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Effects of Some Weak Acids and *Moringa oleifera* Leaf Extract Powder on the Colour of Dried Apple

Washiela Arendse and Victoria Jideani *

Department of Food Science and Technology, Cape Peninsula University of Technology, Bellville 7560, South Africa; washiela.arendse@gmail.com
* Correspondence: jideaniv@cput.ac.za

Abstract: This study aimed to find alternatives to sulphite as a preservative for dried fruits. Granny Smith apples were sanitised in a 200 ppm sodium chlorite solution, de-cored, peeled, and cut into slices. The sliced apples were pre-treated/dipped in a water solution containing the three weak acids, namely, ascorbic acid (AA), citric acid (CA), and potassium sorbate (PS) as well as *Moringa oleifera* leaf extract powder (MOLEP). A screening fractional factorial experiment consisting of five independent variables (AA, CA and PS, time and temperature and MOLEP) constrained at their upper and lower levels (AA: 0.5 to 2.0%, CA: 0.3 to 2.0%, MOLEP: 0.1 to 0.2%, time: 7 to 15 h and temperature: 57 to 70 °C) were evaluated for their effect on the colour of the dried sliced apples. An increase in the concentration of the CA significantly increased the lightness ($p = 0.05$) and decreased the redness ($p = 0.0022$) of the dried apple slices. AA and PS did not impact the lightness of the dried sliced apples. A dipping solution of citric acid at 2.0%, Moringa oleifera leaf extract powder at 0.1%, and drying time of 7 h at 70 °C effectively minimized the discolouration of the dried sliced apples.

Keywords: *Moringa*; apple; ascorbic acid; citric acid; potassium sorbate; antioxidant; polyphenol oxidase

Citation: Arendse, W.; Jideani, V. Effects of Some Weak Acids and *Moringa oleifera* Leaf Extract Powder on the Colour of Dried Apple. *Processes* **2022**, *10*, 206. https://doi.org/10.3390/pr10020206

Academic Editor: Anet Režek Režek Jambrak

Received: 1 November 2021
Accepted: 15 December 2021
Published: 21 January 2022

1. Introduction

Fruits have become a vital part of our everyday life as a result of them being an excellent source of vitamins and minerals [1]. The contemporary lifestyle of today hampers the intake of fresh fruit and vegetables [2]. Giving rise to a need for innovative products that can act in response to the change in lifestyle and working pace. An advantage of this is that consumers are now paying attention to eating nourishing, organic, and flavoursome foods. Dehydrated fruits can fulfil these requirements as they are delicious, healthy food because of their nutritional value and high fibre content [3]. Processing fruits provide a method to make them accessible throughout the year, add value, and increase their shelf life [4]. Furthermore, dehydration also allows for market surplus management [1]. Dehydrated apples used primarily as a snack food, have sparked renewed interest in recent times [5]. Dried apples are used on their own and in quite a few ready to eat food such as breakfast foods and snack mixes [6]. According to [7], apples are eaten in all parts of the world for their health benefits which are attributed to their numerous nutritional components such as vitamins and phenolic constituents. Injury to light flesh fruits (peach, apples, and bananas) will start the oxidation of the phenolic compounds by polyphenol oxidase to quinones to form brown pigments. Polyphenoloxidase is an enzyme and therefore, it is possible to inactivate it by treatments that can denature proteins such as heat, extremes of pH, and high ionic strength solutions. Hence, blanching, acidification, salt dips, and sugar packs will drastically reduce the problem [8]. A study [9] reported that dips containing ascorbic acid as a reducing agent and citric acid as an acidulant, on their own or as a mixture, had been broadly described as anti-browning agents for fresh produce. According to [10], anti-browning agents based on citric acid or ascorbic acid in combination with atmospheric packaging and low temperature increased the storage life of sliced fresh fruit. Phenolic compounds, as well as flavonoids, are vital phytochemicals found in the leaves of *Moringa*

oleifera as reported by [11] and known for a variety of activities which include antioxidant, anti-hypertension, and anti-inflammatory actions [12,13]. Moreover, the aqueous extract of *Moringa oleifera* leaves is antimicrobial [14]. At the correct levels, sorbates prevent the proliferation of spoilage bacteria such as Escherichia coli. They also successfully stopped the growth of moulds, including mycotoxin producing types, and at 0.01–0.2%, can inhibit most yeasts [15]. However, nothing is known about the effect of weak acids in combination with *Moringa oleifera* leaf extract powder (MOLEP), used as a pre-treatment of drying, on dried apples. Therefore, this research aimed to determine the main effects of the weak acids and *Moringa oleifera* leaf extract powder and to identify the acids and *Moringa oleifera* leaf extract powder combination that will reduce discolouration of the dried apple slices, and thus be used as an alternatives to sulphite as a preservative for dried fruits.

2. Materials and Methods

2.1. Source of Materials and Equipment

Granny Smith apples were purchased at a retailer in Cape Town, South Africa. The apples were refrigerated at 4 ± 1 °C until needed for the experiment. MOLEP was purchased from Döhler (Darmstadt, Germany), South Africa Pty (Ltd) (Paarl, South Africa), ascorbic acid from Lake Foods (Johannesburg, South Africa), citric acid from Savanna Fine Chemicals (Pty) Ltd. (Cape Town, South Africa), and potassium sorbate from Bragan Chemicals CC (Johannesburg, South Africa). The sliced apples were dried using a cabinet dehydrator (Excalibur, model no: EXC 10,California, USA). The cabinet dryer consists of a fan (horizontal airflow), 10 trays, a heating element, and a thermostat which are at the back of the dehydrator. Cool air is drawn in heated and distributed evenly over each tray [16].

2.2. Experimental Design for the Drying of the Apples

The apple slices were pre-treated based on an augmented 2^{6-3} fractional factorial design using two levels (low and high) of each variable as shown in Table 1.

Table 1. Factors in augmented 2^{6-3} fractional factorial design *.

Factor	Notation	Factor Level (x_i)	
		Low (−1)	High (+1)
Ascorbic acid (%)	X_1	0.5	2.0
Citric acid (%)	X_2	0.3	2.0
Potassium sorbate (%)	X_3	0.1	0.3
Moringa oleifera (%)	X_4	0.1	0.2
Time (hours)	X_5	7	15
Temperature (°C)	X_6	57	70

* Transformation of the coded variables (x_i) to uncoded (X_i) is given by $X_1 = 0.75x_1 + 1.25$; $X_2 = 0.85x_2 + 1.15$; $X_3 = 0.1x_3 + 0.2$; $X_4 = 0.05x_4 + 0.15$; $X_5 = 4.5x_5 + 11.5$; $X_6 = 6.5x_6 + 63.5$.

The sliced apples were dipped into water containing the weak acids and MOLEP in dosages based on the experimental design in Table 2. The entire design comprised of 19 experimental trials (8 factorial and 3 center points), including triplicates of the center point, as shown in Table 2. Each of the 8 runs was carried out in duplicate. The sliced apples were submerged for 5 min [17]. The excess water was gently dabbed off with a paper towel [7,18]. The independent factors were ascorbic acid (AA), citric acid (CA), potassium sorbate (PS), *Moringa oleifera* leaf extract powder (MOLEP), time, and temperature. The dehydrator was set as per the drying time and temperature set in Table 2.

The pre-treated sliced apples were placed evenly as a single layer on the dehydrator trays. The dried sliced apples were packed in aluminium foil pouches, heat-sealed, and kept at room temperature before analysis. The dried sliced apples were analysed for weight loss and colour characteristics.

Table 2. Experimental runs based on the augmented 2^{6-3} fractional factorial design.

Run	Independent Variables (%)					
	X_1	X_2	X_3	X_4	X_5	X_6
1A	2.00	0.30	0.30	0.10	15	57
2A	1.25	1.15	0.20	0.15	11	64
3A	0.50	2.00	0.30	0.10	7	70
4A	0.50	0.30	0.30	0.20	7	57
4B	0.50	0.30	0.30	0.20	7	57
2B	1.25	1.15	0.20	0.15	11	64
5A	2.00	2.00	0.30	0.20	15	70
6A	2.00	0.30	0.10	0.10	7	70
1B	2.00	0.30	0.30	0.10	15	57
7A	0.50	2.00	0.10	0.10	15	57
5B	2.00	2.00	0.30	0.20	15	70
8A	2.00	2.00	0.10	0.20	7	57
9A	0.50	0.30	0.10	0.20	15	70
2C	1.25	1.15	0.20	0.15	11	64
9B	0.50	0.30	0.10	0.20	15	70
6B	2.00	0.30	0.10	0.10	7	70
8B	2.00	2.00	0.10	0.20	7	57
7B	0.50	2.00	0.10	0.10	15	57
3B	0.50	2.00	0.30	0.10	7	70

X_1 = Ascorbic acid, X_2 = Citric acid, X_3 = Potassium sorbate, X_4 = *Moringa oleifera* leaf extract powder, X_5 = Time, X_6 = Temperature.

Data were modelled using main effect model to establish the variables that have a significant effect on the colour of the dried sliced apples. Analysis of variance (ANOVA) was used to determine the statistical significance of the independent variables (AA, CA, MOLEP, PS, time and temperature) on the lightness, redness, and yellowness of the dehydrated sliced apples. The goodness of the fit was determined by the lack of fit, F-value, and the adequate precision ratio (DesignExpert version 12). Numerical optimization (DesignExpert version 12) was applied to obtain the optimum combination of independent variables that will minimise redness (+a*) and yellowness (+b*).

2.3. Weight Loss

The pre-treated/dipped apple slices were weighed on a scale (UWE UPS 600E, Mettler PE 3000) before and after the drying process. The apple slices before and after the drying were weighed and the change in the weight was calculated as weight loss [19]. The weight loss was expressed as a percentage of the weight before drying.

2.4. Colour Measurement

The surface colour of the pre-treated and untreated dried apples was measured using a spectrophotometer (Spectrocolorimeter Datacolor 600). This method allowed the determination of the trichromatic coordinates CIELAB (L* a* b*) using a spectrophotometer with measurement geometry d/8 (diffuse illumination, directional observation at $8 \pm 2^{\circ}$) and D65 illuminant. The spectrophotometer was calibrated using a black trap and a white tile before the readings. The sample was placed directly on the instrument in such a way that the reading surface is perfectly flat. The colour was recorded as L* a* b* values. L* represents lightness, ranging from 0–100, 0 being black (no light) and 100 white (maximum illumination). The a* is green (negative) to red (positive). The b* is blue (negative) to yellow (positive) [20,21].

2.5. Profiling of the Moringa oleifera Extract Powder (MOLEP)

The MOLEP components were identified and quantified by liquid chromatography-mass spectrometry. Two grams of the MOLEP were accurately weighed into a 50 mL centrifuge tube with a screw-cap. A 15 mL of 50% methanol/1% formic acid was added

and the tubes were tightly capped. Thereafter, the samples were vortexed for 1 min, followed by extraction in an ultrasonic bath for 1 h. Two millilitres of the sample were then withdrawn and centrifuged at 14,000 rpm for 5 min. The clear supernatant was then transferred into 1.5 mL glass vials for analysis. A Waters Synapt G2 quadrupole time-of-flight (QTOF) mass spectrometer (MS) connected to a Waters Acquity ultra-performance liquid chromatography (UPLC) (Waters, Milford, MA, USA) was used for high-resolution UPLC-MS analysis. Column eluate first passed through a Photodiode Array (PDA) detector before going to the mass spectrometer, allowing simultaneous collection of UV and MS spectra. Electrospray ionization was used in negative mode with a cone voltage of 15 V, desolvation temperature of 275 °C, desolvation gas at 650 L/h, and the rest of the MS settings optimized for best resolution and sensitivity. Data were acquired by scanning from m/z 150 to 1500 m/z in resolution mode as well as in MSE mode. In MSE mode, two channels of MS data were acquired, one at low collision energy (4 V) and the second using a collision energy ramp (40−100 V) to obtain fragmentation data as well. Leucine enkaphalin was used as lock mass (reference mass) for accurate mass determination and the instrument was calibrated with sodium formate. Separation was achieved on a Waters HSS T3, 2.1 × 100 mm, 1.7 µm column. An injection volume of 2 µL was used and the mobile phase consisted of 0.1% formic acid (solvent A) and acetonitrile containing 0.1% formic acid as solvent B. The gradient started at 100% solvent A for 1 min and changed to 28% B over 22 min in a linear way. It then went to 40% B over 50 s and a wash step of 1.5 min at 100% B, followed by re-equilibration to initial conditions for 4 min. The flow rate was 0.3 mL/min and the column temperature were maintained at 55 °C. Compounds were quantified relatively against a calibration curve established by injecting a range of catechin standards from 0.5 to 100 mg/L catechin. Data were processed using MSDIAL and MSFINDER (RIKEN Centre for Sustainable Resource Science: Metabolome Informatics Research Team, Kanagawa, Japan).

2.6. Statistical Analysis

Statistical analysis was performed by testing significant differences ($p \leq 0.05$) between treatments using multivariate analysis of variance, and Duncan's multiple range test was used to separate means where differences existed.

3. Results and Discussion

3.1. Model Adequacy

The summary of the linear model parameters for the effect of the independent variables on the colour (L*, a*, b*) of the dried apple slices are shown in Table 3. The linear model for L* (lightness) was not significant (p = 0.0836) in describing the effect of the independent variables (AA, CA, MOLEP, time and temperature) on the colour of the dried apple slices. The overall mean may be a better predictor for the response than this model as indicated by the negative predicted R-square value. Thus, this model will not be used to predict the effects of the independent variables (AA, CA, MOLEP, time and temperature) on the colour of the dried apple slices. The effect of the AA, CA, MOLEP, time, and temperature on a* (redness) was sufficiently explained by the linear model (p = 0.0112) as indicated in Table 3. The model F-value of 4.72 suggests only a 1.12% likelihood that an F-value this big could occur because of noise. The model lack-of-fit of 0.11 suggests that the lack of fit is not significant, indicating a model with adequate goodness of fit. This was validated by the adequacy precision ratio of 6.136, which indicated that this model could be used to navigate the design space. The impact of the independent variables (AA, PS, MOLEP, time and temperature) on b* (yellowness) was significant (p = 0.0106). The model F-value of 4.78 suggests that the model is significant with only a 1.06% possibility that an F-value this big could occur because of noise. The lack-of-fit of 0.02 implies the lack of fit is not significant, indicating a model with acceptable goodness of fit. This is supported by the adequate precision ratio of 6.56; therefore, this model can be used to navigate the design space.

Table 3. Model parameters for dried apple slices.

Model Parameter	Colour		
	Lightness (L*)	Redness (+a*)	Yellowness (+b*)
p-value	0.0836	0.0112 #	0.0106 #
F-value	2.52	4.72	4.78
R2	0.4918	0.6448	0.6478
Predicted R2	−0.2213	0.1779	0.1882
Adeq precision	4.566	6.136	6.555

Significant, $p \leq 0.05$.

The linear model for lightness (L*) was not adequate to explain the variation in the colour of the apple slices; however, the linear models for redness (a*) and yellowness (b*) adequately described the colour variation of the dried apple slices. Hence, in searching for the optimal combination of the independent variables for the optimum colour of the apple slices, the models for the redness and yellowness will be used for numerical optimisation.

3.2. Effect of the Ascorbic Acid, Citric Acid, Potassium Sorbate, Moringa oleifera Leaf Extract Powder, Time, and Temperature on the Weight Loss of the Dried Apple Slices

The weight loss of the dehydrated sliced apples is presented in Table 4 and ranges from 85 to 90% with a mean of 87.7%. Studies done by [6] recorded the moisture content of fresh apples as approximately 86.2% and [22] reported it as 85.8%. Hot air drying is a process in which moisture is removed, this action reduces the weight of foodstuff [23]. The weight loss is thus a result of the hot air removing the moisture from the apple slices during the drying process.

Table 4. Weight loss of the dried apple slices.

Run	Independent Variables (%)						Weight Loss (%) [1]
	X_1	X_2	X_3	X_4	X_5	X_6	
1	2.00	0.30	0.30	0.10	15	57	85.4 ± 0.4
2	1.25	1.15	0.20	0.15	11	64	87.8 ± 5.3
3	0.50	2.00	0.30	0.10	7	70	86.6 ± 4.3
4	0.50	0.30	0.30	0.20	7	57	90.2 ± 3.8
5	2.00	2.00	0.30	0.20	15	70	88.3 ± 2.0
6	2.00	0.30	0.10	0.10	7	70	88.2 ± 6.1
7	0.50	2.00	0.10	0.10	15	57	87.8 ± 3.8
8	2.00	2.00	0.10	0.20	7	57	85.4 ± 3.4
9	0.50	0.30	0.10	0.20	15	70	90.3 ± 6.5

[1] Values are mean + standard deviation of duplicate for the 8 factorial runs and triplicate for center points. X_1 = Ascorbic acid, X_2 = Citric acid, X_3 = Potassium sorbate, X_4 = *Moringa oleifera* leaf extract powder, X_5 = Time, X_6 = Temperature.

The temperature range in this study was 57–70 °C. A study by [6] showed that in the temperature range of 50–70 °C, the difference in moisture content of dehydrated apples was not significant. This might be the reason why the independent variables did not significantly affect the weight loss of the dehydrated sliced apples ($p = 0.8855$).

3.3. Effect of the Ascorbic Acid, Citric Acid, Potassium Sorbate, Moringa oleifera Leaf Extract Powder, Time, and Temperature on the Colour of Dried Apples

Table 5 details the lightness (L*), redness (a*) and yellowness (b*) of the different combinations of the weak acids with Moringa oleifera leaf extract powder (MOLEP). The results indicate that run 3 with citric acid at 2.00% and the MOLEP at 0.10% dosage had the greatest effect on the redness (2.1) and yellowness (21.3) of the dehydrated sliced apples. Images of the dehydrated sliced apples for the different runs are illustrated in Figure 1.

Table 5. Colour parameters of dried apples pre-treated with various combinations of weak acids and *Moringa oleifera* leaf extract powder (MOLEP).

	X_1	X_2	X_3	X_4	X_5	X_6	Colour Parameters [1]		
Run	**(%)**	**(%)**	**(%)**	**(%)**	**(h)**	**(°C)**	**L***	**a***	**b***
1	2.00	0.30	0.30	0.10	15	57	78.9 ± 2.6	4.0 ± 2.5	22.8 ± 4.3
2	1.25	1.15	0.20	0.15	11	64	77.8 ± 1.4	3.7 ± 1.1	25.3 ± 1.9
3	0.50	2.00	0.30	0.10	7	70	81.90 ± 1.2	2.1 ± 0.3	21.3 ± 1.9
4	0.50	0.30	0.30	0.20	7	57	75.0 ± 4.4	6.7 ± 2.6	23.9 ± 4.7
5	2.00	2.00	0.30	0.20	15	70	82.0 ± 1.2	3.4 ± 0.3	28.0 ± 0.8
6	2.00	0.30	0.10	0.10	7	70	78.2 ± 0.7	4.3 ± 0.9	24.5 ± 2.0
7	0.50	2.00	0.10	0.10	15	57	81.4 ± 0.5	2.4 ± 0.5	23.5 ± 0.5
8	2.00	2.00	0.10	0.20	7	57	77.7 ± 3.7	3.7 ± 1.8	27.0 ± 0.8
9	0.50	0.30	0.10	0.20	15	70	76.0 ± 5.7	6.5 ± 1.2	29.2 ± 0.8

[1] Values are mean + standard deviation of center point triplicate and duplicate for other points. L*, lightness; a*, red (+a); b*, yellow (+b). X_1 = Ascorbic acid, X_2 = Citric acid, X_3 = Potassium sorbate, X_4 = *Moringa oleifera* leaf extract powder, X_5 = Time, X_6 = Temperature.

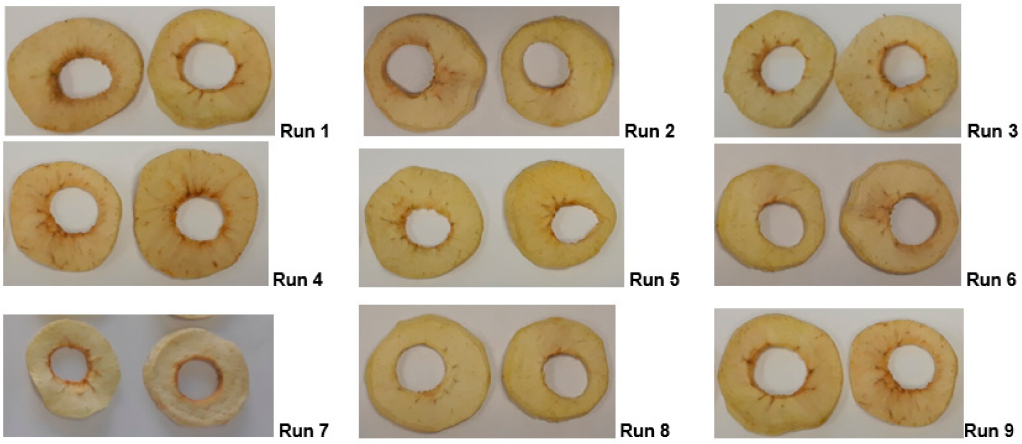

Figure 1. Images of the dried apple slices.

Table 6 indicates that the effect of ascorbic acid, time, and temperature on the lightness, redness, and yellowness were not significant. Similarly, potassium sorbate did not significantly affect the yellowness of the dehydrated sliced apples. The effect of the citric acid on the lightness and redness of the dehydrated sliced apples were significant. The impact of MOLEP on the lightness, redness, and yellowness of the dried apple slices was significant. The response surface for the effect of ascorbic and citric acid as well as that of ascorbic acid and MOLEP on the lightness of the dehydrated sliced apples are illustrated in Figure 2.

Table 6. Effect of the independent variables on the dried apple slices.

	p-Value		
Model Parameter	**Lightness (L*)**	**Redness (+a*)**	**Yellowness (+b)**
Ascorbic acid	0.7034	0.3646	0.3151
Citric Acid	0.0539 #	0.0022 #	-
Potassium sorbate	-	-	0.0714
MOLEP	0.0149 #	0.0136 #	0.0022 #
Time	0.8403	0.8169	0.1307
Temperature	0.8849	0.8698	0.1817

Significant, $p < 0.05$; MOLEP = *Moringa oleifera* leaf extract powder.

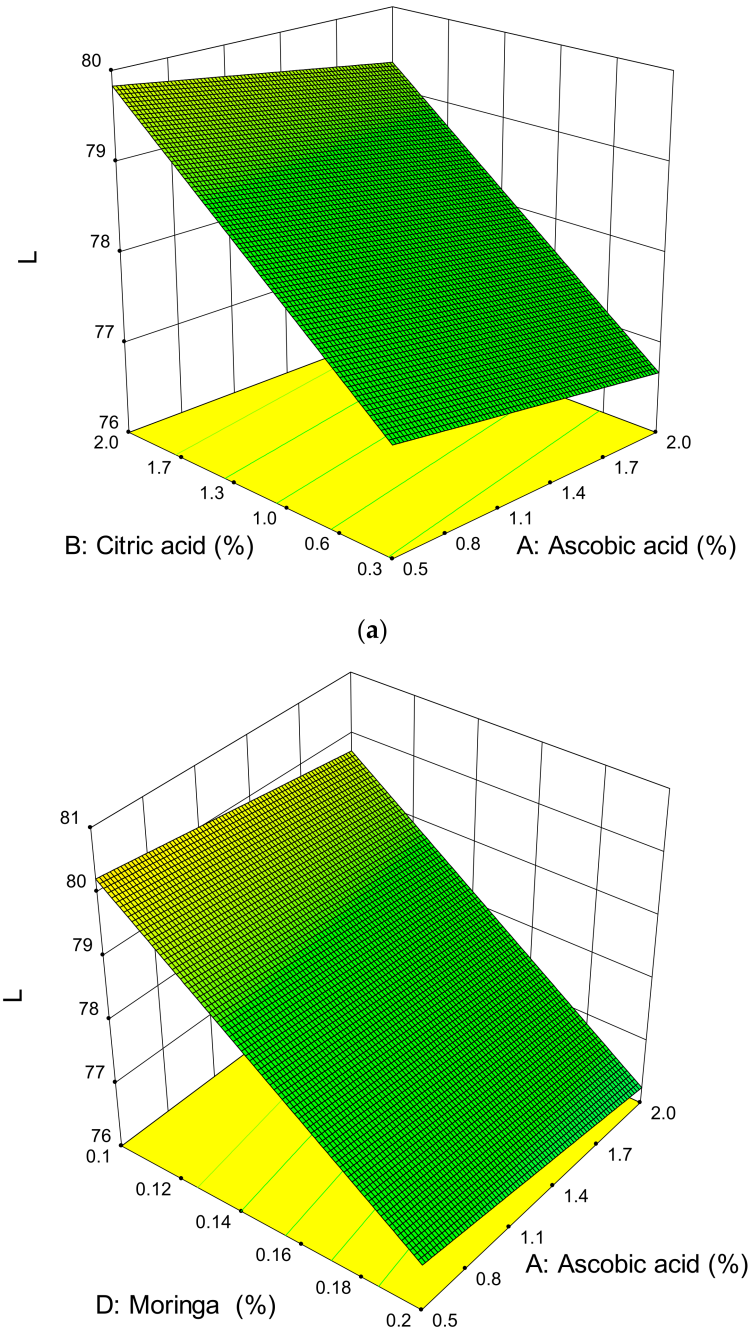

Figure 2. Response surface plot for the effect of; (**a**) citric acid and ascorbic acid and (**b**) *Moringa oleifera* leaf extract powder and ascorbic acid on the lightness (L*) of dried apple slices.

Figure 2a indicates that an increase in the concentration of citric acid significantly (p = 0.05) increased the lightness (L*) of the dehydrated sliced apples. Figure 2b illustrates that an increase in the concentration of MOLEP significantly (p = 0.01) reduced the lightness (L*) of the dried apple slices. The response surfaces for ascorbic and citric acid as well as for MOLEP and ascorbic on the redness (a*) of the dried apple slices are illustrated in Figure 3. Figure 3a indicates that an increase in the concentration of citric acid significantly (p = 0.0022) decreased the redness (a*) of the dried apple slices. A unit increase in citric acid decreased the redness of the apple slices by −1.24. The three-dimensional response surface plot (Figure 3b) for MOLEP and ascorbic on the redness (a*) of the dried apple

slices indicated that an increase in the concentration of MOLEP increased the redness (a*) of the dehydrated sliced apples significantly (p = 0.0136). The equation of coded factors (1) indicated that the impact of MOLEP is positive (+0.93) on the redness of the dehydrated sliced apples.

$$a = +4.06 - 0.31 \text{ Ascorbic acid} - 1.24 \text{ Citric acid} + 0.93 \textit{ Moringa oleifera} \text{ leaf extract powder} - 0.08 \textit{ Time} - 0.05 \text{ Temperature} \quad (1)$$

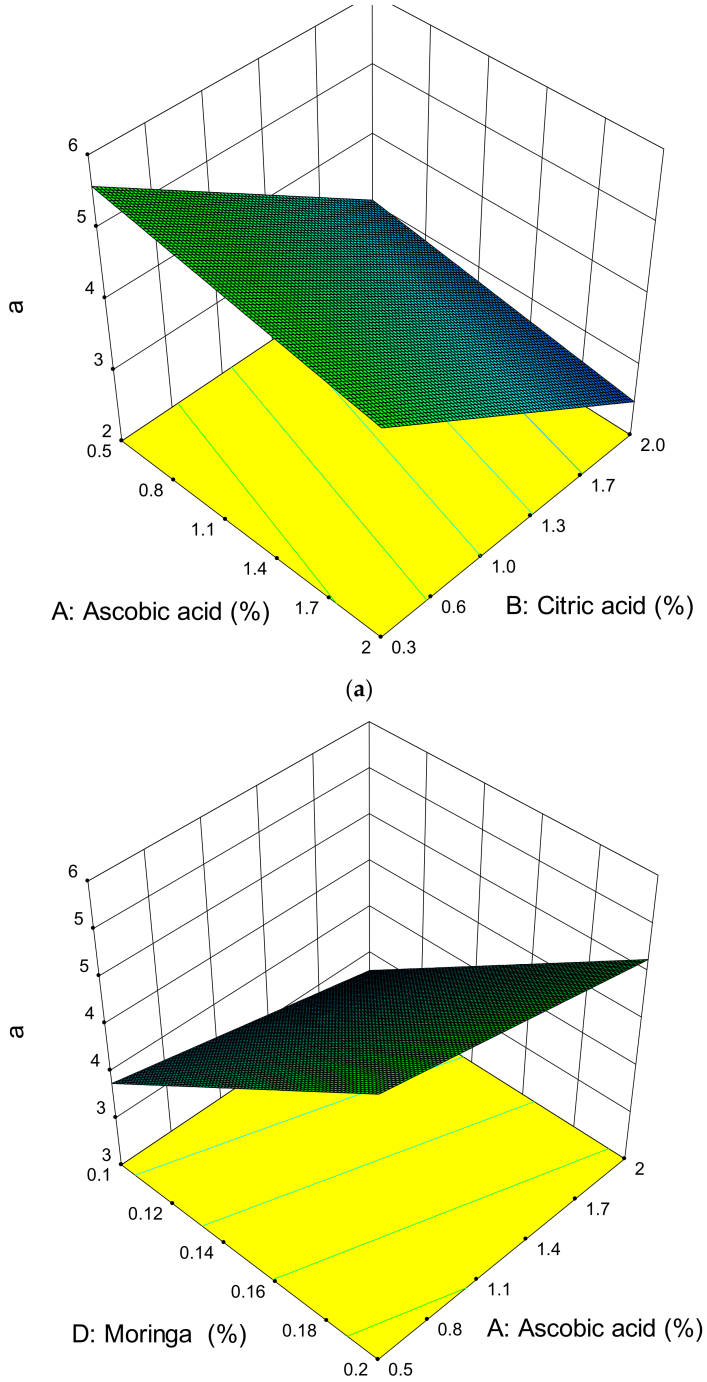

Figure 3. Response surface plot for the effect of (**a**) ascorbic acid and citric acid and (**b**) *Moringa oleifera* leaf extract powder and ascorbic acid on the redness (a*) of dried apple slices.

The response surfaces for citric acid and ascorbic as well as MOLEP and ascorbic acid on the yellowness (b*) of the dried apple slices are illustrated in Figure 4. The three-dimensional response surface plot (Figure 4a) indicates that an increase in the concentration of ascorbic acid increased the yellowness (b*) of the dehydrated sliced apples, however not significantly (p = 0.3151). The impact of ascorbic acid on the yellowness of the dehydrated sliced apples was positive (+0.55). The plot (Figure 4a) indicated that yellowness decreased with an increase in citric acid.

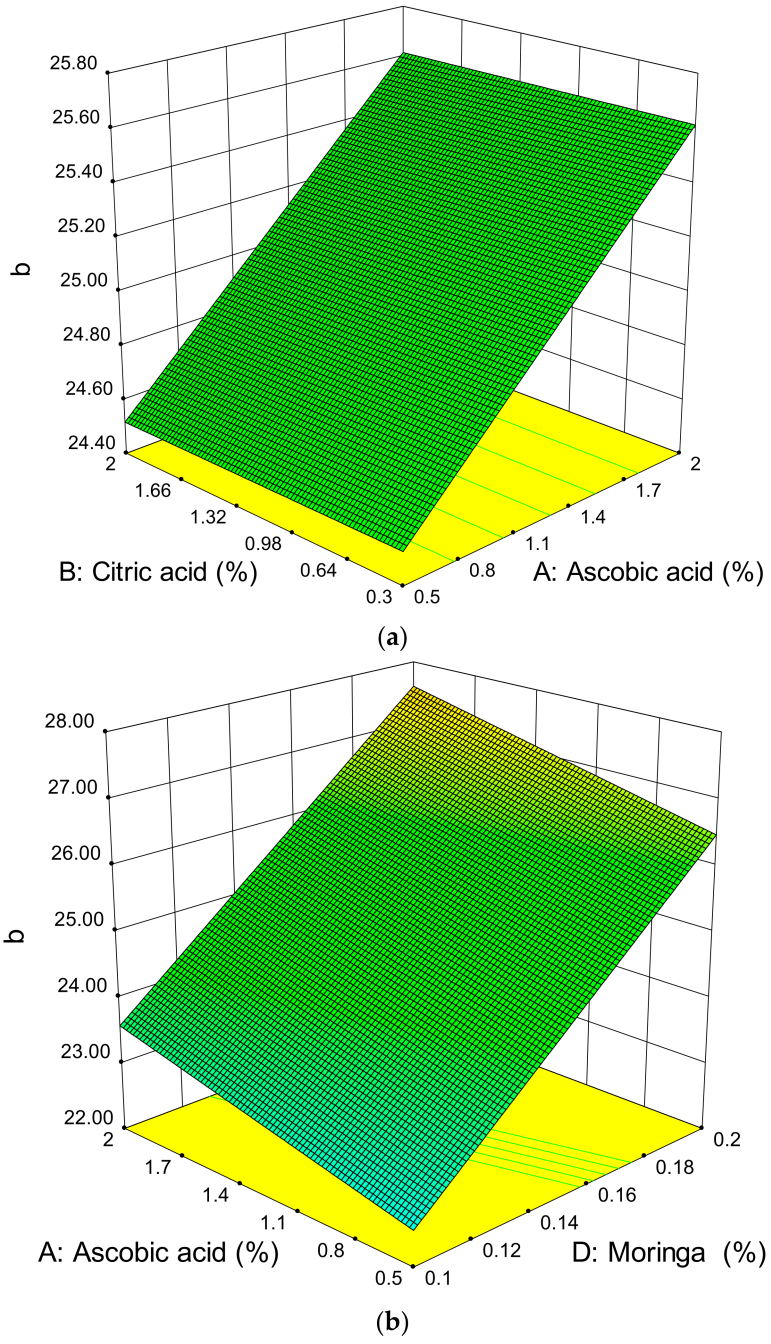

Figure 4. Response surface plot for the effect of (**a**) citric acid and ascorbic acid and (**b**) ascorbic acid and *Moringa oleifera* leaf extract powder on the yellowness (b*) of dried apple slices.

The response surface plot (Figure 4b) indicated that an increase in the concentration of MOLEP increased the yellowness (b*) of the dried apple slices significantly (p = 0.0022).

The impact of MOLEP was positive (+1.99) on the yellowness (b*) of the dehydrated sliced apples indicated by the equation of coded factors (2).

$$b = +25.07 + 0.55 \text{ Ascorbic acid} - 1.03 \text{ Potassium sorbate} + 1.99 \textit{ Moringa oleifera} \text{ leaf extract powder} + 0.85 \text{ Time} + 0.74 \text{ Temperature} \quad (2)$$

The positive effect of citric acid on the redness and yellowness of the dried apple slices can be explained by its pH lowering effect and the fact that it is a copper chelating agent [24,25]. The enzyme polyphenol oxidase needs copper to function as reported by [26]. According to [26], the binding of the copper at the active site of the enzyme becomes looser at pH values below 4, hence allowing the copper ions to be removed by the citric acid. The pH of the dipping solutions were all <4 (2.36–3.68), allowing the copper ions to be removed by the citric acid at the active site of the PPO enzyme and thus prevent browning [27–29]. It was reported by various studies that ascorbic acid reduces the quinones which are responsible for the brown or black pigments and therefore surface browning; however, the effect does not last, as it is permanently oxidized over time to dehydro-ascorbic acid [7,30]. Polymerization of o-quinones takes place after it is depleted and thus darkening of the product occurs ([7,24,30–34]. Thus, the effect of ascorbic acid on the lightness (L*), redness (a*), and yellowness (b*) of dehydrated sliced apples was not significant. The response surface plots (Figures 2b, 3b and 4b) illustrated that decreasing MOLEP caused a decrease in redness and yellowness of the dried sliced apples. According to [35], Moringa oleifera leaves are an excellent source of natural antioxidants and can extend the storage time of food containing fat. Phenolic compounds and flavonoids are the main phytochemical components in the leaves of *Moringa oleifera*, [11,12] and are known to inhibit PPO activity. An author [36] also reported that Moringa oleifera leaves are an excellent source of phenolic constituents and have effective antioxidant activity. He reported that a 0.1% extract (100 mg/100 g) were sufficient to prevent lipid oxidation in goat meat patties stored at refrigeration temperatures. This is in agreement with the study by [35] which reported that a lower dosage of Moringa leaves indicated a slightly higher antioxidant activity over time. The presence of phytochemicals (polyphenols and flavonoids) may, therefore, be responsible for the overall antioxidant effect.

3.4. Optimum Combination of Some Weak Acids (Ascorbic Acid, Citric Acid and Potassium Sorbate), Moringa oleifera Leaf Extract Powder, Temperature, and Drying Time for the Apple Slices

Redness and yellowness due to good model fit were used to search for an optimal combination of the weak acids and *Moringa oleifera* leaf extract powder. Ascorbic acid and potassium sorbate did not have a significant impact on the colours and were constrained to zero, and the other variables were in the range. The goal for optimization was to minimize the redness (a*) and yellowness (b*) of the dehydrated sliced apples. The optimal solution with the desirability of 0.721 was to pre-treat the apple slices in a solution with 2.0% citric acid and 0.1% *Moringa oleifera* leaf extract powder, drained, and dried for 7 h at 70 °C.

3.5. Phytochemical Constituents of the Moringa oleifera Leaf Extract Powder

Figure 5 details the phytochemicals identified in the *Moringa oleifera* leaf extract powder used in this study with nodes sizes ranked according to betweenness centrality, which is a measure of important nodes in networks in terms of information diffusion and connectedness. Hence, the lineolic acids and derivatives, o-glycosyl compounds, and phenolic glycosides are influential metabolites in *Moringa oleifera* leaf extract powder. The diagram also indicates the link between the different components. The majority of the phytocompounds present in the *Moringa oleifera* leaf extract powder are flavonoids and alkaloids and are presented in Table 7. This agrees with the various studies regarding the phytoconstituents present in the Moringa oleifera leaves [37–39].

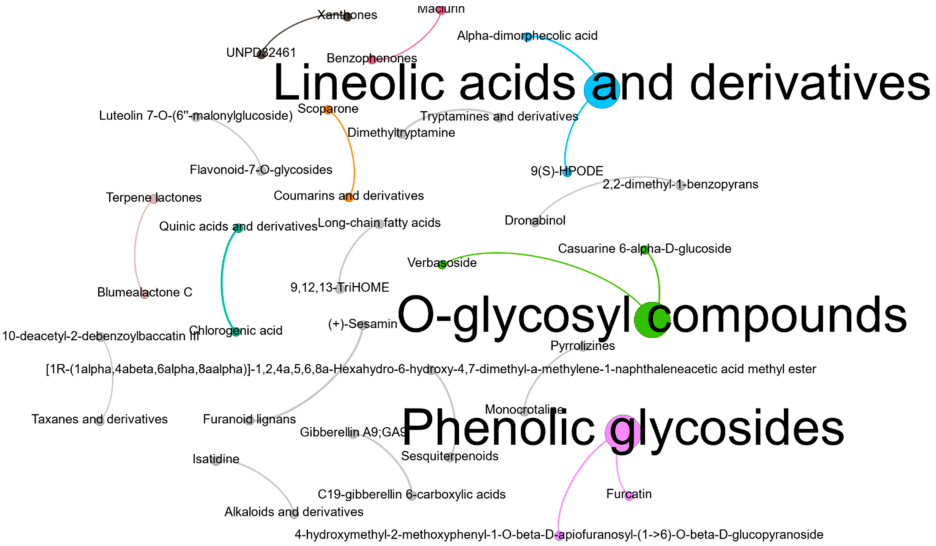

Figure 5. Phytochemicals identified in the *Moringa oleifera* extract powder.

Table 7. Phytocompounds identified in the *Moringa oleifera* extract used in this study.

Average Rt (min)	Average Mz	Structure Rank 1	Formula	Total Score	Ontology	Classification
7.097	570.093	UNPD32461	$C_{30}H_{21}NO_{11}$	5.902	Xanthones	Alkaloid
7.186	205.063	Scoparone	$C_{11}H_{10}O_4$	5.961	Coumarins and derivatives	Flavonoid
7.490	261.026	Maclurin	$C_{13}H_{10}O_6$	5.438	Benzophenones	Flavonoid
7.602	353.102	Chlorogenic acid	$C_{16}H_{18}O_9$	7.943	Quinic acids and derivatives	Flavonoid
7.707	323.145	Blumealactone C	$C_{17}H_{24}O_6$	5.829	Terpene lactones	Flavonoid
7.824	315.129	Gibberellin A9; GA9	$C_{19}H_{24}O_4$	7.719	C19-gibberellin 6-carboxylic acids	Phytohormone
8.115	353.108	(+)-Sesamin	$C_{20}H_{18}O_6$	8.836	Furanoid lignans	Flavonoid
8.404	447.160	4-hydroxymethyl-2-methoxyphenyl-1-O-beta-D-apiofuranosyl-(1->6)-O-beta-D-glucopyranoside	$C_{19}H_{28}O_{12}$	6.893	Phenolic glycosides	Flavonoid
8.718	427.185	Furcatin	$C_{20}H_{28}O10$	6.067	Phenolic glycosides	Flavonoid
9.006	461.175	Verbasoside	$C_{20}H_{30}O_{12}$	5.839	O-glycosyl compounds	Flavonoid
9.126	439.192	10-deacetyl-2-debenzoylbaccatin III	$C_{22}H_{32}O_9$	5.483	Taxanes and derivatives	Alkaloid
9.295	324.129	Monocrotaline	$C_{16}H_{23}NO_6$	7.420	Pyrrolizines	Alkaloid
9.987	261.157	[1R-(1alpha,4abeta,6alpha,8aalpha)]-1,2,4a,5,6,8a-Hexahydro-6-hydroxy-4,7-dimethyl-a-methylene-1-naphthaleneacetic acid methyl ester	$C_{16}H_{22}O_3$	7.599	Sesquiterpenoids	Flavonoid
10.227	533.098	Luteolin 7-O-(6″-malonylglucoside)	$C_{24}H_{22}O_{14}$	5.766	Flavonoid-7-O-glycosides	Flavonoid
10.478	187.126	Dimethyltryptamine	$C_{12}H_{16}N_2$	7.863	Tryptamines and derivatives	Alkaloid
10.628	366.138	Isatidine	$C_{18}H_{25}NO_7$	6.541	Alkaloids and derivatives	Alkaloid
10.954	366.137	Casuarine 6-alpha-D-glucoside	$C_{14}H_{25}NO_{10}$	7.134	O-glycosyl compounds	Alkaloid
12.919	329.249	9,12,13-TriHOME	$C_{18}H_{34}O_5$	6.984	Long-chain fatty acids	Fatty Acid
13.938	313.261	Dronabinol	$C_{21}H_{30}O_2$	6.485	2,2-dimethyl-1-benzopyrans	Alkaloid
14.123	311.242	9(S)-HPODE	$C_{18}H_{32}O_4$	5.954	Lineolic acids and derivatives	Fatty acid
14.351	295.244	Alpha-dimorphecolic acid	$C_{18}H_{32}O_3$	6.983	Lineolic acids and derivatives	Fatty acid

Rt = retention time, Mz = molecular weight.

The phenolic compounds capability to scavenge free radicals is associated with their capacity to donate their phenolic hydrogen atom to a free radical [40,41]. Studies by [42,43] stated that flavonoids can stop auto-oxidation by chelating the free radical producing metal ions. Moreover, according to [44], flavonoids are oxygen scavengers and inhibit peroxidation. Several studies also mentioned that phenolic compounds such as flavonoids also exhibit antiviral, antibacterial, and anti-inflammatory activity [40,44,45]. The ability of flavonoids to chelate with metal ions as well as being oxygen scavengers may be the reason why the Moringa oleifera leaf extract contributed to reducing the browning and microbial count of the dried apple slices.

4. Conclusions

The hypothesis of whether the optimum combination of weak acids (ascorbic acid, citric acid and potassium sorbate) and *Moringa oleifera* leaf powder will preserve the colour of the dried apples was tested in this study. The results of this work indicate that ascorbic acid and potassium sorbate did not impact the colour of the dehydrated sliced apples. Citric acid had a positive effect on the colour of dried sliced apples, whereas that of *Moringa oleifera* at the high dosage was negative. A dipping solution with citric acid at 2.0%, *Moringa oleifera* leaf extract at 0.1%, and a drying time of 7 h at 70 °C minimized the discolouration of the dried apple slices. The objective to identify the best weak acid and *Moringa oleifera* leaf extract powder combination to minimize the discolouration of the dried apple slices was thus achieved.

Author Contributions: Conceptualization, V.J. and W.A.; methodology, V.J. and W.A.; formal Analysis, V.J.; investigation, W.A.; resources V.J. and W.A.; writing—original draft preparation, W.A.; writing—review & editing, W.A. and V.J.; supervision, V.J. All authors have read and agreed to the published version of the manuscript.

Funding: The research was funded by Pioneer Foods Group, South Africa and Cape Peninsula University of Technology, Bellville, South Africa.

Institutional Review Board Statement: Ethical clearance obtained from the Faculty of Applied Sciences Ethics Committee, Cape Peninsula University of Technology, Bellville, South Africa.

Informed Consent Statement: Informed consent obtained from the sensory panellists.

Data Availability Statement: No other data other than the content of this manuscript.

Acknowledgments: The author would like to thank Pioneer Foods Group South Africa and the Cape Peninsula University Research Funding for funding this work.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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