol by heating at 85°C for 20 min, and then the mixture was cooled to 40°C. The dried yam chip samples were dipped in the mixture for 5 seconds and then dried for 5 seconds at room temperature. Then the cocrystallized sucrose was adhered to the surface of each sample by manually mixing the sample and cocrystallized sucrose together in the glass bottle. The sugar-adhered samples were dried at room temperature for one hour, dipped in corn zein alcoholic solution for 3 seconds, and then dried again at room temperature for one hour. The samples coated with ascorbic acid cocrystallized sugar were sealed in foil-laminated pouches until used.

Determination of color and texture The Hunter L (lightness), a (+redness to -greenness), and b (+yellowness to -blueness) values were measured using a color difference meter (Tokyo Denshoku, Digital Color Meter TC-3600, Japan). The instrument was calibrated using the standard plate (L=90.4, a=0.8, and b=3.0).

The texture was measured with a texture analyzer (TA-XT2, Stable Micro Systems, London, England) with a 5

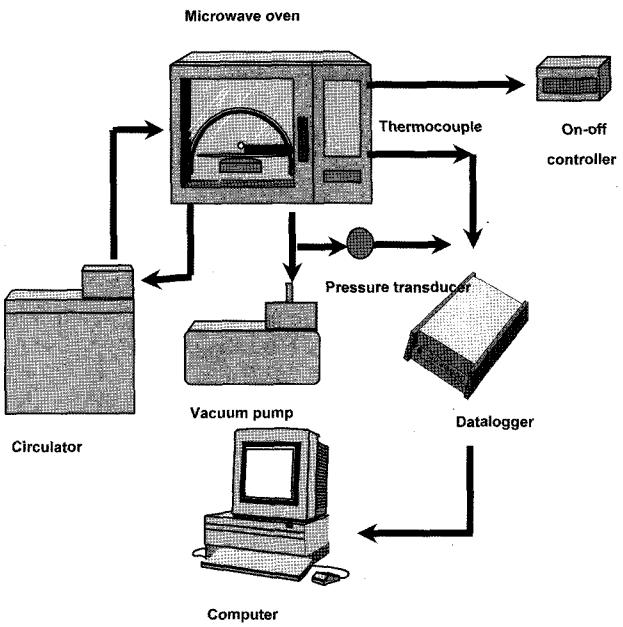


Fig. 1. Schematic presentation of a laboratory microwave vacuum drier.

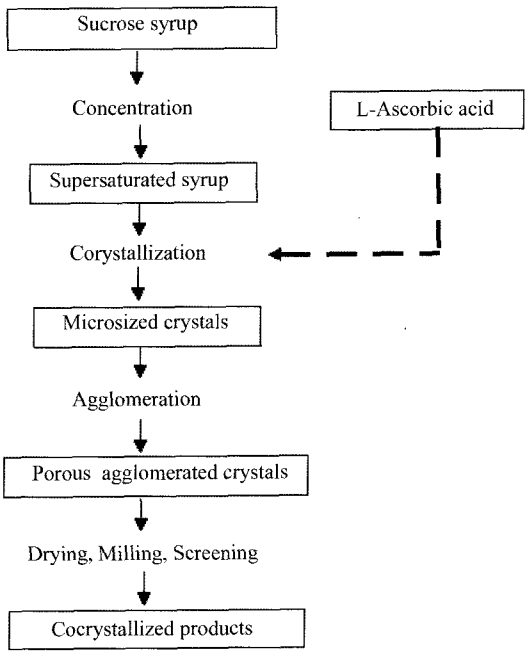


Fig. 2. Cocrystallization procedures.

kg load cell and cylindrical probe of 30 mm diameter. Initial grip separation was 50 mm, cross-head speed 500 mm/min, and deformation rate 50%.

Observation of surface structure The surface structure of the dried/coated yam chip snack was observed with scanning electron microscope (JEOL Scanning Microscope, model JSM-5410LV, JEOL USA Inc., Peabody, MA, USA) at a 1,500 magnification level.

Organoleptic evaluation and statistical analysis Twenty-five panels evaluated the organoleptic characteristics of yam snack samples based on the sheets in Table 1. The analysis of statistical differences ($p<0.05$) was performed using the Duncan's multi-range test of SAS (Statistical Analysis System).

Results and Discussion

Changes in moisture content and drying rate Fig. 3 shows the changes in sample moisture content during hot air drying and microwave vacuum drying at 40°C. The freeze drying results were omitted the changes were relatively slow compared to the former drying methods. The time for the yam sample to reach a moisture content of 0.02 kg water/kg solid was 90 min during microwave vacuum drying and 120 min during hot air drying. In the case of freeze drying, at least 14 hrs were required to reduce the moisture content to 0.02 kg water/kg solid.

Fig. 4 shows the changes in drying rates during hot air drying and microwave vacuum drying at 40°C. The drying rate began to fall at the start of drying for hot air drying and microwave vacuum drying due to the mucilage of yam that may hinder the moisture movement. The drying rate of microwave vacuum drying was higher than that of hot air drying down to a moisture content of 0.3 kg water/kg solid. The initial drying rate (0.031 kg water/kg solid/min) of microwave vacuum drying was 1.7 times higher than that (0.018 kg water/kg solid/min) of hot air drying, possibly because the moisture is driven out through the mucilage from the inside due to the high vapor pressure caused by the internal heat generation of the microwaves to the outside with vacuum pressure. In short, the yam samples were dried much faster by microwave vacuum drying than by hot air drying. This result is in agreement with previous reports in the literature (15, 21, 22).

Table 1. Sheet for organoleptic evaluation

white	Color	brown
rough	Surface smoothness	smooth
low	Sweetness	high
low	Astringency	high
low	Hardness	high
low	Chewiness	high
coarse	Mouthfeeling	soft
bad	Overall evaluation as a snack	good

Surface structure of dried yam samples and cocrystallized sucrose Fig. 5 shows the surface structure of three yam samples dried by hot air drying, freeze drying, and microwave vacuum drying (Figs. 5-1, 5-2 and 5-3). The globules on the surface seem to be starch granules. The hot air dried sample shows severer damages on the surface than the microwave vacuum dried sample does, while the

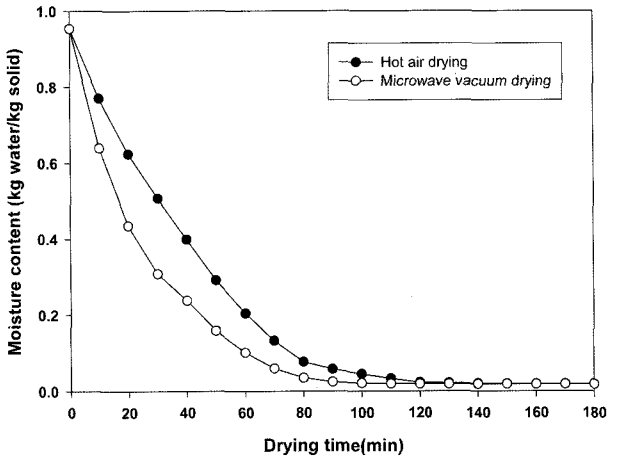


Fig. 3. Changes in moisture content of yam during hot air drying and microwave vacuum drying at 40°C.

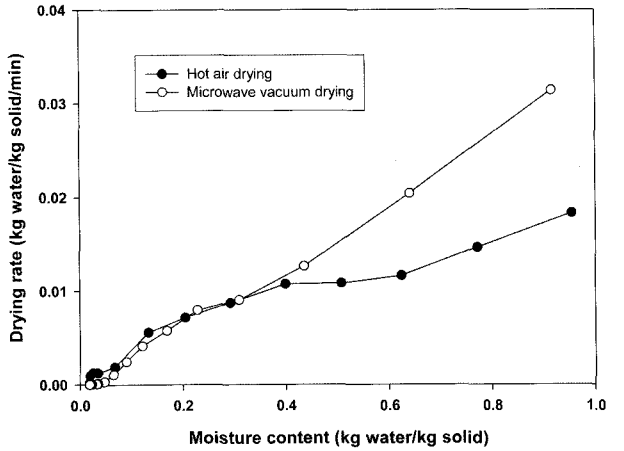
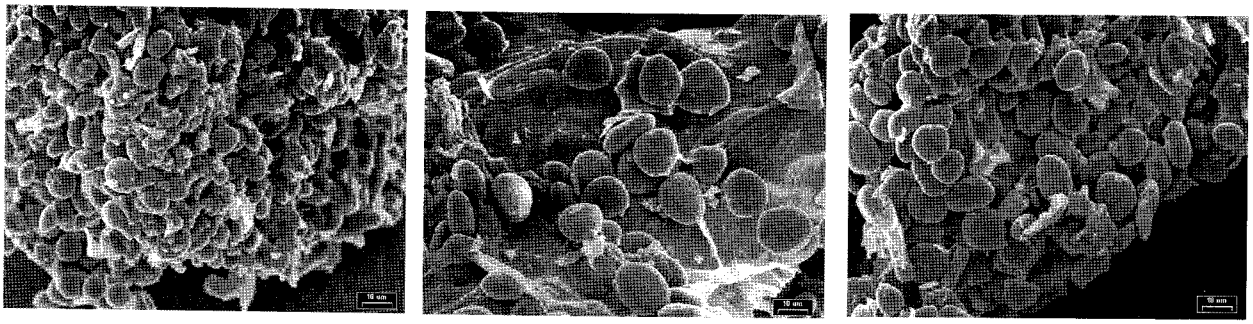


Fig. 4. Changes in drying rate of yam with respect to moisture content during hot air drying and microwave vacuum drying at 40°C.



(1) (2) (3)

Fig. 5. Scanning electron micrographs (1,500X) of surface structure of yam samples by hot air drying (1), freeze drying (2), and microwave vacuum drying (3).

latter shows similar surface features to the freeze dried one. Kim (22) also reported similar results for the case of yeast cells.

Fig. 6 shows the surface structure of the cocrystallized sucrose sample. The sample has many, small, round or rectangular crystals adhering to the surface. The surface structure was similar to the cocrystallized sucrose of Kim et al (19-20) who reported that 98% of ascorbic acid was retained inside the sugar matrix.

Shape and color of dried/coated yam samples Fig. 7 presents pictures of a fresh yam sample, hot air dried sample and its coated sample, freeze dried sample and its coated sample, and microwave vacuum dried sample and its coated sample. The hot air dried/coated sample shrank, wrinkled and showed a yellow-brownish color. In contrast, the freeze dried/coated sample showed few changes in shape and color. The microwave vacuum dried/coated sample showed slight shrinkage and wrinkles and a slight brown tint, but these changes were much less than those of the hot air dried/coated sample. The shape and color of the microwave vacuum dried/coated sample were between those of the other two samples but much closer to those of the freeze dried/coated sample.

Hunter color values of dried/coated yam samples Table 2 lists the Hunter color values of fresh yam, dried yam, and dried/coated yam samples. All the samples showed Hunter L values (lightness) of 77~87, indicating that the sample colors were basically light (white), possibly because the yam mucilage is white and the mucilage is concentrated during drying. The freeze dried sample showed the highest Hunter L-values, followed by the microwave vacuum dried one and the hot air dried one. Each sucrose coated sample showed higher L values than the corresponding dried sample due to the adherence of sucrose crystals on the surface.

All the samples had Hunter a values (redness) of -12~-28, and Hunter b values (yellowness) of 9~14, indicating

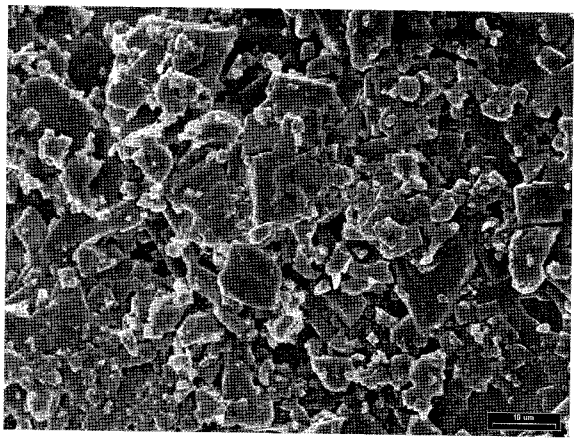


Fig. 6. Scanning electron micrographs (1,500X) of surface structure of cocrystallized sucrose.

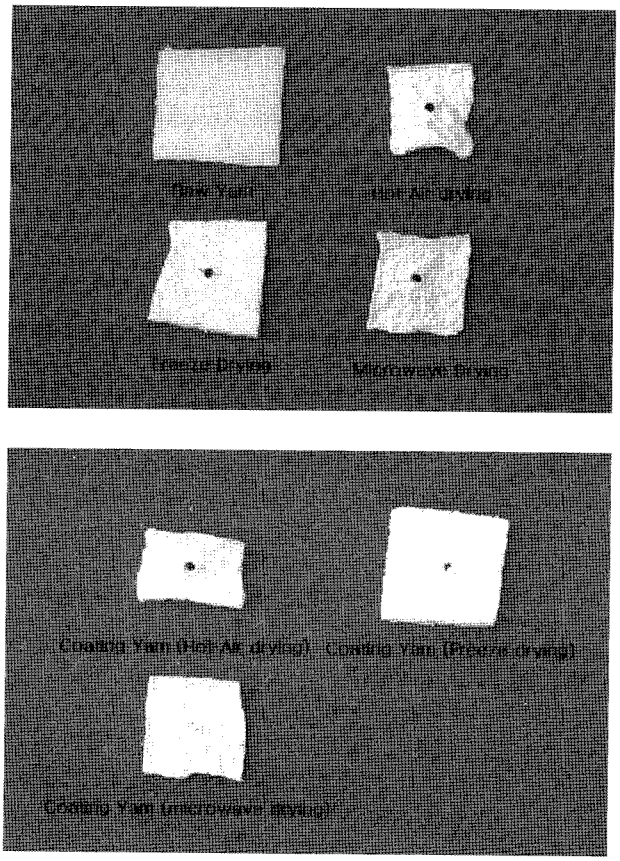


Fig. 7. Pictures of fresh yam sample, hot air dried sample and its coated sample, freeze dried sample and its coated sample, and microwave vacuum dried sample and its coated sample.

Table 2. Hunter color values of fresh yam, dried yam, and dried/coated yam samples

Yam samples	Hunter color values			
	L	a	b	ΔE
Fresh yam	76.76±0.25 e	-18.02±0.58 c	10.90±0.39 c	79.60±0.38 e
Hot air dried yam	77.28±1.28 de	-27.54±1.03 e	14.20±0.83 a	83.27±0.97 d
Hot air dried and coated yam	78.58±0.18 d	-27.12±0.47 e	13.76±1.27 a	84.27±0.34 cd
Freeze dried yam	87.20±0.89 a	-11.60±1.11 a	9.02±0.61 d	88.44±0.87 a
Freeze dried and coated yam	86.92±0.70 a	-13.64±1.44 b	11.00±0.60 c	88.68±0.70 a
Microwave vacuum dried yam	81.58±2.13 c	-21.30±1.45 d	12.28±0.91 b	85.23±1.71 bc
Microwave vacuum dried and coated yam	83.44±1.98 b	-16.94±3.05 c	10.48±0.67 c	85.85±1.35 b

*Common superscript letters before the number in a column indicate no differences at α=0.05

that the sample colors were basically not red but yellow due to browning. The freeze dried sample showed the highest Hunter a values, followed by the microwave vacuum dried one and the hot air dried one. Each coated sample showed higher a values than the corresponding dried sample except the freeze dried/coated sample. In case of Hunter b values, however, the hot air dried sample was the highest, followed by the microwave vacuum dried one and the freeze dried one. In other words, the hot air dried sample showed the highest degree of browning, followed by the microwave vacuum dried one and the freeze dried one.

All the samples showed Hunter ΔE values (color difference) of 80~89, indicating that the sample colors were basically different. The freeze dried sample showed the highest Hunter ΔE values, followed by the microwave vacuum dried one and the hot air dried one. Each coated sample showed higher ΔE values than the corresponding dried sample due to the adherence of sucrose crystals n the surface. The tendency of color difference was similar to that of lightness.

Texture of dried/coated yam samples Table 3 lists the springiness, cohesiveness, chewiness, and hardness of fresh yam, dried yam, and dried/coated yam samples. For springiness, the microwave vacuum dried/coated sample was the highest, followed by the hot air dried/coated, microwave vacuum dried, freeze dried, freeze dried/coated, and hot air dried samples. However, there were no significant differences in springiness among the samples. For cohesiveness, the hot air dried sample showed the highest value, followed by the hot air dried/coated, microwave vacuum dried/coated, microwave vacuum dried, freeze dried, and freeze dried/coated samples. For chewiness, the hot air dried sample was the highest, followed by the microwave vacuum dried and freeze dried samples. Each sucrose coated sample showed higher chewiness than the corresponding dried sample due to the adherence of sucrose crystals on the surface. For hardness, the data for the hot air dried sample and its coated sample were not available, since the sample surface was too rugged and wrinkled to measure. The freeze dried/coated sample was the highest, followed by the microwave vacuum dried/coated, microwave vacuum dried, and freeze dried samples. Especially, the highest hardness of the freeze dried/coated sample may be due to the high amount of corn zein penetrated through the porous structure during the coating process.

Organoleptic characteristics of dried/coated yam samples Table 4 lists the organoleptic characteristics of the hot air dried/coated, freeze dried/coated, and microwave vacuum dried/coated samples. The organoleptic characteristics of the dried samples were omitted due to their relatively poor acceptability values as compared to those of the dried/coated samples. For color, the hot air dried/coated sample was the highest, followed by the microwave vacuum dried/coated and freeze dried/coated samples. However, there were no significant differences between the microwave vacuum dried/coated and freeze dried/coated samples. This coincided with the Hunter b-value results previously mentioned. Surface smoothness was the highest in the microwave vacuum dried/coated sample, followed by the freeze dried/coated and hot air dried/coated samples, but the differences were not significant. Sweetness was the highest in the freeze dried/coated sample, followed by the microwave vacuum dried/coated and hot air dried/coated samples, but the

Table 3. Textural parameters of fresh yam, dried yam, and dried/coated yam samples

Yam samples	Textural parameters			
	Springiness	Cohesiveness	Chewiness	Hardness
Fresh yam	0.55±0.19 a	0.31±0.09 c	1865.80±519.89 d	8800.34±2670.35 c
Hot air dried yam	0.46±0.11 a	2.60±1.94 a	4098.08±874.19 b	-
Hot air dried and coated yam	0.57±0.14 a	1.54±0.89 b	5382.86±205.33 a	-
Freeze dried yam	0.51±0.11 a	0.51±0.06 c	2392.25±947.46 cd	10415.12±2956.18 bc
Freeze dried and coated yam	0.48±0.06 a	0.40±0.06 c	3034.90±780.76 bc	15772.46±1308.69 a
Microwave vacuum dried yam	0.55±0.10 a	0.59±0.07 c	3832.61±1065.19 b	12835.13±3323.47 ab
Microwave vacuum dried and coated yam	0.58±0.08 a	0.65±0.04 c	3921.41±483.94 b	14966.10±4596.38 a

*Common superscript letters before the number in a column indicate no differences at α=0.05

Table 4. Organoleptic evaluation of dried/coated yam samples which had been hot air dried, freeze dried, and microwave vacuum dried

Organoleptic attributes	Yam samples		
	Hot air dried	Freeze dried	Microwave vacuum dried
Color	9.00±2.44 a	4.48±3.03 b	5.34±2.08 b
Surface smoothness	4.77±2.47 d	6.30±2.37 a	6.58±3.09 a
Sweetness	6.46±2.67 a	7.98±3.25 a	6.54±2.51 a
Astringency	8.18±2.31 a	7.25±1.65 a	8.80±1.77 a
Hardness	11.27±0.85 a	3.78±1.99 c	8.03±2.24 b
Chewiness	10.16±1.56 a	4.34±2.06 b	9.69±1.77 a
Mouthfeeling	4.94±2.15 b	9.55±1.74 a	6.49±2.40 b
Overall evaluation as a snack	5.70±3.32 a	5.85±2.33 a	6.25±3.00 a

*Common superscript letters before the number in a row indicate no differences at α=0.05

differences were not significant. Astringency was the highest in the microwave vacuum dried/coated sample, followed by the hot air dried/coated and freeze dried/coated samples, but the differences were not significant. Hardness was the highest in the hot air dried/coated sample, followed by the microwave vacuum dried/coated and freeze dried/coated samples, and these differences were significant. Chewiness was the highest in the hot air dried/coated sample, followed by the microwave vacuum dried/coated and freeze dried/coated samples, but the differences were not significant. Mouthfeeling was the highest in the freeze dried/coated sample, followed by the microwave vacuum dried/coated and hot air dried/coated samples, but the difference between the latter two was not significant. Finally, overall evaluation as a snack was the highest for the microwave vacuum dried/coated sample, followed by the freeze dried/coated and hot air dried/coated samples. The poor evaluation of the freeze dried/coated sample as a snack may have been due to its excessively low hardness and chewiness, and that of the hot air dried/coated sample to its deep color, wrinkled surface, excessively high hardness and chewiness, and excessively low mouthfeeling.

Conclusion

The microwave vacuum dried sample showed the highest drying rates and much less surface damage than the hot air dried sample did. The shape and color of the microwave vacuum dried/coated sample were between those of the freeze dried/coated and hot air dried/coated samples, but much closer to those of the former. The freeze dried/coated sample was excessively low in organoleptic hardness and chewiness to be suitable as a snack. The hot air dried/coated sample was too deep in color, wrinkled, excessively high in organoleptic hardness and chewiness, and excessively low in mouthfeeling. Therefore, it can be concluded that the microwave vacuum dried/coated sample presented the best overall attributes as a snack, with respect to organoleptic characteristics, shape, color, and drying rates.

Acknowledgments

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