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RESEARCH ARTICLE

OPTIMIZATION OF THE NUTRITIONAL AND TECHNOLOGICAL VALUE OF TOMATO PRODUCTS THROUGH OSMOTIC DEHYDRATION ASSISTED BY SALINE AND ACID SOLUTIONS

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ABSTRACT

Effective preservation techniques are essential to ensure tomatoes are available year-round, given their high perishability. This study aimed to identify the most effective drying technique for preserving the nutritional and nutraceutical quality of tomatoes. To achieve this, different saline (sodium chloride) and acidic (lemon juice) solutions were used at various concentrations to determine the optimal level. Standard methods were employed for nutritional and bioactive characterisation. The results showed that the T3T5 solution (6% salt + 3% lemon juice) produced the best colour, pH and water content. Analysis showed that tomato powder treated with this solution had the lowest protein (21.07% DM) and lipid (7.72 ± 0.70% DM) contents, as well as the highest Brix degrees (50.63 ± 1.10 °Brix) and sugar content (47.36 ± 2.17% DM), and the greatest energy value (343.21 kcal/100 g DM). The ash (9.03 ± 0.05% DM) and mineral contents were high in the treated tomato powder. Similarly, the treated tomato powders had the highest vitamin C, beta-carotene, lycopene and polyphenol contents. Based on these results, it can be concluded that osmotic dehydration enables tomatoes to be dried using minimal energy while concentrating nutrients for the consumer's benefit.

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INTRODUCTION

The tomato (*Lycopersicon esculentum* Mill) is one of the most widely produced and consumed fruits in the world. Between 2022 and 2023, tomato production increased by more than 5.6 million tons. Over the last decade, production has increased by 13.5%, rising from 166.29 tons to 192.32 tons (FAO, 2024). Despite this increase in global production, some regions still struggle to meet demand at all times. This situation is the result of problems related to pests, low yields, and, above all, post-harvest losses (Titti *et al*., 2024). Tomatoes are climacteric fruits, which means they continue to ripen after harvesting. Research has shown that tomatoes produce higher levels of ethylene after being harvested than when they are still on the plant. It has been demonstrated that this synthesis is even more pronounced when tomatoes are stored at high temperatures (Khalid *et al*., 2024). There is a range of approaches available to minimise post-harvest losses, especially those relating to storage. Among the methods employed are techniques for brine preservation. These involve cutting the tomatoes into large pieces and storing them in salt water (Ogwu & Ogunsola, 2024). This technique allows tomatoes to be stored for a few days, but it is very limited because these tomatoes need to be rinsed several times, which can dissolve certain water-soluble compounds. Furthermore, it should be noted that this technique is only suitable for use with small quantities, as is the case with storage in sterilised jars. One of the most appropriate techniques would be to store the product in a refrigerated environment (Dhanya *et al*., 2023). This technique is an effective solution for the large-scale preservation of tomatoes, while ensuring optimal nutritional integrity (Loayza-Salazar *et al*., 2024). Unfortunately, the cost and complexity of implementation in low-income countries where electricity access remains limited for the majority of the population are significant challenges (van den Wall Bake *et al*., 2025). For these countries, alternative preservation techniques must be considered in order to alleviate the burden on the population. In light of this, a growing number of studies are focusing on drying. Drying would be a beneficial alternative, as it is both economical and suitable for tropical climates that are conducive to tomato cultivation (Houetohossou *et al*., 2024). When executed properly, the drying process preserves nutritional compounds and, most significantly, bioactive phytochemicals. Vitamin C, one of the heat-labile compounds present in tomatoes, can be preserved by drying at temperatures below 60°C for a relatively short period of time in order to limit oxidation (Pravitha *et al*., 2024). Research has demonstrated that drying after pretreatment is a more cost-effective process, as it results in increased dry matter and crude ash content. Furthermore, phenolic compounds are better preserved, especially flavonoids and total phenolics (Nzimande *et al*., 2024). It has been reported by other authors that the drying process limits the oxidation of carotenoids, particularly lycopene. Lycopene is the main antioxidant found in abundance in the human body (Gat & Gawande, 2024). Furthermore, as reported in a number of other relevant studies, tomatoes possess significant nutritional and nutraceutical value, attributable to their high level of bioactive compounds (Nzimande *et al*., 2024). Indeed, the antioxidant capacity that endows tomatoes with their anti-inflammatory, analgesic, antidiabetic and anticancer properties is believed to be associated with the presence of these compounds (Rana *et al*., 2022). Tomatoes are a valuable dietary component, with a proven role in the prevention of both diabetes and cardiovascular disease. The former benefit arises from their impact on alpha-amylase activity, while the latter is attributed to their high antioxidant content (Chabi *et al*., 2024). The low sugar and fat content of tomatoes makes them a highly effective solution in the global fight against the increasingly prevalent issue of obesity, especially in low- and middle-income countries (Chabi *et al*., 2024). Drying is an effective method of preserving the beneficial properties of tomatoes (Oboulbiga *et al*., 2020). However, it is important to note that the drying process must be adapted to the climate, variety, type of pre-treatment, and dietary habits of the population in order to ensure optimal results. The objective of this study was to develop a tomato drying technique that would allow for the preservation of its nutritional and technological properties.

MATERIALS AND METHODS

Study materials

Biological material and ingredients: The study material consisted mainly of fresh tomatoes (*Lycopersicon esculentum*. Mill) belonging to the F1 COBRA 26 variety, lemons (Citrus lemon), and salt used as pre-treatment ingredients. In order to verify the quality of the drying process, these powders were used to produce concentrates. The F1 COBRA 26 tomato variety was collected from the fields of the Institute for the Environment and Agricultural Research (INERA) in Farako-ba, Bobo Dioulasso (longitude 4° 20' West, latitude 11° 06' North, and altitude 40 m). Physiologically ripe tomatoes were picked by hand, packed in crates, and transported to the Food Technology Department (DTA) of the Institute for Research in Applied Sciences and Technologies (IRSAT). The ingredients (table salt and lemon juice) used in the pre-treatment solution formulations were purchased on the market in Ouagadougou.

Solvent and reagent sources: The reagents and solvents used are sourced from CARLO ERBA, VWR, and HIMEDIA in AnalaR NORMAPUR quality from authorized distributors.

Methods

Drying technology: The pretreatment solution is obtained by dissolving salt in distilled water in which lemon juice has been diluted. The solutions were prepared at concentrations of 1 to 9% (m/v) for salt and 3% and 6% (v/v) for lemon juice at a temperature maintained between 80 and 85°C. Plain distilled water was kept at the laboratory's ambient temperature as a control solution. The washed tomatoes were cut and seeded into slices approximately 1 cm in diameter. Drying was carried out at the Technopole workshop of the Food Technology Department of the Institute for Research in Applied Sciences and Technologies (DTA/IRSAT), in accordance with hygiene rules and manufacturing guidelines. The different formulas used for pre-treatment are listed in Table 1-3. For drying, the batches for each test were dried in an Attesta gas dryer. The dryer was preheated to the product drying temperature (50-60°C) for 15 minutes before the racks containing the products to be dried were placed inside.

Choosing the best pretreatment: The choice of the best pretreatment was based on three criteria according to the physicochemical characteristics of the dried tomato quality. Six trials were conducted for preliminary testing of different pretreatments prior to drying. The first selection criterion was based on comparing the treatments by trial according to pH (4.6) as described by UNECE Standard (NORME CEE-ONU DDP-19, 2007). The second criterion was to compare the water content of six pretreatments that were selected based on low pH. The third criterion is the color ratio, which indicates the darkening of the product (Tulasidas *et al*., 1995). Thus, the pretreatment with the lowest pH, low water content, and lowest maturity index was selected as the best pretreatment prior to drying for the rest of the study.

Analysis of physicochemical and biochemical parameters and bioactive compounds

Determination of dry matter and moisture content: The water content was determined based on the amount of dry matter following desiccation. The water content of the samples was determined by differential weighing before and after oven drying sample (ISO-712, 1989). To do this, 5g of the product, which had been crushed beforehand, was weighed in a tared pan and placed in the oven at 103°C105 ± 2°C for 24 hours. The weight was then cooled in a desiccator for 30 minutes and weighed. The water content, expressed as a percentage by weight, was calculated using the following formula:

$$\% \text{ Moisture} = \frac{Pe \ \ (Pf - P \ )}{Pe} \times 100$$

P0 = empty weight of the baskets in grams, Pf=final weight (baskets plus test samples) in grams ; Pe=test sample in grams. The dry matter content can be deduced using the following equation:

DM% = 100 – % Moisture.

Determination of total ash: Ash is the non-combustible mineral residue remaining after the product has been incinerated under specified conditions at a temperature of 550°C. Ash was obtained in accordance with International Standard (ISO 2171, 2023). This method involves weighing the samples before and after dry mineralization. The incineration process is designed to convert all the cations into carbonate and other anhydrous mineral salts. In a clean, dry, pre-weighed crucible, 5 g of ground sample is weighed. The sample is then mineralised in an oven at 550 °C for five hours. Once mineralisation is complete, the crucible is removed and cooled in a desiccator for 30 minutes before being weighed again. The percentage of ash is given by the following equation:

$$\% \text{ Ash} = [\frac{pf - p0}{PE} \times 100] \frac{100}{100 - \% \text{ Moisture}}$$

P0 = empty weight of crucibles; Pf = final weight (crucible + calcined sample); Pe = test sample; MS = dry matter; % moisture = percentage by mass of water previously determined.

Mineral content analysis: Minerals such as calcium, magnesium, zinc, iron, manganese, and copper were analyzed by flame atomic absorption spectrometry according to AOAC 999.11-2005 (2006). Specific instrumental parameters (lamp, wavelength, lamp current, and slit width) were used for each mineral. Extraction was performed after incineration of 3 g of each sample in a muffle furnace at 550 °C for 10 h, followed by dissolution of the ashes with fuming hydrochloric acid (37%). Phosphorus was determined by continuous flow spectrometry (autoanalyzer) (Skalar Analytical B.V., Tinstraat

12, 4823 AA Breda, Netherlands). Potassium and sodium were determined by flame photometry (Sherwood model). The concentration ranges of the standard solutions were 0.5 mg/l, 2.5 mg/l, 5 mg/l, 7.5 mg/l, and 10 mg/l for zinc and iron, and 0.5 mg/l, 2 mg/L, 5 mg/L, and 15 mg/L for magnesium, potassium, and sodium. Highly concentrated samples were diluted before being analyzed with an atomic absorption spectrometer.

Color determination: The color of the pretreated and untreated tomato powder was measured using the method described by (Farooq *et al*., 2020). It was measured using a colorimeter (PCE-CSM 1, PCE instruments, Im Langel 4) based on the International Commission on Illumination (CIELAB) color system : L*, a*, b* and *, C*, h°, a*/b*. The L*, a*, and b* parameters were measured three times for each sample by placing the colorimeter lens on a homogeneous surface of the products. The L* parameter measures approximately brightness or luminance and is expressed on a scale between black and white (0=black, 100=white). The a* parameter takes positive values for reddish colors and negative values for greenish colors, while b* takes positive values for yellowish colors and negative values for bluish colors. The a*/b* ratio values were calculated, and this color ratio essentially indicates the darkening of the product.

Determination of pH: The pH was determined using a digital pH meter (HI 991300, PH/EC/TDS meter) (ISO 1842:1991(F), 1991). A 1 g test sample of the ground sample was taken from a Falcone tube. Then, 25 ml of distilled water was added and the mixture was stirred in a rotary shaker for one hour. After homogenisation, the pH of the suspension was measured using the pH meter, which had been calibrated beforehand using standard buffer solutions at pH 4 and pH 7.

Détermination de l'acidité totale: The acidity of the sample is defined as the total amount of free organic and mineral acids present, including malic, citric and oxalic acids. Acidity was determined using the method described by ISO 750:1998(E) (1998). The solution used to measure the pH of each sample was centrifuged at 5000 rpm for five minutes, then filtered. A few drops of phenolphthalein were added to the supernatant, after which the resulting solution was titrated with NaOH (0.1 N) until a pink colour appeared, indicating the transition zone. Total acidity is expressed as a percentage of citric acid using the following equation:

$$\text{Acidity (\%)} = \frac{N \times V \times Vt}{Vp \times Pe} \times 0{,}070 \times 100$$

N = normality of NaOH ; V = volume of NaOH required to titrate the sample ; Vt = total volume of the solution to be titrated ; Vp = volume to be sampled ; Pe = test sample ; 0.070 = conversion factor (to citric acid).

Determination of total sugars: Total sugars were determined by the sulfuric orcinol method described by Montreuil & and Spik (1969) In the presence of concentrated hot sulfuric acid, carbohydrates undergo quantitative hydrolysis, releasing free sugars and osidic units that are dehydrated into furfuryl derivatives, which condense with orcinol to form an orange-brown complex. This coloration develops maximum absorption at 510 nm. To do this, 0.05 g of each tomato powder sample is placed in a beaker and 5 ml of distilled water is added. The mixture is stirred magnetically for 10 min, transferred to a 100 ml volumetric flask, and the volume is made up with distilled water and then homogenized. Then, 1 mL of the homogenate is taken into a test tube and 2 mL of orcinol reagent and 7 mL of 60% H_2SO_4 are added. The test tubes are shaken and then placed in a boiling water bath for 20 min. They are then placed in the dark for 45 minutes and then at room temperature for 10 minutes. After homogenization, the absorbance is measured at 510 nm using a spectrophotometer. The total sugar content is determined from the previously established D-glucose calibration curve. Carbohydrate contents were calculated using a calibration curve with D-glucose as the reference sugar.

$$\text{\% Total sugars} = \frac{C \times F \times V}{Pe} \times 100$$

C: solution concentration; F: dilution factor; V: total volume; Pe: test sample

Determination of the Brix degree: The percentage of soluble dry matter or Brix degree was determined using the standardized refractometry method (ISO 2173, 2003). The measurement was taken directly using a digital refractometer. This process involves the placement of a drop of the wet sample on the prism of a refractometer. The device provides the Brix and refractive index values. The results, expressed as a percentage, are clearly displayed on the device's dial. The operation is repeated at least three times to ensure the reliability of the values.

Determination of lipid content: The fat content of samples was determined by Soxhlet extraction, adapting the international standard with hexane (ISO 659, 2009). Dried clean flasks were cooled in a desiccator after being heated at 105°C for 45 minutes. The empty flasks were weighed (Pv), 5 g of the sample (Pe) was placed in a cartridge, covered with dehydrated cotton and placed in a Soxhlet extractor. The Soxhlet extractor was then mounted in a flask containing approximately 200 ml of hexane and fitted to the condenser. The heating system was switched on and water was circulated through the condenser. After four hours of extraction, the solvent was evaporated using a rotary evaporator. The flask containing the fat and traces of solvent was placed in an oven at 105 °C for one hour and then cooled in a desiccator. The flask was weighed (Pf) until a constant weight was reached, after which the fat content was expressed as a percentage by weight according to the following formula:

$$\text{\% Lipids} = \left[\frac{pf - p0}{PE} \times 100\right]\frac{100}{100 - \%\text{Moisture}}$$

Lipids : lipid content relative to dry matter; Pf: final weight (flask + fat); Pv: empty weight of flask; Pe: test sample; % Moisture : percentage by mass of water determined beforehand.

Determination of proteins content: The protein content of the samples was determined using the Kjeldahl method described in ISO_20483 (2013). In this procedure, a 2 g sample is weighed, placed in a heat-resistant tube and heated with concentrated H_2SO_4 in the presence of potassium sulfate and a catalyst at a temperature of 400 °C. This step essentially involves the wet oxidation of the sample, whereby the organic components are first carbonised and turn black. Continued heating leads to the sample being completely oxidised to CO_2 and digestate. This digestion step converts the nitrogen in the sample into a soluble, non-volatile form: $(NH_4)_2SO_4$. The digestate is then cooled, appropriately diluted and made alkaline by adding an excess of sodium hydroxide, releasing the nitrogen in quantifiable form as free NH_3. The neutralised digestate is then subjected to steam distillation to separate the volatile NH_3 from the other components. The condensed NH_3 is then trapped in dilute boric acid. The final step is to quantify the trapped NH_3 by titration with dilute hydrochloric acid.

The protein content is obtained using the following formula:

$$\%P = \frac{\left((Ve - 0{,}1) * 0{,}014 * 0{,}1 * 6{,}25\right)}{Pe} * 100$$

With : Ve: Volume of sulfuric acid poured at equivalence; Pe: Weight of test sample; 0.014: Molar weight of nitrogen; 0.1: Normality of sulfuric acid

Evaluation of energy value: The energy value of the samples was calculated using the coefficients of (Atwater & Rosa, 1899) according to the following formula:

Energie (Kcal/100g) = % glucides × 4 Kcal + % protéines × 4 Kcal + % lipides × 9 Kcal

Determination of bioactive compound content

Determination of lycopene and beta-carotene: Lycopene and beta-carotene contents were determined as previously described by Nagata & Yamashita (1992). Lycopene and beta-carotene contents were expressed in mg/100 g dry matter (DM). A 100 mg sample was dissolved in 10 ml of 70 :30 (v/v) acetone-water. After centrifugation for 10 min, the supernatant was collected and readings were taken using a spectrophotometer at different wavelengths of 453 nm, 505 nm, 645 nm, and 663 nm. The lycopene and beta-carotene contents were calculated using the following formulas:

Lycopene (mg/100 ml) = -0, 0458-A_{663} + 0,204-A_{645} + 0,372-A_{505} - 0, 0806-A_{453}

β-Carotene (mg/100 mL) = 0, 216-A_{663} - 1,22-A_{645} - 0,304-A_{505} + 0,452-A_{453}

Where the letter A represents absorbance and the underlined numbers are wavelengths.

Determination of vitamin C: The method used for quantifying ascorbic acid is based on its ability to decolorize 2,6-dichlorophenolindophenol (DCPIP) (Mehta *et al*., 2018). The extracts (250 µl) were added to 750 µl of DCPIP (0.2 mM). The absorbance was read at 515 nm relative to a blank compound prepared under the same conditions. A calibration curve was plotted with ascorbic acid at concentrations ranging from 10 µg/ml to 100 µg/ml. Vitamin C contents are expressed in mg of ascorbic acid equivalent per 100 g of dry matter (mg AAE/100 g DM). The absorbance was read at 515 nm and a calibration curve was plotted with ascorbic acid and the contents expressed in mg of ascorbic acid equivalent per 100 g of dry matter (mg AAE/100 g DM) :

$$AA = \frac{C \times D}{Ci} \times 100$$

Polyphenol measurement: Total polyphenol measurement was performed using the method described by Singleton & Rossi (1965). This method is based on the reduction of Folin Ciocalteu reagent, consisting of phosphotungstic and phosphomolybdic acids, in a slightly alkaline medium by phenolate ions. The reduction products (tungsten and molybdenum) have a blue color and absorb at 760 nm. This color generally reflects the of phenols contents expressed as gallic acid equivalent. The results are expressed in milligrams of gallic acid equivalent per gram of dry matter (mg GAE/g DM) with reference to a calibration curve established under the same conditions.

Statistical analysis The analyses were performed in triplicate to minimize bias and facilitate statistical processing. XLSTAT software was used for ANOVA analyses. Excel and Prism GraphPad software were used to construct the figures.

RESULTS AND DISCUSSION

Results

Choice of the best treatment: The results in Table 4 shows the pH variation of different treatments in the tomato powder test with or without pretreatment by osmotic dehydration (OD). The pH of the first test ranged from 3.5 ± 0.00 (T1T8) to 4.3 for test 5. ANOVA analysis showed a statistically significant variation in pH between the different treatments and tests. In order to meet the treatment selection criteria, the treatments with the lowest pH values were identified. These results are shown in Table 5. Among the treatments with the lowest pH values, treatment T1T8 had the highest water content (18.2 ± 0.04%) and treatment T5T5 had the lowest (14.5 ± 0.11%) (Table 5). Measurement of the a*/b* ratios of the red color showed that the lowest maturity index was recorded at 0.9 ± 0.02 (sample T3T5) and the highest at 1.4 ± 0.07 for sample T4T8. Based on the established criteria, it appears that sample T5T5 recorded the lowest water content (14.5 ± 0.11%) but with a higher red color index (a*/b* =1.0 ± 0.21) than sample T3T5, which recorded the lowest index (a*/b* =0.9 ± 0.02) and a water content (14.8 ± 0.04%) closer to that of T5T5. The T3T5 pretreatment was the most satisfactory compared to the other pretreatments and was the subject of the rest of this study for the evaluation of the nutritional and sanitary quality of the tomato pretreated with DO and dried.

Tomato powder rehydration test: The results in Table 6 showed that the Brix values of the samples from the rehydrated treated powder ranged from 10.3 ± 0.1 (F11) to 50.63 ± 1.10 (F1). For samples from untreated powder, Brix values ranged from 10.06 ± 0.05 (F11) to 45.06 ± 0.4 (F1). Samples of untreated powder (P-TNT) had Brix values of 34.3 ± 0.1 °Birx (F2); 27.3 ± 0.43 °Brix (F2) and 15.1 ± 0.1 °Brix (F7) respectively for the Brix of the triple concentrate, double concentrate and paste are the most satisfactory. However, it was found that tomato powder pretreated (P-TT) by DO had a non-homogeneous texture in the paste; two phases separated 30 min after rehydration (water and powder deposit). Therefore, tomato powder without DO pretreatment was the best product for the formulation of concentrates.

Biochemical characteristics of tomato powder pretreated with 6% NaCl + 3% lemon juice: The results (Figure 1) show that the highest total sugar content was recorded in the treated tomato powder (47.36 ± 2.17% DM) compared to the untreated control (36.28 ± 1.45% DM). The lipid content (Figure 1) is slightly higher in the untreated powder at 8.21 ± 0.19% DM compared to the control (7.72 ± 0.70% DM). However, pretreatment resulted in a loss of approximately 5.97% of the value of the untreated powder. The results in Figure 1 show that the lowest protein content was obtained in the treated powder (21.07% DM) and the highest content in the untreated powder (33.62% DM). The protein loss in the treated powder is approximately 37.32% (Figure 1). The lowest energy value was observed in the untreated tomato powder (279.6 Kcal/100 g DM) and the highest in the treated tomato powder (343.21 Kcal/100 g DM). The energy value is higher in the treated tomato powder, with an 18% increase over the untreated powder. The results (Figure 1) show that the highest total ash content was found in the tomato powder treated with 9.03 ± 0.05% DM. The untreated powder had a lower rate of 3.48 ± 0.25% DM of crude ash. This increase in total minerals was 159.48% compared to the control powder. As demonstrated in Figure 2, calcium and magnesium are the predominant minerals in the treated powder, while copper, zinc, and iron are present in the lowest concentrations in the untreated powder. It has been demonstrated that minerals are generally more concentrated in the treated powder.

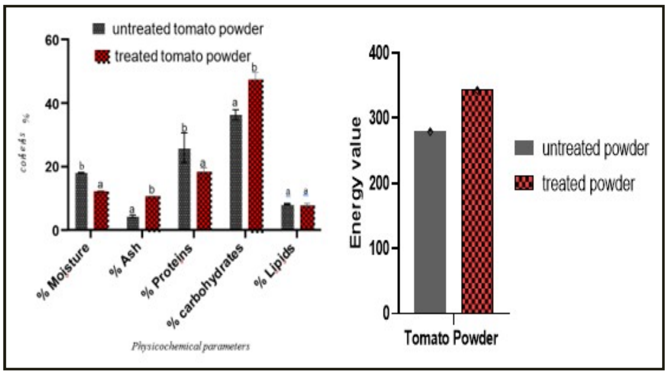

Figure 1. Proximal composition and energy values of treated and untreated tomatoes

Bioactive compounds: Lycopene is one of the most abundant carotenoids in tomatoes and plays a very important role in their coloration. The results in Figure 3 showed that the lycopene content is higher in the treated tomato powder (53.98 mg/100 g) than in the control (46.51 mg/100 g). Beta-carotene is a red-orange organic compound that is abundant in tomatoes. Analysis of the results (Figure 3) shows that β-carotene content is higher in untreated powder (113.06 mg/100 g DM) and lowest in treated powder (36.61 mg/100 g DM). These differences are statistically significant at the 5% level. Vitamin C is the most abundant vitamin in vegetables, particularly in tomatoes.

Table 1. First and second test of different pretreatments before drying

Treatments	Test 1	Test 2
T1	Control without any pre-treatment	Control sample without any pre-treatment
T2	Soaking in hot water (80 to 85°C)	Soaking in hot water (80 to 85°C)
T3	Soaking in hot water + salt (1%) + lemon (3%)	Soaking in hot water + salt (1%) + lemon (6%)
T4	Soaking in hot water + salt (2%) + lemon (3%)	Soaking in hot water + salt (2%) + lemon (6%)
T5	Soaking in hot water + salt (3%) + lemon (3%)	Soaking in hot water + salt (3%) + lemon (6%)
T6	Soaking in water + salt (1%) + lemon (3%)	Soaking in water + salt (1%) + lemon (6%)
T7	Soaking in water + salt (2%) + lemon (3%)	Soaking in water + salt (2%) + lemon (6%)
T8	Soaking in water + salt (3%) + lemon (3%)	Soaking in water + salt (3%) + lemon (6%)

Table 2. Third and fourth trial of different pretreatments before drying

Treatments	Test 3 :	Test 4 :
T1	Control without any pre-treatment	Control without any pre-treatment
T2	Soaking in hot water (80 to 85°C)	Soaking in hot water (80 to 85°C)
T3	Soaking in hot water + salt (4%) + lemon (3%)	Soaking in hot water + salt (4%) + lemon (6%)
T4	Soaking in hot water + salt (5%) + lemon (3%)	Soaking in hot water + salt (5%) + lemon (6%)
T5	Soaking in hot water + salt (6%) + lemon (3%)	Soaking in hot water + salt (6%) + lemon (6%)
T6	Soaking in water + salt (4%) + lemon (3%)	Soaking in water + salt (4%) + lemon (6%)
T7	Soaking in water + salt (5%) + lemon (3%)	Soaking in water + salt (5%) + lemon (6%)
T8	Soaking in water + salt (6%) + lemon (3%)	Soaking in water + salt (6%) + lemon (6%)

Table 3. fifth and sixth trial of different pretreatments before drying

Treatments	Test 5 :	Test 6 :
T1	Control without pre-treatment	Control without pre-treatment
T2	Soaking in hot water (80 to 85°C)	Soaking in hot water (80 to 85°C)
T3	Soaking in hot water + salt (7%) + lemon (3%)	Soaking in hot water + salt (7%) + lemon (6%)
T4	Soaking in hot water + salt (8%) + lemon (3%)	Soaking in hot water + salt (8%) + lemon (6%)
T5	Soaking in hot water + salt (9%) + lemon (3%)	Soaking in hot water + salt (9%) + lemon (6%)
T6	Soaking in water + salt (7%) + lemon (3%)	Soaking in water + salt (7%) + lemon (6%)
T7	Soaking in water + salt (8%) + lemon (3%)	Soaking in water + salt (8%) + lemon (6%)
T8	Soaking in water + salt (9%) + lemon (3%)	Soaking in water + salt (9%) + lemon (6%)

Table 4. pH of tomato powder with or without pretreatment

Valeurs du pH des différents traitements						
Traitements	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
T1	4.1 ± 0.00^{f}	4.1 ± 0.15^{d}	4.1 ± 0.01^{f}	4.3 ± 0.01^{c}	4.3 ± 0.01^{d}	4.1 ± 0.01^{e}
T2	4.0 ± 0.00^{e}	3.9 ± 0.01^{c}	4.1 ± 0.01^{f}	4.3 ± 0.02^{abc}	4.3 ± 0.00^{d}	3.9 ± 0.02^{d}
T6	3.7 ± 0.01^{d}	3.8 ± 0.01^{b}	3.8 ± 0.01^{d}	4.1 ± 0.00^{abc}	4.1 ± 0.00^{c}	3.7 ± 0.01^{ab}
T3	3.5 ± 0.00^{a}	3.7 ± 0.01^{ab}	3.7 ± 0.02^{bc}	4.0 ± 0.00^{ab}	4.1 ± 0.01^{c}	3.7 ± 0.00^{b}
T5	3.5 ± 0.01^{abc}	3.8 ± 0.02^{b}	3.7 ± 0.00^{a}	4.3 ± 0.05^{bc}	4.0 ± 0.00^{a}	3.7 ± 0.00^{b}
T7	3.6 ± 0.00^{c}	3.7 ± 0.01^{ab}	3.7 ± 0.00^{a}	4.0 ± 0.01^{ab}	4.0 ± 0.02^{ab}	3.7 ± 0.01^{ab}
T4	3.5 ± 0.01^{ab}	3.7 ± 0.00^{a}	3.7 ± 0.02^{b}	4.05 ± 0.01^{abc}	4.1 ± 0.00^{c}	3.7 ± 0.00^{b}
T8	3.5 ± 0.00^{a}	3.7 ± 0.00^{a}	3.8 ± 0.00^{c}	3.9 ± 0.00^{a}	4.0 ± 0.00^{b}	3.6 ± 0.00^{a}
Pr > F	0.00	0.00	0.00	0.12	0.00	0.00
Significant	Yes	Yes	Yes	Yes	Yes	Yes

The mean values in the same row with the same superscript letters are not significantly different at the probability threshold. E=Test (ranges from 1 to 6); T=Treatment (ranges from 1 to 8)

Table 5. Moisture content of tomato powder from six (06) selected samples

Tests (T)/ Treatments (T)	pH	Moisture (%/MS)	a*/b*
T1/T8 : Soaking in water + 3% NaCl + 3% lemon juice	3.5 ± 0.00	18.2 ± 0.04	1.1 ± 0.07
T2/T7 : Soaking in water + 2% NaCl + 6% lemon juice	3.7 ± 0.01	16.5 ± 0.11	1.0 ± 0.14
T3/T5 : Soaking in hot water + 6% NaCl + 3% lemon juice	3.7 ± 0.00	14.8 ± 0.04	0.9 ± 0.02
T4/T8 : Soaking in water + 6% NaCl + 6% lemon juice	3.9 ± 0.00	18.8 ± 0.06	1.4 ± 0.07
T5/T5 : Soaking in hot water + 9% NaCl + 3% lemon juice	4.0 ± 0.00	14.5 ± 0.11	1.0 ± 0.21
T6/T8 : Soaking in water + 9% NaCl + 6% lemon juice	3.6 ± 0.00	15.9 ± 0.06	0.9 ± 0.03

Table 6. Brix content of the eleven tomato concentrates formulations developed

Tests / Formulations	Quantity of powder (mg)	Volume of hot water (ml	Quantity of rehydrated powder (g/l)	Brix P-TT	Brix P-TNT
F1	5	5	1000	50.63 ± 1.10^{de}	45.06 ± 0.47^{cd}
F2	5	8	625	37.46 ± 0.2^{d}	34.3 ± 0.1^{bc}
F3	5	11	455	28.06 ± 0.95^{c}	27.3 ± 0.43^{c}
F4	5	14	294	22.26 ± 0.77^{bc}	22.5 ± 0.1^{bc}
F5	5	17	250	20.23 ± 0.23^{abc}	18.13 ± 0.15^{abc}
F6	5	20	217	16.76 ± 0.57^{b}	16.36 ± 0.05^{b}
F7	5	23	192	15.1 ± 0.00^{b}	15.1 ± 0.1^{b}
F8	5	26	172	13.8 ± 0.00^{ab}	12.83 ± 0.05^{ab}
F9	5	29	156	12.1 ± 0.1^{a}	12.1 ± 0.00^{a}
F10	5	32	143	11.4 ± 0.00^{a}	10.8 ± 0.00^{a}

[illegible]

The vitamin C assay results presented in Figure 3 show that the amount of ascorbic acid is higher in pretreated tomato powder (P-TT) at 10.02 ± 0.17 mg/100 g DM compared to the control (7.35 ± 0.61 mg/100 g). For polyphenols, the contents varied from 359.45 ± 3.5 to 539.88 ± 17.48 mg EAG/100 g DM for untreated and treated tomato powder, respectively (Figure 3).

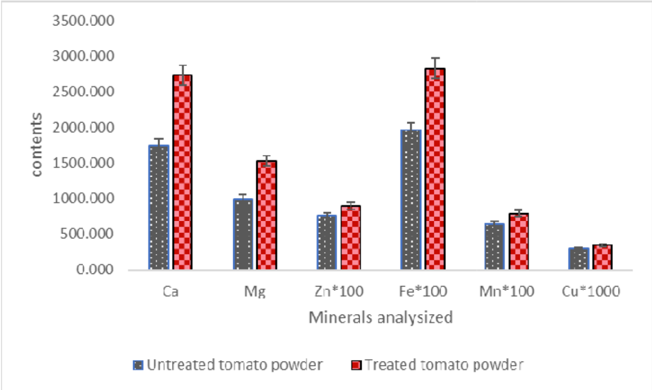

Figure 2. Mineral content of the two tomato powders

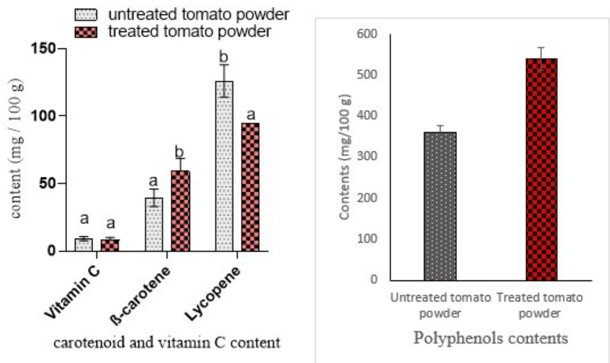

Figure 3. Bioactive compound content of the two tomato powders

DISCUSSION

Promoting healthy and safe food is a significant challenge for low- and middle-income countries when it comes to implementing sustainable development strategies. In a context where the challenge is to reduce food losses while ensuring optimal long-term food preservation, agri-food processing is a strategic priority. Due to their high water content, tomatoes are highly perishable and require processing to ensure optimal preservation. In this study, which focused on the testing of an osmotic dehydration drying method, it was found that pH levels varied significantly from one pre-treatment to another. This may be due to the addition of lemon, which is rich in citric acid, or the salt concentration, which causes the tomatoes to dehydrate. As the water content of tomatoes decreases, there is an increase in the concentration of organic acids, which can have an impact on the pH level. This observation corroborates the findings of other studies (Oboulbiga *et al*., 2020). Furthermore, the salt concentration could have an impact on the ripening ratio. Furthermore, the selection of the most effective pretreatment in this study was informed by the sodium chloride content. Consequently, the option with lower sodium content is prioritised in order to safeguard consumers from cardiovascular diseases, particularly hypertension.

An analysis of the biochemical composition of the powder produced by the best pretreatment showed that osmotic dehydration increases the total soluble solids content compared to powder produced from untreated tomatoes. It is evident that, in addition to extending the shelf life of tomatoes, pretreatment also increases the dry matter content. This method is designed to concentrate the nutrients found in tomatoes. For the same quantity, more nutrients are consumed in pretreated tomato powder than in untreated powder. It has been reported by other authors that pretreatment also reduces oxidation in tomatoes, thereby increasing their antioxidant capacity (Oboulbiga, 2018). An analysis of the results indicates that the values found are in alignment with those outlined in the Codex Alimentarius CXS 57-1981, with amendments as of 2022. The findings range from 7% to 22% for paste, 22% to 32% for double concentrate, and a minimum of 32% for triple concentrate. The best paste, double concentrate, and triple concentrate were selected through visual assessment based on consistency. It is unfortunate that the powder produced by pre-treatment in this study is not well suited to rehydration for tomato concentrates. The presence of these two phases is believed to be a result of the low solubility of the powder, which is in contrast to the findings reported in other studies. Proximate composition analysis indicates that pretreatment significantly increases total sugar content. The increase was 23.40% compared to untreated powder. This would be related to the increase in total soluble solids content. Other researchers have obtained comparable results, finding that sweetness is enhanced through osmotic dehydration (Galus *et al*., 2025). In contrast to the effects of osmotic dehydration on carbohydrates, the lipid content of the sample decreased. This was unexpected, as one might have expected these levels to increase with the decrease in water content. For lipids, pre-treatment resulted in a loss of approximately 5.97% compared to untreated powder. As noted by other authors, the decrease in lipid content could contribute to the stability of tomato powder (Hassan *et al*., 2024). Nevertheless, the lipid levels documented in this study exceeded those reported by the aforementioned authors (Hassan *et al*., 2024). This variation may be attributable to the NaCl concentrations present in the pretreatment solution, the specific tomato variety examined, and the applied drying temperature. Lipids are vital nutrients for human health. While lipids are vital for optimal bodily function, excessive consumption of saturated fatty acids can lead to elevated postprandial triglycerides, which, as we know, promote atherosclerosis (Bravo-Núñez *et al*., 2024). As with lipids, the protein content of the treated tomato powder was reduced. This decrease was estimated at 37.32%. The decrease in protein content could be explained by the action of citric acid and NaCl. Proteins precipitate when they come into contact with a strongly acidic solution. Research has demonstrated that, in the presence of NaCl, proteins can undergo conformational changes and that at elevated temperatures, they can denature (Mateo-Roque *et al*., 2024). Despite a decrease in lipid and protein content, the energy value of the treated tomato powder increased by 18% compared to the untreated powder. This increase can be attributed to the rise in total sugar content. It is therefore evident that osmotic dehydration enhances the dry matter content and, consequently, the energy content of treated tomatoes. This observation has been made in other studies, which have shown that dehydration significantly improves the nutritional value of treated tomatoes (Asghari *et al*., 2024 ; Lamesgen & Lejalem Abeble, 2022).

Among the parameters studied, total ash content was the most significant, with other factors such as moisture content and ash yield also being considered. The increase in total minerals compared to the control powder was 159.48%. Azumah *et al*. (2024) Similar results were found and this increase in ash content was justified by the decrease in water content, which leads to a concentration of nutrients. Of the analysed minerals, calcium had the highest content, followed by magnesium, while copper had the lowest concentration. Therefore, pre-treated tomatoes are better able to combat mineral deficiencies and enable the body to function normally. It has indeed been shown that fruits and vegetables play a crucial role in a healthy diet and are an excellent source of minerals (Ouattara & Konate, 2024). Therefore, these pre-treatments could be recommended for pregnant women, the elderly and children, who generally have calcium, magnesium and iron deficiencies (Ikram *et al*., 2024). The nutritional importance of fruit and vegetables also lies in their high bioactive compound content. This study shows that osmotic dehydration prior to processing results in better preservation of the colour of tomatoes. Indeed, the lycopene and β-carotene content increased after dehydration. This could be due to the decrease in water content leading to a concentration of nutrients (Azumah *et al*., 2024). Lycopene is one of the most abundant carotenoids in tomatoes. It is responsible for their red color. It is also a major antioxidant in the human body. It's really important for preventing and treating oxidative stress and the start of a bunch of chronic diseases (Irina *et al*., 2024). Consuming tomatoes regularly has been shown in studies to offer protection against cancer and cardiovascular disease, thanks to their lycopene content (Kaboré *et al*., 2022). However, the results are not consistent when isolated lycopene is used as a supplement. In addition to lycopene, tomatoes contain a range of bioactive compounds that offer significant health benefits, including β-carotene, vitamin C and phenolic compounds (Szabo *et al*., 2025). As with lycopene, β-carotene is an antioxidant that can protect the human body from free radical damage and limit oxidative stress. It is also a provitamin A, which is useful in combating vitamin A deficiency. In the human body, β-carotene undergoes biochemical reactions to be converted into vitamin A according to the body's needs under certain conditions (Kaboré *et al*., 2022). Treatment of the tomato powder resulted in higher levels of vitamin C compared to the untreated powder. Given the vital role of vitamin C in the human organism, it is important to consume fruits that are rich in this nutrient, such as tomatoes that have been pretreated by osmotic dehydration. In addition to combating fatigue, vitamin C contributes to collagen synthesis and increases the absorption of non-heme iron. Vitamin C is a powerful antioxidant that helps prevent many chronic diseases and slow premature aging (Dakuyo *et al*., 2023). Phenolic compounds are recognised as antioxidant molecules for the human body. The levels obtained in this study are lower than those in previous studies (Bahanla Oboulbiga, 2018). This could be due to variations in soil and climate conditions. While they are not considered essential metabolites, they play a crucial role in maintaining wellbeing and ensuring optimal functioning (Corrado *et al*., 2025). Their function is to trap free radicals, reduce inflammation, and prevent cell oxidation. In addition to their antimicrobial properties, they have analgesic effects (Hay Mele *et al*., 2025).

CONCLUSION

This analysis demonstrates that osmotic dehydration is an effective pretreatment technique for accelerating the drying process and optimising the nutrient content of the final product. The macronutrient and micronutrient content was significantly influenced by pretreatment. This pretreatment also optimised the preservation of bioactive compounds, thus ensuring the nutraceutical properties of the treated tomatoes. It is therefore essential to optimise this pretreatment in order to increase and/or maintain the lipid and protein contents in the final product.

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Consent for publication: We consent to the publication of this article which is the result of collaboration.

Authors contributions

CP, PMJSK et MAET: conceptualization; data validation, design ; manuscript writing

PMJSK ; MAET: conceptualization; analysis, manuscript writing, data research, design ; CP, CID, MKS : conceptualization; data validation ; supervision IMA, MS, AL, OB, AT, COT : supporting, analysis KK, : manuscript writing, data research, data analysis, design PMJSK ; MAET, KK : conceptualization; data analysis; CP : manuscript writing, supervision

Declaration of competing interest: The authors declare that there is no conflict of interest.

Data availability: The data that support the findings of this study are available from the corresponding author, (K. K), upon reasonable request.

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