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ORIGINAL ARTICLE

Use of sodium metabisulphite and citric acid to control the degradation of nutraceutical compounds in dried tomato powder during prolonged storage

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Abstract

Application of weak acid and preservatives on tomatoes has the potential to reduce the loss of functional properties during drying. The effects of using sodium metabisulphite (SMB) and citric acid (CA) to control the degradation of nutraceuticals in dried tomatoes were studied. The following treatments: T_0 (control, no additives), T_1 (1% w/v CA), T_2 (0.5% w/v CA +0.5% w/v SMB), and drying methods (dehydration, sun, and solar) were used. The T_2 pretreated samples, dried using the sun, solar, and dehydration had total soluble solids (TSS) (5.10%), total sugar (TS) (7.32 g/100 g), and rehydration ratio (RR) (2.0) and β-carotene (30.0 mg/100 g), lycopene (51.3 mg/100 g), ascorbic acid (14.1 mg/100 g), respectively. The T_2 pretreated and dehydrated samples had a high Trolox equivalent antioxidant capacity (TEAC) and 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity. By using T_2 treatment and dehydration, the tomato had the best functional properties, which would be used as optimal conditions for preserving tomatoes.

Novelty impact statement: Hybrid Amukela Plus tomatoes pretreated with 0.5% w/v CA +0.5% w/v SMB and dried -in a food dehydrator preserved -further degradation of nutraceutical compounds and resulted in a β-carotene (30.0 mg/100 g), lycopene (51.3 mg/100 g), and ascorbic acid (14.1 mg/100 g) content during storage. These treatments produced dried tomatoes with over 50% Trolox equivalent antioxidant capacity (TEAC) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity. Solar and sun-drying treatments have significant damage on the nutraceutical compounds in the dried hybrid tomatoes.

1 | INTRODUCTION

Tomato (*Solanum lycopersicum* L) is the most widely grown vegetable which is consumed raw and processed (Farooq et al., 2020; Obadina et al., 2018). Nutrients that are present in tomatoes include carotenoids, essential amino acids, fiber minerals, monounsaturated fatty acids, vitamins, protein, and phytosterols (Chaudhary et al., 2018).

Nutraceuticals are defined as food or part of food that supports the body's function, in addition to being nutritious (Sawicka et al., 2019). These foods are important in providing health, medical benefits, and disease prevention and treatment (Torabally & Rahmanpoor, 2019). The presence of these nutrients and bioactive compounds which are normally referred to as secondary metabolites at relatively high levels in fruits and vegetables has been correlated with the prevention of cardiovascular disease (CVD), cancer, and neurodegenerative diseases (Cheng et al., 2019; Li et al., 2020). Further, the high concentrations of different natural antioxidants, such as vitamin C (ascorbic acid), carotenoids (β-carotenoids and lycopene), tocopherol (vitamin E), phytonutrients including flavonoids (kaempferol, naringenin, and quercetin and rutin), hydroxycinnamic acids (caffeic, coumaric acid, and ferulic), and

FIGURE 1 Drying methods (a) Food dehydration, (b) Solar drying and (c) Sun drying

chlorogenic acids in tomatoes can help to improve chronic diseases and other health-related conditions (Aderibigbe et al., 2018; Navarro-González et al., 2018).

Tomato is among the world's most popular vegetables with Africa, taking 11.9% of the total world production (Anonymous, 2019). Statistics on tomato production from the Food and Agriculture Organization have showed that over 23,000 tons were produced in Zimbabwe in the year 2019 (Anonymous, 2019). Tomato production occupies a significant position in the vegetable industry in Zimbabwe. The lack of proper processing and storage facilities has resulted in tomatoes being spoiled on the market during the peak harvesting period in Zimbabwe. The problem of postharvest losses of tomatoes is increasing with each harvesting and marketing period. Arah et al. (2015) reported a major problem in postharvest losses of tomato in most developing countries.

To attain a better level of food security and to reduce losses in the value chain of tomatoes, the tomatoes must be processed into value-added products and preserved for a longer storage period (Farooq et al., 2020). Drying of tomatoes can be used by many small scale food processors as a suitable low-cost processing method that is aimed at preserving food by reducing the moisture content and water activity (Castoldi et al., 2015). The drying processing becomes important in reducing packaging and transportation costs as it significantly lowers the weight and volume of the dried product, and improves its keeping quality in storage (Cuq et al., 2011). Many drying methods can be employed on tomatoes and their efficiency is affected by the tomato variety, air temperature, size of tomato slices, drying rate, total soluble solids (°Brix) of the fresh tomato, air humidity and velocity, and type of drying process (Jayathunge et al. (2012). The high temperatures used in conventional air drying affect the color, texture, flavor, and nutritional composition of the dried product (Penarrieta et al., 2011). Therefore, it is important to pre-treat the tomatoes and limit the degradation of compounds during and after the drying process. Information on the effect of using weak acid and preservatives to reduce the degradation of bioactive compounds in dried hybrid tomatoes varieties, especially the Amukela plus is scarce. Therefore, this study aimed to evaluate the use of SMB and CA to control the degradation of nutraceuticals in dried tomato powder during storage.

2 | MATERIAL AND METHODS

2.1 | Raw material

Fresh tomatoes (Hybrid Amukela Plus variety from Zimbabwe) without any visible microbial infection or mechanical openings were purchased from farmers in Murombedzi (a rural growth point area located 17° 42'S 30° 12'E in Agro farming region 2) in Zvimba District, Zimbabwe. The Hybrid Amukela Plus tomato variety was chosen because it is disease resistant, widely produced, high in yield, and early maturity variety, and has adapted to the Zimbabwean climatic conditions. The purchased fresh tomatoes were taken to the laboratory, sorted, washed using tap water, and kept at room temperature before analysis.

2.2 | *Experimental design*

The washed tomatoes were cut into 10 mm thick slices using a stainless steel knife. A 3 × 3 factorial design for treatments: T_0 (control, no additives), T_1 (1% w/v CA), T_2 (0.5% w/v CA +0.5% w/v SMB) and drying methods (solar, sun and dehydration) were used. The slices were treated by dipping into T_0, T_1, and T_2 prepared solutions for 10 min. The treatment solutions were then drained and tomato slices were sun-dried, solar-dried, and dehydrated.

2.3 | Drying processes

Drying of the pretreated tomato slices was done using three methods, viz. dehydration, solar and sun drying (Figure 1). In dehydration, the tomato slices were spread on 2 horizontal trays of size 0.3 m × 0.3 m each and were spaced 0.13 m apart. The height of the food dehydrator was 0.44 m. The temperature and humidity inside the food dehydrator

(BK002, Mellerware Biltong King, South Africa) were monitored. Solar drying of the tomato slices was carried out using a solar dryer purchased by Chinhoyi University of Technology. The tomato samples were spread on a drying tray that was mounted at 20° from the transparent plastic cover and placed into the drying chamber of the solar dryer. The drying chamber was painted black and had air holes to allow air to enter and exit the drying chamber. The samples were constantly checked and monitored until constant moisture content was obtained in the dried tomato samples. In sun drying, the sliced tomato samples were placed and distributed evenly on a horizontal open tray that was assembled to a wooden frame (0.8 m × 1 m) and dried under direct sunlight at temperatures between 25°C and 28°C. The tray was placed on a platform that was 0.5 m from the ground and elevated at an angle of 20°. The tray was then covered with a perforated film to prevent dust, insects, and rodents. The average wind speed in the area was 2.2 ms^{-1}. The total exposure time of the tomato slices to the sun was determined according to the angle of the drying tray toward the sun rays, temperature, and air movement. The experiments were conducted on a bright sunny day from 8 a.m. to 5 p.m. The drying time was approximately 9 hr and the samples were constantly turned and checked after every 3 hr. All dried samples were then ground to powder. The powdered tomato samples were packed in low density polyethylene (LDPE) plastics and then stored at room temperature until analysis.

2.4 | Moisture content, pH, titratable acidity, and total soluble solids

Proximate analysis on moisture content was determined using the Association of Official Analytical Chemists (AOAC) (AOAC method 925.45), ash content using dry ashing (AOAC method 938.08), and mineral content using Inductively Coupled Plasma–Optical Emission Spectrometer (ICP-OES) (Agilent 5100, Agilent Technologies, Santa Clara, California, USA) according to the standard methods by the AOAC (Anonymous, 2005). Vitamin C (ascorbic acid) content was determined using the Dichlorophenolindophenol (DCPIP) titration method and pH was determined using a digital pH meter (BT-675, BOECO, Hamburg, Germany) which was calibrated with pH 4.0 and 7.0 according to the AOAC method (Anonymous, 2005). TSS (°Brix) was determined using a digital refractometer (MA871, North Carolina, Milwaukee Instruments, USA) at 20°C. Titratable acidity (TA) was determined following a standard method by AOAC (Anonymous, 2005). Ten grams of sample was diluted with 100 mL distilled water and titrated against 0.1 M NaOH solution. The TA was expressed as g /100 g of CA by multiplying the volume of NaOH used by a correction factor of 0.064. The TS content was determined following the sulphuric acid method described by Debebe et al. (2018).

2.5 | β-carotene and lycopene

The extraction of carotenoids was conducted following a method described by Rodriguez-Amaya and Kimura (2004) with slight modifications in the extraction solvent and absorbance level. A 15 g sample was weighed with a digital balance (B204-S, MK II, Mettler Toledo, Switzerland) and 25 mL of acetone was then added to obtain a paste. The paste was then placed in a sintered funnel (5 μm) and filtered under vacuum into a 250 mL flask. The filtration process was repeated until a colorless sample was obtained. The colorless extract was then mixed with 40 mL of petroleum ether in a 500 mL flask. Ultrapure water was added to remove the acetone. The extract was then mixed with 15 g of anhydrous sodium sulfate in a 50 mL volumetric flask. Petroleum ether was added to fill up the volume to 50 mL. The β-carotene content of tomato samples was determined by drying a 2 mL sample of the carotenoid extract and then diluting it with 100 μL acetone using a vortex mixer (Genie 2-Scientific Industries). The resultant mixture was then transferred to a 2 mL amber flask of the HPLC for analysis. The absorbance of the sample was measured at 436 nm for β-carotene and petroleum ether was used as a blank. The β-carotene was determined following an equation by Rodriguez-Amaya and Kimura (2004) and expressed in mg/100 g.

The lycopene content was determined following a method described by Srivastava and Kumar (2004). A 10 g sample was extracted with acetone and the colorless extract was transferred to a separating funnel containing 15 mL petroleum ether. Sodium sulfate (5%) solution was then added. The mixture was repeatedly extracted with petroleum ether until it became colorless. The volume of the upper petroleum ether extract was filled up to 50 mL with petroleum ether. The color of the extract was then determined using a Uv-vis spectrophotometer (Genesys 10S, Thermo Scientific, Waltham, Massachusetts, USA) with 1 cm path length cuvettes at 503 nm. Petroleum ether was used as a blank. The lycopene content was then calculated.

2.6 | Rehydration analysis

The rehydration test was conducted according to a method described by Farooq et al. (2020). A 5 g sample of the tomato powder was placed in a beaker and mixed with 150 mL of distilled water. The mixture was then covered with a watch glass and heated to boiling point on a hot plate oven. After the rehydration process, the sample was then transferred to a Buchner funnel and covered with Whatman filter paper No. 4. Excess water was then removed and the sample was weighed. The RR was then calculated.

2.7 | Antioxidant radical scavenging and total antioxidant activity assay

The radical scavenging activity of the dried tomato samples was determined using a method described by Chawafambira et al. (2020) with slight modification. Five milliliters of (1.5 mL, 1 mM) methanolic solution of 2,2-diphenyl-1-picrylhydrazyl (DPPH) was mixed with 0.1 mL of methanol extracts of dried tomato sample and incubated in the dark for 20 min at 27°C. The absorbance was recorded at 517 nm on a Spectronic Genesys Spectrophotometer (Genesys 5, Thermo

Fisher Scientific, Waltham, Massachusetts, USA) after calibration with methanol. The radical scavenging activity was determined as the percentage decrease in absorbance with time.

The total antioxidant activity was determined according to the ABTS method reported by Miller and Rice-Evans (1997) with slight modifications. The decolorization of the $ABTS^{\bullet+}$ radical cation by sample extract was recorded using a Spectronic Genesys Spectrophotometer (Genesys 5, Thermo Fisher Scientific, Waltham, Massachusetts, USA) at 734 nm in relation to a Trolox® (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid, Sigma-Aldrich) standard. The absorbances of the $ABTS^{\bullet+}$ radical cation scavenging capacity of the dried tomato samples were plotted against the concentration of the antioxidant. The results were expressed as μmol TEAC/100 g DM.

2.8 | Statistical analysis

All results were expressed as mean ± standard deviation (*SD*). Data analysis was carried out using SPSS package version 18.0 (Coakes and Ong, John Wiley & Sons, Queensland, Australia) at a 5% level of significance. Mann–Whitney U test was used to compare the observed data.

3 | RESULTS AND DISCUSSION

The proximate composition of fresh tomatoes is presented in Table 1. The observed results showed that fresh tomatoes had a 90.1% moisture, 7.7% ash, 0.45% titratable acidity, pH 4.2, 3.7 g /100 g TS, 11.6 g /100 g total fiber, and 4.3% °Brix. Proximate analysis is important in food characterization, mainly for the identification of nutrients. Results of this study were not significantly different ($p > .05$) from previously reported data for fresh tomatoes by Abdullahi et al. (2016) and Ramos-Bueno et al. (2017). A recent review study by Ali et al. (2021) indicated that fresh tomatoes consists of 34.67 kcal /100 g energy, 91.18 (g /100 g) moisture, 8.75% ash, 0.48% acidity, 5.96 (g /100 g), lipid 4.96 (g /100 g) carbohydrates, 17.71 (g /100 g) protein, 11.44 (g /100 g) fiber, 94.17 (g /100 g) water, pH 3.83, 35.84% reducing sugar, glucose 2.45%, fructose 2.88%, sucrose 0.02%, and TS 50.60 (g /100 g). The β-carotene, lycopene, and ascorbic acid contents of fresh tomatoes were 1.12, 10.11, and 18.5 mg /100 g, respectively. Aderibigbe et al. (2018) reported high values on ascorbic acid (40.50 mg /100 g), lycopene (9.60 mg /100 g), and β-carotene (1.33 mg /100 g) contents as compared to the results observed in this research.

3.1 | Moisture

The moisture content of dried tomato samples is shown in Table 2. The control (T_0) tomato samples dried in a solar drier had a low moisture content of 9.3%. The analysis of the moisture content is important because it affects the physicochemical properties of food, which define its freshness and storage stability (Aurand, 2013). The drying process causes a great reduction in moisture content and an increased concentration of nutrients. The observed results indicated that the moisture content range was 9.4–8.8, 10.1–9.8, and 10.4%–9.8% for samples pretreated using T_1 and T_2 then solar-dried, sun-dried, and dehydrated respectively. These results were higher when compared to values obtained by Jayathunge et al. (2012) in their study on the production of dehydrated tomato powder and its acceptability.

Solar and sun-drying were significant ($p < 0.05$) and effective in reducing the moisture content of tomato samples pretreated with both T_1 (1% w/v CA) and T_2 (0.5% w/v CA +0.5% w/v SMB) to below 10% before storage. The moisture content of all pretreated and dried tomato samples increased during storage from 0 to 20 days. This could be attributed to the water vapor permeability of LDPE packaging material and the hygroscopic nature of tomato powder (Saqib et al., 2020). Owureku Asare et al. (2018) also reported the hygroscopic properties and high affinity to moisture by sugars and cellulose in dried tomatoes. After drying, the pretreated tomato samples with T_1 (1% w/v CA) and T_2 (0.5% w/v CA +0.5% w/v SMB) become hard with a deformed texture and noticeable shrinkage which might be due to loss in moisture during drying. The dehydrated tomato slices had the least structural deformation as compared to other drying techniques as shown in Figure 2.

TABLE 1 Proximate composition of fresh hybrid tomato

Parameter	Value
Moisture content (%)	90.1 ± 5.2
Ash (%)	7.7 ± 2.1
Total fibre (g/100 g)	11.6 ± 4.2
pH	4.2 ± 0.1
Titratable acid (%)	0.45 ± 0.05
Total sugar (%)	3.7 ± 0.2
Total soluble solids (°Brix)	4.3 ± 0.03
Ascorbic acid (mg/100 g)	18.5 ± 0.6
Antioxidant activity (μmol TEAC/100 g DM)	2812.1 ± 180.3
DPPH free radical scavenging capacity (%)	39.5 ± 5.2
β-carotene (mg/100 g)	1.12 ± 0.05
Lycopene (mg/100 g)	10.11 ± 0.08
Mineral content (mg/100 g)	
Na	68.3 ± 10.2
K	413.2 ± 261.1
Ca	97.3 ± 18.6
Mg	181.1 ± 50.3
Fe	4.4 ± 2.1
Zn	2.2 ± 1.1
Cu	0.55 ± 0.11
P	305.6 ± 42.3

Note: Values indicate the means of three replications ± SD, DPPH=2,2-diphenyl-1-picrylhydrazyl.

TABLE 2 Effect of pretreatments, drying methods, and storage time on physicochemical properties of tomato powder

Treatment	Storage (days)	Moisture content			Ash			TA			pH		
		Solar	Sun	Dehydration	Solar	Sun	Dehydration	Solar	Sun	Dehydration	Solar	Sun	Dehydration
T_0	0	9.3 ± 0.1^{aA}	9.8 ± 0.2^{aA}	10.1 ± 0.1^{bB}	1.6 ± 0.1^{aA}	1.8 ± 0.1^{bA}	2.1 ± 0.2^{cB}	3.8 ± 0.1^{aA}	3.7 ± 0.1^{aA}	4.0 ± 0.2^{bB}	1.2 ± 0.1^{cA}	1.1 ± 0.1^{cA}	1.3 ± 0.1^{dB}
	10	9.7 ± 0.1^{aA}	10.6 ± 0.1^{bA}	11.8 ± 0.1^{cB}	1.4 ± 0.1^{aA}	1.5 ± 0.2^{aA}	1.8 ± 0.2^{bB}	3.9 ± 0.1^{aA}	4.0 ± 0.1^{bA}	4.1 ± 0.1^{bB}	1.1 ± 0.1^{cA}	1.0 ± 0.2^{cA}	1.2 ± 0.1^{cB}
	20	10.3 ± 0.2^{bA}	11.6 ± 0.1^{cB}	12.4 ± 0.1^{dC}	1.2 ± 0.2^{aA}	1.3 ± 0.3^{aA}	1.5 ± 0.3^{aA}	4.0 ± 0.1^{bA}	4.1 ± 0.1^{bA}	4.0 ± 0.2^{bA}	1.0 ± 0.1^{bB}	0.8 ± 0.1^{bA}	0.9 ± 0.1^{bA}
T_1	0	9.4 ± 0.1^{aA}	10.1 ± 0.3^{bB}	10.4 ± 0.2^{bB}	1.8 ± 0.2^{bA}	1.6 ± 0.1^{bA}	1.9 ± 0.2^{bA}	4.1 ± 0.2^{bB}	4.0 ± 0.1^{bA}	3.9 ± 0.1^{aA}	0.9 ± 0.2^{bA}	0.8 ± 0.2^{bA}	0.9 ± 0.2^{cA}
	10	10.0 ± 0.1^{bA}	10.8 ± 0.2^{bA}	11.6 ± 0.3^{cB}	1.6 ± 0.3^{bA}	1.4 ± 0.1^{aA}	1.7 ± 0.1^{bA}	4.0 ± 0.3^{bB}	3.8 ± 0.1^{aA}	4.0 ± 0.1^{bB}	0.8 ± 0.2^{bA}	0.7 ± 0.2^{aA}	0.8 ± 0.2^{bA}
	20	11.2 ± 0.2^{cA}	11.3 ± 0.1^{cA}	12.7 ± 0.3^{dB}	1.3 ± 0.3^{aA}	1.2 ± 0.2^{aA}	1.6 ± 0.2^{aA}	4.0 ± 0.2^{bA}	3.9 ± 0.3^{aA}	3.9 ± 0.1^{aA}	0.7 ± 0.2^{aB}	0.6 ± 0.1^{aA}	0.7 ± 0.1^{aA}
T_2	0	8.8 ± 0.1^{aA}	9.8 ± 0.2^{aB}	9.8 ± 0.1^{aB}	2.0 ± 0.1^{cA}	1.7 ± 0.1^{bA}	1.8 ± 0.1^{bB}	3.8 ± 0.1^{aA}	4.0 ± 0.2^{bB}	4.0 ± 0.1^{bB}	0.9 ± 0.1^{aA}	1.0 ± 0.2^{cB}	1.1 ± 0.1^{cC}
	10	9.8 ± 0.1^{aA}	10.6 ± 0.1^{bB}	10.5 ± 0.2^{bB}	1.4 ± 0.1^{aA}	1.4 ± 0.2^{aA}	1.6 ± 0.2^{aA}	3.9 ± 0.1^{aA}	3.8 ± 0.1^{aA}	3.9 ± 0.1^{aA}	0.8 ± 0.1^{aA}	0.9 ± 0.1^{bA}	0.9 ± 0.2^{cB}
	20	11.4 ± 0.3^{cA}	12.1 ± 0.1^{dB}	11.6 ± 0.1^{cA}	1.2 ± 0.1^{aA}	1.3 ± 0.2^{aA}	1.4 ± 0.1^{aA}	4.0 ± 0.1^{bB}	3.7 ± 0.1^{aA}	3.8 ± 0.1^{aA}	0.7 ± 0.1^{aA}	0.8 ± 0.2^{bB}	0.7 ± 0.1^{aA}

Note: T_0 = control, no additives; T1 = Tomato powder pretreated with 1% w/v CA; T_2 = Tomato powder pretreated with 0.5% w/v CA +0.5% w/v SMB.

Values are means of three replications ± SD.

Means values within the same column with different superscript letters ($^{a, b, c, d}$) are significantly different ($p < 0.05$).

Means values within the same row with different superscript letters ($^{A, B, C}$) are significantly different ($p < 0.05$).

3.2 | Ash

The analysis of ash content is important in determining the nutritional element contents in any food material. Ash is the inorganic residue (mineral content) that is collected after the removal of water and complete oxidation of organic matter by heating a food sample using a furnace (Harris & Marshall, 2017). In this study, the ash content of the control tomato samples that were solar-dried, sun-dried, and dehydrated was 1.6%, 1.8%, and 2.1%, respectively (Table 2). Tomato samples pretreated with T_1 (1% w/v CA) and T_2 (0.5% w/v CA +0.5% w/v SMB) and dried using a food dehydrator and solar dryer had an ash content of 1.9% and 2.0%, respectively. Aderibigbe et al. (2018) found an ash content of 2.55%, 3.00%, and 2.02% in sun-dried tomato samples that were non-treated, pretreated with sodium benzoate, and SMB, respectively. Saqib et al. (2020) noted a similar trend in a decrease in ash content during storage of tomato samples pretreated using 0.5% ascorbic acid +0.5% CA and then freeze-dried and hot-air-dried, respectively.

3.3 | pH and TA

The non-pretreated (T_0) samples that were solar-dried, sun-dried, and dehydrated had a pH of 1.2, 1.1, and 1.3 and TA of 3.8%, 3.7%, and 4.0, respectively (Table 2). The T_1 pretreated tomato samples and dried using solar, sun, and dehydration had a pH of 0.9, 0.8, and 0.9 at 0 days of storage. The T_2 pretreated samples and dried using solar, sun and dehydration had a pH of 0.9, 1.0, and 1.1 at day 0 of storage. This study observed that dried tomato samples that were pretreated with T_1 had lower pH when compared to T_2 pretreated and dried samples. This can be explained by the high concentration of CA which is acidic in nature. The TA increased as pH decreased in the storage of tomato powder. This increase in TA and decrease in pH could be attributed to the breakdown of pectin into pectic acid (Ajayi & Oderinde, 2013).

In addition, the increase in TA could be due to differences in the drying method which increases the concentration of organic acids present in the tomato (Aderibigbe et al., 2018). CA is the main contributor of TA and is the dominant naturally occurring organic acid present in tomatoes (Anthon & Barrett, 2012). A study by Aderibigbe et al. (2018) indicated a pH of 4.07 and 4.10 in tomato samples pretreated with sodium benzoate and calcium chloride respectively. There was a significant decrease ($p < .05$) in TA in all samples pretreated with T_1 and T_2 in storage from 0 to 20 days. This observed decrease in TA during storage might be explained by the breakdown of organic acids and similar results were reported by Castro et al. (2005).

3.4 | Rehydration ratio

The RR results are indicated in Table 3. The microstructure of the dried product is an important factor that determines the RR. The T_1 and T_2 pretreated samples and dried using solar, sun and dehydration had RR of 1.68, 1.40, 1.12, and 2.00, 1.80, 1.62 at 0 days of storage, respectively. McMinn and Magee (1997) describe rehydration

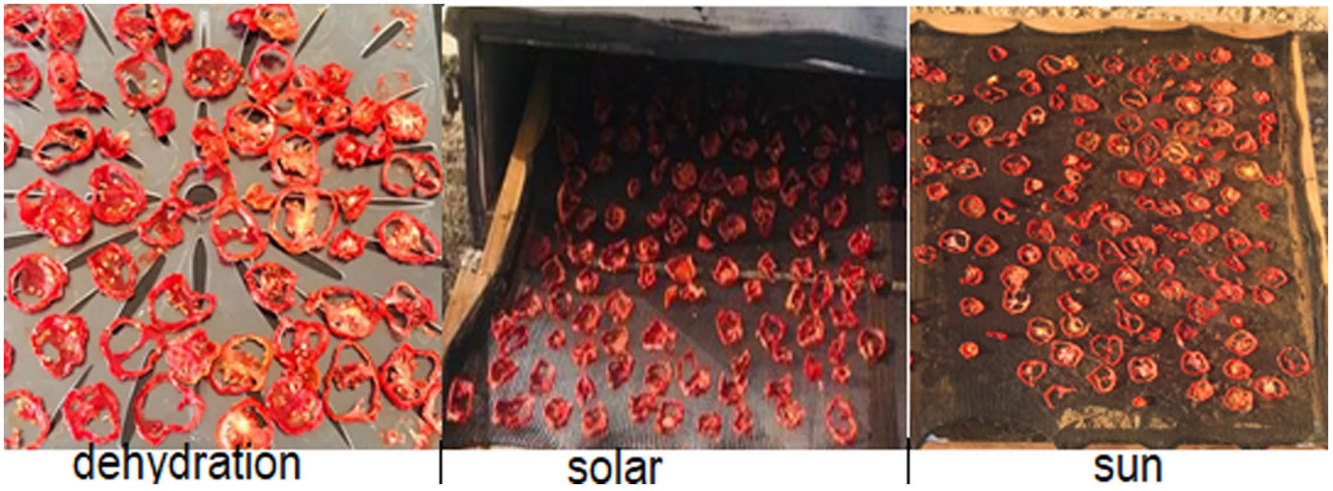

FIGURE 2 Tomato slices dried using solar, sun and dehydration

as an analysis of the damage to the food material caused by drying and treatment preceding dehydration. A decrease in the RR in all dried samples during storage from 0 to 30 days was noted and this might be attributed to the high water absorbance of the tomato powder. Also, another possible explanation might be due to the coagulation process of proteins in the dried tomato samples (Giordani et al., 2011). The drying-air temperature, air velocity, and thickness of pretreated and dried tomato samples have a great effect on the RR (Abano et al., 2012). Further, the drying process alters the osmotic properties of the cell membrane that make up the tissues of the tomato and cause less swelling (Galvez et al., 2008).

Tomato samples pretreated with T_1 and T_2 and then solar-dried had a lower moisture content hence the higher RR. This is because of the high temperature (approximately above 40°C) used to dry the tomato in the solar dryer. Additionally, Yusufe et al. (2017) reported that at high drying temperatures there will be the formation of a more porous organization in the product which promotes the rehydration process. This occurs at a high drying temperature as the rate of moisture loss is rapid and this leads to the minimal shrinkage of the dried tomato samples. Krokida and Marinos (2003) noted that exposure of the food product to the air during sun or shade drying may lead to a lower RR. This could explain the low RR in sun-dried samples as compared to solar drying. Brenndorfer et al. (1985) reported that as the food product loses more moisture it becomes hard and sticky thereby reducing its ability to absorb water. The lower RR of the tomato samples pretreated and dried at relatively high temperature in a food dehydrator could be explained by the increased case hardening that occurs to the tomato slices resulting in decreased moisture diffusivity during the drying process (Abano et al., 2012).

3.5 | Total soluble solids (TSS)

TSS measures the sum of sugars (sucrose and hexoses), acids (malate and citrate), and other components (amino acids, soluble pectin, phenols, and minerals) present in the tomato (Kader et al., 1978). The results of TSS are shown in Table 3. The TSS of the control tomato samples (T_0) that were dehydrated, solar, and sun-dried was 5.20, 4.56, and 4.92%, °Brix respectively. The tomato samples that were pretreated with T_1 and T_2 and dried using sun-dried, solar-dried, and dehydrated had TSS of 4.80,5.00, 4.86 and 4.90,5.10,5.00% °Brix at 0 days of storage, respectively. The results from this study indicated that the decrease in TSS in all dried samples during storage and could be attributed to the breakdown of solids during storage (Saqib et al., 2020). This was also supported by Yusufe et al. (2017). Khazaei et al. (2008) reported that the TSS value increases with an increase in drying-air temperature and tends to reduce at a drying temperature above 80°C.

3.6 | Total sugars

The TS of non-pretreated (T_0) samples and dried using dehydrated, solar, and the sun was 6.82, 4.81, and 5.30, respectively (Table 3). This study showed that TS content was 6.32, 5.80, 6.72% and 6.88, 6.58, 7.32% for tomato samples pretreated with T_1 and T_2 and then sun-dried, solar-dried, and dehydrated at 0 days of storage, respectively. The pretreated and dried tomato samples had high TS content when compared to fresh tomato due to loss of moisture. The T_1 and T2 pretreated samples and then dehydrated had a significantly ($p < 0.05$) higher TS content than sun and solar-dried samples during storage. Also, the TS decreased in treatments (T_0, T_1, and T_2) powdered tomato samples in storage from 0 to 20 days. Okanlawon et al. (2002) observed similar results and attributed the decrease to the degradation of sugars during storage. The sugar content was positively correlated with TSS and this was supported by Beckles, (2012). The sum and type of sugars present in the tomato fruit play an important role in postharvest tomato quality by affecting the sensorial properties (Beckles, 2012; Kader et al., 1978).

TABLE 3 Effect of pretreatments, drying methods, and storage time on total sugar, TSS and rehydration ratio of tomato powder

Treatment	Storage (days)	Solar	Sun	Dehydration	Solar	Sun	Dehydration	Solar	Sun	Dehydration
		TSS(°Brix)			Total sugar (%)			Rehydration ratio		
T_0	0	4.56 ± 0.11^{bA}	4.92 ± 0.01^{cA}	5.20 ± 0.10^{dB}	4.81 ± 0.1^{aA}	5.30 ± 0.1^{aB}	6.82 ± 0.2^{bC}	1.08 ± 0.02^{bB}	0.88 ± 0.01^{aA}	0.72 ± 0.05^{aA}
	10	4.31 ± 0.01^{aA}	4.60 ± 0.01^{bA}	4.82 ± 0.08^{cB}	4.78 ± 0.1^{aA}	5.25 ± 0.2^{aB}	6.50 ± 0.2^{bC}	0.90 ± 0.01^{aA}	0.72 ± 0.02^{aA}	0.58 ± 0.01^{aA}
	20	4.12 ± 0.02^{aA}	4.32 ± 0.05^{aA}	4.61 ± 0.05^{bAB}	4.55 ± 0.2^{aA}	5.05 ± 0.3^{aB}	5.85 ± 0.3^{aC}	0.85 ± 0.05^{aA}	0.63 ± 0.01^{aA}	0.48 ± 0.07^{aA}
T_1	0	4.80 ± 0.10^{cA}	5.00 ± 0.07^{cdB}	4.86 ± 0.10^{cA}	5.80 ± 0.2^{bA}	6.32 ± 0.1^{bB}	6.72 ± 0.2^{bC}	1.68 ± 0.01^{bB}	1.40 ± 0.04^{bA}	1.12 ± 0.02^{bA}
	10	4.66 ± 0.12^{bA}	4.75 ± 0.20^{bA}	4.53 ± 0.07^{aA}	5.62 ± 0.3^{bA}	6.12 ± 0.1^{bB}	6.60 ± 0.1^{bC}	0.70 ± 0.01^{aA}	0.53 ± 0.01^{aA}	$0.40 \pm 0.03^{a}A$
	20	4.51 ± 0.02^{bA}	4.48 ± 0.02^{aA}	4.32 ± 0.05^{aA}	5.47 ± 0.3^{bA}	6.00 ± 0.2^{bB}	6.51 ± 0.2^{bC}	0.32 ± 0.03^{aA}	0.22 ± 0.03^{aA}	0.10 ± 0.05^{aA}
T_2	0	4.90 ± 0.01^{cA}	5.10 ± 0.05^{dB}	5.00 ± 0.10^{dA}	6.58 ± 0.1^{cA}	6.88 ± 0.1^{dB}	7.32 ± 0.1^{cC}	2.00 ± 0.01^{cA}	1.80 ± 0.02^{cA}	1.62 ± 0.07^{cA}
	10	4.73 ± 0.10^{bA}	4.83 ± 0.03^{cA}	4.75 ± 0.08^{bA}	6.33 ± 0.1^{cA}	6.65 ± 0.2^{cA}	7.25 ± 0.2^{cB}	1.67 ± 0.01^{bB}	1.51 ± 0.07^{bA}	1.30 ± 0.03^{cA}
	20	4.62 ± 0.05^{bA}	4.68 ± 0.01^{bA}	4.56 ± 0.10^{aA}	6.12 ± 0.1^{cA}	6.42 ± 0.1^{cA}	7.17 ± 0.1^{cB}	$1.56 \pm 0.02^{b}A$	1.32 ± 0.01^{bA}	1.11 ± 0.06^{bA}

Note: T_0 = control, no additives; T_1 = Tomato powder pretreated with 1% w/v CA; T_2 = Tomato powder pretreated with 0.5% w/v CA +0.5% w/v SMB.

Values are means of three replications ± SD.

Means values within the same column with different superscript letters ($^{a, b, c, d}$) are significantly different ($p < 0.05$).

Means values within the same row with different superscript letters ($^{A, B, C}$) are significantly different ($p < 0.05$).

TABLE 4 Effect of pretreatments, drying methods, and storage period on carotenoids and ascorbic acid

Treatment	Storage (days)	Solar	Sun	Dehydration	Solar	Sun	Dehydration	Solar	Sun	Dehydration
		β-carotene (mg/100 g)			Lycopene (mg/100 g)			Ascorbic acid (mg/100 g)		
T_0	0	25.3 ± 0.1^{cB}	10.1 ± 3.01^{eA}	26.4 ± 3.1^{bB}	46.1 ± 0.1^{bB}	22.1 ± 2.2^{cA}	49.2 ± 1.2^{dC}	12.1 ± 0.2^{cB}	9.8 ± 0.08^{cA}	13.1 ± 0.02^{dB}
	10	21.1 ± 0.8^{bB}	8.1 ± 0.01^{bA}	24.2 ± 0.08^{aB}	43.8 ± 1.1^{bB}	18.5 ± 0.2^{aA}	46.1 ± 0.2^{aB}	9.6 ± 0.05^{aB}	7.3 ± 0.05^{bA}	10.2 ± 0.02^{aC}
	20	18.2 ± 0.2^{aB}	6.2 ± 0.05^{aA}	22.1 ± 0.15^{aC}	38.5 ± 1.2^{aB}	16.5 ± 1.3^{aA}	44.4 ± 1.3^{aC}	6.3 ± 0.05^{aB}	5.1 ± 0.04^{aA}	7.8 ± 0.04^{aC}
T_1	0	28.2 ± 0.1^{dB}	11.0 ± 0.2^{dA}	27.8 ± 0.10^{bB}	48.8 ± 0.2^{cB}	21.2 ± 0.1^{bA}	50.7 ± 0.8^{dB}	13.2 ± 0.02^{dB}	11.2 ± 0.05^{dA}	13.6 ± 0.06^{dB}
	10	24.2 ± 0.1^{bB}	9.5 ± 0.2^{cA}	25.5 ± 0.08^{aB}	40.6 ± 0.3^{aB}	18.2 ± 1.1^{aA}	45.6 ± 0.5^{aC}	11.2 ± 0.03^{bB}	9.4 ± 0.04^{cA}	11.8 ± 0.02^{bB}
	20	21.1 ± 0.5^{bB}	8.3 ± 0.5^{bA}	24.3 ± 0.6^{aB}	38.7 ± 0.3^{aB}	16.8 ± 1.2^{aA}	40.5 ± 1.2^{aB}	9.3 ± 0.08^{aB}	8.2 ± 0.03^{bA}	9.6 ± 0.02^{aB}
T_2	0	27.1 ± 0.3^{cB}	12.5 ± 0.1^{dA}	30.0 ± 0.1^{dC}	50.8 ± 0.4^{dB}	25.8 ± 0.7^{dA}	51.3 ± 0.3^{dB}	12.8 ± 0.05^{dB}	10.2 ± 0.02^{cA}	14.1 ± 0.08^{eC}
	10	25.3 ± 0.1^{cB}	10.1 ± 0.2^{cA}	28.5 ± 0.8^{cC}	46.3 ± 0.8^{bB}	23.5 ± 0.5^{cA}	48.2 ± 1.2^{cC}	11.6 ± 0.04^{cB}	9.2 ± 0.05^{cA}	12.8 ± 0.05^{cC}
	20	23.2 ± 0.05^{bB}	9.4 ± 0.5^{cA}	26.5 ± 0.5^{bC}	43.1 ± 1.1^{bB}	20.4 ± 1.1^{bA}	46.1 ± 1.1^{bC}	10.1 ± 0.04^{aB}	8.3 ± 0.05^{bA}	10.2 ± 0.06^{aB}

Note: T_0 = control, no additives; T_1 = Tomato powder pretreated with 1% w/v CA; T_2 = Tomato powder pretreated with 0.5% w/v CA +0.5% w/v SMB.

Values are means of three replications ± SD.

Means values within the same column with different superscript letters ($^{a, b, c, d, e}$) are significantly different ($p < 0.05$).

Means values within the same row with different superscript letters ($^{A, B, C}$) are significantly different ($p < 0.05$).

TABLE 5 Effect of pretreatments, drying methods, and storage time on DPPH free radical scavenging and Antioxidant activities

		Solar	Sun	Dehydration	Solar	Sun	Dehydration
Treatment	Storage (days)	DPPH free radical scavenging (%)			Antioxidant activity (μmol/TEAC/100 g DM)		
T_0	0	70.1 ± 4.11^{cB}	69.8 ± 2.03^{bA}	73.2 ± 2.02^{cB}	5013.1 ± 187.3^{cB}	4890.1 ± 186.2^{dA}	4986.5 ± 321.2^{dB}
	10	68.2 ± 2.11^{bB}	67.8 ± 1.02^{aA}	70.1 ± 1.00^{bB}	4658.5 ± 165.1^{bB}	4467.6 ± 197.2^{bA}	4676.8 ± 186.2^{bB}
	20	63.1 ± 1.11^{aA}	62.7 ± 1.26^{aA}	68.2 ± 1.71^{aB}	4095.5 ± 269.2^{aA}	3982.2 ± 288.2^{aA}	4206.3 ± 201.4^{bB}
T_1	0	68.1 ± 3.16^{bA}	70.1 ± 2.81^{cA}	71.1 ± 3.01^{cB}	5113.4 ± 102.2^{cB}	5060.5 ± 102.3^{dA}	4889.2 ± 165.1^{cA}
	10	70.3 ± 1.21^{bB}	68.3 ± 3.01^{bB}	69.4 ± 1.25^{bA}	4562.3 ± 289.4^{bB}	4695.5 ± 278.2^{cB}	4494.8 ± 169.5^{bA}
	20	67.3 ± 2.19^{bA}	66.1 ± 2.14^{aA}	66.3 ± 1.02^{aA}	4295.9 ± 199.3^{aA}	4098.7 ± 399.1^{bA}	4176.8 ± 245.2^{aA}
T_2	0	72.1 ± 2.30^{cA}	73.1 ± 1.62^{dA}	75.4 ± 1.03^{cB}	4982.4 ± 186.3^{cA}	4998.6 ± 200.6^{dA}	5180.3 ± 302.1^{dB}
	10	69.4 ± 1.85^{bA}	70.5 ± 2.31^{cB}	70.3 ± 0.56^{bA}	4682.3 ± 176.2^{bA}	4798.5 ± 223.6^{dB}	4845.2 ± 128.9^{cA}
	20	67.3 ± 2.41^{bA}	68.8 ± 2.56^{bB}	68.1 ± 1.07^{aA}	4488.4 ± 201.2^{aB}	4200.1 ± 233.2^{aA}	4561.7 ± 287.1^{bB}

Note: T_0 = control, no additives; T_1 = Tomato powder pretreated with 1% w/v CA; T_2 = Tomato powder pretreated with 0.5% w/v CA +0.5% w/v SMB.

Values are means of three replications ± SD.

Means values within the same column with different superscript letters ($^{a, b, c, d}$) are significantly different ($p < 0.05$).

Means values within the same row with different superscript letters ($^{A, B, C}$) are significantly different ($p < 0.05$).

3.7 | β-carotene

The β-carotene content of T_0, T_1, and T_2 pretreated and then sun and solar-dried samples were 10.1, 11.0, 12.5 and 25.3, 28.2, 27.1 mg /100 g respectively at 0 days of storage (Table 4). The β-carotene content of tomato samples pretreated with T_0, T_1, and T_2 and dehydrated was 26.4, 27.8, and 30.0 mg /100 g at 0 days of storage. The use of pretreatments, T_1 (1% w/v CA) and T_2 (0.5% w/v CA +0.5% w/v SMB) was beneficial in reducing the thermal degradation, oxidation of the carotenoids and acted as an inhibitor of browning reactions. Further, the drying methods significantly ($p < 0.05$) reduced the β-carotene levels in the untreated (T_0) and dried tomato samples. There was a significant interaction between pretreatment and drying method on the β-carotene content which could be explained by the high values recorded for tomato samples treated with T_2 (0.5% w/v CA +0.5% w/v SMB). The reduction in β-carotene observed in tomato powder during storage might be attributed to extrinsic factors, such as exposure to light, storage temperature, and packaging material (Farooq et al., 2020).

3.8 | Lycopene

Lycopene belongs to the phytochemical group of carotenoids and is most abundant in the ripened tomato, accounting for about 80%–90% of the total pigments (Shi & LeMaguer, 2000). The lycopene content was high in samples pretreated with T_0, T_1, and T_2 and dehydrated at 0 days of storage (Table 4). The reduced loss in lycopene content in T_2 (0.5% w/v CA +0.5% w/v SMB) pretreated and dried samples could be attributed to the protective effect of SMB for lycopene pigments against heat damage. This is also supported by Owureku Asare et al. (2014). Davoodi et al. (2007) reported the same protective effect of potassium metabisulphite on lycopene content in dried tomato samples. Pizzocaro et al. (1993) reported that bisulphites react with the o-quinones forming colorless complex compounds thereby acting as competitive inhibitors by binding to a sulphydryl group at the active site of the enzyme and irreversibly inhibiting polyphenoloxidase.

The degradation of lycopene in pretreated and dried tomato powder samples during storage might be caused by the isomerization and oxidation processes. Thermal processes such as drying can lead to lycopene isomerization and cause its change from *trans*-steric to *cis* form (Knockaert et al., 2012) and improve its functionality. The isomerization process increases the bio-assimilation of lycopene *cis* isomers by destroying the tomato cells, breaking the lycopene-protean complex in the food matrix, and releasing free lycopene by *cis* isomerization (Shi & LeMaguer, 2000).

3.9 | Ascorbic acid

Tomatoes contain a high concentration of ascorbic acid (Kaur et al., 2002) and drying of tomatoes has been reported to cause a significant reduction in ascorbic acid content (Toor & Savage, 2006). The ascorbic acid content of samples pretreated with T_0, T_1, and T_2 and dried using the sun, and solar-dried was 9.8, 11.2, 10.2, and 12.1, 13.2, 12.8 mg /100 g, respectively, at 0 days of storage (Table 4). The ascorbic acid content of T_2 pretreated and dehydrated tomato samples was significantly ($p < .05$) higher than samples dried using the sun and solar. Samples pretreated with T_2 had minimal ascorbic acid degradation after drying, especially in dehydrated samples. This is linked mostly to the protective effect of SMB although CA has some antioxidant properties. Sun-drying had a significant effect on the decrease in the ascorbic acid content in control samples during storage because of the direct heat from the sunlight (Rajkumar et al., 2007). Further, the process of oxidation might have significantly affected ascorbic acid in sun-dried samples. Solar-dried tomato samples had higher retention of ascorbic acid as compared to sun-dried tomato samples. This was supported by Hussein et al. (2016). Giovanelli et al. (2002) reported the

effect of temperature, time of exposure to direct sunlight, the thickness of slices, and the presence of air on the reduction of ascorbic acid in dried tomatoes. Also, the reduction in the ascorbic acid in untreated (control samples) could be attributed to the leaching of the vitamin in longer periods of drying. This was also supported by Shi et al. (1999).

3.10 | Antioxidant activity

Tables 1 and 5 indicate the mean radical scavenging capacity and antioxidant activity of fresh and dried tomato powder. The observed results showed that the antioxidant activity of tomato samples was affected significantly ($p < .05$) by the pretreatment and drying method. The TEAC values for T_1 pretreated and dried tomatoes samples ranged between 4098.3 and 5131.4 μmol TEAC/100g DM and the DPPH radical scavenging capacities of the dried tomatoes varied between 66.1%–71.1%. Also, the TEAC values for T_2 pretreated and dried samples ranged between 4316.7 and 5180.3 μmol TEAC/100g DM and the DPPH radical scavenging activity varied between 67.3%–75.4%. In earlier researches, it was reported that the drying and processing of tomatoes will cause the release of bound antioxidants (Tonucci et al., 1995). Further, the drying process might have caused some destruction of other labile antioxidant compounds (Abushita et al., 2000) hence resulting in the observed reduction in the antioxidant activity in sun-dried samples.

4 | CONCLUSION

The study concluded that tomato slices that were pretreated with T_1 (1% w/v CA) and dried had high moisture (%), TA contents and samples pretreated with T_2 (0.5% w/v CA +0.5% w/v SMB) had high lycopene (mg/100 g), β-carotene (mg/100 g), ash (%), pH, TSS (°Brix), TS (%), RR, and ascorbic acid content when compared with control samples. Further, results indicated a significant ($p < 0.05$) decrease in TS, TSS, pH, RR, β-carotene, lycopene, and ascorbic acid of all dried tomato samples in storage period from 0 to 20 days. The T_2 (0.5% w/v CA +0.5% w/v SMB) pretreated and dehydrated tomato samples had high TEAC and DPPH radical scavenging activities. The T_2 pretreated and dehydrated tomato samples had minimal loss in TS, TSS, ascorbic acid, lycopene, β-carotene, lycopene and a reduction in pH and RR during storage. Suggestions for future development include the use of 0.5% w/v CA +0.5% w/v SMB as a preservative of many dried foods such as fruits in the food industry. Also, future researches on the interactions of the SMB and CA on sensorial qualities of the tomato powder.

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CONFLICTS OF INTEREST

The authors declare there is no conflict of interest.

AUTHOR CONTRIBUTIONS

Armistice Chawafambira: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Supervision; Validation; Writing-original draft; Writing-review & editing. **Best Maramba:** Conceptualization; Formal analysis; Investigation; Methodology.

ETHICAL STATEMENT

This study does not involve any human or animal testing.

DATA AVAILABILITY STATEMENT

The data of this research are available and will be provided on request by the corresponding author.

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