

The Effects of Drying Processes on Organoleptic Characteristics and the Health Quality of Food Ingredients Obtained from Goldenberry Fruits (*Physalis peruviana*)

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Abstract

Goldenberry fruit (*Physalis peruviana* L.) is an excellent source of provitamin A (3,000 IU of carotene per 100 g), vitamin C and bioactive phenolic compounds. This fruit also contains some vitamins of B complex and exceptionally high levels of fiber (4.8%), protein (0.3%) and phosphorus (55%), highlighting the potential health benefits of this fruit. There are no studies indicating that the fruit characteristics are altered in the process of transformation of this raw material. In this study, we compared three drying processes using goldenberry fruit: oven (60°C), drum (110°C), and freeze drying. The influence of each drying method on the chemical and antioxidant content and the capacity of the fresh peel and developed ingredients was determined. The results indicate that all the drying processes affected the color and the chemical characteristics of the ingredients. Furthermore, total phenolic content and antioxidant capacity were lower in the dried products. The preservation of phenolic compounds in the product was higher using freeze drying (94%). The drum-drying process retained over 75% of the putatively healthy phenolics and was the most economical system for obtaining goldenberry ingredients.

Keywords: *Physalis peruviana*; Freeze drying; Oven drying; Drum drying; Phenolic compounds; Antioxidant capacity; Vitamin C

Introduction

Non-traditional exports in South America increasingly include more high quality products that appeal to international audiences. In this context, agricultural products represent a great advantage, considering the large area of workable land in South America. In Chile, one of these new products is the goldenberry (*Physalis peruviana*), also known as *physalis*, Cape gooseberry, or uvilla. This small fruit is a member of the nightshade family that grows in the wild from Colombia to Chile, and it is increasingly desired in the international market [1]. Goldenberry or Cape gooseberry (*Physalis peruviana* L.) is a solanaceous plant native to tropical South America that has an ecological resilience granted by a papery husk or calyx. The berry is approximately 2 cm wide and 4-5 g in weight, with smooth, orange-yellow skin and juicy pulp containing numerous small yellowish seeds. During ripening, the fruit color turns from green to orange due to chlorophyll breakdown and carotenoid accumulation (mainly β -carotene), and a progressive softening occurs [2-4]. When fully ripe, the fruit is sweet with a pleasant grape-like tang [4]. The fruit is eaten cooked or fresh in salads and cocktails. The fruit is very high in pectin and is well suited for pies and jellies [5]. Orange-toned goldenberries, also known as gooseberries or Incan berries, have been cultivated in South America for centuries and revered for their health benefits and sweet and sour flavor. A handful of goldenberries provides a significant amount of antioxidants [6-10], and in traditional folk medicine practices, goldenberries are believed to help maintain a healthy weight, ward off disease, and improve organ function. Goldenberries are also promising because they grow quickly and produce a high yield [4,5]. A single plant may yield 300 fruits, and a carefully tended plant can provide approximately 33 ton ha⁻¹. In addition to having a commercial future as an exotic fresh fruit, the general chemical composition of the goldenberry has many medicinal and edible uses [4-8]. Goldenberry fruit contains high levels of nutritional and antioxidant compounds: its pulp contains vitamins A, B and C; β -carotene; phosphorus and

iron [7,9,11,12]. The fruit is an excellent source of provitamin A (3,000 IU of carotene per 100 g) and vitamin C, and it also contains some B vitamin complexes. Furthermore, the fiber (4.8%), protein (0.3%) and phosphorus (55%) contents of this berry are exceptionally high for a fruit [2]. Plant extracts show antioxidant activity [7-9,11-13], anti-inflammatory activity [13-16] and anti-hepatotoxic [14] and antiproliferative effects on hepatoma cells [16]. In addition, this fruit has excellent potential as a food-based strategy for anti-diabetic and anti-hypertensive products [17].

Physalis fruit is perishable and seasonal and is therefore intended mainly for export as fresh fruit; however, on average, close to 15% of the production does not meet the size and quality levels required for export [1,2]. There are interesting processing alternatives to address this problem, such as the production of individual quick frozen fruit IQF, puree, pulp, jams, preserves, and recently, the production of fruit in the dehydrated form (to consume as a snack). There is a real market opportunity for *physalis*, especially for sauces and dried fruits. The latter can be exported whole or in the form of flour because of the richness of the fruit fiber. The fiber content can be used as a functional ingredient to preserve the fruit, similar to what occurs in other fruits, such as apples, pears and pineapple, among others [18]. The international market is coordinated by intermediaries who export the

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dehydrated product, buying large volumes for subsequent packaging as different brands. The main markets are Canada, the USA, Czech Republic, Germany and Japan and, to a lesser extent, the countries of Eastern Europe, where significant growth in the consumption of this fruit has occurred. The international market for these types of products is growing, with an emphasis on organic certified products [19,20]. In the dried form, *physalis* can be consumed similarly to dried grapes, but most opportunities for this fruit in Europe are expected to be found in the confectionary, bakery and breakfast cereal industries. These industries incorporate dried *physalis* as an ingredient in healthy snacks, cereals and chocolate [20]. *Physalis* fruits sold in the European market, alone or together with other berries, are no longer an exotic item and have become a commodity [19].

A number of epidemiological studies and clinical trials have established that a high dietary intake of fruits and vegetables is strongly associated with a reduced risk of developing chronic pathologies, such as cardiovascular diseases, diabetes, and various types of cancer, among others [21-28]. This association may be partly attributable to the presence of dietary antioxidant vitamins (C and E) and bioactive phytochemicals, such as carotenoids and phenolic compounds [23,29-33]. Phenolics are produced as secondary metabolites in plants and exert various protective roles; in addition, these compounds are responsible for the major organoleptic characteristics of plant food, such as visual appearance (color), flavor, bitterness, astringency, and aroma [24,25]. Phenolics are effective antioxidants and can exert anti-microbial, anti-inflammatory, anti-mutagenic, anti-carcinogenic, anti-allergic, anti-platelet, vasodilatory, and neuroprotective effects [24-26].

A high antioxidant capacity has been demonstrated for goldenberry juice [7,9,12], and the synergistic effect of different antioxidants has also been suggested. Furthermore, a high level of phenolics was reported for the fruit [7-11]. These phenolic compounds seem to be mainly responsible for the antioxidant activity of fruit juices and wines [29,31-36], whereas AA seems to play a minor role. Less than 15% of the total antioxidant activity of a fruit is due to vitamin C [35]. Recently, many phenols and polyphenols have been confirmed to have a stronger antioxidant capacity compared to vitamin antioxidants [34]. Phenolic compounds have been associated with a lowered risk of heart disease via their action on Low Density Lipoproteins (LDL). In addition, phenolics are also important because of their contribution to the sensory quality of fruits (color, astringency, bitterness and flavor). Finally, the total content of antioxidants in a fruit depends on the species and cultivar and can be affected by many factors, such as environmental growing conditions, harvest time, ripening stage, storage and processing conditions.

Fruits and vegetables need to be processed to extend their shelf life. Drying is increasingly used to extend the shelf life of raw materials with high moisture content due to their microbial instability. Drying allows for longer periods of storage and minimizes packing requirements, transport, handling and distribution, in addition dehydrated products exhibit high acceptability [37-40]. It is typically believed that dried products have lower nutritional value due to the loss of nutrients (such as vitamins) and bioactive compounds (such as phenolics). In effect, the drying process may affect the content, activity and bioavailability of these compounds, causing an increase or decrease of their putative health-112 promoting bioactivity due to physical, chemical, and biochemical changes affecting their original structures [40-44]. However, controlled drying might also lead to an overall improvement in the quality of the final product [45].

The drying systems assayed include oven with, convective air, drum

drum dryer, and freeze dryer systems. As expected, freeze drying allowed for the highest retention of polyphenols. Previously, a dried ingredient was developed from Granny Smith apple peel using a pilot scale double drum-dryer, and this product/system was compared with other drying systems, such as oven and freeze dryer systems [45]. There are no studies indicating that fruit characteristics are altered in the process of raw material transformation. Drying may represent a promising tool for preserving nutrients and bioactive compounds during food production. In addition, *physalis* is a promising fruit with a high level of antioxidant capacity. Therefore, the objectives of this study were 1) to develop a food ingredient from *physalis* fruit using three different drying systems (freeze, oven, and drum dryer), controlling all the steps involved in the process, and 2) to determine the influence of each drying process on the physical, chemical and antioxidant quality of the *physalis* fruit ingredient developed.

Materials and Methods

Raw matter

Goldenberry fruits (*Physalis peruviana*) were hand-picked from a commercial field located at Villa Alemana, Valparaíso Region, Chile (33°01' S, 33°07' W; 143 masl). Plants in the field correspond to a Colombian *Physalis* cultivar that was imported to Chile as seeds and vegetation propagated by farmers. Two harvests were performed in two consecutive seasons: on April 4, 2010, and on April 18, 2011. The fruit was dehusked, and uniform fruits without defects were selected by size, sanity, and ripening stage [3]. Goldenberry fruit in the orange ripe stage (OR) was used as raw material, as this variety contains a high phenolic content (83 mg/100 g of raw matter on a dry basis) and has a long shelf life [8]. Four batches of fruits (ca. 10 kg per batch) were collected from the commercial field during both seasons. Immediately after harvest, the fruits were packed into polyethylene bags, frozen at -20°C, transported to the laboratory, and stored in a freezer at -80°C until use. Samples were evaluated and characterized by physical and health properties. Subsequent evaluation of the properties was made after the different dehydration systems were employed. The samples correspond to a pool of fruits randomly chosen from different commercial plantations from the same geographical zone.

Pre-processing conditioning

Two goldenberry fractions were dried either frozen or as a slurry. To prepare the slurry, water was added to form a mix suitable for drum drying. The selected solid to water ratio was 100 g frozen fruit to 60 mL distilled water. For this purpose, a Waring blender (51 BL 32, Torrington, CT, USA) with variable speeds was used. An important factor that needed to be controlled during the pre-processing step was the level of polyphenoloxidase (PPO) activity, as goldenberries are moderately susceptible to enzymatic browning that could affect the level of antioxidant compounds. For this reason, after homogenization with water, 5 g/kg ascorbic acid was added to the mix to inactivate PPO [46]. This anti-browning agent was chosen because it proved to be the most efficient compound for decreasing PPO activity and avoiding the loss of phenolics compared with 20 g/kg ascorbic acid, 5 g/kg citric acid, 2 g/kg citric acid, or blanching (data not shown). Blanching decreases the total phenolic content, most likely due to leaching in the water or enzymatic oxidative damage catalyzed by PPO [42,46-48].

Drying of frozen fruit

A goldenberry fraction (such as frozen or slurry) was dried using three different systems: an Oven dryer (Tau Steril Automatic, Momasco, Como, Italy) at 60°C until the peel reached a constant weight; a Double drum dryer (ADD, Food & Chemical Equip. Inc., Buffalo, New York,

USA) at 110°C with a drum rotation of 0.15 rpm and a drum clearance of 0.2 mm; and a freeze dryer (Ilshin, FD-5518, Seoul, Korea) at 52°C (condenser temperature) with 5 mTorr of pressure and a total time cycle of 26 h (freeze-drying time).

It was not possible to use the drum dryer system to dry the frozen goldenberry due to the large particle size (1 cm x 1 cm). Consequently, we prepared a slurry mix formed by water and fruit in the water:peel ratio indicated in the pre-processing conditioning section to allow for the use of all three drying systems. Immediately after drying, the goldenberry fruits were stored in high density polyethylene (HDPE) plastic bags and kept at room temperature until analysis.

Analytical methods

Analysis of the goldenberry ingredients: All reagents and solvents were analytical grade chemicals from Merck (Darmstadt, Germany) or Sigma Chemical Co. (St Louis, MO, USA).

The moisture content was determined gravimetrically by heating the sample in an oven at 70°C for 16h until a constant weight was reached. The moisture content was expressed as the grams of water in 100 g of the original sample (wet basis) (g water/ 100 g sample) (AOAC, 2006).

The water activity (a_w) was determined at 25°C using an a_w meter (AQUA LAB 4 TE Decagon Device, Pullman WA, USA).

For color, the parameters of CIELab, L^* , a^* and b^* , were measured in a tristimulus reflectance colorimeter (Chroma Meter CR 400, Minolta Osaka, Japan). L^* indicates brightness or lightness (0 = 184 black, 100 = white), a^* indicates chromaticity on a green (-) to red (+) axis, and b^* indicates chromaticity on a blue (-) to yellow (+) axis. Numerical values of a^* and b^* were converted into hue angle ($H^\circ = \tan^{-1} [b^*/a^*]$) and chroma ($C = [a^{*2} + b^{*2}]^{1/2}$). Hue represents an angle in a color wheel of 360°, with 0°, 90°, 180° and 270° representing the hues red-purple, yellow, bluish-green and blue, respectively, whereas chroma is the intensity or purity of hue [49].

The pH, titratable acidity and soluble solids content of the samples were also measured. A 20g sample of raw matter (goldenberry fruit) or 1g of dried fruit was homogenized in 200mL of water in a Waring blender (51 BL 32, Torrington, CT, USA) for 1 min. The homogenate was filtered under vacuum, and the juice was used for the analysis. The pH was measured using a digital pH meter (Orion, model 420A, Boston, USA). Titratable acidity was determined with 0.1 mol/m³ NaOH until reaching pH 8.1. The results were expressed as mEq of citric acid per gram of fresh sample. The soluble solids content was determined using a digital refractometer (Atago, model Pal-1, Tokyo, Japan) at 20°C. For this measurement, 10 mL of filtrate was centrifuged at 3,000 rpm (Medifuge Heraeus Sepatech, Berlin, Germany) for 10 min, and the soluble solids content was determined in the supernatant. The results were expressed as gram of sucrose per gram of fresh weight.

Antioxidant content and capacity

Preparation of the extract: In total, 10 g of raw matter or 2 g of goldenberry fruit fraction was mixed with 90 mL of solvent extraction (50:50 methanol:water) and drops of orthophosphoric acid. The mix was homogenized (OMNI International, GLH-02, USA) for 5 min, and the extracts were shaken in a water bath (Memmert, Schwabach, Germany) at 150 rpm for 60 min at room temperature. Three samples (2 mL) were centrifuged at 4,000 rpm for 20 min, and the supernatants were used for the analysis.

The total phenolic content was determined using a colorimetric method with Folin-Ciocalteu reagent as described previously [50]. The measurement was compared to a standard curve prepared with a gallic acid solution. The total phenolic content was expressed as milligrams of gallic acid equivalents per gram of dry weight (mg GAE/g DW). The analyses were run in triplicate.

The antioxidant activity by DPPH (2, 2-diphenyl-1-picrylhydrazyl) was evaluated by measuring the free radical scavenging activity of DPPH using a modified colorimetric method [51]. The methanol extract solution used in the assay of total phenolic content was used to determine the antioxidant activity. First, 100 μ L of extract was mixed with 3.9 mL of DPPH radical (103.5 μ M) in methanol. The reaction mixture was shaken well, and the mixture was left for 60 min at room temperature in the dark. The reduction of the DPPH radical was determined by measuring the absorption at 517 nm in a UV/V is spectrophotometer (Perkin Elmer, Lambda 25, Beaconsfield, Bucks, UK). The scavenging activity of the DPPH radical was determined using Trolox as a standard. The results were expressed as micromoles of Trolox equivalents per gram of dry weight (μ M Trolox/g DW). The analyses were run in triplicate.

The ascorbic acid (AA) content of the raw material and ingredients was determined by HPLC [8]. A standard curve in the concentration range of 10-100 mg ascorbic acid was used. Dehydroascorbic acid (DHA) was quantified after its reduction to AA by dithiothreitol (DTT). For that procedure, samples were incubated for 24 h at room temperature in the presence of 1mM DTT and then subjected to a new HPLC separation and quantification in which the values correspond to the total vitamin C content. The DHA content corresponds to the difference between total vitamin C and AA. The values were expressed as mg ascorbic acid per 100 g FW. The determinations of each biological replicate were performed in quadruplicate, and the data correspond to the mean \pm SE.

Statistical analysis

A completely randomized design was used with four replicates of each condition evaluated. All the measurements were analyzed in quadruplicate and all results were expressed as the mean \pm SE, and. The data were performed using a one-way analysis of variance and statistical significance by LSD test for quality assessment. All statistical analysis and correlations were performed using SAS software (SAS

Parameter	Raw material	Lyophilized	Oven-dried	Drum-dried*
Acidity (mEq gFW ⁻¹)	15.50 \pm 1.17 a	12.87 \pm 1.35 b	11.76 \pm 1.27 b	16.53 \pm 1.19 b
pH	3.54 \pm 0.21 a	3.43 \pm 0.14 a	3.78 \pm 0.16 a	3.39 \pm 0.21 a
SSC (g*gFW ⁻¹)	15.76 \pm 0.27 a	14.62 \pm 0.12 b	14.34 \pm 0.06 b	14.87 \pm 0.23 b
A _w	0.85 \pm 0.04 a	0.32 \pm 0.02 b	0.25 \pm 0.02 b	0.29 \pm 0.02 b

*Ingredient obtained using the slurry fruit. The data correspond to means \pm SE. A different letter for the same ripening index indicates significant differences by ANOVA (P<0.05). Goldenberry (*Physalis peruviana*) fruits were collected from a commercial field located at Villa Alemana, Valparaíso Region, Chile. After harvest, the fruit was selected by ripening stage using only fruit in the OR stage. Four replicates of fifty fruits for each dehydration system were tested.

Table 1: Physicochemical parameters of the original raw material and the ingredients obtained from dehydrated *Physalis peruviana* fruits.

Institute Inc., Cary, North Carolina, USA). Differences at ($p \leq 0.05$) were considered to be significant.

Results and Discussion

Effect of the drying method in physical-chemical attributes of fruit

In the present study, the quality parameters of the goldenberry fruit, such as total soluble solids (ranging from 15.49 to 16.03 °Brix), titratable acidity (ranging from 14.33 to 16.67 mEq gFW⁻¹) and pH (ranging from 3.33 to 3.75), were determined (Table 1). The different dehydration systems resulted in differences for some of the evaluated chemical composition parameters of the goldenberry fruit ingredients (Table 1). The acidity was slightly reduced, and pH was maintained without significant differences among treatments ($p < 0.05$). All of the dehydration systems evaluated reduced the soluble solids content, but there were no significant differences among the systems. The final water activity varied between 0.25-0.32, with no differences among treatments. The drying was achieved at 24 hr for the oven process, at 48 hr for the lyophilization process and after a few minutes for the drum dryer process. The moisture content of the fresh fruit was 82.1 g/100 g sample (Table 1). In addition, the moisture content of the ingredients obtained was similar in the goldenberry fruit products (Table 2), independent of the drying system used ($p \leq 0.05$), and the values ranged from 4.3 to 4.8 g/100 g a_w. This value is a major determinant of the product stability because water acts as a solvent to support enzymatic and chemical reactions that influence antioxidant stability, color, flavor and nutritional value [52]. The water activity measurement is used to predict the stability and safety of foods with respect to microbial growth, rates of deteriorative reactions and chemical/physical properties. Previous research reported that the stability of dehydrated goldenberry is higher at an a_w below 0.33, most likely due to lower lipid oxidation [53]. In this situation, the product may be an excellent source of antioxidants as long as environmental moisture absorption is avoided. For this reason, the final a_w of the ingredients produced was set near this value (0.33). We observed similar a_w values in the dry products, independent of the drying system used ($p \leq 0.05$). The values ranged from 0.29 to 0.32 (ingredients produced from fresh fruit) (Table 1).

There were no significant differences in the pH, acidity and soluble solids content among the ingredients obtained by different drying systems (Table 1). The pH of the fresh goldenberry fruit was 3.54. The pH values of the oven-dried samples were slightly higher than the fresh fruit values; however, there were no significant differences among treatments. Similar results have been found in aloe vera and red pepper [54,55]. The ingredients obtained from fresh fruit had acidity values ranging from 11.76 to 16.53 mEq citric acid gFW⁻¹ sample. The higher acidity of the dry samples obtained from fruit slurry may be associated with the addition of ascorbic acid as an anti-browning agent.

The soluble solids content of the raw matter was 15.76 g sucrose gFW⁻¹ in fresh fruit. This value ranged from 14.34 to 14.87g sucrose for the developed ingredients, depending on the drying system used and the starting material. The soluble solids content decreased in all of the dried samples compared to the fresh fruit (the content diminished between 32.6 and 72.5%). This finding is in agreement with a study reporting that the soluble solids content of air-dried red pepper decreased from its original value [55].

The effects of the drying method on color

Food color is a major determinant of product quality and affects consumer preferences [52]. Color may be used as an indicator to

predict the chemical and quality changes due to thermal processing. The color parameters (L*, a*, b*, chroma and hue) of the raw matter and the developed goldenberry fruit ingredients are shown in table 3. In the raw matter, the goldenberry fruits were lighter, orange (a* 17.12), and slightly yellow (b* 60.78). The hue angle and chroma values were 74.26 and 63.15, respectively. Similar L*, a*, and b* values were reported previously [8,9,12].

The drying system had a significant influence on the color of the final product (Table 3). Compared to the original goldenberry fruit (either fresh or slurry), the drying process decreased the lightness (L*) and the yellow index (b*) but increased the hue angle. Consequently, the ingredient obtained was darker, slightly yellow and duller than the raw matter. L* is also an indicator of the oxidative browning reaction and pigment concentration. In effect, changes in browning may be well represented by the decrease in L* and b* [52]. The color of the freeze-dried ingredient was similar to the fresh fruit compared with oven and drum drying. This finding is reflected in the values of L*, a* and b* that were observed after the fresh and slurry goldenberry were evaluated. This difference may be associated with the removal of water by the sublimation of ice that prevents enzymatic browning reactions and results in a relative stability of the color [56]. In contrast, the drum-dried samples were slightly red compared with the oven-dried samples, which exhibited more browning and redness that resulted in decreased L* and b* values and increased hue angles (102.54 in slurry fruit). An increase in drying duration reduced the chroma values for the fruits, regardless of the drying method ($P < 0.001$). The lower values of chroma indicate a reduced purity of color (darkening). Furthermore, the browning increased as the drying duration increased. The same trends were observed with the lightness of color values. These results clearly demonstrate that each drying method affects the browning reactions that occur during the process in a different way.

The undesirable brown color of these samples is not only attributable to the evaporation of surface water but also to enzymatic browning (catalyzed by PPO) and non-enzymatic browning (Maillard and caramelization reactions) that take place during the process. Various intermediate products (e.g. 5-309 hydroxymethyl-2-furfural) and brown pigments (melanoidins) are generated and may contribute to the development of new flavors, colors and changes in the nutritional value and antioxidant activity of the products. The Maillard reaction is considered one of the major causes of quality loss (discoloration, off-flavors, and nutrients loss) and is a useful indicator of temperature abuse [44]. This reaction accelerates with increasing temperatures (especially above 50°C) and pH values over the range from 4 to 7, which are quite typical in foods [56]. In addition, the gradual decrease of a_w aids in the progression of Maillard reactions, leading to the formation of colored polymers [57].

Drying System	Humidity (%)	
	Fresh fruit goldenberry	Slurry golden berry
Lyophilized	23.07 ± 1.62 a	24.69 ± 1.22 a
Oven-dried	22.32 ± 2.50 a	22.66 ± 1.49 a
Drum-dried	21.53 ± 1.53 a	23.27 ± 3.14 a

The data correspond to means ± SE. A different letter for the same ripening index indicates significant differences by ANOVA ($P < 0.05$). Goldenberry (*Physalis peruviana*) fruits were collected from a commercial field located at Villa Alemana, Valparaíso Region, Chile. After harvest, the fruit was selected by ripening stage using only fruit in the OR stage. Four replicates of fifty fruits for each dehydration system were tested.

Table 2: Moisture content of the ingredients obtained from dehydrated *Physalis peruviana* fruits.

Parameter	Raw material	Dehydration system		
		Lyophilized	Oven-dried	Drum-dried*
L*	69.56 ± 2.12 a	59.76 ± 1.07 b	31.76 ± 2.13 D	42.42 ± 2.98 c
a*	17.12 ± 1.30 a	15.89 ± 0.65 a	-7.88 ± 3.33 B	-5.63 ± 4.41b
b*	60.78 ± 2.74 a	46.97 ± 1.38 b	37.99 ± 1.89 C	25.32 ± 2.01 d
c*	63.15 ± 2.68 a	49.59 ± 1.23 b	38.80 ± 2.76 C	25.94 ± 1.95 d
H*	74.26 ± 1.30 b	71.29 ± 1.05 b	101.72 ± 3.85 A	102.54 ± 0.76 a

*Ingredient obtained using the slurry fruit.

Data correspond to means ± SE. A different letter for the same ripening index indicates significant differences by ANOVA ($P < 0.05$). Goldenberry (*Physalis peruviana*) fruits were collected from a commercial field located at Villa Alemana, Valparaiso Region, Chile. After harvest, the fruit was selected by ripening stage using only fruit in the OR stage. Four replicates of fifty fruits for each dehydration system were tested.

Table 3: Color parameters in the CIELAB space of the ingredients obtained from dehydrated *Physalis peruviana* fruits.

Effect of the drying method on the total antioxidant content and capacity

The total phenolics content in the dried goldenberry fruit ingredients obtained using different drying systems are shown in figure 1. The total phenolics in the raw matter were 2.46 and 8.27 g GAE/100 g DW for fresh and slurry fruit, respectively. The phenolic levels in the ingredients obtained from the slurry goldenberry fruit were higher (3-fold) in comparison with the fresh fruit because ascorbic acid was added to inactivate PPO and avoid the loss of phenolics during the pre-processing stage. This result demonstrates that it is possible to retain a high proportion of these putatively bioactive compounds during the drying process [58].

There was a significant reduction in the amount of phenolics during the drying process. The samples dried as fresh fruit reached 1.31, 1.24 and 0.33 g GAE/100 g DW for lyophilized, drum-dried and oven dried samples, respectively. The loss of phenolics ranged from 47 to 86% for freeze and oven drying, respectively. In contrast, in the samples dried as fruit slurry, the total phenolics content ranged from 4.72 to 7.35 g GAE/100 g DW, depending of the drying system used. In these samples, the loss ranged between 11.12% and 42.00%. Thus, the reduction in phenolics observed in the ingredients developed from fresh fruit was higher; in addition, the samples produced from the fruit slurry showed higher antioxidant content than those dried as frozen fruit, with values that were 2.5-334 and 3.2-fold higher in the freeze- and oven-dried products, respectively ($p < 0.05$). These data indicate that freeze drying retained most of the phenolics contained in the raw matter. The drum-drying system allowed for the retention of over 70% of the phenolics and is also the most economical system. Other reports indicate that the drying processes applied to different products resulted in significant declines in total phenolics [39,40,55,59]. Phenolics are highly unstable to thermal processes because they are rapidly transformed into various products, mainly due to plant cell damage that causes biochemical and chemical changes [22,56]. The loss of phenolics could also be a result of thermal instability or enzymatic oxidation, especially during the pre-processing operations [40]. The mechanisms that cause the reduction of these phytochemicals include chemical decomposition, enzymatic and non-enzymatic degradation, and the formation of insoluble oxidation and polymerization products, among others [59]. Our results indicate that the greatest loss of phenolic compounds was associated with oven drying, most likely due to the length of the drying period, which allows aerial oxidation and enzymatic degradation, while enzymatic inactivation may have occurred in the lag phase [60]. The level of ascorbic acid determined in fresh fruit was 32 mg 100 g⁻¹ (Figure 1) which is similar to the values reported previously [9,10]. The ingredient obtained by dehydration by drum dryer process showed the highest retention of ascorbic acid content, reaching 75.67%, while the greatest loss was obtained by the ingredient obtained in oven dried

(43.24%). The ingredient obtained in the drum dryer was probably favored by the protective effect of ascorbic acid added to the fruit pulp to reduce browning.

Several *in vitro* methods have been developed to assess the total antioxidant capacity of foods. The DPPH assay is based on the measurement of the scavenging ability of antioxidants towards the stable DPPH free radical, which is reduced to the corresponding hydrazine when it reacts with hydrogen donors. The radical scavenging activities of the goldenberry fruit ingredients obtained by different drying methods are shown in figure 1. The antioxidant capacity of the raw matter was 9.45 and 5.84 mmols DPPH/100 g DW for slurry and fresh fruit, respectively. The raw slurry fruit exhibited higher antioxidant capacity (3.68-fold) in comparison with frozen fruit, most likely because of the addition of ascorbic acid to inactivate PPO during the pre-processing stage. This result demonstrates that the application of this compound allows for the retention of a high proportion of phenolics and plays an important role in the total antioxidant potential of the product. Indeed, all the samples dried as slurry had significantly higher antioxidant capacity than the samples dried as frozen peel. Similar results were reported for apple samples [61], indicating that the addition of 1g/kg ascorbic acid increased their antioxidant capacity.

Changes in the overall antioxidant properties of foods during processing can be attributed to events such as the loss of naturally occurring antioxidants, the formation of novel compounds with pro-oxidant activity, the formation of novel antioxidant compounds (e.g., Maillard products) and, as in this case, the addition of other compounds (e.g., ascorbic acid). Depending on these reactions, the overall antioxidant activity can decrease, increase or remain unchanged during food drying [52]. Other researchers have observed a significant decrease in antioxidant capacity during the drying process [39,40,53-55]. Our data show a substantial decrease in antioxidant capacity in all the samples after drying, ranging from 32 to 83%, depending on the drying system used and the preparation of the raw matter (Figure 1). The radical scavenging activities of freeze dried samples were higher, with values of 2.95 (fresh fruit) and 6.37 (slurry fruit) mmols DPPH/100 g DW, in these samples, the antioxidant capacity was 46.1% and 32.6% of the raw matter for fresh and slurry fruit, respectively. Similar results were reported in saskatoon berries [40]. The loss of radical scavenging activity for the drum- and oven- dried ingredients prepared from slurry was 53% and 59%, respectively, while in the oven-dried samples prepared from fresh fruit, the loss was 55 and 83.14%, respectively. These results demonstrate that oven drying caused the greatest reduction in the total antioxidant capacity of the samples. These results are in agreement with previous research [41] that determined the antioxidant capacity was significantly reduced by oven-drying compared to other drying methods (air and vacuum-drying).

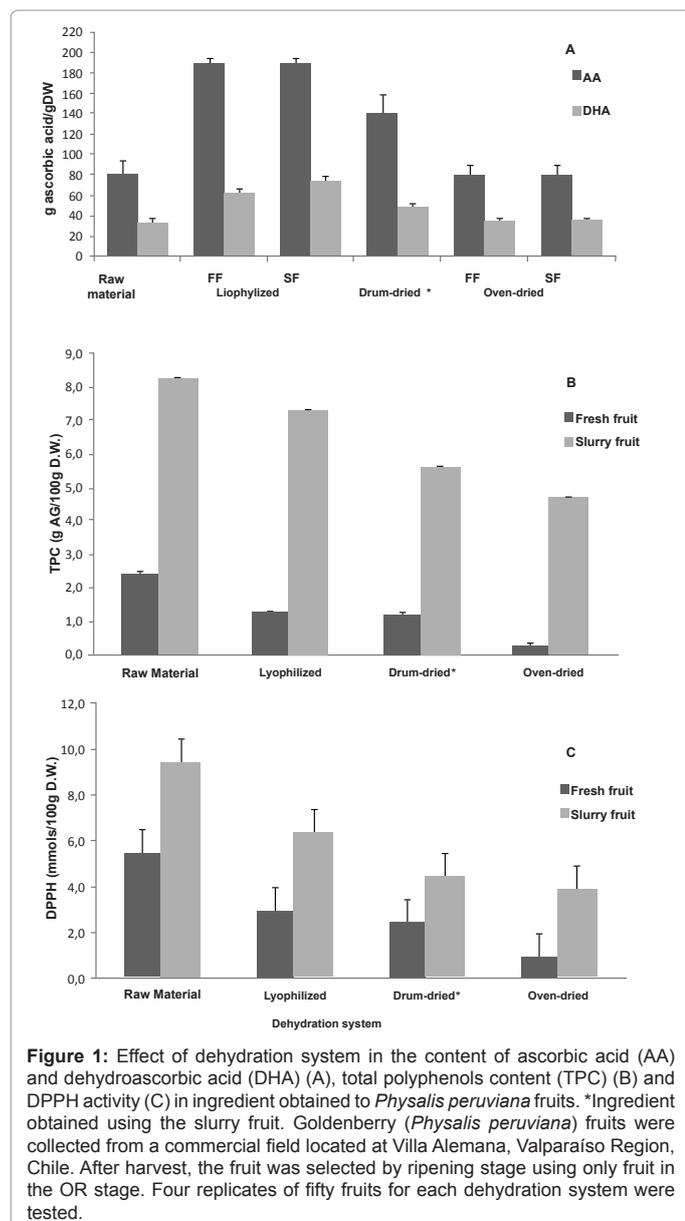


Figure 1: Effect of dehydration system in the content of ascorbic acid (AA) and dehydroascorbic acid (DHA) (A), total polyphenols content (TPC) (B) and DPPH activity (C) in ingredient obtained to *Physalis peruviana* fruits. *Ingredient obtained using the slurry fruit. Goldenberry (*Physalis peruviana*) fruits were collected from a commercial field located at Villa Alemana, Valparaíso Region, Chile. After harvest, the fruit was selected by ripening stage using only fruit in the OR stage. Four replicates of fifty fruits for each dehydration system were tested.

The correlation analysis between all the samples indicates a strong, positive and significant correlation between the antioxidant capacity (DPPH assay) and the total phenolic content ($r=0.99$, $p<0.01$). This result indicates that the radical scavenging activity depends on the phenolic content and could partially determine the antioxidant capacity due to the synergistic effects of the phenolic compounds that constitute the apple sample. Different authors have also observed a high correlation between the total phenolic content and the antioxidant capacity as evaluated by the DPPH assay in fruits [37,39,40,45].

Conclusions

The drying system used to obtain goldenberry fruit ingredients modified a series of chemical parameters, color, and putatively health-promoting properties, such as the antioxidant content and capacity, thus affecting the quality of the final product. As expected, freeze drying retained most of the phenolic compounds present in fruit at the fresh state. Our results indicate that drum-drying, a simple, energy efficient,

low capital investment approach, is an attractive drying system that can retain over 70% of the phenolic compounds in goldenberry fruit.

The goldenberry powder ingredients developed may be used in the formulation of functional foods and beverages as they contain nutrients and bioactive phytochemicals with potentially beneficial health effects.

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