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Research Article
Effects of Natural and Artificial Drying Methods on the Nutritional Value and Functional Properties of Vegetables Grown in Sudan

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Abstract

Background and Objective: The processing technique of drying or dehydration is probably the oldest method practiced by human kind for food preservation. The removal of water from food during this process has been found to prevent microbial growth and enzymatic and nonenzymatic reactions and therefore, the dried food materials can be easily stored under normal ambient temperature. The purpose of this research was to study the effects of natural and artificial drying methods on the nutritional value and functional properties of some locally grown vegetables in Sudan, namely, potatoes (*Solanum tuberosum*), tomatoes (*Lycopersicon esculentum*) and carrots (*Daucus carota*). **Materials and Methods:** The previously mentioned fresh vegetables were divided into two different groups. The first group of fresh vegetable samples was dried under natural convection air flow at room temperature (33-35°C) for three days, while the second group was put in a cabinet dryer for six hours at 75°C. Then, the vegetable samples before and after drying were investigated for their chemical composition and physico-chemical characteristics. **Results:** The natural drying method used in this study was found to decrease the moisture contents in fresh potatoes, tomatoes and carrots from 79.87, 94.17 and 88.27 to 7.12, 5.45 and 4.62%, respectively. Meanwhile, the artificial drying method decreased their moisture contents to 6.23, 5.04 and 3.43%, respectively. In general, the concentrations of dry matter and protein in vegetable raw materials that were dried with the artificial method were found to be higher than those of the same vegetables that were dried naturally at room temperature. In contrast, the naturally dried vegetables recorded higher percentages of reducing sugars in potatoes (0.32%), tomatoes (20.80%) and carrots (5.78%) on a wet basis. On the other hand, the vegetable samples that were dried by the cabinet dryer were found to have better functional properties in comparison with the naturally dried samples. All of the artificially dried vegetable samples were found to have higher bulk density (0.909, 0.619 and 0.781 g mL^{-1}) and water solubility (11.097, 13.484 and 19.071 g/100 g) values along with lower rehydration (24.53, 15.99 and 13.18%) and water absorption index (1.64, 3.32 and 5.56 g gel g^{-1} DM) values in potatoes, tomatoes and carrots, respectively. **Conclusion:** This study found that the fresh potatoes, tomatoes and carrots could be easily dried naturally under convection air flow or by using a cabinet dryer at home or at industrial levels for the production of dried vegetable products with high nutritional values and acceptable functional properties.

Key words: Air drying, cabinet drying, carrot, dried vegetables, potato, tomato

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The removal of water from food during the drying process has been found to prevent the growth and reproduction of microorganisms and minimize the deteriorative enzymatic and nonenzymatic reactions. Moreover, the substantial reduction in food weight and volume increases not only the nutritional value but also the bulk density and therefore, it increases the food's nutritional value while minimizing the costs of food packaging, transportation and storage as the dried food materials can be easily stored under normal ambient temperature[1]. In contrast, a high temperature and long drying time may cause serious damage to the flavor, color, nutritional value, reduction of bulk density and rehydration capacity of the dried product[2,3]. Additionally, Puttongsiri *et al.*[4] studied the effects of the drying temperature and drying time on the moisture content and physical properties of instant mashed potatoes.

In general, the production costs of the dried food products are usually less than any other preserved food products. Therefore, dried vegetable products were extensively used by armies during the First World War and are still in demand, especially since households use dried products that could be easily used for the preparation of different food items in just few minutes. In addition, the dried vegetable products are considered to be excellent sources of minerals (Na, K, Mg and Fe) and vitamins, such as vitamin A (beta-carotene), vitamin C (ascorbic acid) and B-vitamins, which have vital roles in the digestion and absorption of carbohydrates, fats and proteins[5,6]. Therefore, the main objective of this study was to investigate the effects of natural and artificial drying methods on the nutritional value and functional properties of some locally grown vegetables in Sudan.

MATERIALS AND METHODS

Materials: Samples of fresh vegetables, namely, potatoes (*Solanum tuberosum*), tomatoes (*Lycopersicon esculentum*) and carrots (*Daucus carota*), were purchased from the Khartoum Central Market and immediately washed, peeled, sliced and dehydrated under natural and artificial processing conditions. At the same time, representative samples from each raw vegetable were taken, tightly packed in polyethylene bags and stored at -20°C until needed for the various investigations.

Experimental processing methods: The fresh vegetable samples (potatoes, carrots and tomatoes) were immediately cleaned, sorted and washed. Then, the cleaned potato and carrot samples were peeled and diced using a dicer machine (Type K. Wisk. USA), while the tomato sample was manually cut by a knife into slices. After that, all of the fresh samples were treated with sodium metabisulphite (0.75 g L^{-1}), divided into two groups and dried by using two different drying methods as follows:

- The first group of fresh vegetable samples was put on drying trays (72×455×52 cm) and dried under natural convection air flow (under a fan) at room temperature (35° C) for 3 days
- The second group of fresh vegetable samples was put on drying trays and dried in a cabinet dryer (Model OV-160, England) for 6 h at 75°C. The processing conditions used during the two different drying methods are described in Table 1.

Analysis methods: The moisture, crude protein, fat, crude fiber, total sugars, reducing sugars, nonreducing sugars, ascorbic acid and ash were determined according to the standard methods of the Association of Official Analytical Chemists(AOAC)[7]. Additionally, the bulk density, water absorption index (WAI) and water-solubility index (WSI) of the dried vegetables were investigated. The results obtained in this study were subjected to statistical analysis using the Statistical Package for Social Science (SPSS) program. Meanwhile, the mean values were tested by using the one-factor analysis of variance (ANOVA) program. A probability of 5 % was used to indicate the differences between the samples.

Table 1: Processing conditions during the drying of potato, tomato and carrot fresh vegetables

Raw vegetable material	Drying method	Weight of raw material (kg)	Loss (g)	Weight after trimming (g)	Weight after drying (g)	Drying (%)
Potatoes	Artificial drying	5	906	4094	862	21.06
	Natural drying	5	968	4032	1042	25.84
Tomatoes	Artificial drying	5	115	4885	120	2.45
	Natural drying	5	113	4887	200	4.09
Carrots	Artificial drying	5	868	4132	440	10.65
	Natural drying	5	905	4095	445	10.87

RESULTS

Table 2 shows the chemical compositions of fresh potato, tomato and carrot samples before drying on a wet weight basis. The moisture, protein, fat, crude fiber, total sugar, reducing sugar, nonreducing sugar and ash contents in the fresh potato sample were found to be 79.89, 2.63, 0.12, 0.64, 0.90, 0.23, 0.67 and 1.05%, respectively. Meanwhile, in tomato and carrot fresh samples the contents were 94.17, 1.20, 0.61, 0.75, 3.50, 3.02, 0.48 and 0.057%, respectively, for the former vegetable and 88.27, 1.17, 0.14, 9.48, 0.65, 7.20, 0.28, 6.92 and 0.94%, respectively, for the latter vegetable. However, when comparing the effects of the two drying methods used in this study on the chemical compositions of the three vegetables (Table 3), the natural drying method was found to decrease the moisture contents in fresh potato, tomato and carrot samples from 79.886, 94.167 and 88.268% to approximately 7.12, 5.45 and 4.62% in the three dried vegetables, respectively, whereas the artificial method decreased their moisture contents to approximately 6.23, 5.04 and 3.43% in the same dried vegetables, respectively. Additionally, when comparing the chemical compositions of the fresh vegetables before and after natural drying, the protein, fat, total carbohydrate, fiber, total sugar, reducing sugar, nonreducing sugar and ash contents were found to increase by approximately 194, 449, 397, 456, 361, 39, 472 and 216% in the dried potato sample; 751, 107, 2118, 1612, 494, 589, 0.00 and 1015%, in the dried tomato sample and 212, 268, 807, 1299, 161, 1964, 88 and 452% in the dried carrot sample, respectively. In comparison, after artificial drying of the same three vegetables, the increases were approximately 178, 309, 407, 338, 269, 0.00, 396 and 214% in the dried potato sample; 768, 137, 2140, 1610, 381, 309, 831 and 881% in the dried tomato sample and 262, 968, 798, 1716, 169, 1814, 102 and 502% in the dried carrot sample with respect to their protein, fat, total carbohydrate, fiber, total sugar, reducing sugar, nonreducing sugar and ash contents, respectively.

However, within the naturally dried vegetable samples, the highest levels of total carbohydrates (86.019%) and nonreducing sugars (12.980%) were found in the dried carrot sample, whereas the highest levels of protein (10.179%), fiber (12.775%) total sugars (20.8%) and ash (6.367%) were found in the dried tomato sample. The dried potato sample recorded the highest moisture content (7.12%). On the other hand,

Table 2: Chemical compositions of potato, tomato and carrot fresh vegetables before drying

	(%, on wet basis, n = 3±S.D.)		
Chemical composition	Potatoes	Tomatoes	Carrots
Moisture	79.886±2.26	94.167±0.59	88.268±0.57
Protein	2.625±0.42	1.196±0.34	1.167±0.41
Fat	0.117±0.29	0.605±0.26	0.142±0.01
Fiber	0.639±0.04	0.746±0.04	0.653±0.28
Total sugars	0.900±0.00	3.500±0.00	7.200±0.00
Reducing sugars	0.230±0.00	3.020±0.00	0.280±0.00
Nonreducing sugars	0.670±0.00	0.480±0.00	6.920±0.00
Ash	1.050±0.09	0.571±0.04	0.942±0.13

n: No. of independent determinations, S.D: Standard deviation

Table 3: Comparison between naturally and artificially dried potato, tomato and carrot vegetables with respect to their chemical compositions

	[% on wet basis, n = 3±S.D.]					
	Convection natural drying method			Artificial cabinet drying method		
Chemical composition	Potatoes	Tomatoes	Carrots	Potatoes	Tomatoes	Carrots
Moisture	7.120±0.2^a	5.453±0.00^a	4.615±0.38^a	6.230±0.04^b	5.043±0.02^b	3.432±1.52^b
Protein	7.292±0.17^a	10.179±0.21^b	3.646±0.83^b	7.729±0.17^b	10.383±1.10^a	4.229±0.17^a
Fat	0.642±0.06^a	1.251±0.47^b	0.522±0.26^a	0.479±0.04^b	1.436±0.13^a	1.517±0.16^a
Total carbohydrates	81.624±0.16^b	76.750±0.95^b	86.019±1.61^a	82.262±0.08^a	77.536±0.16^a	85.147±0.51^b
Fiber	3.552±0.91^a	12.775±0.47^a	9.133±0.91^b	2.798±0.91^b	12.759±0.16^a	11.860±0.23^a
Total sugars	4.150±0.00^a	20.800±0.00^a	18.760±0.00^b	3.320±0.00^b	16.830±0.00^b	19.350±0.00^a
Reducing sugars	0.320±0.00^a	20.800±0.00^a	5.780±0.00^a	0.000±0.00^b	12.360±0.00^b	5.360±0.00^b
Nonreducing sugars	3.830±0.00^a	0.000±0.00^b	12.980±0.00^b	3.320±0.00^b	4.470±0.00^a	13.990±0.00^a
Ash	3.322±0.20^a	6.367±0.27^a	5.198±0.14^b	3.300±0.06^a	5.602±1.10^b	5.675±0.18^a

n: No. of independent determinations, S.D: Standard deviation, Mean values having different superscript letters in each row for each vegetable differ significantly ($p \leq 0.05$)

Table 4: Effects of drying methods on the physical properties of potato, tomato and carrot dried vegetables

	[n = 3±S.D.]					
	Convection natural drying method			Artificial cabinet drying method		
Physical properties	Potatoes	Tomatoes	Carrots	Potatoes	Tomatoes	Carrots
Bulk density (g mL^{-1})	0.811±0.00^b	0.526±0.00^b	0.546±0.00^b	0.909±0.00^a	0.619±0.00^a	0.781±0.00^a
Rehydration (%)	38.820±0.00^a	28.710±0.00^a	21.880±0.00^a	24.530±0.00^b	15.990±0.00^b	13.180±0.00^b
Water soluble index (g soluble solids/100 g DM)	10.767±0.36^a	5.070±1.07^b	17.769±0.00^b	11.097±0.37^b	13.484±0.37^a	19.071±0.36^a
Water absorption index (g gel g^{-1} D/M)	1.662±0.01^a	7.012±0.44^a	5.562±0.03^a	1.642±0.07^b	3.320±0.05^b	5.561±0.04^a

n: No. of independent determinations, S.D: Standard deviation, Mean values having different superscript letters in each row for each vegetable differ significantly ($p \leq 0.05$)

within the artificially dried vegetable samples, the highest levels of total carbohydrates (85.147%), total sugars (19.35%), non-reducing sugars (13.99%) and ash (5.675%) were found in the dried carrot sample, whereas the highest levels of protein (10.383%), fiber (12.759%) and reducing sugars (12.360%) were found in the dried tomato sample. The dried potato sample recorded the highest moisture content (6.230%).

DISCUSSION

According to the literature, the moisture, protein, fat, crude fiber, total carbohydrate and ash contents in fresh potato, tomato and carrot samples were found in the ranges of 75.0-80.0, 2.0-3.5, 0.1-0.9, 1.1-0.6, 19.0-20.6 and 0.9-1.0% in potato samples; 93.0-94.1, 0.1-0.3, 0.1-0.4, 0.5-1.5, 0.4-0.6 and 0.5-1.0% in tomato samples and 88.3-93.4, 0.7-1.1, 0.2-2.6, 1.0-2.9, 4.7-6.4 and 0.5-1.0% in carrot samples, respectively. In general, the results of the chemical compositions of fresh potato, tomato and carrot samples obtained in this study were found to fall within the previous ranges obtained by Seed-Ahmed *et al.*[8] Ibrahim[9] and Hassan[10]. However, after drying of the fresh vegetables, the vegetables that were dried with the cabinet dryer at 75°C were found to be better than the same vegetable samples dried under room temperature (30-35°C) by natural convection air flow with regards to their moisture and protein contents. Meanwhile, the naturally dried vegetables recorded higher values of reducing sugars. These differences may be attributed to the long drying period (3-4 days) during the natural drying method used in this study, which permitted the enzymatic hydrolysis of protein and carbohydrates. Moreover, the heat treatment during the drying of fresh potato, tomato and carrot samples will not only make their energies more available but also will increase their protein digestibility after destroying toxins and protein inhibitors as reported earlier by Brennan and Day[11], Srivastava and Sanjeev[12]. In fact, both the natural and artificial drying methods used in this study were found to be suitable for the production of dried potato, tomato and carrot samples, which can be used in the preparation of dried vegetable products, such as mixed vegetable soups.

Singh *et al.*[13] mentioned that with the removal of a plant's water content by a heat treatment such as drying, major changes will definitely occur in the plant cellular structure and its other physical and chemical characteristics, as the plant tissue usually contains water more than two-thirds of its weight. Therefore, the cabinet drying method used in this study for drying fresh potato, tomato and carrot samples was found to produce dried vegetable products with higher functional properties in comparison with those naturally dried vegetable samples (Table 4). All of the artificially dried vegetables were found to have higher values of the bulk density (0.909, 0.619 and 0.781 g mL^{-1}) and water solubility (11.097, 13.484 and 19.071 g/100 g) but lower values of rehydration (24.530, 15.99 and 13,18%) and the water absorption index (1.642, 3.320 and 5.561 g gel g^{-1} DM) for potato, tomato and carrot samples, respectively. A high bulk density of a dried food material is a desirable physical property, especially when the powdered food is to be packed in a limited space or area with a high nutrient content to reduce shipping transportation costs. Additionally, the dried vegetable products produced in this study could be easily used in the preparation of ready-to-serve mixed vegetable soups, in any other food products such as baby food, or as food supplements to reduce the high incidence of vitamin and mineral deficiencies, especially among young children and pregnant and lactating women.

CONCLUSION

From the results obtained in this study, it can be concluded that both the natural and artificial drying methods used in this study were found to be suitable for the production of dried vegetables that can be used in the production of dried vegetable products with high nutritional value and acceptable functional properties.

SIGNIFICANCE STATEMENT

This study discovered the possible industrial utilization of both a natural convection air flow drying method and a cabinet drying method in the production of ready-to-serve dried vegetable soups or other food products at commercial or home levels, as dried vegetable products or soups are still in demand and can be beneficial, especially for households use because the products can be easily prepared in just a few minutes. Moreover, the present study will help the researchers to uncover the critical areas of food supplementation with some vitamins and minerals to solve the problem of malnutrition, especially among young children and women in developing countries.

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