Handbook of Goldenberry (*Physalis peruviana*)

Cultivation, Processing, Chemistry, and Functionality

Edited by
Mohamed Fawzy Ramadan

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Chapter 39

Chemical characteristics, bioactive compounds, and advances in processing of *Physalis peruviana*

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39.1 Introduction

Consumers are interested in new and exotic fruits that contribute to wellness and health benefits with phytochemical compounds. In this context, Cape gooseberry (CG) (*Physalis peruviana*) also called Inca berry, *uchuva* and Golden berry, is a sweet and exotic fruit originating in the Andes region of South America. It is a fruit rich in several nutrients (provitamin A, vitamin C, vitamin B complex, and minerals), with good consumer acceptability because of its pleasant taste and aroma. Furthermore, the fruit is a source of several bioactive compounds such as carotenoids, polyphenols, ascorbic acid, and dietary fiber, making it a functional food. Although CGs are preferably consumed fresh, nowadays their chemical composition and the presence of bioactive compounds have led to the development of studies that could provide new consumption alternatives to those already commercially available (marmalades, syrups, dried fruits). Therefore this chapter also addresses recently published advances in CG processing, such as the application of high hydrostatic pressures (HHPs), freeze-drying (FD), and the use of ultrasound and osmodehydration (OD). All these technologies aim to increase the consumption of a fruit that is widely distributed throughout the world (Latin America, India, Egypt, and other countries) and could be consumed in many different ways, thus extending its shelf life as a fresh product and making it more attractive to consumers.

39.2 Chemical composition and bioactive compounds

39.2.1 Physical characteristics and chemical compounds

The ripe fresh fruit is ovoid, with a polar diameter between 1.40 and 1.80 cm and an equatorial diameter of 1.30−1.70 cm, a weight varying from 4 to 10 g. The peel color varies greatly from bright yellow to orange (Bazalar-Pereda et al., 2019; Mendoza et al., 2012; Puente et al., 2011).

The pH of the pulp varies between 3.6 and 3.9 (Bazalar-Pereda et al., 2019; Petkova et al., 2021; Rodrigues et al., 2021), the soluble solid content between 13.6 and 15.1°Brix (Bazalar-Pereda et al., 2019; Bravo et al., 2015; Guiné *et al*., 2020; Mendoza *et al*., 2012) and the acidity between 1.25% and 1.88% (Bazalar-Pereda et al., 2019; Bravo et al., 2015; Guiné et al., 2020). Those are the technological characteristics relevant to the processing of the fruit.

The fruit also contains several mineral compounds, of which the most important with significant amounts include Ca, Na, P, Fe, K, Zn, and Mg, some of them with positively recognized effects on human nutrition. Calcium ranged between 0.49 and 17.8 mg/100 g fresh fruit, sodium between 2.76 and 16.87 mg/100 g fresh fruit, phosphorus between 38.00 and 94.75 mg/100 g fresh fruit, iron between 0.54 and 2.09 mg/100 g fresh fruit, potassium between 210.00 and 487.00 mg/100 g fresh fruit, zinc between 0.15 and 11.00 mg/100 g fresh fruit, and magnesium 1.40 and 48.70 mg/100 g fresh fruit (Bazalar-Pereda et al., 2019; Mendoza et al., 2012; Muñoz et al., 2021; Petkova *et al*., 2021; Singh et al., 2019).

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39.2.2 Bioactive compounds

Bioactive compounds are generally recognized as an important contribution to human health, helping to prevent several diseases as is described in other chapters of this book. Among the bioactive compounds present in CG fruits are carotenoids, vitamin C, vitamin B, vitamin E, total polyphenols, and dietary fiber.

39.2.2.1 Carotenoid content

The fruit of *P. peruviana* contains various carotenoids. Fischer et al. (2000) report that β-carotene is the most abundant carotenoid, followed by α-carotene and β-cryptoxanthin. Table 39.1 shows the concentrations reported in the literature in relation to all the carotenoids present in the fruit. Total content ranged between 0.64 and 0.81 mg/100 g in the fresh fruit pulp and 10.86 mg/100 g in the peel.

39.2.2.2 Ascorbic acid and other vitamins

Ascorbic acid is found in high concentrations in the CG fruit. Different authors report values that fluctuate between 19.10 and 48.67 (Table 39.1), depending on the genotype, maturity stage, location, and growing conditions.

The fruit of *P. peruviana* also contains vitamin B and vitamin E. Table 39.1 shows the concentrations reported in the literature in relation to these vitamins.

39.2.2.3 Phenolic compounds

Total phenolic compounds range from 50 to 250 gallic acid equivalents in 100 g of fruit fresh weight and include phenolic acids, like caffeic, gallic, chlorogenic, ferulic and p-cumaric acids; flavonoids, like quercetin, rutin, myricetin, kaempferol, catechin, and epicatechin (Muñoz et al., 2021; Olivares-Tenorio et al., 2016). As can be seen in Table 39.2, the range of variability is quite high and is based on research done under very diverse conditions and plants.

39.2.2.4 Dietary fiber

Many papers have reported the crude fiber content, but what is actually more important, from the physiological point of view, is the dietary fiber (soluble and insoluble) content. Crude fiber is part of dietary fiber and the analysis methods dissolve much of the insoluble fiber and all of the soluble fiber so that the dietary fiber value is underestimated. From a nutritional point of view, the insoluble and soluble fiber contents of foods are of more interest than the crude fiber alone. One of the few reports about dietary fiber content in CG reported concentrations between 0.085 and 0.68 g/100 g

TABLE 39.1 Concentrations reported in the literature in relation to the bioactive compounds of *Physalis peruviana* fruit.

Compounds	Content (mg/100 g f.w.)	References
Total carotenoids	0.64–0.81 in pulp 10.86 in peel	Alvarez-Herrera et al. (2014), Wen et al. (2020)
β-carotene	1.24–2.0	Bazalar-Pereda et al. (2019), Olivares-Tenorio et al. (2016)
Vitamin C (ascorbic acid)	19.10–48.67	Bazalar-Pereda et al. (2019), Mendoza et al.(2012)
Vitamin B		
B1 (thiamin)	0.01–0.018	Mendoza et al. (2012), Singh et al. (2019)
B2 (riboflavin)	0.003	Mendoza et al. (2012)
B3 (niacin)	0.8–3.84	El-Beltagi et al. (2019), Singh et al. (2019)
B6 (pyridoxine)	4.59	El-Beltagi et al. (2019)
Vitamin E (tocopherols)	0.17	Singh et al.(2019)
Total phenolic compounds (mg GAE/100 g f.w.)	50–250	Olivares-Tenorio et al. (2016), Muñoz et al. (2021).
Dietary fiber (g/100 g)	0.085–0.68	Siró et al. (2008)

TABLE 39.2 Antioxidant activity of *Physalis peruviana* fruit.

	Content	References
DPPH (2,2-diphenyl-1-picrylhydrazyl)	237.3−260.7 TE/100 g f.w. 1.54−7.24 μmol TE/g 192.51−210.82 μmol TE/100 g	Guiné et al. (2020) De la Vega et al.(2019) Puente et al. (2011)
FRAP (ferric reducing antioxidant power)	69.58 μmol TE/100 g f.w.	Muñoz *et al*. (2021)
ABTS (2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid))	3.76 μmol/100 g f.w. 24.99 μmol/100 g f.w.	Muñoz et al. (2021) Bazalar-Pereda *et al*. (2019)
ORAC (oxygen radical absorbance capacity)	0.75 g TE/kg f.w. 3126.82 μmol TE/100 g f.w.	Bravo et al. (2015) Muñoz et al. (2021)

of fresh fruit. This is an important dietary component and *P. peruviana* fruit has on average more fiber than other small fruits (Siró et al., 2008).

39.2.2.5 Antioxidant activity

The antioxidant activity of CG is reported in different units, and so it is not easy to compare the data available; however, compared with other fruits recognized for their high antioxidant capacity, CG also shows an interesting activity like those reported for apricots, peaches, and pears, but lower than that of some berries such as blueberry with 5481 μmol ET/100 g f.w. or prune with 5821 μmol ET/100 g f.w (Portal antioxidants, 2022).

Among the methods for determining the antioxidant capacity of foods, the ORAC (oxygen radical absorbance capacity) value is the world's most widely recognized method for determining the antioxidant contribution of foodstuffs in the body (Table 39.2).

39.3 Advances in processing of Cape gooseberry

Food processing, in addition to preserving perishable foods, can give greater added value to a fresh raw material, in this case, the *P. peruviana* fruit. In turn, ensuring that it retains the compounds that make it an appetizing fruit, details of which have already been given in previous chapters and in the first part of this chapter.

As indicated earlier, the CG fruit contains different compounds that can be classified as health-promoting compounds (vitamin C, phenolic compounds, carotenoids, vitamin E, among others), which must be preserved during the different processes applied for their conservation, as these diverse products are an interesting way to contribute to people's diet.

Although the concentrations of these compounds are variable according to the state of maturity of the fruit, cultivation conditions, varieties/cultivars/ecotypes, among others, it is important to preserve them with the different processing methods applied.

Among the preservation methods studied for *P. peruviana*, some of which are already commercially available, are the classic transformation processes that use thermal and non-thermal treatments. Among the former are pasteurization for the preparation of pulp to make jams, juices, and other products; drying, such as FD and vacuum drying; and among the non-thermal and more recent ones, the application of HHP, microwave drying, and spray drying (SD).

39.3.1 Preservation by thermal and non-thermal methods

39.3.1.1 Thermal treatments

Several studies address aspects of the effect of heat on bioactive compounds, microbiological safety, and sensory quality of the products studied. Castro-Sánchez et al. (2014) produced nectars, pulps, and jams using fruit in good condition but discarded as unacceptable for fresh marketing or export, as this can reach a percentage of around 45% in Colombia in times of rainfall, due to cracking and softening. The authors prepared raw pulp (without heat treatment and without sugar), pasteurized natural pulp (72°C for 5 minutes) and without sugar, and pasteurized pulp with sugar. To produce nectars, raw pulp was used, filtered, and clarified with unflavored gelatin at 1% w/w to remove some compounds that confer astringency. Then, three formulations were prepared with different concentrations of pulp in the nectar (20%, 30%, and 40%) by adding water, sugar, thickener [carboxymethyl cellulose (CMC)], and citric acid; the homogenized formulations were subjected to a heat treatment (72°C for 5 minutes), packed, and stored at 4°C. To produce jam, raw pulp was used in different concentration (40%, 50%, and 60%) and cooked to 68°Brix, while gelling agent (fast pectin), sugar and citric acid were added, then packed in glass jars, and stored at ambient conditions (18°C). All products were microbiologically safe. In terms of sensory analysis, the most accepted pulp was the pulp pasteurized with sugar and the most accepted formulations were, in the case of nectar, the one with 20% pulp, in the case of jam, the one with 50% pulp. These studies provide alternative uses for discarded fruit, which is advantageous from an economic and ecological point of view.

Cárcamo-Medina et al. (2019) evaluated the effect of pasteurization on vitamin C, carotenoids, and CG juice color. They used ripe, yellow-orange fruits and processed them, with peel, in a commercial juice extractor. Two pasteurization treatments were evaluated by heating the juice in Pyrex tubes immersed in an oil bath (80°C for 15 minutes and 94°C for 29 minutes). The results indicated that the pasteurization treatments did not significantly affect the vitamin C concentration and brightness (L*) of the juice, which is highly positive. In turn, heat treatments significantly increased carotenoid concentration by 50%− 83%. The authors attribute this effect to the fact that the fruit was only cut with peel, which functions as a reservoir of carotenoids that, when in contact with heat, releases the carotenoids. Something similar was found in studies of tomato pulp (Ordóñez-Santos et al., 2009), where products processed with peel presented higher carotenoid concentrations than products that were peeled. Another reason could be that these pigments are linked to proteins by covalent bonds and when heat is applied, the structure (protein-carotenoid) would be broken allowing for a higher release of carotenoids. The color parameters measured in this study (Cárcamo-Medina et al., 2019) indicate that the treatments studied did not affect most of them, observing that the C* parameter (chroma) increases with heat treatments, consistent with the increase in carotenoid concentration. It would be interesting to scale up this type of study at a trial level, using pasteurization systems like those used by the industry, either plate or tubular pasteurizers, in which heating is more homogeneous and faster. At the same time, in future studies, microbiological analyses are essential.

Bazalar-Pereda et al. (2020) applied a design to optimize the formulation of nectar with juice and pulp from CG. For the preparation of the nectar, a mixture of juice + pulp, water, and sugar (peeled and seedless) was homogenized and heated at 85°C for 15 seconds, then placed in a water bath at 90°C for 10 minutes. The nectars were then cooled to room temperature in a water bath for 30 minutes. After analysis, the authors arrived at an optimal nectar consisting of 65% juice + pulp and 8% sucrose, which met all microbiological requirements. The total acceptability of this nectar was 7.6 evaluated according to a 10-cm unstructured guideline. Regarding β-carotene, the content (1.13 mg/100 mL) is similar to that provided by carrots, which are recognized as a good source of these compounds, so that one glass of nectar (200 mL) would, according to the authors, contribute 32% of the RDI of vitamin A for an adult (WHO World Health Organization, 2005). Another compound of interest provided by nectar is vitamin C (16.6 mg/100 mL), even though pasteurization processes can decrease this compound, there is still enough vitamin C left to contribute to the recommended daily requirement. According to the authors, a 200-mL glass of nectar could cover 74% of the recommended daily intake (RDI) of vitamin C. They used DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS + (2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid)), and FRAP (ferric reducing antioxidant power) to determine the antiradical activity; however, they did not use ORAC, one of the most accepted methods for determining antioxidant activity, highlighting that the FRAP value (10.16 μmol Trolox/mL) is higher than that of other fruits such as oranges, peaches, grapefruit, and mango.

Following these lines, it would be interesting to reduce the added sugar content of nectars, replacing it with sucralose, stevia, or another natural non-caloric or low-calorie sweetener, as health problems can be related to nectars due to their sugar content.

Embaby and Mokhtar (2019) performed a variant in the studies on nectars by adding various proportions of CG juice to carrot juice; the authors were looking for a better sugar/acid balance in carrot nectar by taking advantage of the low pH of CG juice. In the study, they used a control (0% CG juice) and tested 20%−50% addition of CG juice (T1), 20% (T2), 30% (T3), 40% (T4), and 50% (T5); then the mixtures were added to a sucrose solution (1:1) and pasteurized in bottles after maceration with Pectinex Smash XXL at 98°C for 2 minutes. A storage study was carried out at 4°C for 28 days. As expected, CG juice increased the acidity levels of the carrot nectar, as well as the bioactive compounds (Vit C and phenolic compounds) and the antioxidant capacity. In contrast, the β-carotene content decreased. The organoleptic characteristics improved with the addition of CG juice, the one with 30% CG juice addition being the best evaluated (overall acceptability) and all nectars were microbiologically safe.

These blends of CG juice with other vegetables create other alternatives for CG juice. For example, CG juice in blends with vegetable juices that could enhance and produce exotic flavors in more traditional juices and nectars.

Continuing in this line of product development, Hemalatha et al.(2018) studied the shelf life of ready-to-drink (RTD) beverages made from enzymatically treated CG juice to facilitate juice extraction and increase juice yield. This type of beverage is convenient for the consumer because no preparation is required. As the name suggests, they are ready to drink. The beverages were prepared with 10% CG juice, pasteurized at 90°C for 1 minute and sodium benzoate was added as a preservative and citric acid to decrease acidity and further protect the product from microbial attack, before hot packing in PET (polyethylene terephthalate) bottles. To monitor their shelf life, they were kept and analyzed at 2 storage temperatures, refrigeration (4°C), and room temperature (27°C). It should be noted that these ambient temperatures may be lower in other countries; however, they are indicative of the long-term storage behavior of the beverages. The authors observed that beverages kept cold showed less physicochemical deterioration and had good sensory acceptability with respect to sensory attributes (color and overall quality). They were microbiologically safe and retained bioactive compounds (ascorbic acid, β-carotene, and phenolic compounds) better than at room temperature, where more marked changes in deterioration and loss of bioactive compounds were observed. From a sensory point of view, beverages stored at 4°C showed good sensory acceptability with respect to color and overall quality attributes, while being microbiologically safe. In contrast, beverages stored at room temperature showed some microbial spoilage from day 60 onwards, with slight growth of Bacillus-type bacteria; however, the count was within the permitted limits, up to 90 days. The alternative of keeping beverages cold is quite common and this is seen as an interesting alternative that opens up other possibilities for CG juice. This type of beverage could also be made with a higher proportion of CG juice to contribute more bioactive compounds to people's diet.

In another study, Serpa-Guerra et al. (2018) decided to venture into the development of fortified beverages, this being an area of special interest as it provides micronutrients that play an important role in the functioning of the body and also taking into account the growth of the functional food and wellness industry (Farid et al., 2019). The beverages incorporated iron and some berries of interest for Colombia (passion fruit, blackberry, strawberry, and Peruvian Berry). The authors tested various proportions of pulp from these fruits and added iron to achieve 20%−30% of the daily intake requirements, depending on the iron provided by the various fruits used. This is how they arrived at the selected formulation: Passion fruit 6.70%, *P. peruviana* 10.00%, blackberry 10.00%, strawberry 10.00%, sugar 6.90%, iron (ferrous bisglycinate) 0.03%, and water 56.30%—with this drink—they could incorporate more fruit and iron. The drink showed good acceptability and overall quality. With this formulation containing 38% of the RDI of vitamin C, the drink could be labeled as a high source of vitamin C according to the FDA (2013), but the authors, who did not carry out a shelf life study, recommend calculating the loss of vitamin C during storage and fortifying the drink accordingly. The conditions of the pasteurization heat treatment used are also important, although the authors do not give further details about them, such as times and temperatures, which influence the loss of nutrients, such as vitamin C. It is also reasonable, that the authors suggest for future research to review the amount of added sugar and/or change it to non-caloric sweeteners. This type of product can go into the functional food niche, a market that is currently in high demand.

Continuing along the lines of functional foods, Valencia García, et al. (2012) and Valencia et al. (2013) developed CG soft candies fortified with calcium as a contribution to people's bone health. The candies were made without sucrose, compared to candies without calcium. Dairy calcium with 26.5% purity was chosen to fortify the products. The authors do not give too many details about the formulations, which is understandable if they intend to develop them for further commercial interest. Appearance and color are important food attributes for the consumer, as well as texture, all of which were studied in soft candies. As for the color, it remains stable in storage (140 days) at 30°C, but not in the studies carried out at 40°C and 50°C in which a marked darkening is observed with a significant decrease in lightness (L*) and a decrease in yellow tons (b*) as storage time advances; this is probably due to Maillard-type browning reactions, which are favored by time, temperature, and the presence of carbohydrates in the candies. The texture of the candies is enhanced in some parameters such as elasticity and cohesiveness possibly due to the presence of calcium and the interaction that the calcium ion may have with other elements of the candy (protein, fiber, carbohydrates, among others) and the higher ionic strength of the system, which would cause the candy to break down more easily and also to the presence of sorbitol as a plasticizing agent. It would be interesting to know about the details of the sensory study carried out (Román, 2010), to know the acceptability of this product and perhaps be able to make sensory-instrumental correlations of the color and texture attributes.

Another product studied by several authors is CG jellies of different types, which are widely consumed around the world. Hadjikinova et al. (2019) developed various formulations of jellies reduced in sugar, understanding that consumers are concerned about lowering the consumption of this ingredient, which in some countries requires warning labels to be placed on packages if it exceeds limits that are considered harmful to health (MINSAL, 2021). The authors tested different formulations all with 50% CG juice, 47% sucrose, or 47% fructose or 34% and maltitol syrup (13%), pectin (1.8%) carrageenan (0.6%), and citric acid (0.6%). The jellies were prepared by boiling at 108°C and placed in silicone molds at 20°C ± 2°C for 24 hours. The samples with sucrose and fructose had total sugars between 65% and 73%, but the one with the sweetener mixture had 7%. Both the sample with sweeteners and the one with fructose can be labeled as "Foods with no added sugars," according to EC regulation (2006) and the one with sweeteners can also carry the label "Energy"-reduced food. Together with the physical and chemical characteristics, the authors studied the sorption properties of the jellies, considering that this behavior can affect the storage stability of these products by increasing the water activity (aw) and making the food susceptible to greater microbial attack. In fact, the behavior they observed means that sucrose and sweeteners are more recommended for prolonged storage, and the one with fructose should be protected from ambient humidity.

On the other hand, Curi et al. (2018) developed jellies with various species of *Physalis* of America *P. peruviana*, *P. pubences*, and *P. angulata*, *P. exocarp*, and *P. monimos*; they added 59.25% clarified CG juice, 40% sucrose, and 0.75% high methoxyl pectin, sugar + pectin, heating the mixture up to 65°Brix to do this. The *Peruviana, Pubences, and Angulata* species are nutritionally richer, with the highest levels of phenolic compounds, vitamin C, and antioxidants. In addition, they produce jellies with the highest sensory acceptability, either in pure form or in combination with Brie cheese. The color of the jelly makes this combination an appetizing food.

One of the oldest preservation processes used by humans is dehydration, which has also been applied to CG. Vásquez-Parra et al. (2013) address an aspect that is often problematic in these mass transfer processes and that is the speed with which water is removed. CG is not easy to dehydrate; its thick, hard, and waxy peel is a barrier to water vapor; this is an aspect commented on by several authors (Gallón Bedoya et al., 2021), so the search for pre-treatments that facilitate the extraction of water is an interesting point to study. In this study, the effect of chemical pre-treatments (sunflower oil/K_2CO_3 or olive oil/K_2CO_3 at 28°C, and NaOH/olive oil at 96°C) and physical pre-treatments (blanching) to break the waxy surface and accelerate moisture diffusion during drying was evaluated. Drying was carried out for 10 hours in a forced air convective dehydrator at 60°C and air speed at 2 m/s, with R.H 68%−70% and the effect on fruit moisture content throughout the drying process was measured (kg water/kg dry mass), together with color (L, a*, b*), vitamin C content (mg/g), and rehydration capacity of the dried fruits. The best result was obtained with olive oil (9.48%) + K_2CO_3 (4.74%). Oil type and immersion time had no significant effect on moisture loss while oil concentration significantly affected moisture loss. The effective diffusivity of water during drying was higher in CGs exposed to chemical or physical pre-treatment than in untreated fruits.

Junqueira et al. (2017) dried CG in a tunnel dryer with parallel flow at 60°C and 2 m/s; they also tested different pre-treatments: fast and slow freezing and thawing and a chemical treatment with ethyl oleate + Na_2CO_3, which proved to be more effective in removing the wax from the CG peel and at the same time cracking it, which accelerates water removal and increases drying speed. This result is undoubtedly an advantage, since the freezing process is expensive as a pre-treatment, and in terms of chemical characteristics, the behavior of this treatment also gives good results, with a good rehydration capacity, probably due to the rapid drying that leads to the formation of pores, which increases the capacity to absorb water during rehydration; the same pre-treatment showed a high ascorbic acid (46%) retention level and a low aw of less than 0.530, which ensures the microbiological stability of the product. In terms of texture, the oleate-treated CGs are 50% softer than the fresh CGs, indicating that the treatment softens the peel of the fruit. On the other hand, the color of the fruit is affected, darkening (decrease of L* and b* and increase of a*), probably due to browning reactions that have also been observed in the dehydration of other fruits, the sample without pre-treatments being the one that better preserves the color. As the authors indicate, the maintenance of fruit integrity probably preserved pigments (such as carotenoids), while enzymatic browning could be accentuated after cell collapse, in which the phenolic compounds present would play an important role. These studies show the importance of a pre-treatment in the drying of CG, considering the characteristics of this fruit's peel and that a freezing pre-treatment increases the costs of the process.

Vega-Gálvez et al. (2015) carried out dehydration trials of CG in a convective dryer at different temperatures between 50°C and 90°C. The fruit did not receive any pre-treatment and was placed in trays in a thin layer. The water retention capacity reached its highest value at 50°C (47.4 ± 2.8 g water retained/100 g) indicating less damage to the tissue structure; however, the authors recommend temperatures of 60°C for drying based on dietary fiber content, texture, and rehydration properties, and also because the drying time is shorter at this temperature than at 50°C. However, they do not mention other chemical characteristics of interest, such as acidity, which could be a limiting parameter for direct consumption if it increases too much with drying, as shown in another CG drying study (Hincapié & Zapata, 2019). Complementing this type of study with sensory evaluation may provide further information about this process.

Another drying system, suitable for small-sized fruit or small pieces of fruit, is the fluidized bed dryer. This type of dryer has advantages over other drying systems, such as the one using trays. In the fluidized bed, as its name indicates, a stream of hot air makes a small solid (small fruit or pieces) behave like a fluid, creating a turbulence that disperses the products, thus increasing the drying speed. On this type of equipment, on a trial scale, Hincapié and Zapata (2019) carried out some tests to evaluate the behavior of CG, studying the drying kinetics and the characteristics of the dried product at different temperatures (60°C, 70°C, and 80°C, with an air speed of 9.5 m/s). Drying at 60°C appears to be the best temperature for preserving the color of the CG. It should be noted that dehydration, as is widely known, increases the concentration of soluble solids, including acids, and it would be advisable to carry out a sensory study with respect to this since acidity, in this last study, increased to levels that could make this product unpalatable (more than 5%), at least to eat directly, because it would be difficult to achieve a harmonious flavor in the product's characteristics.

A less studied drying system that could be a low-cost alternative for small rural producers is drying with solar energy. There are few in-depth studies related to CG, we have only found one study carried out in Egypt, which could be expanded upon to provide more details with which to make decisions on its use (El-Beltagy et al., 2013).

Vacuum impregnation and OD systems have been studied to possibly improve sensory properties and avoid losses of bioactive compounds, which with relatively low temperatures attempt to conserve the nutrient properties of this small fruit. OD consists of eliminating the water from the fruit by immersing it, in the case of fruit, in highly concentrated sucrose solutions, to obtain a snack-type fruit, suitable for direct consumption. Castro et al. (2008) determined the most favorable temperature conditions for a drying process of CG. Two treatments were carried out: one was dehydrated directly in a tray dryer at 40°C, 50°C, and 60°C; and another applied an OD with a sucrose solution at 70°Brix for 16 hours at 40°C with a fruit–syrup ratio of 1: 3 and then dried at 40°C, 50°C and 60°C, 3 m/s air speed and 55%–60% R.H. of the air, until a humidity of around 2.5% (dry basis) was reached. In both treatments, β-carotene degradation was monitored with time and temperature. In fruit treated with hot air at 60°C and pre-treated with OD, a total β-carotene loss of 98% was obtained. The fruit treated with hot air at 40°C and without OD showed the lowest total β-carotene loss of 28%. Drying times to reach a fruit moisture close to 2.5% dry weight are 7, 9, and 12 hours at 60°C, 50°C, and 40°C respectively, for fruit treated without OD. For fruits treated with OD, drying times are 4, 5 and 6 hours at 60°C, 50°C, and 40°C respectively. The degradation kinetics found are first order.

Velásquez-Barreto et al. (2018) tested different proportions of encapsulating agents (ECs) (maltodextrin and gum arabic) to protect ascorbic acid in CG juice. The juice was mixed with 50% and 100% arabic gum and 50% and 100% maltodextrin, the percentages were related to the Brix of the juice. Drying conditions were air inlet temperature of 150°C, air outlet temperature of 80°C, and flow rate of 0.125 mL/s. A number of ECs were shown to be effective in the retention of ascorbic acid, with retention percentages, after 30 days of storage at room temperature, higher than 97% in all cases, with maltodextrin (M-100%) standing out with 99%; the authors recommend the use of maltodextrin because of its lower cost. The aw of the powders ranged from 0.14 to 0.16, ensuring good preservation of the powders.

Other authors have tested different ECs and studied the protection of other bioactive compounds. Etzbach et al. (2020) compared traditional ECs (maltodextrin, modified starch, inulin, alginate, arabic gum) with cellobiose (disaccharide consisting of two glucose units linked by a beta (1–4) glycosidic bond, obtained by partial hydrolysis of cellulose) to protect carotenoids from CG juice. The juice was diluted with water 1:3 (w/w) and 20% EC was added on a juice weight basis. The drying conditions of the equipment were air inlet temperature to the dryer of 140°C, outlet temperature of 70°C, and an air flow of 473 L/h. All powders had a moisture content of less than 5.25%, which ensures their microbiological stability. The performance of powders with cellobiose and alginate as ECs was somewhat lower than the other ECs. In the case of cellobiose, compared to maltodextrin, this may be due to its lower glass transition temperature, which causes the particles to agglomerate and stick together. The encapsulation efficiency of cellobiose powders was the highest of all (77.2%), thus increasing the protection of these compounds. Regarding carotenoid retention, carotenoids decreased between 38.9% and 69.7% with encapsulation, depending on the EC. Maltodextrin powder retained the most carotenoids, followed by cellobiose. In storage (30°C), after 6 weeks, cellobiose powder provided the best carotenoid retention (32.4%). Cellobiose powders showed twice the carotenoid content after storage than the other ECs. Based on the results obtained, the authors conclude that cellobiose can be a good EC in SD of CG juice.

Another technique used to encapsulate and protect heat-sensitive bioactive compounds, although to a lesser extent than spray-drying, is FD, as in the case of Dag et al. (2017), who encapsulated CG pulp to protect the polyphenols of this fruit. For this purpose, they tested various ECs such as maltodextrin, arabic gum, alginate, and pectin in different concentrations and proportions with respect to CG pulp. The retention of polyphenols with all tested encapsulants was higher than 75%. The mixtures of maltodextrin with the other ECs showed the best encapsulation efficiencies, and among them the best was the maltodextrin:pectin mixture (9:1; 8:2) due to its high encapsulation efficiency (>82%) and antioxidant activity of the powders.

Studies on the encapsulation of bioactive components of CG are still scarce. However, the research carried out has already shed light on ECs and the effects on the retention of important bioactive compounds present in CG such as total phenols and carotenoids.

39.3.1.2 Non-thermal treatments

39.3.1.2.1 Emerging technologies

Many of the thermal treatments mentioned previously can be classified as traditional food preservation technologies. We will now look at other technologies, called emerging technologies, as they have been developed in more recent years. These include HHP, ultrasound, microwave drying, and application of electrical pulses. Traditional technologies are generally characterized by good microbial control, which is essential to guarantee food safety; however, high temperatures can cause some negative organoleptic changes and loss of nutrients. To reduce the negative aspects of heat treatments, so-called emerging technologies have been developed, which, in addition to microbial control, aim to maintain the freshness and natural flavor of foods while preventing deterioration and nutritional losses due to the application of high temperatures.

Although there are few studies that have used any of these technologies to preserve CG pulp or juice, there are some that are of interest and which we will discuss next. One of the emerging technologies that is already being applied to food at an industrial level is HHP. A non-thermal technology that consists of subjecting pre-packaged foods to pressures of 100−1000 MPa, from seconds to a few minutes, this being an effective treatment to eliminate pathogenic and spoilage microorganisms (Varela-Santos et al., 2012). In this context, Vega-Gálvez et al. (2016) studied the effect of HHP on dietary fiber, total phenol content, vitamins, antioxidant capacity, and microbiological characteristics of CG pulp both freshly processed (300−400−500 MPa/1−3−5 min) and after 30 days of storage at 4°C. Treatment at 300 MPa/1 min, the lowest of all, reduced microbial counts to undetectable levels ($<$1.0 log CFU/g), similar results were obtained at higher pressure time. An increase in soluble dietary fiber was observed in all treatments compared to the control sample, an effect that should be further studied. In addition, an increase in vitamin B3 and B6 content was observed compared to the control samples. There was also a trend towards an increase in total polyphenols, which could be attributed to an increase in the extractability of some of the antioxidant components after HHP processing. The maximum values of antioxidant capacity were observed at 500 MPa/5 min. The results obtained in this study suggest that HHP technology is a good alternative for the microbiological stabilization of CG pulp, while preserving its nutritional, antioxidant, and physicochemical characteristics (Vega-Gálvez et al., 2016).

Another emerging drying system for food is the use of microwaves—widely known and used by the public for heating food, but not yet massively disseminated at industrial level (Chong et al., 2021). One of the drawbacks of microwave drying is that it requires expensive electrical energy, which makes this method less economically favorable compared to other methods. In addition, microwave drying is still considered a relatively new technology with several technological problems to be solved compared to convective hot air drying and SD. The microwave drying method has attracted the interest of researchers as microwaves can penetrate deep into food, thus improving the drying speed. However, the inhomogeneity of the drying can result in hot spots that can lead to burning at the final stage. This technology, therefore, is not yet as well accepted at an industrial level as air drying; its economic and technological limitations mean that its use in food at an industrial level is still limited (Chong et al., 2021). Therefore further research is needed. CG has also been treated with this method; thus Nawirska-Olszanska et al. (2017) tested microwave drying to dehydrate CG fruits faster, for which they made 10 punctures in the fruit with a 1-mm penetrator, as their thick and hard peel hinders water evaporation during drying. In their test, they compared conventional drying at 70°C with an air speed of 1.5 m/s and microwave drying at reduced pressure (4−10 kPa) and two power settings, 120 and 480 W. In the first case, the fruit reached temperatures of 70°C and in the second case they reached 90°C. The best results were obtained with the microwave drying at 480 W. The dried fruit was characterized by a higher content of bioactive compounds and better antioxidant properties, and at the same time the lowest water activity (0.232), while also being the brightest and with a soft yellow color attractive for the consumer.

In addition to microwaves, infrared energy can also be used for drying. Puente et al. (2021) compared three drying methods (convective drying, with a constant air flow of 1.5 ± 0.2 m/s at 60 and 80°C, IR at 60°C and 80°C without air flow and FD). The authors indicate that they did not achieve the expected result with FD, which should be further studied, as both antioxidant capacity and some bioactive compounds were affected, probably due to the action of enzymes that are not inactivated at low temperatures. Color was affected in all drying systems, either by changes in porosity in the case of FD or by degradation of carotenes and Maillard reaction in convective and IR drying. Still, the authors suggest convective and IR drying at 80°C as a viable system for CG.

Another emerging non-thermal technology with low cost due to its low energy consumption and reduced process times is the application of ultrasound, which consists of subjecting food to sonic waves of 20−100 kHz and high intensity and low frequency (intensity of 10−1000, 10−1000 W/cm^2, frequency of 20−100 kHz). High-intensity US can be used for food processing as it generally uses power levels high enough to generate cavitation and exert an antimicrobial effect (Bevilacqua et al., 2019; Ordóñez-Santos et al., 2017). In CG, the effect of US on the color and bioactive compounds of CG juice was studied (Ordóñez-Santos et al., 2017). The authors subjected the juice to 42 kHz frequency and a maximum ultrasonic power of 240 W, for 10, 20, and 40 min, observing a decrease in vitamin C and an increase in carotenoids and total polyphenols with increasing treatment time. The authors attribute the increase in the latter possibly to the greater disruption of the cell walls, facilitating the release of phenols bound to traces of pectin, cellulose, hemicellulose, and lignin from the cell wall. These results bode well for the future of this non-thermal treatment, which can be scaled up to trial or industrial levels, while determining its shelf life and microbial behavior.

39.3.1.2.2 Other non-thermal technologies

Other technologies, some of which have been used for a long time, such as the application of cold to make ice cream and other more recent ones such as OD and vacuum impregnation, have also been applied to CG to obtain new products and preserve this small fruit.

Duque et al. (2014) following the trend of fortifying foods did the same with CG pulp, adding calcium, vitamin C, and dietary fiber (oligofructose). The pulp was stored at 10°C for 6 days, and the physical stability of the product was monitored, since it was not pasteurized. Although good results were obtained, from a physical and chemical point of view, with one of the formulations, which contained CMC and pectin as physical stabilizers, it would be good to have complementary studies with treatments that ensure a longer shelf life and give microbiological stability to the products.

Another technique that also uses osmotic solutions is vacuum impregnation, although immersion alone adds vacuum pressure that plays with the gas occluded in the pores of the plant matrix, so that when atmospheric pressure is restored, the external fluid enters the pores, so that the food matrix can be enriched with the components of the osmotic solution (Peña et al., 2013; Andrés et al., 2001). Peña et al. (2013) evaluated the color, texture, and sensory properties of fresh and vacuum-impregnated CG and fortified it with calcium and vitamins B9, C, D, and E. The process affected the orange color, fresh appearance, sweet, and characteristic CG taste, juiciness, firmness, and texture, becoming more elastic. In this case, the overall sensory quality of fresh CG was higher than the impregnated fruit.

Consumer demand for exotic flavored ice creams has increased and in this context Erkaya et al. (2012) studied the influence of different concentrations of dehydrated CG (5%, 10%, and 15%) on the chemical, physical, and sensory characteristics of ice cream as a new functional food. The CG was placed in small pieces in the mixture which consisted of cow's milk, cream, sugar (10%), stabilizers, and emulsifiers. A control was prepared with a sugar ratio of 15%. The mixtures were pasteurized using high temperature short time (HTST) at 85°C for 25 seconds and rapidly cooled to 4°C and left to mature for 24 hours. The ice cream with the highest proportion of CG was shown to have the highest proportion of sugar. The ice cream with a higher proportion of CG showed a higher total solid content, a higher viscosity probably due to the dietary fiber provided by the CG, a higher overrun and total melting time. Both are also indicators of the quality of an ice cream, and a lower proportion of fat, which is good for health. However, the protein, Ca, and P content decreased, so the addition of CG could be managed to decrease this effect. In terms of minerals, the increase in K content stands out, an element that plays an important role in physiological functions of the human body. In terms of sensory evaluation, panelists preferred the ice cream with 15% CG added.

Seeking similar purposes, highlighting in this case the content of total polyphenols, vitamin C, and antioxidant capacity, Naeem et al. (2019) studied several ice cream formulations using CG juice concentrate (41.01% total solids) and buffalo milk, cream, sugar, and stabilizers; the mixture was pasteurized at 81°C and left to mature overnight at 5°C; CG juice was then added in proportions of 0%, 3%, 6%, and 10%, respectively, and frozen. The ice cream with the best characteristics such as overrun, whipping ability, and sensory characteristics, such as flavor, was achieved with an addition of 6% juice. These studies can be the basis for the development of new ice cream flavors for which there is currently an increased demand among consumers.

39.4 Uses of processing by-products

39.4.1 Seed oil

The food industry is always interested in using raw materials in a holistic way, as the fruits of the CG that are used for some foodstuffs leave by-products that also have interesting components. The use of by-products is, on the other hand, a requirement both to care for the environment and make it more sustainable and to revalue agro-industrial waste in view of the increasing world population and the need to feed it. One of the first studies on by-products is that of Ramadan and Moersel (2003), who indicate that the seed has 1.8% oil in relation to the fresh whole fruit.

Subsequently, several authors have studied the use of CG waste from the processing of products such as pulps and juices, these wastes are mainly formed by peel and seeds which can constitute about 30% of the fruit (Mokhtar et al., 2018; Ramadan & Moersel, 2009) of which between 13% and 19% are fats, this value corresponds to laboratory scale, and an extraction with organic solvents. Mokhtar et al. (2018) determined that the GC waste powder was rich in amino acids, fiber, fat, and minerals, components of nutritional interest. In addition to this, the physicochemical and techno-functional properties make this waste powder a special additive for food formulation. Recently, Ugarte-Espinoza et al. (2021) studied various conditions of seed oil extraction in a screw-press, a cheaper and friendlier system than solvent extraction. The authors tested three temperatures (60°C, 80°C, and 100°C) and three seed moisture levels (8%, 10%, and 12%). The highest oil recovery (86.4%) and the highest quality were obtained at 8% seed moisture and 60°C extraction temperature. Under these conditions, the oil showed a high linoleic acid content (76.0%) and other quality characteristics, such as high iodine content, which make it a promising by-product and source of essential fatty acids for the CG industry. It could be said, as Ramadan and Moersel (2003) indicate, that although the oil yield is low, it is rich in essential fatty acids, phytosterols, carotene, and fat-soluble vitamins.

39.5 Conclusion

After analyzing different processes used to preserve the CG, it can be concluded that some of the processes remain to be studied in more depth and others remain to be completed with consumer evaluations. However, the studies carried out so far give reason to believe that this small and healthy fruit from the Andes has prospects for industrialization on a larger scale and in other countries, thus contributing fiber, minerals and bioactive compounds to people's diet.

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