THE PRODUCTION OF A DRIED AVOCADO (*Persea americana*) POWDER

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Abstract*:* This work investigated the technique of vacuum freeze drying of avocado pulp (*Persea americana* var. Pollock) to produce a dried cake which could be blended into a powder to be used in various food applications. Frozen, mashed avocado pulp samples were dried in a Benhay SB-4 vacuum freeze dryer. For comparison, fresh pulp samples were also oven-dried in a Unitemp drying cabinet at 60°C. Samples were dried until constant weight was achieved after which they were blended into powders and analysed. Analyses included determination of moisture content, water activity, pH and total soluble solids content, colour assessment, proximate analyses, physical properties, rehydration behaviour and a preliminary storage assessment. Drying data was used to generate rate and Moisture Ratio (MR) curves and thin layer models applied to the MR data. The moisture content and water activity values of the fresh pulp averaged 3.16 g H_2O/g dry matter (76.0% wet basis) and 0.889, respectively. Samples were successfully dried in the freeze dryer to an average moisture content of 0.02 g H_2O/g dry matter (2.1% wet basis) after 72h, and a final average water activity of 0.356. Drying occurred in the falling rate period and the drying rate constant (k_1) averaged 0.2496 1/h. The Verma model was found to best fit the Moisture Ratio (MR) data. Compared with oven-dried samples, the freeze-dried samples dried to lower equilibrium moisture values, did not show any signs of browning and was higher in protein and fat content. The freeze-dried 'cake' was easier to blend to a light, free-flowing powder which easily rehydrated to a form which closely resembled fresh avocado puree. Freeze drying is therefore an attractive option to produce a high-quality Pollock avocado powder, without the use of heat or the application of chemical preservatives to preserve colour.

Keywords: *Avocado, Freeze-drying, Oven-drying, Drying kinetics, Curve fitting*

https://doi.org/10.47412/DDSD1316

1. Introduction

The avocado (*Persea americana*) fruit, is primarily used in the ripe form as a table vegetable (fresh cut) or used in culinary preparations such as guacamole and smoothies. Processed avocado products include frozen slices and pulp, packaged guacamole and avocado oil. Avocado is rich in monounsaturated fatty acid, health-promoting phytosterols, and phenolic antioxidants [1]. The avocado is a climacteric fruit and for maximum shelf life the fruit is ripened after harvest. Commercially, the fruit is treated with ethylene before retailing but end user ripening is normally accelerated by wrapping the fruit in newspaper or by placing into a brown paper bag and monitoring daily. Once the ripe fruit is cut, the pulp deteriorates rapidly. Rapid discoloration (browning) is a major issue in processing avocados and occurs due to oxidation catalysed by polyphenol oxidase (PPO). Discoloration is a three-step step process that results in the development of dark polymers (melanin). Treatments to prevent pulp discoloration include the application of lemon juice, citric acid, ascorbic acid, sodium bisulfite, tertiary butylated hydroxyquinone (TBHQ), or some combination thereof.

Attempts have been made to produce a dried avocado pulp to extend the shelf life and make available year-round. Drying techniques have included hot air (oven) drying, heat pump assisted drying and drying with superheated steam [2-6]. Works on the hot air drying of avocado pulp slices and cubes investigated drying (5-8h) at temperatures ranging from 50 to 80°C [2,5]. Major issues arising out of hot air drying include shrivelling of slices, tough and rubbery slices, leaking of oils, unappealing colour, incomplete drying to effect safe storage and rancidity during storage. A challenging issue during thermal processing of avocado pulp is the development of a bitter off taste, attributed to a group of compounds called oxylipins [7]. Off-taste can also develop in the fresh avocado fruit due to tissue collapse and in the frozen pulp upon defrosting [1].

Vacuum freeze drying (lyophilization) is a dehydration process by which the material is first frozen and then dried under low temperature and at low pressure [8]. During the primary drying phase water is removed by sublimation as the ice is converted to vapour, through the application of a small amount of heat. During secondary drying unfrozen water molecules are removed as the temperature is raised. The potential advantages of freeze drying include the following: material structure is maintained, superior quality attributes are retained, suitable for heat-sensitive materials and thermo-labile components. The disadvantages of this drying method include high equipment cost, long drying times and high energy consumption. Only a few works studies have investigated the freeze drying of avocado. Castaneda-Saucedo et al. [9] investigated the effect of freeze drying on the chemical composition of avocado pulp (var. Hass). While they concluded that freeze drying resulted in slight changes in pulp nutritional quality, they concluded that the drying method was the best to preserve shelf life and maintain the sensorial and nutritional characteristics of the pulp. Husen et al. [6] noted that freeze dried Hass avocado with a moisture content of less than 2.5% (wb) could have a shelf life of up to 9 months. Souza et al. [10] investigated the effect of freezing and lyophilization pressure on antioxidant activity, texture and browning of cubed avocado pulp (var. Collinson). They also presented information on the drying kinetics of the pulp, including curve fitting using three models.

Pollock avocado belongs to the West Indian race (*Persea americana* Mill. var. americana) and is a large fruit of superior quality. The skin is green, smooth and glossy and the ripe flesh is an attractive deep yellow, changing to yellowish-green close to the skin. The ripe pulp is often described as smooth and 'buttery'. Very little has been reported on the drying of the Pollock avocado. Previous work by the present authors showed the potential for freeze drying as a method to produce high quality dried slices (0.01 m thick) which could be rehydrated or easily blended into a powder [11]. The authors however noted that the formation of ice crystals on the surface of the slices during freezing and the rapid thawing of slices during handling could potentially result in a decrease in dried product quality. To offset these complications, the objective of this study was to investigate the freeze-drying behaviour of mashed Pollock avocado pulp and compare selected quality attributes to oven-dried pulp samples.

2. Materials and Methods

Avocados (*Persea americana* var. Pollock) were obtained from a single tree, harvested at the unripe stage. Each avocado was wrapped in newspaper and left at room temperature to ripen. Fruit weight averaged 0.47±0.03kg, length 0.13±0.0037m and diameter 0.33±0.0060m. The pH and total soluble solids of ripe pulp averaged 7.65±0.02 and 0.73±0.03°Brix, respectively. Twenty-five (25) fully ripe avocados were washed and peeled and the pulp (mesocarp) mashed with a stainless-steel fork to a smooth paste, free of chunks. The mashed pulp was then transferred to petri dishes (0.095m dia) to a depth of 0.05 m. For freeze drying, samples were placed in a domestic freezer (-18ºC) for 48h. Avocado pulp samples were then dried for 72h in a laboratory-scale vacuum freeze drying unit (Benhay SB-4, UK) under vacuum (13.3 Pa) at a condenser temperature of -44°C and heating temperature of 24°C. For oven-drying, samples were dried for 24h in a Unitemp drying cabinet (LTE Scientific Ltd., Greenfield, Oldham) set at 60°C. Internal dimensions of the dryer were H 1.115 x W 0.785 x D 0.610 m. All samples were dried until constant weight was achieved, after which they were blended into powders using a Waring Commercial Laboratory Blender - 51BL30 (Torrington, Connecticut 06790, USA).

Sample weight (g) was recorded (0.01±0.005g) using an Explorer Pro Balance, Model EP2102C (Ohaus Corporation, NJ, USA). Moisture content of the fresh and dried samples was determined using a Halogen Moisture Analyzer HB43-S (Mettler Toledo-AG, Zurich, Switzerland) set at 105°C. Water activity (a_w) was measured using an Aqua Lab CX-2 1021 water activity meter (Decagon Devices Inco., Pullman, WA, USA). Sample pH was measured using an OAKTON 150 pH meter (OAKTON Instruments, IL, USA) and total soluble solids (TSS) content measured using a Reichert AR200 digital hand-held refractometer (Reichert, Inc. NY, USA). Colour was assessed using a CR-410 Choma Meter (Konica Minolta Sensing Americas, Inc., NJ, USA) using Hunter values (L*, a*, b*) [12]. Hue angle (°) was calculated as given in Eq. 1, with a correction of +180° for negative a* values [13].

$$Hue\ (°) = \frac{1}{\tan\left({}^{b}/_{a}\right)} \quad (1)$$

Crude protein content (%) of the dried powders was determined using the AOAC (2005) Official Method 2001.11, crude fat (%) AOAC (1990) Official Method 920.39, crude fibre (%) AOAC (2005) Official Method 978.10 and ash content AOAC (2005) Official Method 923.03 [14,15]. Particle size of the blended dried powders was determined using USA Standard Test Sieves (ATSME-11 Specification). Bulk (g/ml), tapped density (g/ml), solubility time (s), water solubility (%) and water absorption (%) were also determined [16-18]. Flowability and cohesiveness of the powder were evaluated in terms of Carr index (CI) and Hausner ratio (HR), respectively [16].

For a preliminary check on storage life, freeze-dried powders were placed into vacuum sealed bags and stored in a room at approximately 22ºC for a maximum of 12 weeks, during which moisture, water activity and objective colour measurements were made. Any changes in texture, colour, odour and appearance were also recorded.

For the collection of drying data, petri dishes containing frozen avocado purees were prepared in duplicate and placed into labelled petri dishes and dried for specific time intervals. Weight, moisture content and the water activity before and after drying (4-72 h) was recorded. Drying data obtained during freeze drying was analysed using the standard approach to drying studies, that is, the generation of drying rate and moisture ratio (MR) curves based on Eq. 2 as previously reported [19]. The drying rate constant (k) was determined from a plot of ln MR versus time (t) and used to calculate the moisture diffusivity (Eq. 3), using 0.005 m as the sample thickness.

$$MR = \frac{M - M_e}{M_0 - M_e} = A\ exp^{-kt} \quad (2)$$

$$k = \frac{\pi^2\ D_{eff}}{4L^2} \quad (3)$$

A total of nineteen (19) empirical and semi-empirical thin layer models [20, 21] were applied to the MR data and the performance (fit) of the models assessed through the use of the coefficient of determination (R^2), root mean square error (RMSE) and the chi-square statistic (χ^2). Model fit was done using Curve Expert Professional software (Version 2.3.0) [22].

3. Results and Discussion

3.1 General observations and colour

With respect to overall appearance, the oven-dried samples darkened severely, became hard and crisp, suffered severe shrinkage. Upon cooling, the samples became dense and difficult to remove from the petri dishes. Freeze-dried 'cakes' were an attractive yellow/green colour similar to that of the fresh puree. The freeze-dried "cake" was lightweight, airy, spongy and "puffed" in appearance. The dried "cake" maintained its structural integrity as it maintained its shape of the dish in which it was dried in and there were no noticeable signs of shrinkage. The freeze-dried cake was easily ground within 15s into a fine, airy and lightweight powder with a "dust-like" texture and a vibrant green attractive colour. Grinding of the oven-dried cakes was a more difficult process since the samples quickly became hard and dense. These samples were therefore ground for 2 minutes. The yield (%) of pulp was determined to be 71.2%. The yield of dried pulp from fresh pulp averaged 14.3% for oven-dried samples and 17.1% for freeze-dried samples.

The browning observed during oven drying may have be due to non-enzymatic browning or the Maillard reaction. The avocado is rich in unsaturated fatty acids which are responsible for oxidation which leads to the formation of volatile compounds responsible for off-colours, off-flavours and nutritional losses [23]. Valentina et al. [24] stated that browning reactions reduces the nutritive value of foods and results in off-odours and off-flavours as rancidity develops as a result of lipid oxidation. Freeze drying utilizes a low temperature and removes water by the sublimation of ice under vacuum which not only prevents enzymatic browning but also produces a highly porous structure.

The colour attributes of fresh and dried avocado samples are given in Table 1. As expected, the L*, a* and b* values for oven-dried samples reflected the darkening, browning and loss of yellow colour. The Hue (°) values of the freeze-dried samples was similar to that of the fresh puree.

Table 1: Colour attributes of fresh and dried avocado samples

Colour attribute	Fresh	Dried	
		Oven-Dried 60°C	Freeze-Dried
L*	62.3 ± 1.16^b	30.97 ± 0.31^b	82.96 ± 0.59^a
a*	-7.7 ± 0.21^b	2.79 ± 0.1^c	-14.32 ± 0.02^a
b*	40.44 ± 0.13^b	13.17 ± 0.18^c	60.38 ± 0.29^a
Hue (°)	100.78 ± 0.25^a	78.03 ± 0.54^c	103.34 ± 0.07^b

Values are means ± SEM, n = 3 per treatment group.
$^{a-c}$ Means in a row without a common superscript letter differ ($P<0.05$) as analyzed by one-way ANOVA and the LSD test.

3.2 Physico-chemical analyses

The moisture content and water activity of the fresh avocado pulp averaged 3.16 g H_2O/g DM (76.0% wb) and 0.889, respectively. As given in Table 2, samples were successfully dried in the freeze dryer to an average moisture content of 0.021 g H_2O/g DM (2.1% wb) after 72h, and a final average water activity of 0.356. The moisture content of oven dried cakes averaged 0.042 g H_2O/g DM (4.03% wb), but after blending the moisture content of the samples increased to 0.053 g H_2O/g DM (5.03 % wb). The pH and total soluble solids content of the fresh and dried avocado samples are also given in Table 2. The fresh pulp was alkaline and drying resulted in a decline in pH and therefore an increase in acidity of the pulp. The soluble solids content of the dried samples was higher than the fresh puree due to the removal of water. When calculated on a dry matter basis the soluble solids content of the dried samples were similar, averaging 0.018 and 0.020 g/g DM for oven and freeze-dried powders, respectively.

Table 2: Physicochemical properties of fresh and dried avocado samples

Physicochemical property	Fresh	Dried	
		Oven-Dried 60°C	Freeze-Dried
MC (g H_2O/g DM)	3.164 ± 0.14^a	0.053 ± 0.003^b	0.021 ± 0.002^c
a_w	0.889 ± 0.053^a	0.644 ± 0.007^b	0.356 ± 0.015^c
pH	7.65 ± 0.02^a	5.31 ± 0.01^c	6.78 ± 0.02^b
TSS (°Brix)	0.73 ± 0.03^c	1.70 ± 0^b	1.93 ± 0.03^a

Values are means ± SEM, n = 3 per treatment group.
$^{a-c}$ Means in a row without a common superscript letter differ (P<0.05) as analyzed by one-way ANOVA and the LSD test.

3.3 Proximate composition

Compared with oven-dried samples, freeze dried samples were significantly (p<0.05) higher in fat and protein content, but lower in crude fibre and % ash (Table 3). Casteneda-Saucedo et al. [9] found that for fresh versus freeze-dried Hass avocado pulp, the values remained unchanged with fat values of 70.09% (wb) and 70.7% (wb), protein values of 5.61% (wb) and 6.27% (wb) and ash values of 9.87% (wb), respectively.

Table 3: Proximate composition of dried avocado samples

Proximate composition	Oven-Dried 60°C	Freeze-Dried
Crude Fat %	40.66 ± 1.22^a	47.22 ± 0.55^b
Crude Protein %	1.06 ± 0.07^a	6.87 ± 0.47^b
Crude Fibre %	10.31 ± 0.80^a	8.67 ± 0.33^b
Ash %	7.13 ± 4.13^a	4.13 ± 0.65^b

Values are means ± SEM, n = 3 per treatment group.
^{a,b} Means in a row without a common superscript letter differ (P<0.05) as analyzed by one-way ANOVA and the LSD test.

3.4 Physical properties

Due to the lightweight, porous nature of the dried cake, grinding of the freeze-dried samples into the powder was a quick process taking approximately 30 seconds to produce a fine powder with mesh size of 600uM. Grinding of the oven-dried cake was a more difficult process since the samples were hard and dense, taking approximately two minutes to achieve a "powder' of uneven particle size, with an average particle size of 850uM.

Freeze dried and oven powders were mixed with water at room temperature (30°C) until a creamy thick consistency similar to that of the fresh avocado puree was achieved. Freeze dried powders rehydrated within 10 seconds of mixing to produce a thick paste, with a puree-like consistency and vibrant green colour. Oven-dried powders required a longer stirring time of up to a minute, but the hard, granular particles failed to fully rehydrate, producing a chunky, granular unattractive dark green paste. According to Souza et al. (2011), the avocado powder obtained from grinding the puree obtained a higher moisture content at saturation (2.59 g/g DM in 60 minutes) than other geometries of slices and cubes.

The physical properties of the oven and freeze-dried powders are shown in Table 4. The properties listed would be directly impacted by the degree of grinding and average particle size of the powders.

Table: 4. Physical properties of dried avocado samples

Physical property	Oven-Dried 60°C	Freeze-Dried
Bulk Density (g/mL)	0.47 ± 0.018^{a}	0.16 ± 0.009^{b}
Tapped Density (g/mL)	0.56 ± 0.013^{a}	0.21 ± 0.006^{b}
CI %	16 ± 3.3	24 ± 3
HR	1.19 ± 0.05	1.32 ± 0.08
Water Solubility %	8.8 ± 2.5	11.4 ± 3.9
Water Absorbance %	8.12 ± 0.24^{b}	10.6 ± 0.5^{a}
Oil absorption capacity (ml/g)	4.40 ± 0.057^{a}	3.25 ± 0.07^{b}
Solubility	Insoluble	Insoluble

Values are means ± SEM, n = 3 per treatment group.
[a,b] Means in a row without a common superscript letter differ (P<0.05) as analyzed by one-way ANOVA and the LSD test.

The bulk density value is important for characterizing, handling and processing of powders [25]. The bulk density depends on both the density and the arrangement of the powder particles. As expected, compared to the oven-dried powders, the freeze-dried powder had lower bulk and tapped densities as an equivalent mass of the freeze-dried powder would occupy a larger volume than the oven-dried powder. A free-flowing powder consists of bulk and tapped densities that are closer in value while for poorly flowing powders, the difference between the bulk and tapped densities are greater due to greater inter-particulate interactions [26]. There were no significant differences in the CI% and HR of the dried powders. Both the oven-dried and freeze-dried powders did not dissolve as the powders were insoluble. The addition of water resulted in the formation of a thick paste, similar to that of a fresh avocado puree. A slight bitter taste was detected possibly due to heating temperature used in the present study. The water absorbance value for the freeze-dried powder was significantly higher ($p \leq 0.05$) than for oven-dried powder. A study by Nygyen et al. [27] suggested that the ability for a powder to absorb water is due to a protein-water interaction where the protein matrix absorbs and retains bound water molecules. Water absorbance may be affected by protein denaturation and unfolding as a result of heating. A low water absorbance affects the texture, mouthfeel, juiciness, taste and shelf life of food formulations. Oven-dried samples showed higher oil absorption values. Oil absorption determines the emulsifying capacity, i.e. the ability for a substance to absorb and retain oil. This ability is important to help improve the binding of the powder structure, enhance flavour retention and improve the mouthfeel [28].

3.5 Drying data analysis

Based on the above results, freeze-drying was considered to be the preferred method of drying of avocado pulp. Drying data was therefore collected for the freeze-dried samples only. Initial drying rate for freeze dried puree averaged 0.841 g H_2O/g DM/h. Drying was found to occur in the falling rate period (Fig. 1), as was also previously reported [5,11]. The transition to the second falling rate period occurred at a moisture value of 0.645 g H_2O/g DM (39.21% wb) after 12.5h of drying. The drying rate constants (k_1 and k_2) averaged 0.2125 1/h (R^2 = 0.9954) and 0.053 1/h (R^2 = 0.9959), respectively. Diffusivity (D_{eff}) values averaged 1.50 and 0.35 x 10^{-10} m^2/s for the first and second falling rate periods, respectively. The initial drying rate previously reported [11] for freeze-dried Pollock slices (0.01m thick) was lower at 0.562 g H_2O/g DM/h, which is expected as the slices would be denser in structure compared with the mashed puree. The drying rate constant (k_1) was therefore also lower than what was determined in this study, averaging 0.151 1/h (R^2 0.9970). Compared with slices, the drying rates for Pollock avocado puree were higher for the first 11h of drying.

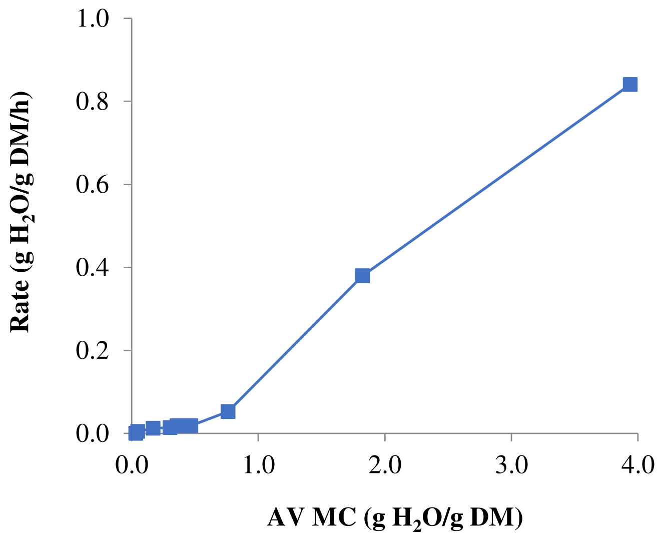

Figure 1: Plot of drying rate versus average moisture content during the freeze drying of avocado pulp.

The Verma model was found to best fit the Moisture Ratio (*MR*) data for Pollock avocado puree (Fig. 2). Model constants, RMSE and the chi-square statistic ($\square^2$) are given in Table 5. The Verma model was also reported to best describe the drying data for freeze-dried Pollock avocado slices [11]. Souza et al. [10] found the Page model to best fit the drying data for freeze-dried, cubed Collinson avocado pulp while Temu [5] reported that the Henderson and Pabis model best fit the drying data for avocado slices dried at 50-70°C.

3.6 Storage trial: freeze-dried samples

The changes in the colour attributes of the freeze-dried powders over the 12-week storage trial are summarized in Fig. 3. Changes in the moisture values are given in Fig. 4. There was a slight visible darkening of the powders as storage time increased, and this is reflected in the decline in L* values. Powders also appeared slightly less green and this is reflected in less negative a* values. After 12 weeks of storage, the moisture value of freeze-dried samples increased from 0.02 to 0.05 g H_2O/g DM (1.9 to 4.6% wb). There was a corresponding increase in water activity values from 0.352 to 0.534.

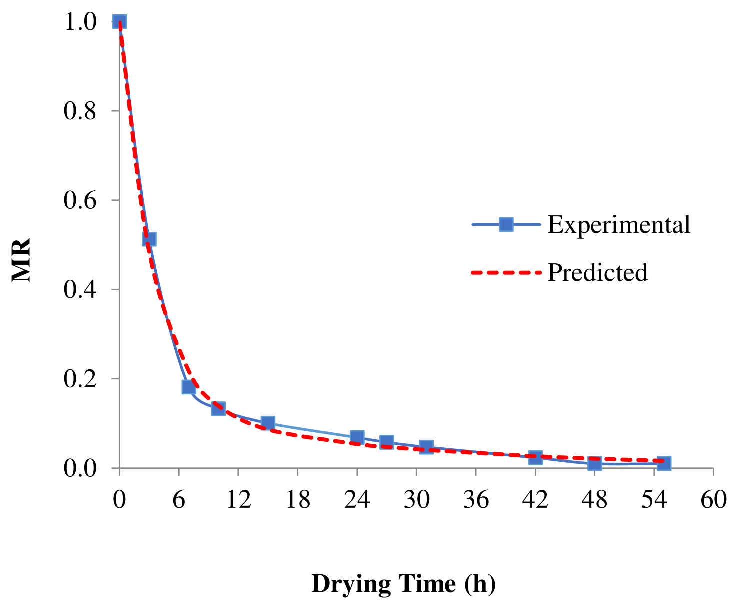

Figure 2: Plot of Predicted (Verma model) versus experimental MR values for freeze-dried avocado pulp during drying.

Table 5: Thin layer models constants for freeze-dried avocado pulp.

Model name	Equation	Model constants			R^2	RMSE	χ^2
		K	a	g			
Verma	MR = a exp(-Kt)+(1-a) exp(-gt)	0.3362	1.0707	1.8524	0.9998	0.005436	0.000035

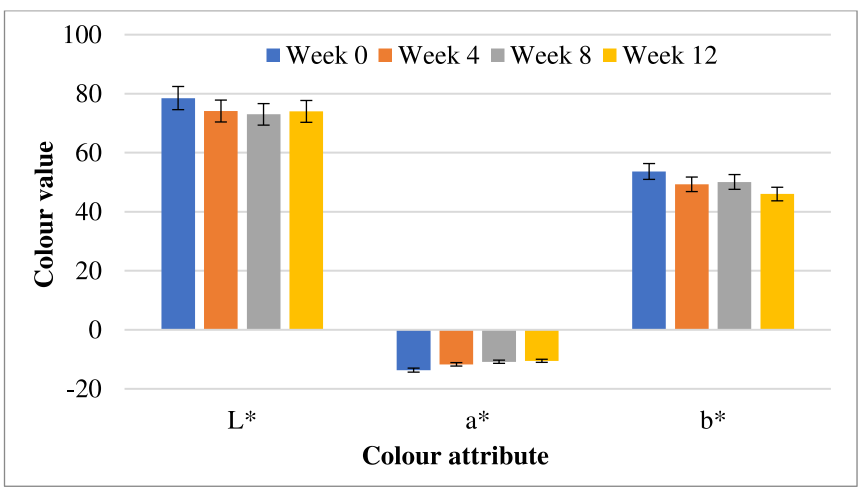

Figure 3: Changes in the colour attributes of the freeze-dried powders over a 12-week storage period.

The pH values of freeze-dried samples decreased over the 12-week period from 6.78 to 5.47, indicating an increase in acidity with storage time, while total soluble solids content remained stable. Gomez and Bates [29] studied the effect of storage temperature, time and atmosphere on the chemical and organoleptic characteristics of freeze-dried avocado puree and guacamole using Waldin, Lula and Booth-8 varieties of avocado. They reported that oxidation rates were slower at 21°C than at 38°C and storage in nitrogen atmospheres reduced peroxide formation. They noted that significant differences existed in oxidation rates between avocado varieties and while a commercial butylated hydroxyanisole (BHA) antioxidant reduced the oxidation rate of Lula puree it did not increase shelf life in air storage at 38°C.

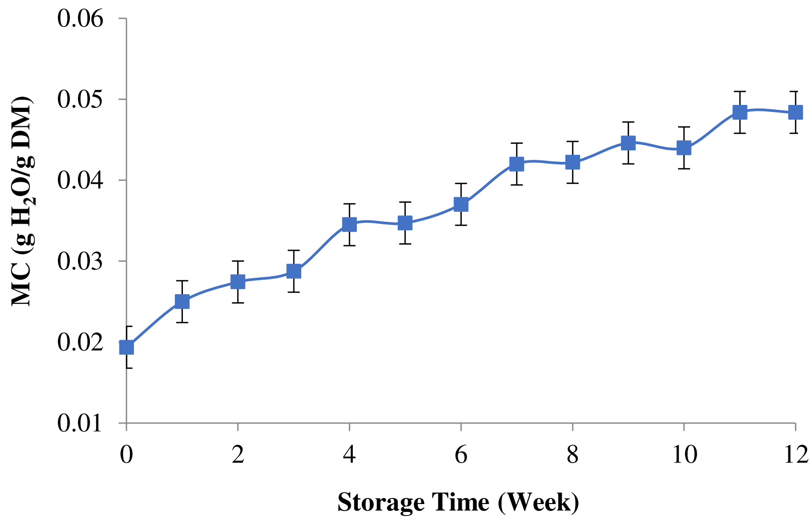

Figure 4: Plot of changes in the moisture content of freeze-dried powders over a 12-week storage period.

3.7 Conclusions

Compared with oven-dried samples which suffered severe shrinkage and darkening, freeze dried pulp samples dried to light 'cakes' which were easily blended to powders. Freeze dried powders were lower in moisture and water activity compared with oven-dried powders, while the pH of the oven-dried powder was lower. Compared with oven dried samples, freeze-dried powders were higher in fat content, had lower bulk and tapped density values with higher water solubility and water absorbance values. Freeze-dried powders resembled fresh avocado puree when rehydrated, however, a slight bitter taste was detected. There was an increase in moisture content, slight deterioration in colour and a slight increase in acidity recorded during the 12-week storage of the freeze-dried powder. This highlights the importance of appropriate packaging for this powder. Freeze-drying of avocado puree occurred in the falling rate period only and the Verma model was found to best fit the MR data. The results of this study show the clear potential for the use of freeze drying to produce a high-quality avocado powder, without the use of heat or the application of chemical preservatives to preserve colour. Future work will investigate the effect of rapid freezing on the subsequent drying rate and varying the sublimation temperature in an attempt to prevent undesirable changes which may have led to the development of a bitter taste in the final powder.

Nomenclature

A	Drying constant
a_w	Water activity
D_{eff}	Diffusion coefficient (m^2/s)
DM	Dry matter (g)
k	Drying rate constant (1/h)
L	Half thickness of sample (m)
L*, a*, b*	Colour attributes
M	Moisture content (g H_2O/g DM) at time = t
M_o	Initial Moisture Content (g H_2O/g DM)

M_e	Equilibrium Moisture Content (g H_2O/g DM)
MR	Moisture Ratio $(M-M_e)/(M_o-M_e)$
R^2	Coefficient of determination
RMSE	Root Mean Square Error
K, a, g	Model constants
t	Time (h)
wb	Wet basis (g H_2O/100g FW)
□^{2}	Chi-Square

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