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Chemical, Sensory and Microbiological Properties of Fleshy Tomatoes, Orange-fleshed, and Sweet Potatoes dried by Different Techniques

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Abstract

Fresh tomatoes and sweet potatoes are highly perishable and have a relatively short shelf life due to their high moisture content, causing a great loss during transportation, distribution, and storage. Therefore, the aim of this study was to evaluate the effect of different drying techniques on the chemical composition, sensory properties and microbiological quality of dried fleshy tomatoes and orange-fleshed sweet potatoes. The raw materials were prepared and cut into slices with thicknesses of 7±2 and 5±2 mm, respectively. Three drying techniques, namely open sun-drying, conventional hot-air drying (50±2°C) and swell-drying were adopted in this study. The conditions of the treatment by instant controlled pressure drop (DIC) were saturated steam pressure of 0.4 MPa and processing time of 15 s. The obtained results showed that the chemical composition, the sensory properties and the microbiological quality mainly depended on the drying technique used as well as the drying conditions applied. The drying of Tomato and sweet potato by DIC results in better retention of phenolics (56.49 ± 0.83 and 109.23 ± 5.20mg/100 g db), antioxidant activity (101.5 ± 1.32 and87.59± 2.02 %) and Vit C (21.293 ± 0.04 and 17.67 ± 0.18 mg/100 g db), lycopene(52.04 ± 1.60),and Beta-carotene(52.31 ± 0.87) respectively . Swell-dried fleshy tomatoes and orange-fleshed sweet potatoes had the highest overall acceptability with sensory characteristics superior to those of sun-dried and conventionally hot-air-dried products. Besides, swell-drying significantly inactivated or destroyed all The microorganisms studied showed no growth of total bacteria, fungi and yeasts, coliforms, *E. coli* and total mesophilic. Similarly, the conventional hot-air drying caused decrease in value observed, in total bacterial, fungi and yeasts, coliforms and total mesophilic were 0.4×10^2 cfu/g 0.5×10^1 cfu/g , Nd and 0.1×10^1 cfu/g, and 6.5×10 cfu/g , 8cfu/g ,10 cfu/g and 12 cfu /g respectively for dried fleshy tomatoes and orange-fleshed sweet potatoes.

Keywords: fleshy tomatoes; orange-fleshed sweet potatoes; sun-drying; hot-air drying; swell-drying; Chemical components; sensory characteristics; microbiological load.

Introduction

Tomatoes (*Solanum Lycopersicum*) belong to the Solanum genus of the Solanaceae family and are widely used in food preparations in fresh and dried states. Dried tomatoes can be used in the preparation of pizza and in various ready-to-eat meals as well. Tomatoes can be processed in various products including juices, sauces and ketchup [1] [2]. The consumption of tomatoes is recommended for people who follow a healthy diet regime due to their low-fat content [3]. Tomatoes are one of the most significant and nutrient-dense vegetable crops that humans eat. Numerous studies have demonstrated the nutritional value of tomatoes, highlighting their high concentration of pro-vitamin A, lycopene, β-carotene, vitamin C, and secondary metabolites like flavonoids, phytosterols, and polyphenols. After processing, some of these nutrients are preserved, making them vital for human health [4]. Besides, tomatoes are also an important source of dietary fibers, essential amino acids, and minerals such as sodium (Na), potassium (K), magnesium (Mg), phosphorous (P), and calcium (Ca).

Sweet potatoes (*Ipomoea batatas* L.) are tuberous roots that belong to the Convolvulaceae family [5] with low fat content and protein. Sweet potatoes are high in vitamins, minerals, dietary fiber, carbohydrates, and iron (K, P, Ca, Mg, Fe, Mn, Cu). Furthermore, bioactive substances like phenolic acids and anthocyanins are present and contribute to the colour of the pulp and skin. Moreover, elevated levels of vitamin C (6–10 mg 100 g–1) and β-carotene (273–400 μg 100 g–1) have been noted, particularly in sweet potatoes with orange flesh [6], [7]. According to research, tubers can benefit human health by acting as an antioxidant, hepatoprotective, anti-inflammatory, anti-tumor, antibacterial, and anti-aging agent, which lowers the incidence of obesity and diabetes mellitus. Antioxidants including phenols, flavonoids, carotenoids, and vitamins provide antioxidant activity and have also health-promoting effects such as anti-mutagenic, anti-proliferative, and anti-inflammatory properties [8].

Tomatoes and sweet potatoes are highly perishable and have a relatively short shelf life due to their high moisture content (93–96%) and (77%), respectively, causing a great loss during transportation, distribution, and storage. Due to increasing consumer awareness, the consumption of fresh and raw foods increases every year [9], however, these raw foods may be contaminated with yeasts, fungi, or various pathogen microorganisms such as *Escherichia coli*. This contamination generally results from contact with soil, dust, and wastewater during harvest and post-harvest periods. These microorganisms may cause various serious diseases such as diarrhea, vomiting, cramps, even death. Due to this microbial load, there are some

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limitations of such food's consumption without any treatment. Among them, short shelf life, they should be more easily degraded due to microbial load and are likely to cause food poisoning or foodborne infection [10]. Therefore, the preservation of tomatoes and sweet potatoes is necessary to maintain their quality and to reduce the loss during the storage period.

Drying is one of the oldest methods of food preservation and widely used to extend their storage period [11] as a result of water removal and lower water activity which in turn inhibit the microbial growth and reduce the enzymatic reactions. However, the quality attributes of dried foods greatly depend on the drying method used and on the drying conditions applied. Although Sun-drying is the conventional technique for preserving fruits, vegetables, and crops. It is an additional strategy to stop the depletion of natural resources. However, conventional sun drying degrades the quality of food and is unable to stop birds, dust, or any other insects [12]. Sun dried food results in colour loss, shrinkage, and an unappealing end product. The traditional open sun drying method is being replaced by new industrial drying methods, such as hot-air drying, to improve the quality and value of dried goods [13].

These drawbacks are related to the shrinkage phenomenon and texture compactness, which occur during conventional hot air drying, decreasing the effective moisture diffusivity [14].

In order to overcome these drawbacks, swell-drying (SD) could be used to produce dried tomatoes and sweet potatoes as an alternative technique. SD is an energy-efficient and cost-effective technique [15] compared to other conventional drying techniques such as conventional hot-air drying and freeze-drying. This technique is based on the combination of conventional hot air drying with instant controlled pressure drop process (DIC). DIC is a high temperature-short time (HTST) treatment followed by an abrupt pressure drop towards a vacuum causing an auto-vaporization of some product's moisture content which help to cool down the product and maintain the obtained new structure [16] . The drying time is less than other techniques due to the open porous structure and the large specific surface area (exchange surface) exposed to drying air which accelerate moisture removal [17] therefore the quality of the swell-dried products is higher than that obtained by conventional drying techniques [18]. For these reasons, the objective of this work was to compare the effect of different drying techniques, namely sun-drying, conventional hot-air drying, and swell-drying on the sensory characteristics and microbiological quality of dried fleshy tomatoes and orange-fleshed sweet potatoes.

1. Materials and Methods

RAW MATERIALS

Fully ripe red fleshy tomato fruits (*Solanum Lycopersicum*) and orange-fleshed sweet potato tubers (*Ipomoea batatas* L.) that had reached maturity and showed no signs of damage were purchased from the local market (Zagazig city, Sharkia, Egypt), and they were carried in a clean polythene bag to the lab of food science, Horticulture Research Station, EL-Kssassin, Ismailia, Egypt.

Sample Preparation

Immediately transported samples to the laboratory and stored under cooling conditions; at temperature of 5±1°C. Tomatoes fruits and sweet potatoes tubers were first manually sorted and washed with running clean tap water. Inedible parts were manually removed and re-washed with running clean tap water. Tomatoes fruits and sweet potato tubers were manually cut using a kitchen knife into slices with thickness of about 7±2 and 5±2 mm, respectively. Subsequently, the slices were divided into three batches referred to as: sun-drying, hot-air drying (HAD), and swell-drying (SD).

DRYING TECHNIQUES

Figure (1) shows the protocol used in the production of dried tomatoes and sweet potatoes by different techniques.

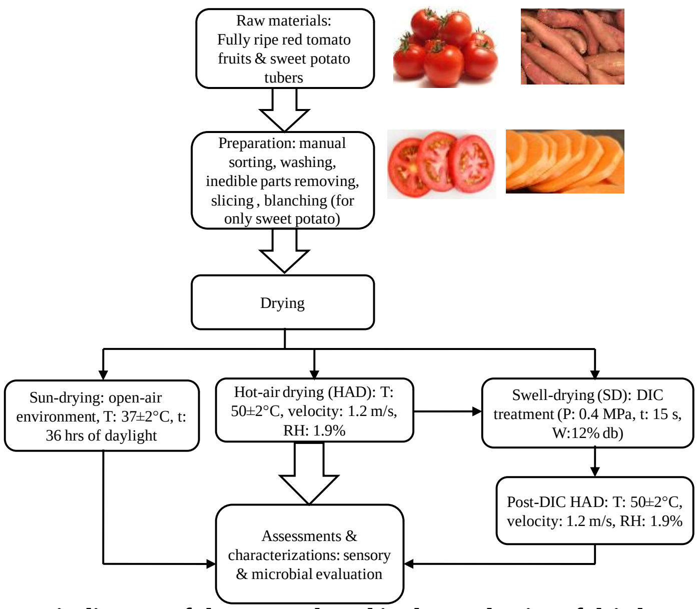

Fig. 1: by different Schematic diagram of the protocol used in the production of dried tomatoes and sweet potatoes techniques.

Sun-Drying

Sun-drying was carried out in open air during August at temperature of about 28 °C - 34.8°C between 9: 30 am to 5 : 30 pm for 3 days or for 36 hrs. in daylight. The slices were loaded on perforated drying trays mounted on raised stands to reduce the contamination risk, with a continuous turning of the slices every day. The process was finished when a constant weight was obtained [19].

Conventional Hot-air Drying

Conventional hot-air drying (HAD) was performed at 50±2°C with air characteristics of 1.5 m/s as velocity and 260 Pa (relative humidity of air 1.9%). The process was finished when a constant weight was obtained after 10 hrs. for sweet potato and 12 hrs. for tomato [20].

Swell-Drying

Swell-drying involves a treatment by DIC after a partial hot-air drying [21] [22]. In this study, the conventional hot-air drying is stopped when the moisture content of the products was about 12% db. The products having 12% db moisture content were subjected to a DIC treatment at saturated steam pressure of 0.4 MPa for 15 s. After DIC accomplished, the post-DIC hot-air drying was carried out under the same conditions of the conventional hot-air drying, until the water content attained 4% db or less. Figure (2) shows the main parts of DIC reactor used in this study.

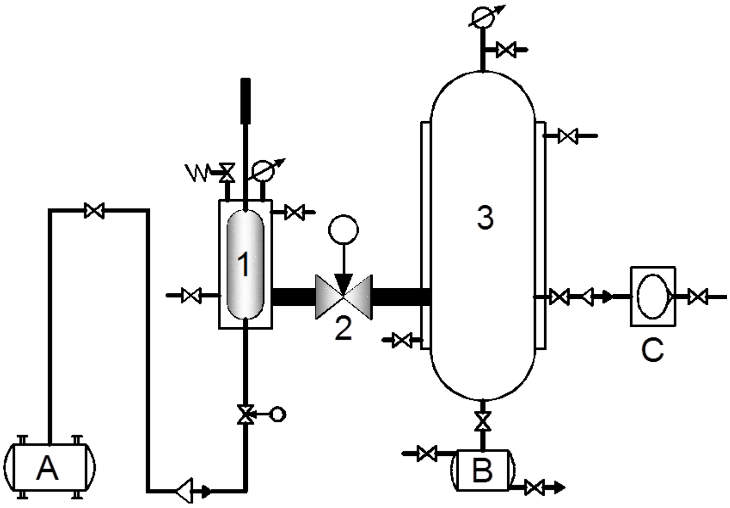

Fig.2: Schematic diagram of DIC reactor: (1) treatment vessel; (2) controlled instant pressure-drop valve; (3) vacuum tank; (A) steam generator; (B) condenser; and (C) vacuum pump

Chemical analysis

Proximate Composition

The moisture content, crude protein, extract, ash and fiber content were determined according to method [24]. Total carbohydrate was calculated by the differences between one hundred and the summation of the percentage of moisture, protein, fat, ash, and crude fiber [25]. The total energy value of the food formulation was calculated according to [24] using the formula as shown in the equation:

$$\text{Total energy (Kcal)} = (\%\ \text{Protein}\times4) + (\%\text{Fat}\times9) + (\%\text{Carbohydrate}\times4)$$

PHYTOCHEMICAL ANALYSIS

Determination of Vitamin C

Vitamin C was determined using the method described by [24]. Ten grams of the sample were weighed into 250ml flask and 50 ml acetone and then filtered. The filtrate was measured and equal volume of saturated NaCl was added to wash the filtrate. The mixture was shaken then transferred to a separating funnel and the layer of the filtrate was removed. The upper layer was washed again with 100% Potassium carbonate (IV) (K_2CO_3), then separated and finally washed with about 10 – 20ml of distilled water. The absorbance was read in a spectrophotometer.

Determination of total phenolic content

Total phenolic content (TPC) of the methanolic extract was quantified according to [26] using the Folin– Ciocalteu method. Briefly, 0.5 mL of the methanolic extract was added to 0.5mL of Folin– Ciocalteu reagent and vortexed for 3 min followed by adding 4 mL of Na_2CO_3 solution (IM). The mixture was incubated at 45 °C for 5 min in darkness and then cooled in a cold water bath. The absorbance was read at 765 nm using a spectrophotometer against a blank sample containing a distilled water. The TPC was calculated on the basis of the calibration curve of gallic acids and expressed as mg equivalents of Gallic acids per 100gm dry basis (mg GAE/100g db).

Determination of antioxidant capacity by DPPH method

Antioxidant capacity was carried out using 2, 2-Diphenyl-1- Picrylhydrazyl (DPPH) as a free radical. Reduction of DPPH by an antioxidant or a free radical produces decreased absorbance at 515 nm. 20 %L of the extract were mixed with 200 %L DPPH (125 %M in 80 % methanol). After 90 min, the plate was read at 520 nm in a spectrophotometer and the antioxidant capacity was calculated as a percentage of DPPH discoloration according to [27]. The analysis was performed in triplicate.

Determination of Lycopene

Lycopene extraction from tomato samples was done using acetone: hexane (4-6) (v/v) mixture as described in [28] Briefly; 100mg of extract was mixed with 10ml of acetone-hexane mixture (4:6) for 1 minute and filtered. The absorbance was read in a spectrophotometer at three different wavelengths (453,505&663nm). The lycopene content was calculated by:

Lycopene (mg/100 ml) = -0.0458xA663 + 0.372xA505 - 0.0806xA453.

Total carotenoids content analysis

The harvest plus procedure for β-carotene analysis was used to analyze the total carotenoids content of the fresh orange-fleshed sweet potato roots and the dry orange-fleshed sweet potato were determined from the the dried methanolic extract according to [28] 100mg of extract was mixed with 10ml of acetone-hexane mixture (4:6) for 1 minute and filtered. The absorbance was read in a spectrophotometer at three different wavelengths (453,505 & 663nm). The β-carotene content was calculated by:

β-Carotene (mg/100 ml) = 0.216×A663 - 0.304xA505 +0.452xA45

SENSORY EVALUATION

Dried samples of tomatoes and sweet potatoes were subjected to a sensory evaluation by a panel composed of ten untrained members irrespective of their age and sex. The samples were coded using random three-digit numbers and the panelists were provided with a glass of water to rinse and swallow water between each sample. They were given written instructions with the description of each textural term and asked to evaluate the sun-dried, HAD and SD tomatoes and sweet potatoes for their overall acceptability based on the appearance, color, taste, odor/aroma, crispness, and chewing. The panelists were asked to give a score ranging from 0 to 15 for each property according to [29].

MICROBIOLOGICAL ANALYSIS

Ten grams of each sample were added to conical flask contained on 90-ml of 0.85 % saline solution (0.85 g NaCl /100 ml distilled water) and placed on a mechanical shaker for 15 minutes. Pour plate method used to cultivate serially diluted portions of the samples up to 10^4. Nutrient agar medium was used to estimate total bacterial count, and the plates were incubated at 37 °C for 48 h [30]. Total yeast and moulds count were estimated on Potato Dextrose agar medium [31] with incubation at 25°C for 72 hours. Total *coliforms* were estimated on violet, red bile agar (VRBA) (Microbial) incubated for 24–36 h at 37°C and 44°C respectively [32]. Coliform group to be counted will produce purple colonies surrounded by purple halos. *Escherichia coli* was estimated on MacConkey agar medium [33] with incubation at 37°C for 24-48h. Total mesophilic aerobic bacteria was determined on plate count agar [34] incubated at 37 °C for 48 hours. For each sample, triplicate plating was carried out. The microbial counts (colony forming units, CFU/g) were transformed into logarithms (log) and means were determined.

Statistical Analysis

The results were expressed as mean ± S.D. of three replicates. The data were subjected to ANOVA followed by Duncan's multiple range tests with $p \leq 0.05$ significance level on SPSS 18.0 statistical software (SPSS Inc.).

2. Results and Discussion

Chemical composition of tomato

The data in Table (1) show the proximate chemical composition of tomato slices dried with open sun drying (OSD), hot air drying (HAD) and swell drying (DIC). The moisture content of the fresh tomato slices was 94.05 % (db.). The OSD, HAD, and DIC were run until the sample weight fluctuations stabilized. The moisture content dropped quickly as it dried. The final moisture content (db.) for the OSD, HAD and DIC was 10.42%, 8.19%, and4.6 %, respectively. DIC drying was more effective in removing moisture compared to other drying methods. This is due to the increased temperature. Compared to the sun, which varied depending on the weather and season when the drying process occurred, the convective cabinet provides heat more consistently. Consequently, variations in drying techniques were the cause of variations in moisture content. A comparable pattern was noted by **[35]** reported that the moisture content of the fresh tomatoes was 91.62 ±4.327%, 13.85 % and 12.51 % from fresh, sun drying and oven drying respectively . Crude protein content for the fresh sample of tomatoes was significantly lower compared to dried samples**.** the protein values ranged between (1.23±0.35%) for fresh tomato, (9.68± 0.37%) oven drying ,(12.03±0.46%) open sun drying and (11.05 ±0.42 %) The protein content was found highest in cabinet drying followed by sun and DIC drying. There was no significant difference in the protein concentrations of the samples that were heated, suggesting that the heating time had no effect on protein denaturation. However, the treatments that were heated had lower protein contents, which was explained by the protein denaturation that results from the high temperature applied in those treatments**.** The fat content of fresh tomatoes **(**0.22±0.08 %) was significantly lower and different from other forms of drying. (0.71 ±0.16%), (1.83 ± 0.15 %), and (0.35 ± 0.01%) were the values obtained for open sun drying, oven drying, and DIC drying, respectively. Fresh tomatoes had a lower ash concentration than the dried samples, with 0.47±0.07 %. After being dried in an oven (7.17± 0.07 %), under the open sun (14.88±0.15%), and DIC drying (7.46 ± 0.07%), the dried samples had an ash content. Protein, lipids and ash contents of tomato fruit were 0.30, 0.70 and 0.55%, respectively [36]. For the fresh tomatoes, the crude fibre result was (1.61±0.04 %), which was substantially less than the values for the oven dryer (12.96± 0.97 %), open sun (12.57± 0.94 %), and DIC drying (12.3± 0.92%).The carbohydrate content of tomatoes powder dried in a DIC drier was measured at (64.22 ± 0.62 %); this was significantly greater than the carbohydrate content of tomatoes dried in oven drying (60.17± 0.33 %), open sun drying (49.39 ± 0.79 %), and fresh tomatoes (2.64±1.58 %). The result indicated that the total carbohydrate content of dried tomato increased with duration and temperatures of drying. This is expected because carbohydrate content was obtained by difference, since the other proximate composition was slightly degraded with increasing duration and temperature of drying. Similarly, **[37]**, who reported lower total carbohydrate content (0.43%) in control samples compared to oven dried samples at 60 ^{o} **C.** Energy value was range from 252.07 ± 3.50 to 304.23 ±1.52 kcal/100g, which was similar to [25] found 268.21kcal/100g . The results in Table (1) also show that DIC drying method caused a lower reduction of vitamin C for both HAD and OSD compared to the fresh tomatoes. It ranged from 1.71 ±0.01 to 21.293 ± 0.04 mg/100 g (dry matter) in sample drying while it was 85.17±0.16 mg/100 g (dry matter) for fresh tomatoes. These results are in a good agreement that the nutritive values of DIC-treated products were evaluated thanks to its effective heating and rapid cooling, DIC-dried products are characterized by higher content and availability of bioactive compounds. As a result, tomatoes with longer drying times and higher temperatures have lower ascorbic acid values [18][38]. This may be since the ascorbic acid content of food is destroyed by exposure to heat. Our results are in agreement with previous studies [39] reported that the ascorbic acid content in fresh, oven operated at temperatures of 40, 50 and 60 °C and open sun drying were 17.78±0.15, 14.97±0.11, 13.33±0.63, 3.23±0.07 and 10.23±0.62 (mg/100g) respectively. The total phenolic contents of dried tomato by OSD, HAD and DIC compared to the fresh tomato are given in Table (1). The drying treatment greatly decreased the total phenolic content of the tomato samples. The total phenolic content of fresh sample was 63.4 7±0.93 mg/100g while of the DIC dried was 56.49 ±0.83, 55.85±0.82 for the oven and 53.32 ±0.78 for the open sun. Compared to DIC, oven dried and open sun drying tomatoes exhibited a decreased phenolic concentration. The long drying process, which has been shown to break down exact phenolic compounds, may be the cause of the sun-dried tomatoes' low phenolic content [40]. Various researchers showed that as drying temperatures rise, tomatoes' total phenolic content rises as well. In a study conducted in [40] found that tomatoes dried in a vacuum oven at varying temperatures (50, 60, and 70 C) with an air velocity of 0.1 m/s had higher phenolic contents than tomatoes dried at a lower temperature.

Table 1. The effect of drying methods on the chemical properties and Phytochemical analysis of tomato fruit

Nutrient	Fresh	OSD	HAD	DIC
Moisture (% wb)	94.05^{a}±0.01	10.42^{b} ± 0.72	8.19^{c}± 0.17	4.6^{d} ± 0.36
Crude protein(% db)	1.23^{d}±0.35	12.03^{a}±0.46	9.68^{c} ± 0.37	11.05 ^{b} ±0.42
Total lipids (% db)	0.22^{c}±0.08	0.71^{b} ±0.16	1.83^{a} ± 0.15	0.35^{c} ± 0.01
Ash(% db)	0.47^{d}±0.07	14.88^{a}±0.15	7.17^{c}± 0.07	7.46^{b} ± 0.07
Crude fiber (% db)	1.61^{b}±0.04	12.57^{a}± 0.94	12.96^{a}± 0.97	12.3^{a}± 0.92
Total carbohydrates (% db)	2.64^{d}±1.58	49.39^{c} ±0.79	60.17^{b}± 0.33	64.22 ^{a}± 0.62
Energy kcal	43.08^{d}±4.12	252.07^{c}±3.50	295.87 ^{b} ±1.23	304.23 ^{a}±1.52
Phytochemical analysis				
Ascorbic mg/100g	85.17^{a}±0.16	1.71 ^{d} ±0.01	6.13^{c}±0.01	21.293 ^{b} ± 0.04
Phenolic mg/100g	63.4 7 ^{a}±0.93	53.32^{c}±0.78	55.85^{b} ± 0.82	56.49 ^{b}± 0.83
Antioxidant (DPPH) mg/100 g	98.1^{b}± 0.90	49.05^{d} ± 0.45	72.593^{c} ± 0.67	101.5^{a} ± 1.32
Lycopene mg/100g	2.7^{c} ±0.85	14.35^{b} ±0.32	36.87^{b} ±0.95	52.04 ^{a} ± 1.60

(DIC) instant controlled pressure drop, (OSD) open sun drying, (HAD) hot- air drying. Mean value ± SD (n =3). Different letters in the same column indicate significant differences at $p < 0.05$. wb: Wet Basis, db: Dry Basis

The phenolic content of tomatoes increased as the drying temperature rose from 60 to 100 degrees Celsius, according to [41]. The data in (Table 1) shows the lycopene content in (mg/100g) of dried tomato slices which ranged from 14.35 ± 0.32to 52.04 ±1.60 and that of fresh sample was2.7 ±0.85 Lycopene content significantly (at $p<0.05$) increased with increase in temperature and decrease in the moisture content (i.e. in concentration). Sample dry by DIC had significantly greater lycopene content than samples oven and open sun drying respectively. [42] Who reported the increase in lycopene content in all dried samples could be due to break down of cell walls by thermal process, which weakens the bonding matrix between lycopene and tissue matrix and hence, make lycopene more accessible. Antioxidant activity of raw and thermally processed tomato slices are presented in Table 1. A significant decrease in antioxidant activity was recorded for all tomato slices drying by the oven and the sun compared with fresh tomato. While antioxidant activity of tomato slices increased by drying used DIC 101.5±1.32 compared with the fresh 98.1 ± 0.90. Our findings show a similar trend to previously published results obtained for tomato [40] which showed antioxidant activity of tomato slices increased with increasing drying temperature from 50 °C to 70°C but decreased as drying time progressed from 30 to 300 min.

Chemical composition of sweet potato

(Table 2) shows the proximate composition of sweet potato powder samples dried by different methods 100 g of fresh sweet potato contained 80.01± 0.73 % of moisture, 1.79± 0.17 % of protein, 0.46 ± 0.56 % of fat, 1.19 ± 0.42% of ash, 2.753 ± 0.47 % of crude fiber, 13.797 ±0.99 %of carbohydrate, 66.5± 2.24K.cal of energy this results agreement [43] who found that moisture content of orange fresh sweet potato was (79%), the protein content was (4.51%), ash and crude fiber were (3.65%) and (2.82 %) respectively. The moisture content of all dried chips of OFSP varieties ranged between4.2 ±0.02 -9.99 ±0.30 %. OSD had the highest moisture content 9.99 ±0.30 %, while the DIC drying had the lowest moisture content 4.2 ±0.02 %. The lower moisture contents the better shelf life and denser nutrient composition [44].

Proteins are vital components for the human body's structural and functional factors of various biomolecules because they supply the critical amino acids needed for metabolism. Apparent also from the same Table that, open sun drying sweet potato, HAD and DIC contain 5.96 ± 0.23, 4.99 ±0.19 and 4.53 ± 0.17 % crud protein respectively.

Results indicate no significant effect on the protein content, although DIC dried samples showed higher values compared to oven and sun-dried samples. The high values of protein content of dried samples (5.96 ± 0.23) were due to the fact that during drying, food loses significant amount of moisture causing increase in nutrients in the remaining mass. Open sun drying samples were observed to have reduced crude protein content due to protein denaturation, leaching and prolonged drying. Fat content of sweet potato for dried sample ranged 1.33 ± 0.04 to 1.38 ± 0.04 %, it was observed that there was no significant difference in all dried samples.

Table 2. The effect of drying methods on the chemical properties and Phytochemical analysis of sweet potato (on dry weight).

	Fresh	OSD	HAD	DIC
Moisture (% wb)	80.01^{a}± 0.73	9.99^{b} ± 0.30	7.37^{c} ± 0.46	4.2^{d}± 0.02
Protein (% db)	1.79^{d}± 0.17	4.53^{c} ± 0.17	4.99^{b} ±0.19	5.96 ^{a} ± 0.23
Fat (% db)	0.46 ^{b} ±0.56	1.33^{a} ± 0.04	1.38^{a}± 0.04	1.36 ^{a} ± 0.05
Fiber (% db)	2.75 ^{b} ± 0.47	5.36^{a} ± 0.40	5.62^{a} ± 0.42	5 ^{a} ± 0.37
Ash (% db)	1.19 ^{c} ± 0.42	8.98 ^{a} ± 0.09	9.25^{a} ± 0.09	8 ^{b} ± 0.08
Carbohydrate (% db)	13.80 ^{d}±0.99	73. 47^{c} ± 0.34	77.54^{b} ± 0.49	81.91^{a} ± 0.28
Energy Kcal	66.5^{d}± 2.24	329.68^{c}± 9.69	342.54 ^{b} ±2.72	358^{a} ±1.38
Phytochemical analysis				
Ascorbic mg/100g	34.67^{a}± 0.72	1.08^{d} ± 0.56	5.65^{c} ± 0.058	17.67^{b} ± 0.18
Phenolic mg/100g	122.73^{a} ±5.84	103.1^{b} ± 4.91	108^{b} ±5.14	109.23^{b} ± 5.20
Antioxidant (DPPH) mg/100 g	43.80^{d} ±0.01	64.82^{c} ± 0.49	82.71^{b} ±3.42	87.59^{a}± 2.02
β. carotene mg/100g	55.23^{a} ± 0.75	41.32^{d} ± 0.56	50.21^{c} ± 0.68	52.31^{b} ± 0.87

(DIC) instant controlled pressure drop,(OSD) open sun drying ,(HAD) hot -air drying . Mean value ± SD (n = 3). Different letters in the same column indicate significant differences at $p < 0.05$, wb: Wet Basis, db: Dry Basis

The reason for deviation from the fresh value may be due to the fact that during drying, food loses significant amounts of moisture causing an increase in nutrients in the remaining mass. The ash content of dried samples ranged between 8 ± 0.08 and 9.25 ± 0.09 on dry matter basis. Among the oven dried samples had the highest value. The crude fibre of dried samples ranged between 5 ± 0.37 and 5.62± 0.42 % dry matter basis, having higher value compared to fresh samples. The carbohydrate content of fresh samples was 13.797 ±0.99 % on dry matter basis. Fresh samples have significantly low value compared to dried samples. The variety observed with low carbohydrate content had high moisture content. Carbohydrate content of dried samples ranged between 73. 47± 0.34and 81.91 ± 0.28% on dry matter basis. Sample dry by the DIC showed high significant value compared with other dried samples. [45] reported 86.86±0.44, 85.80±0.61 and 85.80±0.61 percent carbohydrate in yellow, orange and purple varieties. [46] reported that the moisture content of fresh samples for all varieties studied ranged between 64.5 ± 0.32 and 70.4 ± 0.17%, protein content 1.9 ± 0.08 and 2.7 ± 0.41, fat content 1.1±0.06 and 1.7±0.08%, fiber content 3 ± 0.05 and 3.6 ± 0.08 %, the ash content 2.8 ± 0.01% to 4.2 ± 0.07% and the carbohydrate content 18±0.07 and 26.8±0.34% on dry matter basis.

With respect to the micronutrients (vitamins and phenolic compounds) (Table2), the total phenolics content of fresh sweet potato was 122.73 ±5.84mg/100 g. The results of TPC content were similar to the total phenolics ranged between 79 mg/100 g and 166 mg/100 g for the Blanquita and Yema de huevo cultivars, respectively [47] . Higher levels of phenolic compounds were found in sample dry by the DIC (109.23 ± 5.20) which are higher than the phenolic content of oven and sun drying. Phenolic compounds have some stability when exposed to high temperatures [48]. Sweet potato contains vitamin C 34.67± 0.72 mg/100g. [49] reported that vitamin C ranged between 21.5 to 30.1 per 100 g in sweet potato tubers. We discovered that the sweet potato type examined in this study had comparable to higher vitamin C contents. The highest retention was observed in DIC treatment, (vitamin C 17.67 ± 0.18) . The lowest retention of vitamin C was recorded in the open sun drying method. Similarly, [50] found that combining DIC treatment with hot air drying preserves vitamins more effectively; thermal degradations were low, also found that Vitamin C content of fresh, hot air dried apple and Swell dried-DIC apple were 290, 17 and 64 (mg ⁄100 g dry basis) respectively.

The antioxidant capacity of extracts was also shown in Table 2. Fresh sweet potato samples 43.80 ± 0.01mg/g DW . Orange sweet potatoes displayed distinctive antioxidant activity patterns. DIC treatment started the highest values, indicating potent free radical scavenging ability. The DIC texturing creates an open porous structure that increases the availability of these compounds. While sun drying the lowest values [51] Looked into the antioxidant properties of I. batatas tubers where 43.3–81.2 Mm TE/g of scavenger activity against DPPH radicals was reported for four different colored batatas. .In addition, hot air drying of sweet potato samples at temperatures ranging from 60 to 110 ◦C [52] was carried out to find the best drying conditions for the preservation of the antioxidants that are currently present. The temperature of 80 ◦C produced the highest ORAC antioxidant activity result of 130.94 μmol TE/g. Antioxidant activity was strongly influenced by temperature and drying time, and higher TPC levels are associated with increased antioxidant activity [53]

The results (Table 2) indicated that beta carotene content of fresh sweet potato was 55.23± 0.75 mg⁄100g on dry matter basis. [46] Indicated that beta carotene content of sweet potato varieties ranged between 24.2 ± 1.52 and 73.9 ± 5.84 mg per 100 g on dry matter basis for fresh samples. β-carotene content of dried samples ranged from 41.32 ± 0.56 to 52.31 ± 0.87mg per 100 g on dry matter. These beta carotene results are similar to findings reported by other researchers. Sun drying was observed to retain 63 - 73%, oven drying 89 – 96%, boiling 84–90% and frying 72– 86% β-carotene in OFSP varieties studied [54].

SENSORY CHARACTERISTICS

The sensory characteristics of dried fleshy tomatoes and orange-fleshed sweet potatoes are shown in Figures (3) and (4). It is observed that the sensory characteristics greatly depended on the drying technique used as well as the drying conditions applied. For instance, swell-dried fleshy tomatoes and orange-fleshed sweet potatoes had the highest overall acceptability with sensory characteristics superior to those of sun-dried and conventionally hot-air dried (HAD) products. It may be due to the shortened drying time for swell-drying as a result of the large specific area. The increased specific area caused by the expansion of vapor within the product results in higher heat transfer coefficients and inceasing thus the drying rate particularly in the falling rate period [22]; [17] As a result, the thermal degradation of the products was prevented, maintainig thus the sensory characteristics particulary the color and flavor. On the other hand, the poor sensory characteristics of HAD-dried and sun-dried products may be related to the long drying time as well as Maillard reaction and enzymatic activity, producing brownish producs which in turn contribute to darkening the color of dried fleshy tomatoes or dried orange-fleshed sweet potatoes using these drying techniques.

Texture characteristics of dried foods are used as indicator of product acceptability by consumers where crispness and crunchiness are considered as primary textural parameters affecting the consumer preference;[55] [56] .SD-dried fleshy tomatoes and orange-fleshed sweet potatoes had the best textural characteristics in terms of crispness and chewiness; this may be due to the exapansion occurred by DIC treatment as a result of breaking down of the cell walls of fleshy tomatoes and orange-fleshed sweet potatoes caused by mechanical stress induced by the expansion of vapor generated within the products. The abrupt pressure dropping twords a vacuum is another supporting explanation, wherein the steam is forced out from the product, causing the expansion of the product [16]. On the other hand, the higher the crispness, the lower the chewiness of the product, because the crispness of the product is inversely propotional to the chewiness owing to the low hardness of the product [57]. The crispy product does not require more energy and time to be masticated or to desintegrate its structure untile it becomes ready to swallow, compared to harder products. Furthermore, swell-dried products have generally glassy state owing to the expansion and the abrupt pressure dropping towards a vacuum (cooling effect) which helps the product to cross the glass transition border. As a result of the DIC treatment, the matrix of product undergoes phase transition from soft rubbery (the sate of partially dried product) to stable glassy state at temperature generally below the product's glass transition temperature Tg. In the rubbery state, the product has viscoelastic character which allows the vapor generated inside the product to expand and thus expand the existing structure of the product or create a new internal structure, producing crispy product with an open porous structure. Once the superheated steam pressure is released from the expanded products towards a vacuum, the matrix cools down rapidly and crosses the glass transition border to glassy state, which allows maintaining the final expanded structure of the product [57]; [16]. Wherase, the low texture characteristics of sun-dried and hot-air dried fleshy tomatoes and orange-fleshed sweet potatoes may be related to many phenomena such as 1) the shrinkage and structure collapse occurred during the longtime drying, and **2)** the leathery texture matrix (rubbery sate) which is hard to deform, owing to the plasticizing effect on the solid matrix [58].

Comparing the two products, dried fleshy tomatoes showed higher sensory characteristics than that of orang-fleshed sweet potatoes, this may be due to the variation in the chemical composition, cell wall composition, and water content **[57]. Besides,** the degree of starch retro gradation after blanching may also affect the crispness or the hardness of dried products; higher degrees of starch retro gradation tended to increase the hardness of dried products [58]**.** Indeed, the textural characteristics of dried products are related to the glass transition temperature T_g and greatly depend on the texture morphology; porous or compact texture [59]. Similarly, [60]found that the mechanical properties of dried apple were related to the changes that may be occurred during the drying process, including the changes in its physical state (glassy or rubber) and the structure evolution due to the changes in the cells (shrinkage/swelling) as well as the intercellular spaces and the rupture of cellular bonds.

The results obtained of sensory and textural characteristics are in concurrence with those obtained by **[57]** who reported that sensory and textural characteristics of swell-dried ready-to-eat Zaghloul date **snacks** higher than that dried by conventional hot-air drying; this can be also explained by the open porous structure. Likewise, [61] who reported that the hardness and chewiness were lower for freeze-dried cabbages than that of hot air-dried cabbages, which can be also explained by the open porous solid matrix of freeze-dried cabbages.

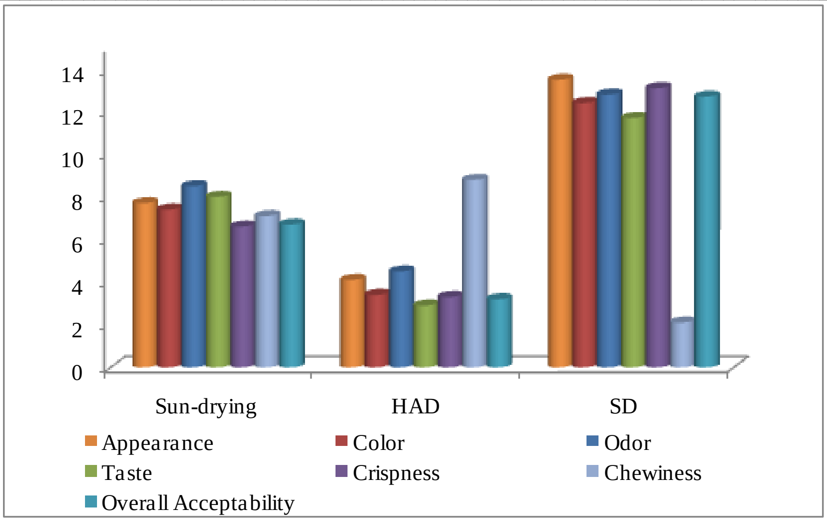

Fig. 3: sensory characteristics of dried fleshy tomatoes by different techniques; sun-drying, conventional hot-air drying (HAD), and swell-drying (SD).

MICROBIOLOGICAL QUALITY

The raw foods may be contaminated with molds, fungi, or various pathogen microorganisms such as Escherichia coli. These microorganisms may cause several serious diseases such as diarrhea, vomiting, cramps, even death. The drying process prevents the growth of these microorganisms resulting from contamination or naturally present in foods, and also contributes to inactivating the enzymatic or non-enzymatic browning reactions [62].

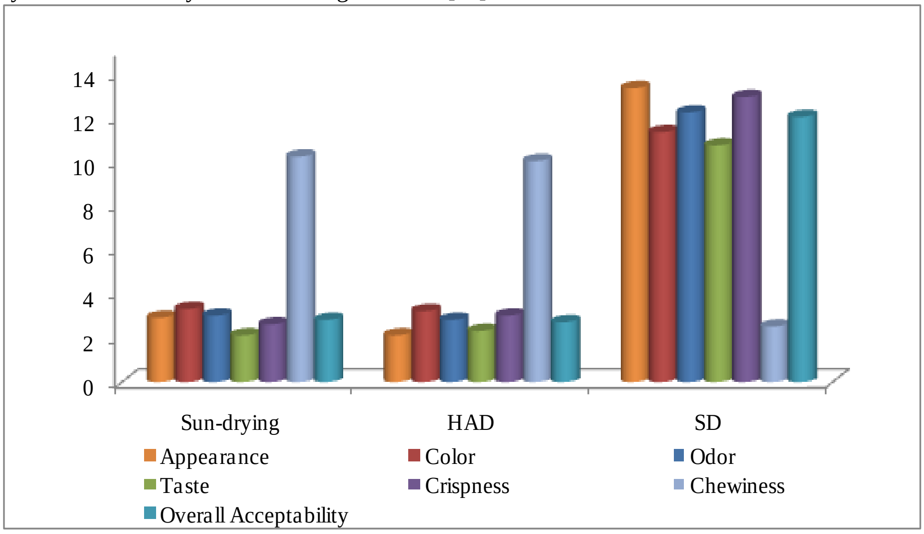

Fig. 4: sensory characteristics of dried orange-fleshed sweet potatoes by different techniques; sun-drying, conventional hot-air drying (HAD), and swell-drying (SD).

The microbiological quality of dried fleshy tomatoes and orange-fleshed sweet potatoes is shown in Table (1). It is observed that the fresh fleshy tomatoes or orange-fleshed sweet potatoes had the highest microbial load, compared to the dried products, where bacteria, fungi, and yeasts coliforms and total mesophilic were found in these fresh products. This may be due to the contamination resulting from contact with soil, dust, and wastewater during harvest and post-harvest periods [10]. The high moisture content of fresh products that promotes microorganism growth is another supporting explanation.

The different drying techniques greatly reduced the microbial load of dried fleshy tomatoes and orange-fleshed sweet potatoes, which may be due to the lower water activity of dried products as a result of water removal. However, the microbiological quality of dried products mainly depended on the drying technique used as well as the drying conditions applied. Among the drying techniques, swell-drying (SD) significantly inactivated or destroyed all the microorganisms studied where no growth of total bacteria, fungi and yeasts, coliforms, *E. coli* and total mesophilic were detected. This microbial destruction may be attributed to thermomechanical impacts resulted from thermal and mechanical stress causing irreversible changes in the microbial cell, including 1) protein denaturation, 2) shrinkage of the cellular membrane, 3) denaturation of the enzyme's protein, and breakdown of the cell structure; [63] [64].These changes are mainly due to the heat shock to which microorganisms are exposed as the temperature increase.

Table (3): Microbiological quality of fresh and dried fleshy tomatoes and orange-fleshed sweet potatoes.

Sample	Total bacterial count (cfu/g)	Fungi and Yeasts count (cfu/g)	Coliforms count (cfu/g)	*E. coli* count (cfu/g)	Total mesophilic count (cfu/g)
			Dried fleshy tomatoes		
Fresh	2.0×10^{3}	8.0×10^{2}	13	Nd	2.70×10^{1}
Sun-drying	1.9×10^{2}	6×10	10	Nd	3×10^{1}
HAD	0.4×10^{2}	0.5×10	Nd	Nd	$0.1\text{x}10^{1}$
SD	Nd	Nd	Nd	Nd	Nd
			Dried, orange-fleshed sweet potatoes		
Fresh	17.2×10^{3}	11×10^{2}	3.2×10^{1}	Nd	3×10^{2}
Sun-drying	3.75×10^{2}	2×10^{1}	17	Nd	6.7×10^{1}
HAD	6.5×10	8	10	Nd	12
SD	Nd	Nd	Nd	Nd	Nd

HAD: Hot-air dried; SD: Swell- drying; Nd: Not detected; cfu: Colony forming unit

The sun-drying was found to reduce significantly the microbial load, where the count of bacteria, fungi and yeasts, coliforms, *E. coli* and total mesophilic was greatly lower than those of the fresh products. The higher microbial load of sun-dried products compared to the other dried products could be explained by the fact that the open-air drying was carried out under uncontrolled or unhygienic conditions which allow contamination from ambient air, dust, and insects, increasing thus the microbial load of sun-dried products. On the other hand, conventional hot-air drying caused a decrease in value observed, in total bacterial, fungi and yeasts, coliforms and total mesophilic were 0.4×10^{2} cfu/g0.5×10^{1} cfu/g, Nd and 0.1×10^{1} cfu/g and 6.5×10 cfu/g,8cfu/g ,10 cfu/g and 12 cfu /g respectively for dried fleshy tomatoes and orange-fleshed sweet potatoes .

This may be attributed to the thermal effect of the drying air and the hygienic conditions followed during the processing. Besides, sun-dried and hot-air dried products had higher water content than the swell-dried products that allow the growth and the proliferation of different microorganisms in the rubbery state of these products as previously mentioned. This hypothesis is also consistent with sensory evaluation results particularly the crispness of dried products.

Comparing the two products, it is found that fresh fleshy tomatoes had lower initial microbial load than those of orange-fleshed sweet potatoes, which may be attributed to the acid nature of tomatoes having pH ranging from 4.3 to 4.6 [56]. On the other hand, since the orange-fleshed sweet potatoes are tubers, the potential contamination from contact with soil increased, increasing thus the initial microbial load. Although the higher initial microbial load of orange-fleshed sweet potatoes, the reduction of microbial load for different dried sweet potatoes was more obvious than that of dried tomatoes, which may be due to the combined effect of drying. It is worthwhile mentioning that *E. coli* was not detected either in fresh or dried fleshy tomatoes and orange-fleshed sweet potatoes.

The results showed that hot air drying significantly reduced the microbial load of dried **tomato slices compared to sun-dried samples [67].** Likewise, the reduction of microbial load of swell-dried apple and onion **[50]**.

3. Conclusion

Drying is one of the oldest methods of food preservation and widely used to extend their storage period as a result of water removal and lower water activity which in turn inhibit microbial growth and reduce enzymatic reactions. However, the quality attributes of dried foods greatly depend on the drying method used and on the drying conditions applied. This work was conducted to study the effect of different drying techniques; sun-drying, conventional hot-air drying, and swell-drying, on the chemical, sensory properties and microbiological quality of dried fleshy tomatoes and orange-fleshed sweet potatoes. The obtained results slowed that swell-drying can be used as alternative drying technique to sun-drying or conventional hot-air drying, due to the high contents of bioactive compounds specifically Ascorbic, Phenolic, Antioxidant, β-carotene and lycopene and improved sensory characteristics, particularly the color, flavor, and crispness of the dried products. Furthermore, swell-drying ensures high microbiological quality of dried products, where a complete destruction of bacteria, fungi, and yeasts was observed.

4. Conflict of interest

All authors declare that they have no conflicts of interest

5. Acknowledgement

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