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Freeze drying of carrots (Daucus carota) and potatoes (Solanum tuberosum) using a locally developed freeze-dryer

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Abstract — An experimental analysis of the freeze-drying of carrot and potato using a locally developed freeze-dryer is presented. The developed freeze-dryer consists of a compressor rated 100W, evaporator pipe length of 14.77m, condenser pipe length of 7.82m and evaporator chamber volume of 0.24m3. The freeze-dryer dried pretreated fresh potatoes and carrot from an initial moisture content of 79.2% and 87% to a final moisture content of 17.8% and 12.3 respectively. The percentage ash content of potatoes was 0.196% and 0.375% for carrots. The drying rate for both produce is approximately 2 degrees Celsius per hour. These values fall within the range of values for dried potatoes and carrot as contained in literature, hence signifying that the nutritional values of the dried vegetables were retained even after freeze drying. Physical examination of the freeze-dried vegetables indicated both aesthetic appeal and minimal loss of shape. This study presents an innovative solution that can be used for extended storage shelf life of vegetables.

Index Terms— Ash content, carrot, freeze-drying, potato, pretreatment, moisture content, vegetables

1 Introduction

FREEZE DRYING, also known as lyophilization, is the process whereby water is removed from a product by freezing and then subliming the ice into vapour [1],[2]. Removing water from food items by the process of freeze drying protects the material against loss of its nutritional value better than conventional drying methods and is a form of preservation to increase the shelf life of a product [3]. The process preserves the actual colour and shape of the original raw material. It also preserves the quality of dried products, while extending the shelf-life ([4],[5],[6],[7]). Successful freeze drying is carried out in three stages namely the freezing stage, primary drying stage, and the secondary drying stage. Freezing is a phase transition of a fluid from liquid state to solid state when the temperature is lowered below its melting point by cooling. The primary stage is whereby the product is dried using vacuum at low temperatures, while the secondary stage is where desorption takes place [4].

Several authors have undertaken freeze drying of different vegetables. Tar et al. [8] designed and constructed a freeze dryer for the preservation of tomatoes, pepper, and okra. The design consisted of two compressors, two condensers and a vacuum pump. The work concluded that tomatoes can be freeze dried at a temperature of -2 degrees Celsius with a vacuum of -30 inHg, pepper at -1.5 degrees Celsius with a vacuum of -24 inHg while okra at -1.4 degrees Celsius with a vacuum of -22 inHg [8]. Caliskan et al. [9] investigated the drying and rehydration kinetics of convective and freeze-dried pumpkin slices (0.5 × 3.5 × 0.5 cm) in a sample. A pilot scale tray drier and freeze drier were used for the drying experiments. Six well-known thin layer drying models were equipped with drying curves. Using the statistical application SPSS 16.0, nonlinear regression analysis was used to test the parameters of the selected models. The effective moisture diffusivity of the convective and freeze-dried pumpkin slices was obtained from the Fick's diffusion model, and they were found to be 2.233 × 10-7 and 3.040 × 10-9 m² s-1, respectively. Specific moisture extraction rate, moisture extraction rate, and specific energy consumption values were almost twice in freeze drying process. The moisture content and water activity values of pumpkin slices were found to be within reasonable limits for secure product storage. The rehydration behaviour of dried pumpkin slices was determined by Peleg's model with the highest R2. The rehydration experiment with a solid: liquid (w:w) ratio of 1:25 resulted in the highest total soluble solid loss of pumpkin slices. Freeze dried slices had a rehydration ratio that was 2–3 times higher than convective dried slices.

Some of the methods of drying food items that are used in households change the structure, constitution, colour and nutritional contents of foods. A portion of commonly used drying methods in households such as sun drying do not provide even drying of vegetables, which motivates the development of molds which spoil the foods [10]. Some Drying methods such as solar drying, air drying and sun drying expose the products to contamination sources such as insects, birds, rodents, and other animals when drying. Therefore, sanitary quality of the final products may be compromised which may cause health complication like food poisoning [11]. These contaminants could spoil food during the process of drying as well.

The present work studied freeze drying of potatoes and carrots which are common seasonal vegetables consumed in Botswana. Given their seasonal nature, there is always scarcity during certain seasons as produced vegetables have very short shelf life. Potatoes grow in cold seasons; hence they need to be planted before average temperatures surpass 27°C. Introduction of freeze drying will help these vegetables be available all year round and reduce wastages due to spoilage. It will also encourage farmers to cultivate larger hectares for these vegetables as they will be assured of preservation. When vegetables are in season, they become available in abundance hence some are left over at the end of the season without being consumed and are usually wasted due to preservation challenges. Therefore, this usually results to resorting to importation and this means money is being spent to reach vegetable sufficiency only for the excess vegetables to get wasted.

2 Materials and Methods

2.1 Development of freeze dryer

An existing casing of a bar refrigerator was utilized for the construction of the freeze dryer. The sized compressor was installed on the refrigerator and the sized evaporator was coiled using a pipe bender and aligned carefully in the inside wall of the casing. One end of the evaporator pipe was connected to the compressor suction port at the backside of the refrigerator. The other end was connected to the capillary tube at the back of the refrigerator as well. All points that were drilled to allow passage of the evaporator pipe to the back of the refrigerator were sealed to create an airtight evaporation chamber. The capillary tube was connected to one end of the condenser pipes while the other end of the condenser was connected to the compressor. The power cables from the thermostat in the evaporator chamber were connected to the compressor. A power cable was linked to the compressor that is used to switch on the refrigerator by connecting to a socket. The top surface of the refrigerator was drilled and a charge line for a vacuum pump was put in place and its edges sealed. A vacuum pump was connected to the charge line of the compressor to clear air in the refrigeration system that filled during the construction and assembly processes. This was done at a pressure of -22inHg (0.0002953inHg = 1Pa) Using the same charge line, refrigerant R134a (1,1,1,2-Tetrafluoroethane) was filled into the system at a gauge setting of 22psi (1psi =6895 N/m^2).

The components of the freeze dryer were sized using relevant relationships ([12],[13]). The components include the compressor, the evaporator, and the condenser. The total heat removed from products by the freeze dryer (Q) was determined to be approximately 13.4 W, and the total cooling load required for the system was calculated to be 92.9 W, hence a compressor rated 100 W was selected for experimentation. The thermal properties of carrot include a freezing point of -1.4 degree Celsius; while that of potatoes is -0.5 degree Celsius [14].

A description of the various components as designed are presented in Table 1, including the thermal properties of carrot and potato.

TABLE 1
Designed Components of the Freeze dryer

Parameters	Size/Material
Evaporator	
Tube material	Copper
Inner diameter	0.0063m
Outer diameter	0.0080m
Length of tube	14.77
Length of evaporator box	0.485m
Height of evaporator box	0.960m
Depth of evaporator box	0.505m
Insulation material	Polystyrene foam
Evaporator inner wall material	ABS plastic
Evaporator outer wall material	Galvanized steel sheet
Condenser	
Tube material	Copper
Inner diameter of tube	0.0028m
Outer diameter of tube	0.0045m
Length of superheat and condensation regions	7.82m
Length of subcooling regions	0.88m

2.2 Experimentation Procedure

Fresh samples of carrot and potatoes were collected from nearby farms, washed and surface-dried with hand towels. Samples were prepared by cutting both the carrot and potatoes into 5 mm slices and pretreated using vinegar. To freeze dry the samples, the refrigerator was switched-on to reach cool temperatures before placing the samples in it. The carrots and potatoes were pretreated by soaking in 6 % acetic acid white vinegar, with pH of 2.2 measured with a strip, for one minute to fight oxidation and hence prevent discoloration. Masses of each of the samples were recorded for further calculations on performance analysis. The samples were placed in the refrigerator and allowed time to freeze. Once the freezing process was complete, the vacuum pump was connected to the refrigerator through the charge line and AC/manifold gauge. Vacuuming was done at a pressure of -22inHg (0.0002953inHg = 1Pa). Figure 1 shows the experimental set up schematics while Figure 2 is a picture of the dryer in operation. Upon complete drying of samples, moisture content and ash content analysis were carried out on the samples to determine the physio-chemical properties.

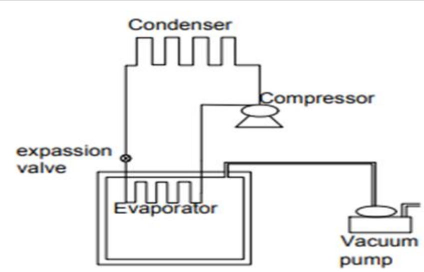

Fig. 1. Experiment set up schematic

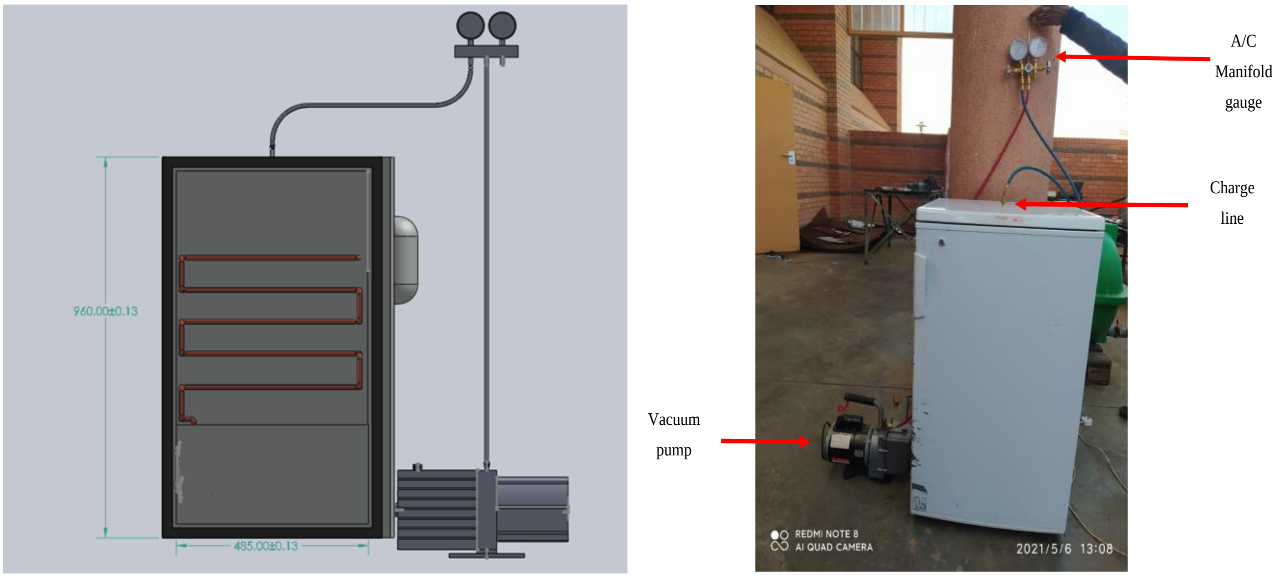

Fig. 2. Back view of experimental setup and a picture of the dryer in operation

2.3 Moisture content analysis procedure

Moisture content analysis, defined as the percentage ratio of the mass of water in a sample to the mass of solids in the sample [15], involves determining the moisture content of a given sample. In the experimentation, the process of determining moisture content of potatoes and carrots sample began with switching on the refrigerator part of the freeze dryer. The samples were cut into thin slices of 5mm. One batch of the potatoes were pretreated with white vinegar, while the carrots were left untreated. The mass of each of the samples (both carrots and potatoes) were measured using a precision balance, then the samples were inserted into the freeze dryer to commence the freezing stage. All samples were frozen to temperatures of -6 degrees Celsius. At this point, the vacuum pump was connected to the system and switched on for a week. During the vacuuming process, it was ensured the system was always airtight. This initiated the drying process. Once the process was complete, the mass of dry specimen was measured and the %moisture content of samples was determined using the following equations [16]:

Wet basis percentage moisture content of initial sample (M)

$$\text{Percentage moisture content} = \frac{\text{mass of water}}{\text{mass of moist sample}} \times 100 \quad (1)$$

$$\text{Percentage moisture content} = \frac{m_w - m_d}{m_w} \times 100 \quad (2)$$

Where:
m_w = mass of moist sample; m_d = mass of dry sample.

Wet basis percentage moisture content of dry sample (M)

$$\text{Percentage moisture content} = \frac{100W_2 + W_1M_1}{W_1 + W_2} \quad (3)$$

Where:
M_1= initial %moisture content; W_1 = mass of initial sample; W_2 = mass of dry sample

Dry basis moisture content (M)

$$\text{Moisture content} = \frac{\text{mass of water}}{\text{mass of dry sample}} \quad (4)$$

$$\text{Moisture content} = \frac{m_w - m_d}{m_d} \times 100 \quad (5)$$

2.4 Ash content analysis procedure

The total amount of minerals contained in a food is measured by its ash [17]. A crucible used in the testing experiment was preconditioned in a muffle furnace to remove pollutants. As a precaution, the crucible was removed from the muffle furnace with tongs and put in a desiccator to cool. A mass balance scale was used to determine the crucible's mass. Then 5 g of freeze-dried potato slices was measured and placed inside the crucible. To ash the samples, the potatoes slices were put inside a muffle furnace preheated to 550ºC for 2 hours [18]. After ashing was complete, the crucible was removed from the furnace and placed in a desiccator to facilitate cooling. Then the mass of the crucible and ashed products was measured on a balance scale. The same process was repeated for the dry samples of carrots. The mass of the ashed products was determined from equation (6):

Mass of ashed proucts = (Mass of crucible and ashed products) – (Mass of crucible) (6)

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The following equation was used to determine the ash content for both wet and dry basis [17].

$$\text{Percentage ash (Dry)} = \frac{m_{ash}}{m_{dry}} \times 100 \qquad (7)$$

Where mash is mass of ashed products and mdry is mass of freeze-dried potatoes.

3 Results And Discussion

3.1 Moisture Content Analysis

The percentage moisture contents of both the potato and carrot samples were determined applying equations 1 – 5 (Table 2).

TABLE 2
MOISTURE CONTENT OF DRIED SAMPLES

Samples	Initial Moisture Content (w.b)	Final Moisture Content (w.b)
Carrot	87.0%	12.3%
Potato	79.2%	17.8%

Using the masses measured of the fresh potatoes and that of the freeze-dried potatoes, the wet basis initial moisture content of the initial potato samples was determined to be 79.2%. This falls within the range of the normal moisture of potatoes which was found to be 79.11 - 83.95 [17]. The moisture content of the dried potato samples was found to be 17.8%.

The wet basis initial moisture content of carrot samples was found to be 87%. This is very close to available literature data of 87.61% - 94.38% moisture content [17]. The percentage moisture content of dried carrots was also found to be 12.3%.

These results established the working efficiency of the developed freeze-dryer as moisture removal rate was at 86% for carrot samples and 78% for potato samples. Drying of vegetables, by way of moisture removal, is a preservation method for prolonging the shelf-life of vegetables for future use [19].

Drying rate of the dried carrot and potatoes is presented in Figure 3. Carrot dried at 2.06 ºC/day while carrot dried at 2.49 ºC/day.

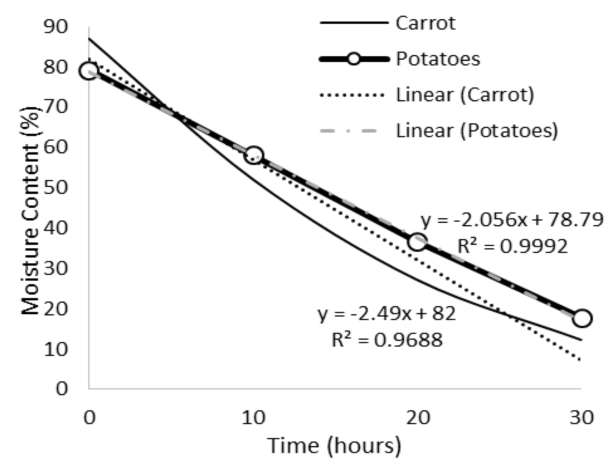

Fig. 3. Drying rate of Carrot and Potatoes

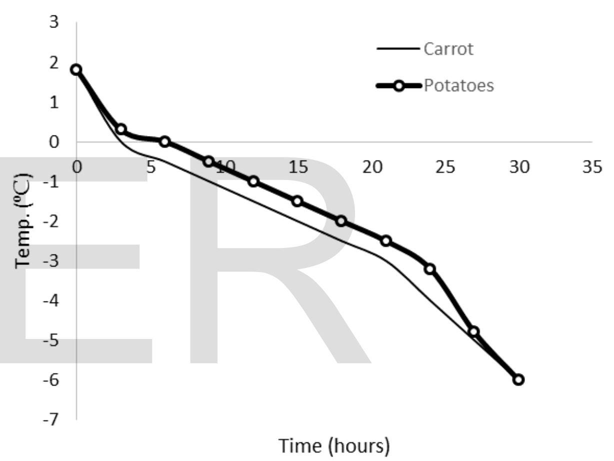

Fig. 4. Freeze-drying temperature achieved by the drier

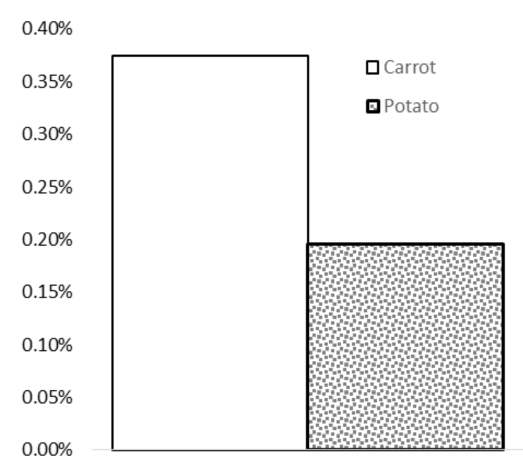

Fig. 5. Ash content of dried sample

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The obtained ash content for potato and carrot samples is 0.196% and 0.375% respectively (Fig. 2). These values are within ranges provided in literature as the average range of percentage ash content for fresh potatoes (0.20% - 0.47%) and the average range of percentage ash content for carrots (0.25% - 0.76%) [3]. The amount of total minerals available in any organic matter that can be used as a fuel is represented by percentage ash content or total ash [18]. Hence the obtained ash content percentages for the samples represents the percentage minerals available in the vegetables and these values fall within ranges available in literature. The result justifies the argument that the freeze-drying method of preservation protects the nutritional value of produce. The samples dried in the freeze-dryer had minerals that fall with the range of those of fresh vegetable produce.

3.2 Visual Comparison of Samples and Effect of Pretreatment

A visual inspection of samples before and after freeze drying and the effect of pretreating the sample using vinegar before freeze drying were undertaken. Pretreated samples of freeze-dried potatoes retained their original colour as shown in Figure 3 (a and b). Similarly, the freeze-dried samples retained their original shapes as there was a very negligible change in shape.

For freeze-dried carrot, Fig 3c shows the original sample before drying. Fig. 3d shows untreated samples after drying while Fig 3e shows pretreated samples after freeze-drying. Pretreated samples retained their original colour very significantly and maintained their original shape with very negligible changes. For the untreated samples, there were significant changes in the colour of carrots with slight changes in their shape.

Fig 6. (a) Samples of potato (b) dried samples of potato (c) original samples of carrot (d) dried samples of untreated carrot (e) dried samples of pretreated carrot

7.2 Acknowledgments

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4 Conclusion

A developed unit freeze dryer with height, length, and width of 0.96m, 0.485m and 0.505m respectively was used for freeze-drying experiments using samples of potato and carrot. The dried potatoes samples were found to have a final moisture content of 17.8% from an initial moisture content of 79.2% and ash content of 0.196%. The dry carrots were found to have a final moisture content of 12.3% from an initial moisture content of 87% and ash content of 0.375%. The freeze-dryer was effective in the drying of the selected vegetables as there was a very significant reduction in moisture content for both samples. The values of the percentage ash content in the dried samples proved that indeed the freeze-dried samples retained their nutritional values after the drying process.

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Conflict of Interest Statement

Authors have no conflict of interest, ethically, financially, or otherwise.

References

[1] Nowak, D. and Jakubczyk, E., 2020. The freeze-drying of foods - the characteristic of the process course and the effect of its parameters on the physical properties of food materials. Foods, 9, 1488.

[2] Liu, Y.Z.; Zhao, Y.F.; & Feng, X., 2008. Exergy analysis for a freeze-drying process. Appl. Therm. Eng., 28, 675–690.

[3] Mellor, J. D. & Bell, G. A., 1993. Freeze drying: the basic process. In: Macrae, R, Robinson, R K and Sadler, M J (eds.). Encyclopaedia of Food Science, Food Technology and Nutrition. 1993; 3:2035-2039.

[4] Bhatta, S., Janezic, T. S. & Ratti, C., 2020. Freeze-drying of plant-based foods. Foods, 9, 87.

[5] Ratti, C., 2001. Hot air and freeze-drying of high-value foods: A review. J. Food Eng., 49, 311–319.

[6] Oyinloye, T. M. & Yoon, W. B., 2020. Effect of freeze-drying on quality and grinding process of food produce: a review. Processes, 8, 354.

[7] Duan, X., Yang, X., Ren, G., Pang, Y., Liu, L. & Liu, Y., 2016. Technical aspects in freeze-drying of foods. Drying Technology, 34:11, 1271-1285.

[8] Tar, S. S., Daniel, M. T. & Theresa, U. N., 2019. Design, Construction and testing of a freeze dryer for vegetables. International Journal of Engineering Science Invention, vol. 8, issue 8, pp. 1-5.

[9] Caliskan, G. & Dirim, S. N., 2017. Drying characteristics of pumpkin (Cucurbita moschata) slices in convective and freeze dryer. Springer, p. 2129–2141.

[10] Lstiburek, J., Yost, N. & Brennan, T., 2002. Mold: Causes, Health Effects and clean up, Somerville: Building Science press.

[11] Bhagat, S., Inchulkar, S. R. & Anant, J. K., 2018. A review article on food poisoning. World Journal of Pharmaceutical and Life Sciences, iv (9), pp. 94-99.

[12] Willhite, G. P., 1967. Over-all Heat Transfer Coefficients in Steam and Hot Water Injection Wells. Journal of Petroleum Technology, 19, 607-615.

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[13] Onyeocha, E. I., Nwaigwe, K. N., Ogueke, N. V. & Anyanwu, E. E., 2020. Design and construction of an integrated tetrafluoroethane (R134a) refrugerator-waste heat recovery dryer for fabric drying in tropical regions. Heliyon, 6, e04838.

[14] American Society of heating, Refrigeration and Air conditioning Engineers, 2006. 2006 ASHRAE Handbook: Refrigeration. 6th ed. United states: ASHRAE (american society of heating, refrigerating and air-conditioning engineers) .

[15] Derome, D., Teasdale-St-Hilaire, A. & Fazio, P., 2001. Methods for the assessment of moisture content of envelope assemblies. Conference proceedings of ASHRAE, Florida.

[16] Park, Y. W., 2008. Moisture and water activity. In: Handbook of processed meats and poultry analysis. L. Nollet and F. Toldra, Eds., CRC press. Boca Raton, FL. pp. 37-67.

[17] Afify, A. S., Abdalla, A. A., Elsayed, A., Gamuhay, B., Abu-Khadra, A. S., Hassan, M., Ataalla, M. & Mohamed, A., 2017. Survey on the Moisture and Ash Contents in Agricultural Commodities in Al-Rass Governorate, Saudi Arabia in 2017. Assiut J. Agric. Sci, 6(48), pp. 55-62.

[18] Keshun, L., 2019. Effects of sample size, dry ashing temperature and duration on determination of ash content in algae and other biomass. Algal Research, Issue 40.

[19] Guiné, R. P., 2018. The Drying of Foods and Its Effect on the Physical-Chemical, Sensorial and Nutritional Properties. International Journal of Food Engineering, 4(2), pp. 93-100.

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