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Nutritional composition of different cape gooseberry genotypes (*Physalis peruviana* L.) – a comparative study

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Abstract

Cape gooseberry (*Physalis peruviana* L.) is a South American fruit with high nutrient content, pleasant taste and antioxidant properties. However, its consumption in some countries is underevalued. The aim of this study was to determine the nutritional composition of two genotypes of Cape gooseberry fruit produced in Bulgaria (CG-F and CG-P) and to compare it with imported Colombian fruits (CG-C). The samples were assayed for size, diameter, moisture, ash, titratable acidity, pH, protein, lipid, carbohydrate, natural pigments, and mineral content. Bulgarian genotypes were smaller in size than the imported Colombian fruits. The protein content (2.54-1.88 g/100 g) was relatively higher in the imported variety, compared with the locally produced fruit. Carbohydrate content (10.23-14.13 g/100 g) slightly varied between the genotypes. The sweetness of the fruit was due to the main detected sugars – sucrose, glucose and fructose. CG-F and GC-C genotypes had similar sweetness indices, and fruit taste was evaluated as sweet-sour. Pectin content did not exceed 1.85%; the cellulose content varied between 4.29% and 6.64%. Moreover, all investigated fruit had a low lipid content (below 1.00%). The total chlorophyll and carotenoids levels were the highest in the local genotype CG-P (3.62 and 22.36 μg/g). Potassium was the predominant macro-element in all genotypes; there were numerical differences in the rest of the minerals (Ca, Mg, Fe, Cu, Zn, Mn), while the heavy metals, Pb, Cd and Cr, were generally absent. Cape gooseberry fruit of Bulgarian origin was evaluated as a low-calorie nutrient, compatible with the imported Colombian fruit.

1. Introduction

Physalis peruviana L. (Solanaceae) is one of the most commercially important species of the genus *Physalis*. Its exotic fruit has been gaining recent popularity in many countries, not only in the tropical and sub-tropical zone, but also in Europe, Asia, Africa, and the Americas (Puente *et al.*, 2011; Joshi and Joshi, 2015; Olivares-Tenorio *et al.*, 2016; Singh *et al.*, 2019; Thuy *et al.*, 2020). The species originated from the Andes, but the benefits of its production, the sensory, nutritional, pharmacological, commercial, and other characteristics, expanded its production worldwide far beyond its natural areas of origin. *P. peruviana*, also known by the common names Cape gooseberry (CG), goldenberry, Inca berry or Peruvian groundcherry, produces edible berries, covered by a protective husk (calyx). The berries are small, shiny, bright orange, flavorful and tender (National Research Council, 1989; Puente *et al.*, 2011). Colombia is the world biggest producer and exporter of fresh and dehydrated fruit, realized mainly on the European market (NRC, 1989; Corporación Colombia Internacional (CCI), 2001; Olivares-Tenorio *et al.*, 2016).

The increasing popularity of CG fruit is due to the favorable combination of several factors such as the attractive outlook, the pleasant taste and aroma, the valuable chemical composition and the associated nutritional, biological and physiological benefits, the high yields and farmer profitability. The fruit contains various phytonutrients and bioactive compounds, making it an excellent functional food and substantiating its antidiabetic, anticholesterolemic, hepatoprotective, anti-inflammatory, immunomodulatory, antioxidant, and other activities (de Carrasco and Zelada, 2008; Hassanien, 2011; Puente *et al.*, 2011; Ramadan, 2011; Eken *et al.,* 2014; Lal *et al.*, 2019; Singh *et al.*, 2019). The fruit is a rich resource of vitamins, minerals, carotenoids, polyphenols, phytosterols, reducing carbohydrates, pectin and other polysaccharides, and

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many additional classes of functional compounds (Rodrigues *et al.*, 2009; Puente *et al.*, 2011; Ramadan, 2011; Yıldız *et al.*, 2015).

The fruit is either consumed fresh (as deserts and salads; as a decoration of various dishes and pastry), dehydrated to raisins or processed to separate the juice/pulp from the seeds and peels (Singh *et al.*, 2019). Due to the high pectin content with gelling properties, the whole fruit and the juice/pulp fraction are used in the production of jellies, jams, fillings, dressings and more. They are also incorporated in novel functional foods - yoghurts, ice-creams, reduced sugar products, and diabetic foods (Valdenegro *et al.*, 2013; Ordonez-Santos *et al.*, 2017; Hegazy *et al.*, 2019).

The physicochemical properties and the nutritional quality of CG fruit are strongly influenced by the variety, cultivar, ecotype, climatic, cultivation, ripeness, and post-harvest storage factors. Therefore, certain diversity has been observed on a regional and genotype basis (Fischer *et al.,* 2007; Olivares-Tenorio *et al.*, 2016; Lal *et al.*, 2019; Thuy *et al.*, 2020).

The consumption of CG fruit in Bulgaria is still negligible and the species remains virtually unknown to the consumers, although it has been promoted recently in some of the bigger supermarkets. Some organic farms have attempted the cultivation of CG during the last decade, and the small scale crops are intended for the contracting restaurants and farmer markets. An original Bulgarian variety of CG has been selected and officially recognized by the national authorities in the early 2000s. The fruit was described as competitive to the reference Colombian varieties. The content of vitamin C in the fruit was estimated to 35.45 mg, total sugars - 10.72%, pectin - 1.03%, total acids - 1.03%, and flavonoids - 0.51% (Panayotov, 2009; Panayotov and Popova, 2014).

The availability of both locally produced and imported CG fruit in Bulgaria deserves reasonable interest in a more detailed investigation of the nutritional properties of the fruit in order to highlight the peculiarities of the genotypes and to contribute to the better evaluation of the potential of the plant in a non-traditional region. As the nutritional composition of fruits is strongly affected by the genetic factor, the environmental conditions, the cultivation practices, and different pre- and post-harvest activities, we hypothesized that certain differences could exist in the nutrient contents between the CG fruit produced in different regions of the country, on one hand, and between the locally produced fruit and the fruit of a recognized origin, marketed internationally, on the other one. To the best of our knowledge, the current investigation could be regarded as the first attempt to evaluate the competitiveness of CG fruit produced in the country in terms of its potential in human nutrition, thus providing new data about the properties of this highly functional fruit on a wider basis. Moreover, a recent study documented the antioxidant activity of different extracts of CG fruit produced in Bulgaria, in a direct comparison with fruit from Colombia (Petkova *et al.,* 2020). Therefore, the objectives of this study were to determine the nutritional composition of CG fruit produced in two different regions of Bulgaria (e.g. proximates, energy value, natural pigments, minerals) and to compare it with imported fruit of Colombian origin, as well as with reference data.

2. Materials and methods

2.1 Fruit material and sample preparation

Three different genotypes of Cape gooseberry (*Physalis peruviana* L.) (CG) fruit available in Bulgaria were used in the study, all from the same crop year. The first one represented the only recognized original Bulgarian Cape gooseberry variety, named "Plovdiv" (CG-P); the fruit of CG-P was harvested in the region of Plovdiv, Central Southern Bulgaria. The second fruit genotype was produced on a certified organic farm, located in the region of Mezdra, North-West Bulgaria (CG-F). The third variety in the study was purchased from one of the bigger supermarkets in Bulgaria, with origin Colombia (CG-C). Undamaged fruit of uniform ripeness, as expressed by berry color, were selected from each of the varieties (Food and Agriculture Organization of the United Nations (FAO) World Health Organization (WHO) Codex Alimentarius (FAO/WHO), 2011). Two samples were further developed: whole (intact) de-husked fruit (berries) and fruit pulp (fruit meal), in order to follow the differences in the composition of fruit structural elements. The prepared samples were immediately frozen, to a temperature of -18°C, and kept in the refrigerator until further analysis. The physical indices of the fresh fruits were recorded in advance; diameter (by measuring, to a precision ±0.01 mm, n = 100), weight and the fruit structural elements (on a Mettler-Toledo precision weight, ±0.0001 g, n = 100).

2.2 Determination of the chemical composition of Cape gooseberry fruit

2.2.1 Moisture

The moisture content of fruit samples was determined by drying to the constant weight at 105±2°C (AOAC, 2012).

2.2.2 Ash

The ash content was determined by igniting the samples (about 3.0 g, on a fresh weight (FW) basis) for 8 hrs at 550°C in a muffle furnace (AOAC, 2012).

2.2.3 Titratable acidity (TA) and pH

The samples (5.0 g fresh weight (FW)) were initially homogenized with 25 mL distilled water and then filtered. The pH of the extract was measured using a 7110 WTW pH meter (Germany) according to AOAC (2012). The titration procedure was performed with 0.1 M NaOH to the pH value of 8.1, and the results were expressed as % citric acid (International Organization for Standardization, 1998).

2.2.4 Protein content

The crude protein content was evaluated by the micro-Kjeldahl method (Bradstreet, 1965). Acetylacetone-formaldehyde colorimetric method using ammonium sulfate as a standard (GB 5009.5-2010) (National Food Safety Standard, 2010) was used for the determination of nitrogen as ammonia content in the digested sample. The crude protein was calculated using 6.25 as a conversion factor.

2.2.5 Lipid content

Total lipid content (%) was determined by exhaustive Soxhlet extraction with n-hexane (AOAC, 2012).

2.2.6 Extraction

For the extraction of phytochemical compounds, 5.0 g fruit (FW) was extracted with distilled water (solid to liquid ratio of 1:20, w/v) for carbohydrate analysis and with 80% acetone in the same solid to liquid ratio for the natural pigments, respectively. The extraction procedure was performed in triplicate, using an ultrasonic bath (VWR, Malaysia, 45 kHz and 30 W) at 45°C for 15 mins.

2.2.7 Carbohydrates

The total soluble carbohydrate content was analyzed by the phenol-sulfuric acid method (Dubois *et al.,* 1956). Water extracts (0.1 mL) were mixed with 1 mL 5% phenol and 5 mL concentrated H_2SO_4. The samples were heated in a water bath at 30°C for 20 mins, and then the absorbance was measured at 490 nm against a blank comprised of distilled water. The content of carbohydrates was determined from the calibration curve for glucose (Dimitrova *et al.*, 2015) and the results were calculated as g/100 g FW.

The reducing sugars were estimated by the PAHBAH method described by Lever (1972). Fruit water extract (0.25 mL) and 0.75 mL of PAHBAH reagent were mixed and boiled for 5 mins in a water bath, then cooled in an ice bath for 5 mins. The absorbance was measured at 410 nm against a blank, prepared with distilled water (Dimitrova *et al.*, 2015).

Chromatographic separations and quantification of sugars in the water extracts were performed on an HPLC instrument Elite Chrome Hitachi, coupled with a Shodex® Sugar SP0810 (300 mm × 8.0 mm i.d.) with Pb^{2+} and a guard Shodex SP - G (5 µm, 6 × 50 mm) columns operating at 85°C, and a refractive index detector (RID) Chromaster 5450, operating at 35°C. The mobile phase was distilled water at a flow rate of 1.0 mL/min. The injected sample volume was 20 µL (Petkova *et al.,* 2014).

Pectic substances were analyzed by the titration method described by Owens *et al.* (1952).

Cellulose content was determined gravimetrically. The finely ground sample (0.5 g) was placed in a round bottom flask of 250 mL and 16.5 mL acid mixture containing 80% acetic acid and nitric acid were added. The sample was boiled for 30 mins with periodical shaking, the sample was filtered through previously tarred sintered glass (G2) filter. The sample was washed in duplicate with the following solvents in the same order: a mixture of 80% acetic acid and nitric acid at 70°C, then with boiling distilled water, 95% ethanol, and 10 mL diethyl ether. The sintered glass with the residual sample was dried to the constant weight in an oven at 105°C, cooled down in a desiccator and then weighed (Lurie, 2003).

2.2.8 Sweetness indices

The sweetness index (SI) and the total sweetness index (TSI) were calculated based on the content of sugars (sucrose, glucose and fructose) in whole fruit and fruit pulp, and their contribution to the sweetness sensory perception (Magwaza and Opara, 2015; Akšić *et al.*, 2019), as follows:

SI = (1.00 × [glucose]) + (2.30 × [fructose]) + (1.35 × [sucrose])

TSI = (1.00 × [sucrose]) + (0.76 × [glucose]) + (1.50 × [fructose]).

The ratio TSI/TA, proposed as a useful predictor of the overall sensory acceptability (Magwaza and Opara, 2015) was also calculated.

2.2.9 Natural pigments

Total chlorophylls and total carotenoids were evaluated spectrophotometrically and the contents were calculated according to Lichtenthaler and Wellburn (1983).

2.2.10 Macro- and microelements

Mineralization of fruit samples was carried out at 450°C. The solid residue was dissolved in concentrated HCl and evaporated to dryness, then the residue was dissolved in 0.1 mol/L HNO_3 solution. An atomic absorption spectrophotometer (AAS) Perkin Elmer/HGA 500 (Norwalk, USA) was used for the determination of elements, under the following parameters: Na, 589.6 nm; K, 766.5 nm; Mg, 285.2 nm; Ca, 317.0 nm; Zn, 213.9 nm; Cu, 324.7 nm; Fe, 238.3 nm; and Mn, 257.6 nm. The identification of metals was carried out by comparison to a standard solution of metal salts. The metal concentrations were calculated from a calibration curve, built by using a standard 1 μg/mL solution.

2.3 Statistics

All chemical analyses were performed in triplicate (n = 3) and the results were expressed as mean value ± standard deviation (SD). Statistical tools, such as ANOVA and Tukey multiple comparison tests were used to assess significant differences ($p<0.05$).

3. Results and discussion

3.1. General indices of fresh fruits

The general characteristics of the fresh fruit of the three genotypes of Cape gooseberry in the study are presented in Table 1.

The results suggested that fruit physical dimensions (diameter and weight) varied by genotype, and the two locally produced fruit samples (CG-P and CG-F) were smaller than the imported Colombian fruit (CG-C). The Bulgarian fruit samples corresponded to size codes A and B (FAO/WHO, 2011). The results were in good agreement with the findings of Yıldız *et al*. (2015) for CG fruit produced in Turkey (region: Bursa) and Fischer *et al.* (2007) for Colombian fruit. The yield of fruit pulp (fruit meal) was close in the two locally produced fruit genotypes (83.9% and 84.5%, respectively), being higher than that of the imported variety (CG-C, 75.4%). The fruit residues were separated as peels and seeds, and the observed numerical differences in the peel/seed percentage between the varieties could be related further to the observed differences in the analyzed chemical indices, like those fruit structural elements had been identified with different compositions (Hassanien, 2011; Ramadan, 2011). Pulp yields in this study were in compliance with the data by Singh *et al*. (2019) and Hassanien (2011); juice about 72.6% of berry weight, peels and seeds – about 27.4%. Thus, our results supported the feasibility of CG juice/pulp production and the utilization of seed/peel waste, and in particular, the potential of processing locally produced fruit.

3.2 Chemical composition of Cape gooseberry fruit

The results from the determination of the major components and some other nutritional characteristics of the analyzed Cape gooseberry fruit are presented in Table 2.

3.2.1 Moisture, ash, pH and titratable acidity

Moisture content varied between 77-85 g/100 g. Moisture in CG ecotypes grown in Colombia was the highest with values 83.07±0.27 g/100 g and 86.63±0.75 g/100 g for whole fruits and pulp, respectively (Table 2). The ash contents in the whole fruit were identical for the three genotypes (5.57-5.79 g/100 g), but pulp ash contents varied significantly in CG-P variety (4.23 g/100 g) compared with the other two genotypes (2.42 g/100 g and 2.69 g/100 g). Our results for titratable acidity (% citric acid) were in good agreement with the data provided by Fischer *et al.* (2000) for three CG ecotypes grown in Colombia (1.63-2.30% FW citric acid), as were the pH values, for example, pH 3.79-3.86 (Hassanien,

Table 1. General indices of fresh CG fruit in the study

Fruit genotype	Indices				
	[1]Diameter, mm (min-max)	Weight, g (min-max)	Pulp content, % of fruit weight	Seed content, % of fruit weight	Peel content, % of fruit weight
CG-C	21.01±2.41 (16.42-26.71)	5.24±1.05 (3.90-8.15)	75.42±4.15	13.21±0.11	11.37±0.09
CG-F	16.79±1.41 (13.63±19.61)	2.79±0.55 (1.76-4.01)	84.55±3.28	11.52±0.09	3.93±0.03
CG-P	19.04±2.44 (13.62-23.44)	3.84±1.05 (1.52-6.74)	83.90±3.99	7.28±0.05	5.82±0.05

[1]The diameter was measured in the widest lateral section of the fruit.
CG-C: fruit imported from Colombia, purchased from a supermarket, CG-F: fruit produced in Bulgaria, representing an introduced variety, CG-P: fruit produced in Bulgaria, representing a locally selected variety. Values are presented as mean±SD, n = 100.

Table 2. Nutritional composition of CG fruit (on a fresh weight basis)

Index	CG-C		CG-F		CG-P	
	Whole fruit	Pulp	Whole fruit	Pulp	Whole fruit	Pulp
Ash, g/100 g	5.57±0.03	2.69±0.02	5.59±0.02	2.42±0.02	5.79±0.04	4.23±0.03
Lipids, g/100 g	0.25±0.00	<0.05	0.78±0.01	<0.05	1.01±0.01	<0.05
Protein, g/100 g	2.54±0.01	0.37±0.01	1.88±0.01	0.28±0.01	2.06±0.01	0.42±0.01
Moisture content, g/100 g	83.07±0.27	86.63±0.75	77.09±0.29	85.09±0.75	82.27±0.32	81.11±0.70
Carbohydrates, g/100 g						
Total	11.34±1.08	15.12±1.20	14.13±0.50	16.34±1.00	10.23±0.98	11.45±1.12
Reducing sugars	4.20±0.08	5.80±0.20	2.30±0.05	6.10±0.20	2.90±0.25	3.65±0.26
Sucrose	1.86±0.02	3.00±0.05	1.00±0.05	3.25±0.10	2.09±0.05	2.31±0.11
Glucose	2.15±0.12	2.96±0.14	1.15±0.05	3.25±0.20	1.44±0.12	1.98±0.23
Fructose	1.87±0.04	2.71±0.23	1.12±0.05	2.74±0.25	1.44±0.24	1.65±0.12
Pectin	1.15±0.03	1.73±0.04	1.25±0.04	1.85±0.04	1.16±0.03	1.85±0.04
Cellulose	6.47±0.04	1.79±0.01	6.64±0.04	1.82±0.01	4.29±0.03	1.77±0.01
pH	3.70±0.02	3.63±0.02	3.80±0.05	3.68±0.02	3.80±0.03	3.93±0.01
Titratable acidity, % citric acid	1.10±0.02	1.42±0.01	1.03±0.01	1.06±0.02	0.92±0.01	0.96±0.02
Natural pigments, µg/g						
Total chlorophylls	0.31±0.02	1.42±0.04	0.34±0.01	0.56±0.01	3.62±0.01	0.26±0.01
Chlorophyll a	0.16±0.01	0.52±0.01	0.12±0.01	0.21±0.01	2.34±0.01	0.10±0.01
Chlorophyll b	0.15±0.01	0.91±0.01	0.22±0.01	0.36±0.01	1.28±0.01	0.17±0.01
Total carotenoids	20.75±0.18	15.66±0.09	13.91±0.11	12.84±0.11	22.36±0.12	8.96±0.09
Energy, kcal/100 g (kJ/100g)	57.65 (241.21)	62.41 (261.12)	71.06 (297.31)	66.93 (280.04)	58.25 (243.72)	47.93 (200.54)

CG-C: fruit imported from Colombia, purchased from a supermarket, CG-F: fruit produced in Bulgaria, representing an introduced variety, CG-P: fruit produced in Bulgaria, representing a locally selected variety. Values are presented as mean±SD, n = 100.

2011) and 3.54 (Valdenegro *et al.*, 2013).

3.2.2 Carbohydrates

The higher carbohydrate content (total carbohydrates, total reducing sugars, mono- and disaccharides, respectively) was found in the pulp fraction, compared with the whole fruit (Table 2). As a general observation, there was no distinct differentiation on a fruit origin base (due to genetics, production and post-harvest conditions), although the local CG-F variety had a relatively higher total carbohydrate content (14.13 and 16.34 g/100 g, in whole fruit and pulp, respectively), compared with both the imported Colombian fruit (CG-C, 11.34 and 15.12 g/100 g) and the second local variety (CG-P, 10.23 and 11.45 g/100 g). Reducing sugars constituted between 16.3% and 37.0% of the total carbohydrate content in the whole fruit and between 31.9% and 38.4% - in the pulp fraction. Glucose, fructose and sucrose were the identified mono- and disaccharides, as in many other fruits. In general, glucose and fructose contents demonstrated similar values in all fruit genotypes, while sucrose content varied in a wider range, most probably in response to environmental conditions (Fischer *et al.*, 2007). Our results about the sugar content were very close to those of Ramadan (2011) (sugar content of 4.9 g/100 g pulp, of which about 29% fructose and 35% sucrose). Similarly, Novoa *et al.* (2006) observed that sucrose was only slightly higher than fructose and glucose in ripe fruit stored at 18°C. Furthermore, the trend of increase in glucose and fructose contents established by the same authors in the fruit of ripeness stage 4 (not fully ripe) during storage corresponded well with the higher glucose and fructose values in the whole fruit of Colombian origin of this study. CG-C represented imported fruit, with the probable harvest at the earlier ripeness stage and longer storage period than the locally produced fruit. CG fruit is known as a good source of dietary fiber, and in particular – of pectins, thus being suitable for making jellies, jams, fillings and sauces without the extensive addition of gelling agents (Valdenegro *et al.*, 2013). Our results were also favorable in that respect. The higher pectin concentrations were found in the pulp compared with the whole fruit (Table 2). The obtained pectin contents were similar to previous findings (Panayotov, 2009; Panayotov and Popova, 2014) and there were not any strong variations between the genotypes. The cellulose content varied between the genotypes only when determined in the whole fruit, while there were no differences in the isolated fruit pulp. The cellulose content was about 3 times higher in the whole fruit, which was the effect of peel/seed cellulose concentration.

3.2.3 Protein

The protein content in whole fruits varied between 2.54 and 1.88 g/100 g FW. The results in Table 2 suggested that CG seeds/peels were reasonably the primary sources of fruit protein, as its content in the extracted pulp were negligible (0.28-0.42 g/100 g). Those results were in good compliance with the findings of Ramadan (2011), who reported protein content of 0.05 -0.3 g/100 g pulp. The protein content was relatively higher in the imported variety, compared with the locally produced fruit, thus correlating well with the observed greater seed/peel share in CG-C fruit (Table 1).

3.2.4 Lipids

Similarly, lipids were found practically only in the whole fruit (they were concentrated primarily in the seed and peel), and not in the pulp. Similar observations were reported previously by Ramadan (2011) (oil yield of about 0.15-0.2 g/100 g pulp) and Hegazy *et al.* (2019) (0.43% lipids in the filtered juice).

3.2.5 Caloric value

The energy (caloric) values of the whole fruit and fruit pulp were calculated using the energy conversion factors, recommended by Food and Agriculture Organization of the United Nations (FAO) (2003), 4 kcal/g (17 kJ/g) for protein, 9 kcal/g (37 kJ/g) for fat and 4 kcal/g (17 kJ/g) for total carbohydrates. Data in Table 2 revealed origin-based differentiation between the studied CG fruit. The energy value of the local CG-P genotype was practically identical to that of the imported fruit of the world's biggest CG supplier (CG-C), 58.25 kcal/100 g and 57.65 kcal/100 g, respectively. Those values were significantly lower compared with the second Bulgarian genotype (CG-F, 71.06 kcal/100 g). The energy value of the pulp fraction was higher than that of the whole fruit in CG-C. However, the ratio was reversed in the two Bulgarian genotypes and the energy values were lower in the two pulp fractions. Regardless of genotype variations, those values characterized CG fruit as a low-calorie nutrient source, compared to many popular fruits, apple, grapes, banana, and others (Kalugina *et al.*, 2017). Regarding the total energy intake for each of the genotypes, it could be observed that carbohydrates were responsible for the highest energy contribution, about 80% of the total energy intake for the whole fruit, and over 95% of the pulp.

3.2.6 Sweetness of Cape gooseberry fruit

The results from the analyses of CG macronutrients were used to calculate two indices important for fruit taste and flavor perception, the sweetness index (SI) and the total sweetness index (TSI) (Magwaza and Opara, 2015; Akšić *et al.*, 2019). As stated previously, those indices take into account the proportions of the individual sugars (sucrose, glucose and fructose) and their relevance in sweetness perception. On the other hand, it is known that the balance between sugars and organic acids is very important for the sensory assessment of fruit taste and flavor, as well as for fruit processing (organic acids strongly influence the jelling capacity of pectins) (Magwaza and Opara, 2015; Akšić *et al.*, 2019). The TSI/TA ratio was also calculated for the fruit genotypes in the study. The results for the SI, TSI and TSI/TA indices of the whole fruit and fruit pulp of the three genotypes are presented in Figure 1.

The SI and TSI values were higher for the fruit pulp, compared with the whole fruit. The calculated SI values varied from 5.08 to 8.96 (whole fruit) and from 8.89 to 13.94 (pulp); the TSI – from 3.52 to 6.30 (whole fruit) and from 6.29 to 9.83 (pulp). The SI and TSI values of CG fruit in the study were comparable with the sweetness indicators of other berries; for example, they were slightly lower than those of strawberries (SI, 17.84-26.21; TSI, 12.30-18.18), but very close to those of blueberries (SI, 7.29-14.56; TSI, 5.39-9.99) (Akšić *et al.*, 2019). The values of the TSI/TA ratio were between 3.48 and 9.27, thus confirming the sweet-sour taste profile of CG fruit and juice (Panayotov, 2009; Hassanien, 2011; Puente *et al.*, 2011). An interesting finding was that the TSI/TA ratio took nearly identical values in CG-P and CG-C genotypes, thus suggesting that the Bulgarian variety (CG-P) could be regarded as indistinguishable from the imported Colombian fruit by taste balance perception, while the second local genotype (CG-F) was deviating more significantly in comparison to the other

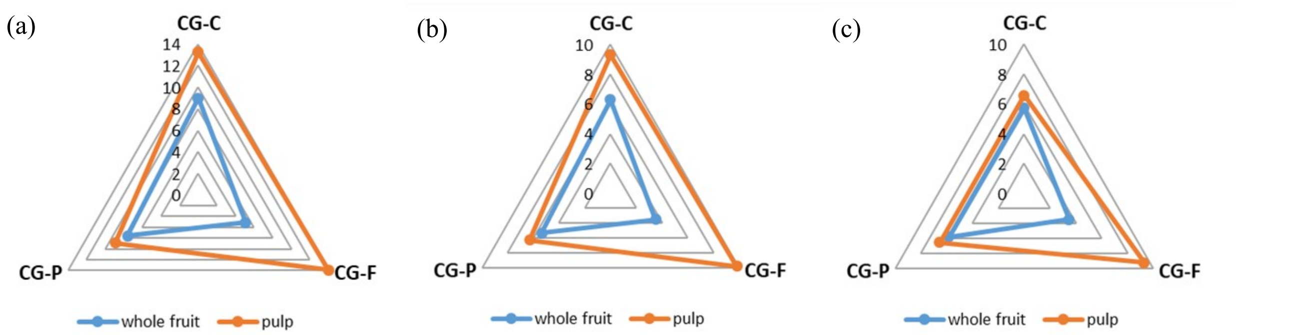

Figure 1. Sweetness index, SI (a); total sweetness index, TSI (b) and total sweetness/titratable acidity ratio, TSI/TA (c) of three genotypes of Gape gooseberry fruit. CG-C: fruit imported from Colombia, purchased from a supermarket, CG-F: fruit produced in Bulgaria, representing an introduced variety, CG-P: fruit produced in Bulgaria, representing a locally selected variety

two samples. With TSI/TA value below 5, the local genotype (CG-F) was considered as having a sour-sweet taste (Dimitrova *et al*., 2015; Magwaza and Opara, 2015).

3.2.7 Natural pigments

Carotenoids are not only natural colorants, but also important functional fruit constituents with diverse biological activities, such as antioxidant, provitamin A, anticancer, anti-degenerative, immunomodulatory, and others (Saini *et al.*, 2015; Olivares-Tenorio *et al*., 2016). Carotenoids have been associated with the bright orange-yellow color of CG berries and juice (pulp) (Puente *et al.,* 2011; Ordonez-Santos *et al.,* 2017).

The current results confirmed the characteristic high carotenoid content of GC fruit, approximating that of peach, grapes, blueberries, sea buckthorn, and others (Andersson *et al.,* 2009; Saini *et al.,* 2015). Moreover, as it has been summarized by Olivares-Tenorio *et al.* (2016), a portion of 50 g fresh CG berries could provide 10-20% of the recommended daily intake of vitamin A. The total carotenoid contents were higher in whole CG fruit, regardless of fruit origin, obviously reflecting the higher concentration of carotenoids in the peel (Etzbach *et al.*, 2018). However, the relative variations between the fruit structures were differently expressed in the three genotypes. In terms of whole fruit carotenoids, the local CG-F variety was with the lowest concentration, followed by CG-P and CG-C. However, the difference between whole fruit and pulp carotenoids was minimal in that genotype, in contrast to the other two genotypes (CG -C and CG-P). The data in the level of pulp carotenoids was low in the local CG-P variety, about 2.5 times lower than that in the whole fruit sample and about 1.5-1.8 times lower than the carotenoid concentration in CG-C and CG-F pulps (Table 2). Total carotenoids in this study were higher than the values by Fischer *et al.* (2000) - carotenoids of 1.57-3.55 μg/g FW, but they were far below the values by Nawirska-Olszanska *et al.* (2017) (168.25 mg/kg DW), and Bilenler and Karabulut (2019) - 139.57 mg/kg. In terms of the second group of natural pigments, CG-P was individually characterized by the highest chlorophyll content (3.62 μg/g as opposed to 0.31 μg/g and 0.34 μg/g in CG-C and CG-F, respectively). This corresponded well with the visual perception of ripe fruit color (lighter orange with greenish hues, compared with the deep orange color of the other two genotypes). The chlorophyll *a*: chlorophyll *b* ratio was typically about 1.0: 0.6, except for CG-C and CG-P whole fruit (1.0: 1.0 and 1.8: 1.0, respectively), which was probably related to the genotype, ripeness and post-harvest storage factors (Lal *et al.*, 2019).

3.2.8 Mineral composition

The supply of dietary minerals is a very important aspect of human nutrition; their intake is vital for the metabolic processes and the normal functioning of the body. Fruits and vegetables have been long identified as the most valuable sources of minerals, and their consumption is promoted as a preventive factor against diseases and malfunctions. CG fruit has been used as a source of minerals (Puente *et al.,* 2011; Hegazy *et al.*, 2019). Therefore, the individual macro- and micro-element composition of the fruit and pulp of CG genotypes was analyzed and the results are presented in Table 3.

The results revealed that there was no uniform trend in the distribution of the minerals between the genotypes. CG-C contained less K, Na, Ca, Cu and Zn than the locally-produced ones, but more Mg, Fe and Mn. As in many other fruits, K was the predominant macro-element in all genotypes, with similar levels in whole fruit and in the pulp (3886 – 4955 mg/kg). Those results supported the previous findings, which outlined CG fruit as a rich

Table 3. Macro and micro minerals in three genotypes of Cape gooseberry fruit

Mineral element, mg/kg	CG-C		CG-F		CG-P	
	Whole fruit	Pulp	Whole fruit	Pulp	Whole fruit	Pulp
K	4043.56±12.01	3886.00±11.67	4467.13±12.99	4595.00±13.66	4876.88±12.98	4955.00±13.22
Na	27.68±0.19	nd	48.09±0.12	9.54±0.05	39.24±0.18	36.93±0.28
Ca	6.48±0.04	8.60±0.04	9.04±0.06	8.36±0.04	10.33±0.09	9.97±0.07
Mg	455.53±2.33	33.65±0.11	154.57±0.57	30.94±0.21	91.42±0.36	30.95±0.21
Fe	20.91±0.11	13.72±0.04	7.60±0.05	4.11±0.03	18.51±0.09	16.44±0.09
Mn	5.37±0.03	1.32±0.01	1.63±0.01	0.55±0.00	1.42±0.01	0.86±0.00
Cu	5.01±0.03	3.16±0.02	39.19±0.14	2.76±0.02	13.88±0.07	2.04±0.01
Zn	11.62±0.07	4.11±0.02	34.60±0.11	2.28±0.01	11.78±0.06	4.07±0.03
Pb	nd	nd	0.14±0.00	nd	nd	nd
Cd	nd	0.12±0.00	2.43±0.01	nd	0.85±0.01	nd
Cr	nd	nd	0.69±0.00	nd	nd	nd

CG-C: fruit imported from Colombia, purchased from a supermarket, CG-F: fruit produced in Bulgaria, representing an introduced variety, CG-P: fruit produced in Bulgaria, representing a locally selected variety, nd: not detected or below 0.1 mg/kg. Values are presented as mean±SD, n = 100.

source of K, an intracellular mineral with important physiological functions – richer than fruits like papaya, orange, strawberry, apple, passion fruit, and others (Leterme *et al.,* 2006; Rodrigues *et al.*, 2009; Puente *et al.,* 2011; Ramaiya *et al.,* 2019). Those values indicated that the consumption of 100 g fresh fruits per day could assure about 12-14% of the recommended daily intake (dietary reference intake, DRI) for males and about 15-18% of the DRI for females (19-30 years age group) (National Academies of Sciences, Engineering, and Medicine, 2019; Rumaiya *et al.*, 2019). Mg content was definitely higher in the whole fruit than in the pulp. It showed the greatest deviation between the genotypes, with about 455.5 mg/kg in CG-C fruit as opposed to 154.6 mg/kg and 91.4 mg/kg in CG-F and CG-P whole fruit, respectively. Mg is an essential element in the human diet, a co-factor in many enzymatic systems and involved in neural and muscle chemical processes. Although considerably lower in Mg content, the two genotypes of Bulgarian origin corresponded to a good percentage of the DRI of Mg, which is 400 mg for males and 310 mg for females in the age group of 19-30 years (National Academies of Sciences, Engineering, and Medicine, 2019; Rumaiya *et al.*, 2019). Thus, a portion of 100 g fruit per day would supply about 2% (CG-P) and 4% (CG-F) of the recommended Mg intake for males and about 3% (CG-P) and 5% (CG-F) for females, while the respective values were higher for the imported fruit (CG-C), 11% (males) and 15% (females) (National Academies of Sciences, Engineering, and Medicine, 2019). Numerically, Mg content was lower than the values obtained by Rodrigues *et al.* (2009) for whole fruit from Brazil, 34.7 mg/100 g DW; Leterme *et al.* (2006), 19 mg/100 g fruit pulp; Hegazy *et al.* (2019), 11.27 mg/100 mL juice, and Eken *et al.* (2014), 145 mg/100 g fruit. In the same group of macrominerals, Na content was generally low, as defined previously for CG (Rodrigues *et al*., 2009; Hegazy *et al*., 2019). It showed a substantial deviation between the whole fruit and the pulp within the genotypes, as well. Na levels in the whole fruit were in a similar range in the three genotypes (27.68-48.09 mg/kg). However, the pulp concentrations in CG-C and CG-F were minimal, while its content was on the upper end and practically identical in CG-P fruit and pulp (39.24 and 36.93 mg/kg). Ca was found in very low amounts both in the whole fruit and in the pulp, regardless of genotype (6.48-10.33 mg/kg). Those results agreed well with previous data about the low Ca content in CG fruit (Rodrigues *et al.,* 2009; Puente *et al.,* 2011; Olivares-Tenorio *et al*., 2016).

The supply of micro minerals in an organic delivery form is an essential element of human nutrition, as they – although required in trace amounts – participate in a variety of metabolic and regulatory processes. The results shown in Table 3 revealed that the studied CG genotypes could be good sources of Fe, Cu, Zn, and Mn, although CG fruit had been associated with low levels of those microminerals in general (Rodrigues *et al.,* 2009; Puente *et al.,* 2011; Olivares-Tenorio *et al*., 2016). As a common trend, the content of all detected microelements was higher in the whole fruit than in the isolated pulp, but the degree of difference varied. For example, the relative differences between the whole fruit and pulp contents of Fe and Mn were less pronounced compared with the distribution of Cu and Zn. On a genotype basis, Fe was characteristically lower (2-3 times) in CG-F fruit and pulp compared to the other two genotypes; Fe contents in this study were higher than the levels reported by Leterme *et al.* (2006), 0.09 mg/100 g but close to those by Rodrigues *et al.* (2009), 1.47 mg/100 g. In turn, the same genotype (CG-F) exceeded the other two in terms of the content of Zn, an important factor in many enzymatic systems in the body (about 3-time difference; 34.6 mg/kg contrary to 11.6-11.8 mg/kg). On a 100 g whole fruit estimated consumption, the Zn content in the studied genotypes corresponded to about 10-30% of the DRI (for males) and about 14-43% of the DRI (for females); respectively, the Fe content – to 10-26% of the DRI (for males) and 4-11% of the DRI (for females) (National Academies of Sciences, Engineering, and Medicine, 2019). Both genotypes produced in Bulgaria had significantly higher whole fruit Cu concentrations when compared with the imported Colombian one. The heavy metals, Pb, Cd and Cr, were generally absent or in trace amounts, with the partial exception of Cd, which was detected at 2.43 mg/kg in the CG-F genotype. Those differences reasonably reflected the influence of the environmental factors during plant vegetation on the availability and the accumulation of minerals in the fruit of different origins.

To the best of our knowledge, there were no previous data about the nutritional characteristics of CG fruit representing different genotypes grown in Bulgaria; therefore, it was assumed rational to present a summarized comparison between the results from this study and selected reference data about the fruit of other origins (Table 4).

The nutritional facts summarized in Table 4 characterized the CG fruit originated from Bulgaria as legitimately competitive to the recognized genotypes worldwide. As seen, there was a very good agreement with published data with respect to most of the data, but certain specifics were also present. The fruit in this study deviated more significantly by ash, Na, K, and fiber content (higher values), as well as by the content of Ca (lower). As stated earlier, most of those differences could be regarded as origin-related, but a certain degree of

Table 4. Summarized nutritional facts of Cape gooseberry fruit produced in Bulgaria – comparison with literature data

Index	USDA (2019)	Rodrigues *et al.* (2009)	de Carrasco and Zelada (2008)	Puente *et al.* (2011); Osorio and Roldan (2003)	CCI (2001)	NRC (1985)	Fischer *et al.* (2000)	Cortés Díaz *et al.* (2015)	Yıldız *et al.* (2015)	Thuy *et al.* (2020)	This study (fruit produced in Bulgaria)
Energy, kcal/100 g (kJ/100 g)	53.00 -221.75	88.72 -371.20	76.80 -321.33	49.00 -205.02	54.00 -225.94	73.00 -305.43	49.00 -205.02	na	na	42.54-44.95 (177.99-188.07)	58.25-71.06 (243.72-297.31)
Proximates, g/100 g											
Carbohydrates	11.20	13.22	17.30	11.00	13.10	19.60	11.00	na	13.86	7.61-7.79	10.23-14.13
Lipids	0.70	3.16	0.00	0.50	0.40	0.20	0.50	0.48	0.18	0.71-0.82	0.78-1.01
Protein	1.90	1.85	1.90	1.50	1.10	0.30	1.50	1.43	1.66	1.68-1.79	1.88-2.06
Ash	0.80	0.80	1.00	0.70	0.70	1.00	0.70	0.75	2.98	na	5.59-5.79
Fiber	na	na	3.60	0.40	4.80	4.90	0.40	na	na	4.23-4.31	5.45-7.89 (Cellulose and pectin); 4.29-6.64 (Cellulose)
Moisture content	85.40	80.97	79.80	85.90	79.60	78.90	85.50	82.43	81.33	77.82-83.10	77.09-82.27
Minerals, mg/100 g											
Ca	9.00	9.00	10.55	na	na	8.00	na	na	na	12.48-13.12	0.90-1.03
Fe	1.00	1.47	1.24	na	na	1.20	na	na	na	na	0.76-1.85
Na	na	1.10	na	na	na	1.00	na	na	na	na	3.92-4.81
K	na	347.00	292.65	na	na	320.00	na	na	na	na	446.71-487.69

na: Data not available

variation could also be attributed to sampling preparation, extraction, analytical methods, etc. (Olivares -Tenorio *et al.*, 2016). Those results provide yet further evidence that CG fruit is a low-calorie, low-fat dietary source of functional nutrients.

4. Conclusion

The current results demonstrated the nutritional potential of different Cape gooseberry genotypes grown in Bulgaria and Colombia. The fruit was evaluated as a natural source of phytonutrients such as major nutrients (protein, lipids and sugars), dietary fibers as pectin, cellulose, natural pigments as carotenoids and essential macro and micro-elements, especially K, Mg, Cu, and Zn. In general, Bulgarian genotypes demonstrated a balanced sweet-sour taste, higher natural pigments and pectin content, as well as good compatibility with the imported Colombian fruits. The summarized data may be useful in the market promotion of fresh CG fruit as a contemporary element in the balanced diet or as a raw material worth processing and consideration as an active ingredient in value-added food products.

Conflict of interest

The authors declare no conflict of interest.

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