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Research Article

The Effects of Spray Drying Conditions on the Physical and Bioactive Properties of New Zealand Tamarillo (*Solanum betaceum*) Powder

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Abstract

This research investigates the effect of spray drying conditions on the chemical and physical characteristics of tamarillo powders encapsulated with either maltodextrin (MD), gum arabic (GA), or a combination of both carriers. Tamarillo puree was spray dried at different inlet temperatures from 100°C to 140°C. The highest yield was at 50.60% obtained at an inlet temperature of 120°C. Colour, water activity and solubility of tamarillo powder were significantly affected by drying inlet temperature and carriers used. The scanning electron micrograph allowed to differentiate control sample, which was highly agglomerated with cracks from powders containing carriers that were spherical, smooth and with low agglomeration. The FRAP assay showed the antioxidant activity of MD-containing sample to be 49.69 mg Trolox/g sample, which was significantly higher than those with other carriers. CUPRAC assay further showed the mixture of GA and MD (2:1) containing sample to be 44.82 mg Trolox/g sample, which yielded significantly higher antioxidant activity compared to other samples.

Keywords: Tamarillo Powder; Drying Temperature; Gum Arabic; Maltodextrin; Antioxidant Activity and Total Polyphenol Content

Introduction

Tamarillo (*Solanum betaceum* Cav), also known as tree tomato, is found in tropical countries at altitude close to 2000 meters under sea level, such as New Zealand, Australia, Chile and Ecuador. It is fast becoming an attractive commodity worldwide with the annual export of tamarillo from New Zealand to be approximately 740 tons with an estimated value of NZ$700,000 [1]. Tamarillos are a beneficial source of antioxidants, vitamins and elements of biological active metabolites [2]. These nutrients can contribute to the reduction of risks of cardiovascular disease, neurodegenerative ailment, cancer, diabetes, and coronary heart disease [2]. Tamarillo is mainly consumed as fresh fruit, but it can also be used as an ingredient in the preparation of juice and desserts [3]. However, the decay and quality deterioration of tamarillo fruit at ambient temperature is a major postharvest issue [4,5]. Although storing fruits at low temperature effectively retard senescence and ripening, fruits may develop chilling injury and become prone to fungal invasion [4]. Therefore, conversion of tamarillo pulp into a shelf stable powder will not only overcome wastage due to post harvest losses but also makes it a more versatile food ingredient.

Spray drying can be used to obtain microencapsulated powders to produce a microbiologically stable product that is able to meet market demand throughout the year [6]. Drying not only reduces the transportation cost of products, but can also provide the food industry an opportunity to market tamarillo powder as a functional ingredient. A number of studies on the spray drying fruits such as, Asian pears [7], pomegranate [7] and banana [8] have reported that powder recovery is a big challenge during spray drying. This is due to the presence of low molecular weight sugars like fructose, glucose, sucrose, and organic acids like tartaric, citric and malic acid that can contribute to undesirable stickiness of powders produced [9]. Moghbeli, Jafari, Maghsoudlou, and Dehnad [10] pointed out the use of carriers such as gum arabic or maltodextrins to eliminate stickiness and increase the glass transition temperature of the mixture. Therefore, use of suitable carriers are necessary in spray drying to increase product yield. These carrier aids not only reduce stickiness, but can also be employed for encapsulating flavours and aroma, as well as preserving colour, nutritive value and the antioxidant capacities of different spray dried materials [11].

Production of a fruit powder with adequate yield, and good quality can be achieved by optimising the spray drying process in terms of drying air (pressure, temperature, humidity), liquid feed characteristics (flow rate, viscosity, particle size), carrier type, carrier concentration and atomiser type [12]. These parameters can affect the quality of the resultant powder in terms of moisture content, hygroscopicity, colour, solubility, total antioxidant capacity and total phenolic content [12]. The effects of spray drying on physical characteristics of fruits have been reported in previous studies. Higher inlet temperatures have been reported to decrease colour due to the thermal degradation of pigments like beta-carotene and lycopene [13]. Wong, Teoh, and Putri [14] further found that a higher inlet temperature yielded porous particles, which diffuses easily in water and becomes more soluble. The author further reported that smaller particles produced at higher inlet temperature resulted in more exposure of the particles to the surrounding air, and lowered moisture content. Therefore, a highly hygroscopic product was produced.

The antioxidant activity of powder are also influenced by the high inlet temperature of spray drying process. Increasing MD concentration was found to diminish the formation of compounds that are able to scavenge free radicals [15]. This decrease in antioxidant activity may be due to the high temperature exposure of the droplet that can form different compounds and thereby reduce total phenolic content of the powder [16]. The general objective of this study was to produce tamarillo powders by spray drying using different carriers, and to determine their physical (colour, water activity, water solubility, hygroscopicity and size distribution) and chemical characteristics (antioxidant activities and total phenolic).

Materials and Methods

Chemicals and materials

Copper (II) chloride ($CuCl_2$), ammonium acetate (NH_4Ac), neocuproine (Nc), 2,4,6-tripyridyl-s-triazine (TPTZ), sodium acetate trihydrate ($CH_3COONa{\cdot}3H_2O$), glacial acetic acid (CH_3CO_2H), iron(III) chloride hexahydrate ($FeCl_3{\cdot}6H_2O$), hydrochloric acid (HCl), Folin and Ciocalteu's phenol reagent, Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid, gallic acid, 3,4,5-trihydroxybenzoic acid, methyl alcohol (CH_3OH) and acetone (CH_3 $COCH_3$) were purchased from Sigma-Aldrich. The maltodextrin (MD) (17-19 DE), maltodextrin (10-11 DE), gum arabic (GA) and guar gum (GG) were purchased from Davis Food Ingredient, New Zealand. Tamarillo fruits (50 kg) were purchased from Fresh Direct in New Zealand.

Sample preparation

Ripened red tamarillo fruits (50 kg, at 22 weeks) were washed and cut in half. The flesh and seeds were scooped and blended at 6100 rpm for 5 min in a Waring blender (Model BBL300 Breville Platinum). The puree was sieved to eliminate the seeds and the resultant pulp solid residue was filtered through a 150 µm mesh cloth to eliminate large solid particles. The pureed tamarillo puree was placed in 1L Schott bottles and stored in a freezer at -18°C prior to drying experiments.

Spray dryer feed preparation

The frozen tamarillo pulp was thawed in a water bath to reach room temperature prior to spray drying. Commercial MD (17-19 DE) and GA were added at different concentrations into preweighed beaker with the thawed puree. The ratio of carrier to pulp was maintained at 3% (w/w), and four combinations of carrier agents were added to the puree: 2% MD and 1% GA (2-1 MD GA), 1% MD and 2% GA (1-2 MD GA), and 1.5% MD and 1.5% GA (1.5-1.5 MD GA). A Silverson L4RT homogeniser was used to homogenise the carriers with tamarillo pulp at a speed of 4500 rpm for 5 minutes.

A Büchi mini open loop spray dryer (Model B-290, Switzerland) equipped with a0.70 mm orifice nozzle was used for spray drying. The feed mixtures consisting of 3% MD and tamarillo pulp were spray dried at different inlet air temperatures (100°C, 110°C, 120°C, 130°C and 140°C). Three feed mixtures comprising different concentrations of both maltodextrin and gum arabic (1.5% MD and 1.5% GA, 2% MD and 1% GA, 1% MD and 2% GA), and neat tamarillo pulp without drying aids were spray dried at 120°C inlet air temperature. The aspiration, pump feed rate, and atomising air flow rate were kept constant at 31 kg/h, 0.29 kg/h and at 0.72 kg/h respectively. After spray drying, the tamarillo fruit powder in the product collection vessel was transferred into air tight polypropylene pouches, and immediately stored in the freezer (-18°C) until further analysis.

The range of maltodextrin concentrations and inlet air temperatures was based on preliminary studies, which will be discussed in the later section.

Physicochemical properties

Product yield

The percentage product yield was measured as the mass ratio of tamarillo powder collected at the end of spray drying process to the initial solid content in the feed, which includes the adjuncts.

$$\text{Yield }\% = \frac{\text{The weight of powder after drying process}}{\text{The total solid weight in the initial feed}} \times 100$$

Water activities (a_w) and solubility (WS)

The water activity (a_w) of the spray dried powder was determined according to the method detailed by Fazaeli, Emam-Djomeh, Ashtari, and Omid [17]. The a_w was measured using a water activity meter (FF instrumentation Ltd).

The determination of water solubility (WS) was conducted according to a centrifugation approach described by Cano-Chauca, Stringheta, Ramos, and Cal-Vidal [18] with some adjustments. Spray dried tamarillo fruit powder (1 g) and 100 mL of deionized water at ambient temperature were homogenized at a speed of 3500 rpm for 2 minutes using a Silverson L4RT homogeniser. Centrifuge tubes (45 mL) were filled with 33 mL of the homogenate and centrifuged at a speed (4000 rpm) for 15 minutes. The upper layer (30 mL) was transferred into a pre-weighed beaker and dried in an oven at 105°C overnight. The samples were cooled down to room temperature and weighed. Sample analysis were done in triplicates for each treatment of the three independent batches and the mean was reported. The percentage of WS was calculated according to weight difference.

Colour characterization

The Nix Pro colour Sensor (Nix Sensor Ltd., Ontario, CAN, Circular, 15mm diameter) was used for colour measurement of spray dried tamarillo powder. The CIE model had three parameters, which represented the lightness of color, L* (L* = 100 indicates white while L* = 0 yields black), its position between magenta and green, a* (positive values specify magenta and negative values specify green), and its position between yellow and blue, b* (positive values shows yellow and negative values shows blue). The CIE values were reported in a* (greenness/redness), L* (lightness or brightness) and b*(blueness/yellowness).

Bulk density

The bulk density of samples was determined according to Bicudo., *et al*. [19]. According to Bicudo., *et al*. [19], bulk density is the given weight of the powder that will fit into its specific vessel. Samples (0.50 g each) were added into an empty 10 mL pre-weighed measuring cylinder. The cylinder was vibrated for 1 min until all the voids are packed. The volume of settled microcapsules and sample weight were calculated by dividing sample weight by the volume obtained in the graduated cylinder (g/mL).

Hygroscopicity of powders

Hygroscopicity was analyzed using a procedure detailed by Caparino., *et al*. [20]. Approximately 1 g of sample was placed and spread evenly on a pre-weighed petri plate (48 mm diameter) to expose the highest amount of surface area of the powder to humidity. Each sample in the plate were placed in an airtight plastic container with a relative humidity and temperature of 74% and 23°C respectively by placing a small container with NaCl saturated solution. After a week, the treated samples were weighed, and the hygroscopicity was calculated by the following equation.

$$Hygroscopicity\ \% = \frac{\text{Weight of the sample after treatment} - \text{Weight of sample before treatment}}{\text{Weight of the sample before treatment}} \times 100$$

Scanning electron microscopy (SEM)

A scanning electron microscope (Model SU-70, HITACHI) was used to evaluate the morphology of the powder microcapsules as described by Villacrez, Carriazo, and Osorio [21]. About 0.50 g of spray dried samples, 2-1 MD GA, 1-2 MD GA, 1.5-1.5 MD GA and control sample were freeze dried and coated with gold–palladium alloy prior to SEM analysis. The coated samples were transferred to the SEM instrument operated at a voltage of 15 kV with the lens at 17.8 mm. The particle size of samples were photographed at a magnification of (15.0kV 17mm × 600 SEM) to measure the diameter of particles and then the majority of particles size were observed.

Analysis of antioxidant properties

Sample extraction

The extraction from dry powder was conducted by the use of both methanol and acetone aqueous solutions [22]. Tamarillo powder (0.10 g) was added into a 15 mL centrifuge tube, 4 mL of 50% methanol aqueous solution was added, and the mixture homogenized for 30 seconds at room temperature. After 1 hour, the solution was centrifuged at a speed of 3500 rpm for 15 minutes and the supernatant was carefully transferred to a 10 mL volumetric flask. Thereafter, the retentate was treated with the same procedure but with 4 mL of 70% acetone aqueous solution. Again, the supernatant was carefully conveyed into the same 10 mL volumetric flask and topped up with deionized water to the 10 mL mark.

The CUPRAC method

The CUPRAC method was described by Assefa, Ko, Moon, and Keum [23] with slight modifications. The stock solution of 1 × 10^{-2} M copper (II) chloride ($CuCl_2 \cdot 2H_2O$) solution, 0.90 M ammonium acetate (NH_4Ac) at pH 7.0 and 7.5 × 10^{-3} M Neocuproine (Nc) in 96% ethanol, were prepared in distilled water. Extracted tamarillo (4 mL) was diluted with distilled water in a 10 mL volumetric flask. Cupric reagent was prepared by mixing 1 mL of Nc solution, $CuCl_2 \cdot 2H_2O$ solution and NH_4Ac buffer solutions in a glass vessel. Trolox at different concentrations ranging from 0.0512 g/L to 0.357 g/L were used as an external standard for the calibration curve with an R2 value of 0.996. The diluted sample or Trolox (1 mL) was added to the initial mixture to reach a volume of 4 mL at ambient temperature. After 20 minutes, 230 µl of the mixture was transferred into a 96-well (microplate reader using micropipette for absorbance measurements). A blank reagent was used as a reference at 450 nm. The results were expressed as mg of Trolox equivalents per 1 g of extracted samples.

FRAP method

The FRAP assay was adapted from the method by Horszwald, Julien, and Andlauer [24] with slight modification. The working solution of 4 × 10^{-2} M TPTZ (0.3124 g TPTZ and 0.04m HCl), 4×10^{-2} M iron (III) chloride hexahydrate solution and 150 mM acetate buffer (1.5564 g $CH_3COONa \cdot 3H_2O$ and 8 mL CH_3CO_2H) were prepared in distilled water. Fresh FRAP reagent was immediately prepared prior to use by using a mixture of acetate buffer (10 mL), TPTZ (1 mL) and $FeCl_3 \cdot 6H_2O$ (1 mL). A calibration curve using Trolox as an external standard was constructed using concentrations ranging between 1.448 mg/L to 0.013 mg/L with an R^2 value of 0.9964 Aliquots of extracted tamarillo (10 µl) or Trolox was pipetted into a microplate with 200 µl of fresh FRAP reagent (the blank was filled with the same reagent to a final volume of 210 µl), and then the plate was kept at room temperature for 5 min before absorbance was measured at 593 nm using microplate reader (BMG LABTECH, FLUOstar Omega).

Total phenolic methods

The total phenolics was determined according to the method described by Singleton, Orthofer, and Lamuela-Raventós [25]. Sodium carbonate (20%) was prepared in 100 mL of distilled water. Sample extract or a series of gallic acid standard solution (1 mL) ranging from 0.1956 g/L to 0.0096 g/L were used to construct a calibration curve. Folin and Ciocalteu's phenol reagent (500 µl) was then pipetted and the samples kept at room temperature for 5 min. Sodium carbonate (1.5 mL) was transferred into the mixture and allowed to incubate for an hour. Aliquots of the mixed solution (220 µl) were added into the microplate using a micropipette, and the absorbance was measured against a blank reagent at 765 nm. Results were reported in g/L of gallic acid equivalents per gram of the extracted powder.

Statistical analyses

The resultant data of the three independent batches were subjected to Microsoft Excel software version 2016 for data collation, and analysis of variance (ANOVA) was carried out using XLSTAT Addinsoft 2016 to assess if significant differences exist among the samples with different spray drying conditions and different carrier concentrations. The results were reported as mean ± standard deviations and all experiments were done in triplicates (n=3).

Results and Discussion

Yield

The yield of spray dried tamarillo puree with 3% MD as carrier was determined using different inlet temperatures during spray drying (Table 1). The final total solid content of tamarillo puree was found to be approximately 9.6%. Spray drying of tamarillo puree at an inlet temperature of 120°C resulted in the highest yield at 50.60% in contrast to other drying temperatures. The increase in yield when spray drying tamarillo pulp in our study is in agreement with yield of spray dried banana powder [14], black mulberry powder [17] and pomegranate powder [26]. The powder yield of tamarillos decreased slightly for higher inlet temperatures at 130°C and 140°C. This could be due to the stickiness of powder that can occur when the spray drying inlet temperature is higher than the glass transition of the sugars in the tamarillo puree [14]. Hence the inlet temperature of 120°C for spray drying tamarillo puree in our study was the best as it produced powder with a yield of 50% and was used in our subsequent experiments. Can Karaca, Guzel, and Ak (2016) have reported that a yield above 50% is considered beneficial to the industry and is an indicator of a successful spray drying process.

Parameters	140°C	130°C	120°C	110°C	100°C
Powder Yield%	48.34 ± 1.63 [ab]	46.50 ± 3.55[abc]	50.60 ± 2.80 [a]	43.26 ± 1.9 [bc]	42.30 ± 2.0 [c]
L* value	66.54 ± 1.39 [a]	63.99 ± 1.42 [b]	63.20 ± 2.60 [b]	63.79 ± 1.81 [b]	63.40 ± 1.02 [b]
a* value	33.15 ± 0.88 [b]	35.11 ± 2.42 [ab]	35.52 ± 1.32 [a]	35.14 ± 2.78 [ab]	35.03 ± 2.54 [ab]
b* value	10.82 ± 1 [ab]	11.47 ± 0.60 [a]	10.74 ± 0.88 [ab]	10.40 ± 0.95 [b]	10.36 ± 0.63 [b]
Water activities (a_w25 °C)	0.15 ± 0.003[bc]	0.14 ± 0.004 [c]	0.19 ± 0.03[ab]	0.22 ± 0.02 [a]	0.22 ± 0.02 [a]
Water solubility (%)	79.10 ± 6.52 [a]	76.73 ± 4.86 [ab]	75.91 ± 4.16 [ab]	75.40 ± 4.21 [ab]	73.03 ± 3.24 [b]
Bulk density (g/mL)	0.41 ± 0.02 [a]	0.40 ± 0.03 [a]	0.44 ± 0.02 [a]	0.43 ± 0.04 [a]	0.43 ± 0.04 [a]
Hygroscopicity (%)	75.62 ± 2.63 [a]	75.19 ± 81 [a]	75.85 ± 2.57 [a]	74.43 ± 3.97 [a]	75.48 ± 2.41 [a]

Table 1: The yield and physical properties of spray dried tamarillo powder with 3% maltodextrin (17-19 DE) at different inlet temperatures.

One-way ANOVA and Fisher LSD tests were used to analyse the results obtained. The mean ± standard deviation of three independent batches with different letter ([a,b,c]) within row indicate a significant difference and the same letter shows no significant differences on the columns.

The effect of different carrier combinations of tamarillo on powder yield when spray dried at 120°C inlet temperature was further investigated. Results in Table 3 indicated that there was some recovery of powder when spray drying pure tamarillo due to low level of sugar content. This is in agreement with results on persimmon powder [28], and banana powder [14]. Drying aids or carriers are therefore essential in spray drying tamarillo puree to minimize stickiness. The carriers used in this study were shown to increase the yield significantly ($p < 0.0001$) compared to the control. An explanation for this is that the increasing molecular-weight of the amorphous fractions by addition of MD and GA into the mixture, reduced the stickiness of powder to the surfaces in the spray dryer. The stickiness of powders are associated with water plasticization of amorphous sugars, such as fructose and sucrose [11]. Therefore addition of carriers with high T_g can reduce the water plasticization of the particle's surface, which leads to less adhesion of the powder onto the spray dryer's chamber wall [11].

Physical analysis

Colour analysis

Colour is a significant factor in food selection and has a direct correlation to acceptability by consumers. An inlet drying temperature of 140°C showed a significant ($p < 0.0001$) increase in lightness (L*) of tamarillo powder compared to lower temperatures (Table 1). The finding is in agreement with Mishra, Mishra, and Mahanta [29] who showed thatamla juice powder encapsulated with 5% MD increased significantly in the L* value when. the spray-dry inlet temperature increase from 125°C to 200°C incrementally. Similarly, a significant increase in L* value of pomegranate power coated with 45% MD was observed at an inlet 143°C temperature compared to 124°C [26]. The phenomenon of lighter coloured powder obtained after spray drying at high temperature was explained by Mishra., *et al*. [29] who claimed that the rapid drying rate prevented the oxidation of tannins in the fruit juice. However, as seen in Table 3, spray dried tamarillo at inlet temperatures from 100°C to 130°C showed no significant changes in L* values. Since all the carriers used in this study is inherently white, the increase in L* value in the spray dried tamarillo powder was expected. This is in agreement with other research on spray-dried mango juice illustrating that the L* value of the powder obtained with MD increased significantly compared to the control [30]. Among the carrier agents used, 1-2 MDGA, 1.5-1.5 MDGA and 2-1 MDGA resulted in significantly lighter tamarillo powder than the 3% maltodextrin carrier. This is because of the ability of GA to create more homogenous droplets and larger molecular particles compared to maltodextrin [31].

The tamarillo predominant colour is red. Hence the parameter, a* value, should distinguish the colour changes resulting from the drying process. Tamarillo powders spray dried using inlet temperatures of 140°C, significantly decreased the redness of powder ($p < 0.0001$) compared to an inlet temperature of 120°C as shown in Table 1. Studies by Ferrari, Germer, and de Aguirre [32] reported that the a* value represents the anthocyanin content that may change during processing as a result of the pigments' susceptibility to heat. Another possible explanation could be due to the carotenoids' chemical structures that are susceptible to oxidation and heat destruction resulting in brighter powder, due to the vast number of conjugated double bonds such as α-carotene, β-carotene, and lycopene [33].

The b* values of tamarillo powder significantly increased ($p < 0.0001$) at an inlet air temperature of 130°C, compared to 100°C and 110°C inlet air temperatures (Table 1). Similarly, Quek, Chok, and Swedlund [34] reported a significant increase in b* value after spray drying watermelon at 175°C. Ahmed, Jiang, and Eun (2017) further reported that a significant increase in b* value of spray dried pear samples at 170°C compared to 130°C. The increase in b* value can be attributed to the Maillard reactions and caramelization of sugars during the drying process at high temperatures, which are responsible for the increase in yellowness [14]. The impact of carrier agents on tamarillo samples containing 1.5-1.5 MDGA and 3 GA after drying treatment also resulted in a significant decrease in b* value compared to other samples as shown in Table 3. Similarly, blackberry powders spray dried at an inlet air temperature of 140°C further showed a significant drop in b* with gum arabic addition (Rigon and Noreña 2016). The changes in b* value due to the carrier used are related to variation in anthocyanins and phenolics content (Choi, Kim., *et al*. 2002).

Water activity (a_w)

Water activity (a_w) is a significant factor influencing the shelf life of spray-dried powder [19]. A stable powder must have a a_w value of between 0.2 and 0.6 [35]. Tamarillo powders spray dried at an inlet temperature of 130°C had significantly ($P < 0.0001$) lower a_w value compared to 100°C, 110°C and 120°C (Table 1). The driving force to remove moisture by evaporation occurs when the rate of heat transfer is increased as spray drying temperature is increased [17].

The use of 1.5-1.5 MDGA in spray dried tamarillo significantly ($P < 0.0001$) lowered a_w compared to control sample as shown in Table 3. Similarly, a study by Kingwatee., *et al*. [36] reported that spray dried lychee juice with the addition of a combination of 15% gum arabic and 5% inulin resulted in a significant drop in a_w value. In our study, all spray dried tamarillo powders are considered to be microbiologically stable as the a_w value was below 0.6 at all drying temperatures.

Water solubility index (WSI), bulk density and hygroscopicity

Solubility is the ability of powder to fully dissolve in aqueous solution to form a suspension in water [19]. This parameter is a fundamental criterion to assess the powder behaviour in an aqueous solution as it is an indicator of reconstitution quality of powders [19]. Powder with high solubility are particularly desirable for applications in the food industry [35]. From Table 1, it can be seen that the inlet spray drying temperature did not have a major effect on the WSI, bulk density and hygroscopicity of the powders as they varied between 73% to 79%, 0.40 to 0.44 g/mL, and 74 to 75% respectively. Table 3 shows that the water solubility of tamarillo powders were significantly increased compared to the control when carriers (3%MD, 1.5:1.5 MDGA and 2:1 MDGA) were added. The carriers had no significant effect on the bulk density and hygroscopicity of the tamarillo powders.

Scanning electron microscopy (SEM)

Scanning electron microscopy provided an image of the morphological characteristics of the spray dried powders to increase understanding of their structure. Tamarillo powders coated with 1.5-1.5 MDGA showed spherical shape and smooth surfaces with low degree of agglomeration, and a particle size that ranged between 1.65 μm to 27.1 μm (Figure 1A). Noticeably, there were small particles that were surrounded by larger particles on the surface (Figures 1A, 1B and 1C). However the micrograph of the control sample showed the highest degree of agglomeration and visible cracks, with multiple creases on their surface. The small particles seen in Figures 1A and 1B were bounded together whereas the large particles were free suggesting partial microencapsulation occurred in which the core material is somewhat coated and isolated from the external environment [37]. The presence of smaller particles explained why powders with carriers had significantly high WSI that made dissolution more efficient.

The micrograph of control sample as seen in Figure 1D showed the highest degree of agglomeration and visible cracks, with multiple creases on their surface compared to samples containing carriers.

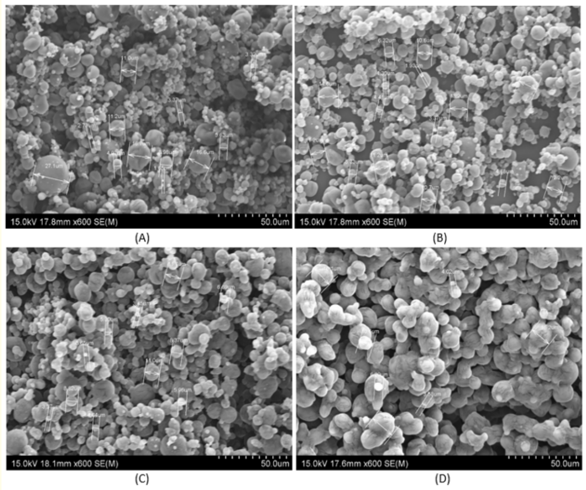

Figure 1: The particle size image of tamarillo powder achieved using three different carriers and control: (A) 1.5-1.5 MDGA, (B) 3 MD, (C) 3 GA and (D) control.

Analysis of antioxidant properties

In this study the cupric reducing antioxidant capacity (CUPRAC), ferric reducing antioxidant power (FRAP) and Folin-Ciocalteu total phenolic content (TPC) assay were used to capture all the bioactives at different conditions. The CUPRAC assay is carried out at neutral conditions (pH = 7) and is sensitive in detecting hydrophilic antioxidants [38]. FRAP assays are carried out at acidic conditions (pH = 3.6) and are particularly efficient in measuring hydrophobic antioxidants such as α-tocopherol acetate, tocotrienols and tocopherols [38]. The Folin-Ciocalteu phenol reagent reacts with phenolics detectable at alkali conditions [39].

CUPRAC assay

After the spray drying process under different temperature and different carrier ratio, antioxidants were extracted from the powder using chemical methods (both methanol 50% and 70% acetone solutions for extraction). The results using the CUPRAC assay are expressed as mg Trolox equivalent per gram dry sample and are shown in Table 2. The CUPRAC assay showed that increasing the inlet temperature to 140°C resulted in significantly ($p < 0.0001$) higher antioxidant activities compared to sample dried at 100°C (Table 2). The results were consistent with the findings from Mishra., *et al*. [29] who reported that higher spray drying temperature prevented tannins from getting oxidized. Tannins are water soluble polyphenols which are known to have antioxidant activities [29] and are particularly sensitive to the hydrophilic nature of the CUPRAC assay. In addition, an increase in drying temperature can promote the formation of Maillard reaction products, which also have antioxidant activities [29].

Parameters	**140°C**	**130°C**	**120°C**	**110°C**	**100°C**
CUPRAC (mg Trolox equiv./g dry sample)	42.47 ± 5 ^{a}	42.34 ± 4 ^{ab}	39.37 ± 3 ^{abc}	38.4 ± 3 ^{bc}	37.26 ± 9 ^{c}
FRAP (mg Trolox equiv./g dry sample)	41.97 ± 7 ^{b}	45.89 ± 7 ^{b}	49.69 ± 9 ^{ab}	45.9 ± 1 ^{b}	54.58 ± 8 ^{a}
Total phenolic (mg gallic acid equiv./g dry sample)	58.3 ± 5.4 ^{a}	56.9 ± 2.6 ^{a}	58.2 ± 3.7 ^{a}	56.6 ± 4 ^{a}	57.7 ± 4.3 ^{a}

Table 2 The analysis of antioxidant properties of spray dried tamarillo powder with 3% maltodextrin (17-19 DE) at different inlet temperatures.

One-way ANOVA and Fisher LSD tests were used to analyse the results obtained. The mean ± standard deviation of three independent batches with different letter (^{a,b,c}) within row indicate a significant difference and the same letter shows no significant differences on the columns. Data expressed as mg of Trolox for both CUPRAC and FRAB and of Gallic acid for total phenolics, all equivalent to gram of sample

Parameters	**Freeze dried sample**	**Control (no carrier)**	**3% Maltodextrin 17-19DE**	**3% Gum arabic**	**1.5% Maltodextrin 17-19DE plus 1.5% Gum arabic**	**2% Maltodextrin 17-19DE plus 1% Gum arabic**	**1% Maltodextrin 17-19DE plus 2% Gum arabic**
Powder Yield%		43.60 ± 1.72 ^{b}	50.60 ± 2.8 ^{a}	49.04 ± 1.91 ^{a}	47.65 ± 2.57 ^{ab}	49.44 ± 2.01 ^{a}	47.83 ± 2.99 ^{a}
L * value		60.17 ± 2.01 ^{c}	63.20 ± 2.60 ^{b}	66.17 ± 1.13 ^{a}	65.20 ± 2.06 ^{a}	66.05 ± 1.11 ^{a}	64.77 ± 1.46 ^{ab}
a* value		37.51 ± 1.67 ^{a}	35.52 ± 1.32 ^{b}	34.33 ± 0.88 ^{c}	33.77 ± 0.75 ^{c}	34.57 ± 0.77 ^{bc}	34.76 ± 0.95 ^{bc}
b* value		10.97 ± 0.57 ^{a}	10.74 ± 0.88 ^{a}	9.07 ± 0.49 ^{b}	9.52 ± 0.61 ^{b}	10.59 ± 0.97 ^{a}	10.48 ± 1.46 ^{a}
Water activities (a_w 25 °C)		0.19 ± 0.03 ^{a}	0.19 ± 0.03 ^{ab}	0.16 ± 0.04 ^{ab}	0.14 ± 0.02 ^{b}	0.16 ± 0.01 ^{ab}	0.16 ± 0.03 ^{ab}
Water solubility (%)		71.85 ± 3.49 ^{b}	76.73 ± 4.16 ^{a}	75.09 ± 5.31 ^{ab}	77.39 ± 5.49 ^{a}	77.69 ± 5.75 ^{a}	75.97 ± 6.29 ^{ab}
Bulk density (g/mL)		0.46 ± 0.06 ^{a}	0.44 ± 0.02 ^{a}	0.48 ± 0.09 ^{a}	0.45 ± 0.06 ^{a}	0.44 ± 0.02 ^{a}	0.46 ± 0.06 ^{a}
Hygroscopicity (%)		73.90 ± 2.66 ^{a}	75.85 ± 2.57 ^{a}	75.53 ± 4.67 ^{a}	72.85 ± 4.31 ^{a}	75.43 ± 2.49 ^{a}	75.32 ± 2.60 ^{a}

Table 3: The yield and the physical properties of spray dried tamarillo powder coated with different carrier ratios at an inlet temperature of 120°C.

One-way ANOVA and Fisher LSD tests were used to analyse the results obtained. Sample mean ± standard deviation of three independent batches with different letters ($^{a, b, c}$) within row indicate a significant difference and the reverse shows no significant differences on the columns.

As expected, freeze dried tamarillo powders had the highest antioxidant activity when evaluated by the CUPRAC method. Overall, there was a significant decrease ($p < 0.0001$) in the antioxidant activities of tamarillo powders encapsulated with carriers compared to the control (Table 4). It was noted that increasing the MD concentration diminished compounds that are able to scavenge free radicals [15]. The only significant differences ($p < 0.0001$) among the powders containing carriers were observed in the 1-2 MD GA sample at 45 mg Trolox equivalent/g sample, which was statistically higher than the rest.

Parameters	Freeze dried sample	Control (no carrier)	3% Maltodextrin 17-19DE	3% Gum arabic	1.5% Maltodextrin 17-19DE plus 1.5% Gum arabic	2% Maltodextrin 17-19DE plus 1% Gum arabic	1% Maltodextrin 17-19DE plus 2% Gum arabic
CUPRAC (mg Trolox equiv./g dry sample)	72.76 ± 5 [a]	52.27 ± 4 [b]	39.37 ± 3 [cd]	43.52 ± 3 [d]	41.44 ± 6 [cd]	40.9 ± 5 [cd]	44.82 ± 5 [c]
FRAP (mg Trolox equiv./g dry sample)	82.84 ± 8 [a]	44.4 1± 1 [bc]	49.69 ± 9 [b]	39.52 ± 7 [c]	38.43 ± 1 [c]	38.05 ± 4 [c]	40.92 ± 6 [c]
Total phenolic (mg gallic acid equiv./g dry sample)	85.9 ± 1.1[a]	69.3 ± 5 [b]	58.2 ± 3.7 [c]	61.6 ± 8 [bc]	58.6 ± 7.5 [c]	58.1 ± 6.2 [c]	58.3 ± 8.3 [c]

Table 4: The analysis of antioxidant properties of spray dried tamarillo powder coated with different carrier ratios at an inlet temperature of 120°C.

One-way ANOVA and Fisher LSD tests were used to analyse the results obtained. Sample mean ± standard deviation of three independent batches with different letters ([a, b, c]) within row indicate a significant difference and the reverse shows no significant differences on the columns. Values are represented as mg of Trolox for both CUPPRAC and FRAP and of Gallic acid for total phenolics, all equivalent to a gram of sample.

FRAP assay

As shown in Table 2, the antioxidant content of dried tamarillo using FRAP decreased at higher inlet temperature compared to 100°C drying temperature. Similarly, Tan, Kha, Parks, Stathopoulos, and Roach [40] reported that the retention of antioxidant content of melon powder encapsulated with MD decreased significantly from 93% to 75% when a higher inlet temperature of 150°C was applied. A possible explanation for this degradation according to a recent study Rigon and Noreña [41], is that the phenolic structure is affected by high temperature resulting in structural breakage, and formation of different compounds. This causes a reduction in the antioxidant capacity. The hydrophobic antioxidant activity of FRAP assay are influenced at higher temperature compared to hydrophilic antioxidant activity of CUPRAC assay [38].

Total antioxidant activity measurement of tamarillo powder using the FRAP method demonstrated some significant differences between the samples as shown in Table 4. Generally, the freeze-dried sample had the highest amount of antioxidant capacity. The antioxidant value of MD-containing sample was not significantly different to that of the control sample but was significantly higher when compared to other carrier-containing samples. The addition of more MD to the tamarillo pulp prior to drying resulted in the formation of an external layer that better protected antioxidative components from high air temperature as well as oxidation reaction during the drying process [42].

Total Phenolic content

The determination of total phenolic content is based on the reduction powder of phenolic compounds in the tamarillo powder. There were no significant differences in total phenolic content of tamarillo powder produced using different inlet temperatures as indicated in Table 2. The freeze-dried sample exhibited significantly higher total phenolic content than other spray dried samples with and without carriers. The results, as shown in Table 4, further showed that the control sample had the highest content of phenolic compounds compared to other powders, except GA-containing tamarillos powders. Samples without carrier addition have more agglomeration, which can lower the exposure of powder to the air [43]. Hence, phenolic compounds are protected from degredation. It was evident that dilution effects from the carriers were prominent as all the phenolic content was significantly lower in all the powders with carriers when compared to the control [15].

Conclusion

The production of spray dried tamarillo powder was successfully carried out in this study. The effect of spray drying conditions on the physical properties, as well as the antioxidant activity and total phenolic content of tamarillo powders were elucidated. The highest yield of spray dried powder was obtained using an inlet/outlet temperature of 120°C/81°C, with the addition of 3% maltodextrin as carrier material. The higher inlet temperature and addition of carriers increased lightness and decreased redness of tamarillo powders. The total phenolic compound significantly decreased in almost all samples containing carriers except for 3% GA compared to control. With respect to powder morphology, all carrier agents assisted in forming tamarillo particles with spherical shape and low degree of agglomeration. This study successfully produced a tamarillo powder with good water soublitiy that could potentially be used as a food ingredient. Further microbiological and shelf life studies are recommended to ensure safety and retain quality of the powder before upscaling production of tamarillo powder.

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