Rocz Panstw Zakl Hig 2023;74(1):49-57
http://wydawnictwa.pzh.gov.pl/roczniki_pzh/ https://doi.org/10.32394/rpzh.2023.0247

ORIGINAL ARTICLE

NUTRITIONAL AND ANTIOXIDANT PROFILE OF THE *PHYSALIS* FRUIT GROWN IN THREE ANDEAN REGIONS OF PERU

Antonio José Obregón-La Rosa[1], *Eliana Contreras-López*[2], *Eduardo Flores Juárez*[1], *Úrsula Gonzales Barrón*[3,4], *Ana María Muñoz*[5], *Fernando Ramos-Escudero*[6]

[1]Universidad Nacional Mayor de San Marcos, Facultad de Farmacia y Bioquímica, Escuela de Ciencia de los Alimentos, Lima, Perú
[2]Facultad de Farmacia y Bioquímica, Grupo de Investigación Revalorización de Fuentes Naturales y Alimentos Funcionales-REVALF, Universidad Nacional Mayor de San Marcos, Lima, Perú
[3]Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança, Bragança, Portugal
[4]Laboratório para a Sustentabilidade e Tecnologia em Regiões de Montanha, Instituto Politécnico de Bragança, Portugal
[5]Instituto de Ciencias de los Alimentos y Nutrición, Universidad San Ignacio de Loyola (ICAN-USIL), Lima, Perú
[6]Unidad de Investigación en Nutrición, Salud, Alimentos Funcionales y Nutraceúticos, Universidad San Ignacio de Loyola (UNUSAN-USIL), Lima, Perú

ABSTRACT

Background. *Physalis peruviana L.* fruit contains nutritional and bioactive compounds of immense importance to public health and represents a potential ingredient for the development of functional foods and beverages.

Objective. This study aimed to determine the chemical and nutritional composition as well as the antioxidant capacity of the *P. peruviana L.* fruit grown in Peru in three areas of the Central Andean region.

Material and methods. Proximal and physicochemical analyses and estimation of mineral content, vitamin C, total carotenoids, total polyphenols, and antioxidant capacity (2, 2-diphenyl-1-picrylhydrazyl [DPPH] and 2, 2′-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) [ABTS] assays) were performed using standardized methods.

Results. The fruits were collected from three regions of the Peruvian Andes (Ancash, Cajamarca, and Cusco). The results showed that the content of potassium (306.54–327.60 mg/100 g) and iron (12.93–14.47 mg/kg) was prominent. The *Physalis* fruit had high levels of vitamin C (47.20–52.20 mg/100 g), total polyphenols (68.17–83.40 mg equivalents of gallic acid/100 g), and carotenoids (1.12–1.73 mg β-carotene/100 g). Higher values for antioxidant capacity were obtained with the ABTS method (896–1003.33 µmol Trolox/100 g) than with the DPPH method (290–309 µmol Trolox/100 g).

Conclusions. This study confirms that the *P. peruviana* fruit has properties that could provide important health benefits and that it could be used for the development of functional foods and food supplement.

Key words: *Aguaymanto, nutritional composition, antioxidant capacity, nutraceutical value, Andean regions, Peru*

INTRODUCTION

Peru is located south of the equator in the Central and Western region of South America. Owing to the presence of the Andes Mountains, Peru has a complex orography and high-altitude gradients. This feature results in great climatic variations within relatively small geographic spaces, with a diversity of microclimates throughout the hydrographic basins [11]. These conditions favor the production of a wide variety of fruits, which makes Peru one of the countries with a good exportable supply. Among the exotic Peruvian fruits meant for export, *Physalis peruviana L.* (family *Solanaceae*) is commercially the most important species of the genus *Physalis* [29]. The major export destinations are the United States, the Netherlands, France, etc. [40].

This fruit is native to the Peruvian Andean region, and its agricultural production has expanded worldwide mainly because of its sensory, nutritional, pharmacological, and commercial characteristics [14, 24, 29]. The most cultivated *P. peruviana* ecotypes

Corresponding author: Fernando Ramos-Escudero, Unidad de Investigación en Nutrición, Salud, Alimentos Funcionales y Nutraceúticos, Universidad San Ignacio de Loyola (UNUSAN-USIL), Campus Gran Almirante Miguel Grau, Av. La Fontana 750, 15024, Lima, Perú, e-mail: diomedes.fernando@gmail

Publisher: National Institute of Public Health NIH - National Research Institute

in the world are Kenya, South Africa, and Colombia. In Peru, there are four ecotypes from the Cajamarca region [38], and they constitute the genetic basis of the world's commercial crops. In Peru, *P. peruviana* is distributed in the Yunga and Quechua regions (2000 and 2500 meters above the mean sea level, respectively) [9], and the agricultural production areas are Ancash, Ayacucho, Cajamarca (main producing area), and Cusco [37].

P. peruviana, is an ovoid, orangish-yellow berry containing between 150 and 300 lenticular-shaped flat seeds [14]. In Peru, it is known as aguaymanto or capulí [37]; in other countries, other common names such as uchuva, golden berry, Inca cherry, Peruvian cherry, Physalis, ras-bhari, cape gooseberry, uvilla, topotopo, harankash, amur en cage, and pokpokare are used [26]. It is consumed fresh, dehydrated, as frozen pulp, liquid extract, or as jam or honey [37]. It is a fruit with gastronomic attributes and is used to prepare juices, rehydrating drinks, snacks, desserts, salads, sauces, and different main dishes as well as for the preparation of new functional foods [29].

The fruit is rich in *beta*-carotene, ascorbic acid, proteins, crude fiber, phosphorus, iron, and bioactive compounds with antioxidant [16, 25, 27]. Its health benefits include blood purification by reduction of urinary albumin in the kidneys, and reconstruction and strengthening of the optic nerve. It is also used to treat prostatitis [27], whooping cough, and dental caries [16]. Furthermore, it has hypoglycemic activity, which is why it is used in traditional medicine for the treatment of diseases such as diabetes and hypertension [30, 13]. These characteristics are important for human nutrition and for the production of functional foods in the food and nutraceutical industries [25].

P. peruviana is one of the "Superfoods Peru" because of its important nutritional properties and health benefits, which has boosted its agricultural production for export. Recently, studies on the genetic characterization and molecular cytogenetics of fruits grown in Peru have been conducted [9, 38] to understand the biological and genetic diversity of this species. However, there are only a few studies that refer to the chemical composition and nutritional and antioxidant capacity of *P. peruviana* cultivated in Peru [20, 25]. This limited knowledge affects the production and export chain, both of the fruit and the processed foods based on this resource.

Therefore, this study aimed to determine the chemical and nutritional composition and the antioxidant capacity of *P. peruviana* L. fruit grown in three areas of the Andean region of Peru. The variables studied included proximal analysis, energy value, physicochemical characteristics, vitamin C content, total carotenoids, total polyphenols, and antioxidant capacity. The results are expected to provide a basis for subsequent studies on the development and formulation of functional processed foods based on *P. peruviana* fruits.

MATERIAL AND METHODS

Vegetal material

P. peruviana fruits were collected in three areas of the Peruvian Andes (Table 1). Plants with the best phenotypes were sampled from each locality, and an average of 50 kg of fruits were manually collected in a state of optimum ripeness and without bumps or bruises. The cap or calyx of the fruit was removed for weighing, and the diameter and height were measured.

Sample preparation

The fruits used for the analyses corresponded to a state of maturity suitable for consumption, established in the norm for Cape Gooseberry of the Codex Alimentarius; CODEX STAN 226-2001. The fruits were washed, ground, lyophilized, and stored at −20°C for subsequent analyses. Later, they were identified by botanical specialists from the Universidad Nacional Mayor de San Marcos, Lima-Peru.

Proximal analysis

The AOAC [3] methods were used for the following determinations: water content, total proteins, ethereal extract, ash, crude fiber, pH, total acidity, soluble solids, and total sugars. Water content was determined by

Table 1. Origin geographical and climatic conditions of *Physalis* fruits

Origin	Location	Climatic conditions
Huantar district, Huari province, Ancash Region	Latitude (9° 27' 7" S, 77°10′35″ W), and 3140 m asl.	Average annual temperature of 11°C and relative humidity between 60-75 percent. UV index max. 10.
Bambamarca district, Hualgayoc province, Cajamarca region	Latitude (6° 40' 46" S, 78° 31' 09" W), and 2532 m asl.	Average annual temp. of 23°C, humidity of 77%, rainfall of 16 mm and UV Index 6.
Calca district, Calca province, Cusco region	Latitude 13° 16' 7.39" S and longitude 71° 57' 28.08" W, and 2949 m asl.	Average annual temperature of 7.8°C, rainfall of 736 mm, humidity of 60% and the UV Index 6.

drying the sample in an oven (Tecnal TE 394/1, Brazil) until it reached a constant weight. Protein content was quantified by the *Kjeldahl* method (the factor used was 6.25) using a protein–nitrogen still (Raypa DNP-3000, Spain). Fiber content was estimated by gravimetric method after acid hydrolysis of the samples. Ether was extracted using *Soxhlet* apparatus (Raypa SX-6MP, Spain) with petroleum ether as the solvent, and ash content was determined by incineration at 550±15°C in a muffle furnace (Thermolyne, USA). The total carbohydrate content was obtained by subtracting the content of water, protein, fat, and ash from 100. The results were expressed as g per 100 g of fresh weight of the fruit and energy was calculated to the Atwater system: kcal/100 g = 4 x (g proteins + g carbohydrates) + 9 x (g fat).

Total sugar, soluble solids, total acidity, and maturity index

Total sugars were quantified using the spectrophotometric method [2]. Soluble solids were measured with a refractometer (Alla France, 0–32) at 20°C, and the results were expressed as °Brix [3]. Total acidity was determined by titration using a potentiometer (TRANS Instruments, TI 9000, Singapore) with a 0.1 M NaOH solution, and the result was expressed as percentage of citric acid. The maturity index was determined by dividing the soluble solids by the total acidity [3].

Determination of minerals content

Minerals content was determined in e ash samples dried in a muffle at 550°C and dissolved in 10 mL of 50% HCl (v/v). The minerals were quantified using an atomic absorption spectrophotometer (Perkin Elmer 3030-B, USA). For each mineral, a standard curve and a blank sample were prepared. Phosphorus content was determined using molybdenum blue spectrophotometric technique and boron with the curcumin colorimetric technique [3]. The macroelements (phosphorus, potassium, calcium, magnesium, sulfur, and sodium) were expressed as mg/100 g of dry matter, and the microelements (zinc, copper, manganese, iron, and boron) as mg/kg of dry matter.

Determination of vitamin C content

The vitamin C content was determined using the 2,6 dichlorophenol indophenol modified titration method [4]. Ascorbic acid was extracted with a 4% (m/v) oxalic acid solution, as recommended by *Benassi* and *Antunes* [7]. This solution was titrated with a 0.01% 2,6-dichlorophenol-indophenol solution. The end point was considered to be reached when the solution turned faint pink for 15 s. The results were expressed as mg of ascorbic acid equivalents per 100 g of sample.

Polyphenols extraction

To obtain the extracts, the methodology suggested by *Jiménez-Escrig* et al. [19] was followed, with some modifications. In this method, 0.5 g of the sample was treated with 20 mL of methanol/water solution acidified with 2 N HCl (50:50 v/v, pH 2) and stirred for 1 h at room temperature. Then, it was centrifuged for 15 min at 3500 rpm, and the supernatant was collected. The remaining residue was treated with 20 mL of acetone/water (70:30 v/v) mixture, stirred for 1 h, and centrifuged under the previously mentioned conditions.

Determination of total phenolic compounds

Total polyphenols content was determined according to the *Folin–Ciocalteau* method described by *Singleton* and *Rossi* [39], starting from a standard curve of gallic acid. The results were expressed as mg gallic acid equivalents per g of the sample. The points of the curve were obtained by measuring the absorbance at 765 nm with a spectrophotometer (Hitachi U-2800 A, Japan).

DPPH (2,2-Diphenyl-1-Picrylhydrazyl) method

The DPPH assay was performed according to the methodology described by *Brand-Williams* et al. [8], with some modifications. Trolox was used as the standard, and the standard curve was constructed using the DPPH reagent. Trolox concentrations ranged from 100 to 800 µM, 80% methanol was used as solvent, and the absorbance was measured at 515 nm with a spectrophotometer (Hitachi U-2800 A, Japan). The results were expressed as µM Trolox/100 g of sample.

ABTS (2,2'-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid) method

The ABTS trial was performed as described by *Re* et al. [34]. To produce the ABTS radical, 38.4 mg of 7 mM ABTS was dissolved in 10 mL of 2.45 mM potassium persulfate solution and maintained in the dark at room temperature for 12–16 h. For the analyses, the solution was diluted with ethanol until the absorbance at 720 nm reached 0.70 ± 0.02. The solution was equilibrated at 30°C. Then, 1 mL of this solution was added to 10 µL of the extracts or 2.5 mM Trolox standard solution, and the absorbance was measured at 734 nm. Aqueous Trolox solutions of concentrations between 0 and 500 µM were used for calibration. The results were expressed as µM Trolox per 100 g of the sample.

Determination of total carotenoids

For the extraction of carotenoids, 0.5 g of lyophilized sample was weighed and 2.5 mL of hexane-acetone mixture (1:1) was added. Subsequently, it was centrifuged at 3,500 rpm for 15 min, and the supernatant was collected (the residue from the lower part was successively extracted, as previously described, until the yellow color disappeared). Then, 2.5 mL of petroleum ether was added to the extract and placed in an ultrasonic bath (Sonorex RK512H) for 1 h. The extracts were washed with distilled water several times. Total carotenoids were determined by measuring the absorbance of the extract in a spectrophotometer (Hitachi U-2800 A, Tokyo, Japan) at 470 nm. A β-carotene (10–200 mg/L) standard curve was constructed, and petroleum ether was used as the blank, as recommended by Talcott and Howard [40]. The results were expressed as mg of β-carotene per 100 g of the sample.

Data analysis

The data were analyzed with the Minitab version 18 (Pennsylvania State University, USA) and GraphPad Prism version 8.0.1 (GraphPad Software, San Diego, CA) programs, and treatments with $p < 0.05$ were considered significant. One-way analysis of variance and *Tukey's* multiple comparisons test were used to compare the treatment means.

RESULTS AND DISCUSSION

Proximal analysis

The results of the proximal analysis of the *Physalis* fruit in each studied zone of the Peruvian Andes are shown in Table 2. No significant differences ($p < 0.05$) were found in most of the components of the proximal analysis of *Physalis* fruits from the different areas studied, except for the protein content.

The greatest energy supply comes from carbohydrates, which consist mainly of reducing sugars such as glucose and fructose. The average

Table 2. Proximate composition, minerals, vitamin C, carotenoids, polyphenols of *Physalis peruviana* L. fruits grown in the central Peruvian Andes

Composition	Origin		
	Huantar	Bambamarca	Calca
Moisture (mg/100 g)	77.57±0.70	78,51±1.27	79.50±0.70
Total protein (mg/100 g)	0.28±0.04b	0,30±0.03b	0.40±0.02a
Total lipids (mg/100 g)	0.79±0.11	0,84±0.06	0.83±0.02
Ash (mg/100 g)	0.98±0.17	0,95±0.03a	1.15±0.05
Crude fiber (mg/100 g)	3.34±0.37	3,23±0.15	2.85±0.10
Total carbohydrate (mg/100 g)	17.05±0.06	15.86±1.32	15.27±0.62
Total solids (mg/100 g)	22.43±0.70	21.19±1.27	20.50±0.70
Energy (kcal/100 g)	76.37±1.39	72.26±5.45	70.15±2.64
Macroelements (mg/100 g)			
Phosphorus	51.23±1.21a	52.53±0.55a	48.77±0.31b
Potassium	306.57±12.61a	307.17±1.22a	327.60±4,72b
Calcium	47.27±1.33a	51.23±0.81b	52.70±1.35 bc
Magnesium	18.73±0.25a	21,23±0.81b	22.80±0.30c
Sulfur	22.23±1.03a	23.23±0.81ab	20.60±0.70ac
Sodium	5.80±0.98a	7.83±0.83b	7.17±0.58c
Microelements (mg/100 g)			
Zinc	0.54±0.04a	0.57±0.03ab	0.64±0.02b
Copper	0.12±0.03	0.16 ±0.01	1.25±0.09
Manganese	0.16±0.02	0.19±0.01	1.97±0.12
Iron	1.31±0.05a	1.42±0.05ab	1.43±0.05b
Boron	0.59±0.01	0.63±0.02	0.64±0.04
Vitamin C (mg/100 g)	47.20±1.89a	49.90 ± 1.20ab	52.20±0.90b
Carotenoids totals (mg β carotene/100 g)	1.12±0.12a	1.52 ± 0.18b	1.73±0.08 bc
Polyphenols totals (mg GAE/100 g)	68.17±2.52a	76.93 ± 2.69b	83.40±4.29 bc

The values are expressed as mean ± SD (n = 3). Values without letters in the same rows are insignificantly different from each other ($p > 0.05$). While different letters in the rows represent a significant difference based on the *Tukey* test ($p < 0.05$).

carbohydrate content (15.86–17.05 g per 100 g) estimated in our study differed significantly from those reported by *Thuy* et al. [41] (7.61–7.79 g per 100 g of sample) and *Bazalar Pereda* et al. [6] (14.22 g per 100 g of sample) for *Physalis* fruits from Taiwan and Argentina, respectively. However, the values are close to those reported by *Petkova* et al. [29] (11.45–16.34 g per 100 g) in pulps of *Physalis* fruits of Bulgarian origin.

The mean fiber content of the *P. peruviana* fruit (2.85–3.34 g per 100 g of sample) was significantly lower than those found by Thuy et al. [41] (4.23–4.31 g per 100 g of sample) and *Bazalar Pereda* et al. [6] (4.15 g per 100 g of sample).

Obregón-La Rosa et al. [25] determined the physicochemical and nutritional characteristics of several native fruits of Peruvian origin, including *Physalis*, from Cuzco, and found a significantly higher fiber value (4.90 ± 0.21 g per 100 g) than that observed in the present study for *Physalis* fruits from the same area (2.85 ± 0.10 g per 100 g). This difference could probably be due to the state of maturity of the fruit.

It should be noted that the fiber content of the *Physalis* fruit is significantly higher than that of other fruits in the region, such as strawberry (1.4 g per 100 g of sample), lucuma (*Pouteria lucuma*; 1.3 g per 100 g of sample), soursop (*Annona muricata*; 1.1 g per 100 g of sample), tangerines (*Citrus reticulate*, 0.5 g per 100 g of sample), and banana (*Musa paradisiaca*, 0.5 g per 100 g of sample), among others [35].

In this regard, *Carvalho* et al. [10] and *Ajila* et al. [1] stated that the consumption of dietary fiber favors a good control of glycemia, diabetes, high cholesterol, colon cancer, and gastrointestinal and cholesterol-related disorders. Hence, the regular consumption of the *Physalis* fruit might help prevent this type of diseases.

Physicochemical analyses

The physicochemical characteristics of the *Physalis* fruits in each evaluated zone are shown in Table 3. The content of total sugars (21.83–25.37 g per 100 g of sample) was within the range reported by *Thuy* et al. [41] (15.56–41.14 g per 100 g of sample. However, it was significantly higher than that reported by *Sharoba* and *Ramadan* [36] (11.3 g per 100 g of sample). The titratable acidity also plays an important role in the flavor and quality of the fruit. The mean value of total acidity (1.63–1.69 g per 100 g of sample) was higher than the value reported by *Thuy* et al. [41] (0.29%–0.79%).

The soluble solids content is a good indicator of the sweetness of the fruits. The results obtained (13.62–14.53 g per 100 g of sample) were significantly similar to those reported by *Thuy* et al. [41] (13.92 –13.96 g per 100 g of sample) and *Puente* et al. [30] (13.73–14.30 g per 100 g of sample).

The SST/AT ratios (maturity index) (8.07–8.93) of the *P. peruviana* fruits from the evaluated areas were similar to those obtained by *Bazalar Pereda* et al. [6] and *Obregón-La Rosa* et al. [25], which were 8.00 and 8.70, respectively. According to the Colombian Technical Standard, a maturity index value of 8 denotes that the fruit is in the optimal maturity state for consumption.

Regarding the mineral content, many of the macro- and micronutrients necessary for human health are found in the *Physalis* fruit (Table 2). The *Physalis* fruit presented calcium levels (47.27–52.70 mg per 100 g) than those of other fruits in the region, such as peach (*Prunus persica*, 4 mg per 100 g), custard apple (*Annona cherimola*, 20 mg per 100 g), plum (*Prunus domestica*, 20 mg per 100 g), coconut (*Cocos nucifera*, 8 mg per 100 g), lucuma (*Pouteria lucuma*, 16 mg per 100 g), and banana (*Musa paradisiaca*, 8 mg per 100 g), among others [21].

Likewise, with regard to phosphorus (48.77–52.53 mg per 100 g), the *Physalis* fruit presented higher values than peach (*Prunus persica*, 22 mg per 100 g), strawberry (*Fragaria vesca*, 26 mg per 100 g), mango (*Mangifera indica*, 15 mg per 100 g), apple (*Malus domestica*, 11 mg per 100 g), watermelon (*Citrullus lanatus*, 15 mg per 100 g), papaya (*Carica papaya*, 14 mg per 100 g), and banana (*Musa paradisiaca*, 20 mg per 100 g) [21].

Table 3. Physico-chemical characterization of *Physalis peruviana* L. fruits grown in the central Peruvian Andes

Composition	Origin		
	Huantar	Bambamarca	Calca
Total sugars (%)	21.83±1.15a	25.37±0.81b	22.57±0.50a
Total acidity (%) (ATT)	1.69 ±0.06	1.63±0.11	1.67±0.03
Soluble solids (°Brix)/(SST)	13.62±0.21	14.53±0.84	13.73±0.21
Maturity index (SST/ATT)	8.07±0.32a	8.93±0.43b	8.21±0.13ab

The values are expressed as mean ± SD (n = 3). Values without letters in the same rows are insignificantly different from each other ($p > 0.05$). While different letters in the rows represent a significant difference based on the *Tukey* test ($p < 0.05$).

Calcium is a mineral involved in the development and growth of bones, which also acts on blood pressure and weight control. Potassium plays a role in the control of hypertension, and phosphorus is an enzymatic component involved in the phosphorylation process, allowing the activation of certain components and hormones of the acid–base regulation in the body [30]. From the results obtained, it was evident that 100 g of this fruit would provide approximately 4%–7% of the daily requirement of macro-minerals (calcium, potassium, and phosphorus) for an adult, according to the Institute of Medicine [18].

Potassium content (306.57–327.60 mg per 100 g of sample) found in *Physalis* fruits was higher than those reported by *Leterme* et al. [21] for various fruits grown in the Andes, such as carambola (*Averrhoa carambola*, 102 mg per 100 g), pineapple (*Ananas comosus*, 39 mg per 100 g), jicama (*Pachyrhizus erosus*, 150 mg per 100 g), mamoncillo (*Melicoccus bijugatus*, 171 mg per 100 g), passion fruit (*Passiflora edulis*, 100 mg per 100 g), lulo (*Solanum quitoense*, 264 mg per 100 g), and oca (*Oxalis tuberosa*, 236 mg per 100 g), among others. In their research, *Leterme* et al. [21] also found that the macromineral with the highest content in *Physalis* fruits was potassium, representing on average of 32% in the total content of minerals.

The prominent microelements were zinc, copper, and iron; 100 g of the *Physalis* fruit would provide an average of 16.3% of the daily iron requirement for an adult person, according to the Institute of Medicine [18]. In the case of zinc, the contribution of 100 g would be 4.9% of the recommended daily intake.

Iron is a component of several proteins, including enzymes and hemoglobin, the latter being important for the transport of oxygen to the tissues throughout the body for metabolism. The recommended daily allowance (RDA) of iron for all age groups of men and postmenopausal women is 8 mg/day, and for premenopausal women it is 18 mg/day. Zinc is a component of several enzymes, and it maintains the structural integrity of proteins and regulates gene expression. The RDA of zinc for adults is 8 mg/day for women and 11 mg/day for men [18].

Bioactive compounds and antioxidant capacity

Table 2 shows the results obtained from the analysis of bioactive compounds of *Physalis* fruits from the three cultivation zones studied. Regarding the content of vitamin C, the sample from the Calca area presented the highest content (52.20 ± 0.90 mg per 100 g of sample), while the one from the Huantar area had the lowest value (47.20 ± 1. 89 mg per 100 g of sample). The obtained values (47.20 ± 1.89 to 52.20 ± 0.90 g per 100 g of sample) exceeded, with a slight significance ($p < 0.05$), those reported by *Thuy* et al. [41], *Bazalar Pereda* et al. [6], *Ramadan* [32], and *Obregón-La Rosa* et al. [25], which were 46.86 mg, 33.35 mg, 43.0 mg, and 43.00 ± 0.153 mg per 100 g of the sample, respectively.

Vitamin C is an essential nutrient for collagen synthesis and a cofactor in the biosynthesis of catecholamines, L-carnitine, cholesterol, amino acids, and some peptide hormones. Lack of vitamin C causes scurvy, a pathological condition that leads to blood vessel fragility and connective tissue damage. This vitamin is also potentially involved in the prevention of cancer and cardiovascular diseases [15]. Although the recommended dietary allowance of vitamin C remains controversial, the approaches regarding the requirements are established between 40 to 220 mg vitamin C per day [42]. In this regard, it should be noted that the *Physalis* fruit is a good source of vitamin C; for an adult, consuming 100 g of this fruit would provide 52.4%–58% of the recommended daily intake of vitamin C, according to the Institute of Medicine [18].

The carotenoids present in the *Physalis* fruit are mainly composed of β-carotene (55%), followed by other esters such as lutein [17, 32]. The value obtained from the Calca area (1.73 ± 0.08 mg per 100 g of sample) was higher than that of the Huantar area (1.12 ± 0.12 mg per 100 g of sample). The result obtained for β-carotene from the Calca area (1.73 ± 0.08 mg per 100 g of sample) was slightly higher than those reported by *Thuy* et al. [41] (1.63 mg per 100 g of sample), *Bazalar Pereda* et al. [6] (1.24 mg per 100 g of sample), and *Ramadan* [32] (1.6 mg per 100 g of sample); however, the value of the Huantar area was lower. These variations could be explained by the differences in the state of maturity, variety, cultivation method, type of soil, climatic conditions, altitudes, etc. It should be noted that the carotenoids are responsible for the orange color of the fruit [30]. β-carotene is crucial for the prevention of certain diseases such as cancer because it reacts with the free radicals generated by the tissues [32]. *Puente* et al. [30] stated that the most active carotenoids in vitamin A are α-carotene, β-carotene, and β cryptoxanthin, the latter being the one with the highest provitamin A activity.

Regarding the total polyphenols content, the sample from the Calca area had a value (83.40 ± 4.29 mg gallic acid eq per 100 g) that was significantly higher than those of the Huantar (68.17 ± 2.52 mg gallic acid eq per 100 g) and Bambamarca (76.93 ± 2.69 mg gallic acid eq per 100 g) areas. The values of the three zones were slightly higher than that found by Thuy et al. [41], which was 60.53 mg gallic acid eq per 100 g. *Häkkinen* et al. [17] have indicated that the main phenolic components present in *Physalis* fruit are quercetin, myricetin, and kaempferol.

When compared with other fruits, the average content of total polyphenols found in the *Physalis*

fruit was than the usual values found in banana (*Musa paradisiaca*, 11.8 mg gallic acid eq per 100 g), mango (*Mangifera indica*, 6.25–56 mg gallic acid eq per 100 g), papaya (*Carica papaya*, 57.6 mg gallic acid eq per 100 g), and pineapple (*Ananas comosus*, 2.58 mg gallic acid eq per 100 g), but lower than those of strawberry (*Fragaria vesca*, 161 mg gallic acid eq per 100 g), apple (*Malus domestica*, 296.3 mg gallic acid eq per 100 g), blueberries (*Vaccinium myrtillus*, 270–930 mg gallic acid eq per 100 g), and melons (*Cucumis melo*, 174 mg gallic acid eq per 100 g) [5].

Figure 1 presents the results of the antioxidant capacity of *Physalis* fruits determined by ABTS and DPPH methodologies. The antioxidant capacities of *P. peruviana* fruits from the Calca and Bambamarca areas were higher than those of the Huántar area in both methods. The value estimated by the DPPH method (286.60 ± 7.44 µM Trolox per 100 g of sample) was slightly higher than that reported by *Puente* et al. [30] (192.51–210.82 µM Trolox per 100 g sample) in Chile; however, it was lower than that reported by *Ozturk* et al. [28] (514.06–604.69 µM Trolox per 100 g of sample) in Turkey. In the case of the ABTS method, the values obtained (896.00 ± 44.14–1003.33 ± 7.64 µM Trolox per 100 g of sample) for the *Physalis* fruits grown in the central Peruvian Andes were higher than those reported by *Curi* et al. [12] and *Licodiedoff* et al. [22], which were 619 and 749–807 µM Trolox per 100 g of sample, respectively. According to *Licodiedoff* et al. [22], the content of phenolic compounds and antioxidant activity depend on the state of maturity of the fruit. *Ramadan* et al. [31] specified that the high levels of antioxidants found in the ethanolic extracts of *Physalis* when using the DPPH and ABTS methods are mainly due to oxygenated monoterpenic compounds, such as bisabolol, a monocycled sesquiterpene alcohol with high antioxidant and anti-inflammatory properties. Several researchers have concluded that the antioxidant capacity of these fruits is mainly due to the presence of phenolic compounds and, to a lesser extent, to the content of vitamin C [23, 33]. The high polyphenols content of the *Physalis* fruit could be responsible for its high antioxidant capacity.

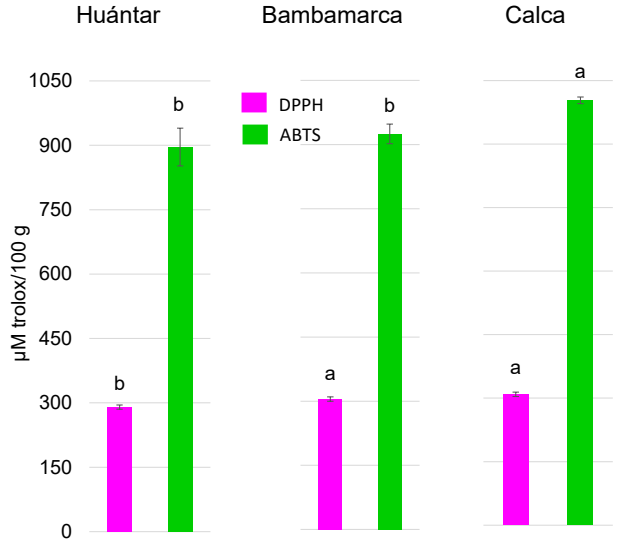

Figure 1. Antioxidant capacity (DPPH and ABTS methods) in *Physalis peruviana* L. fruits grown in the central Peruvian Andes. Different letters in the grouped columns represent a significant difference based on the *Tukey* test ($p < 0.05$).

CONCLUSIONS

The results of the present work show that the *Physalis* fruit cultivated in the Central Andes of Peru contains several nutrients and bioactive compounds, such as minerals, vitamin C, total polyphenols, carotenoids, and antioxidants. The *Physalis* fruit presented levels of calcium (47.27–52.70 mg per 100 g) and phosphorus (48.77–52.53 mg per 100 g) that were significantly higher ($p < 0.05$) than those of other fruits in the region. The most prominent microelements were zinc (5.03–6.23 mg per kg), copper (1.18–1.25 mg per kg), and iron (12.93–14.47 mg per kg). The *Physalis* fruit was also found to be a key source of vitamin C (47.20–52.20 mg per 100 g). Furthermore, the contents of total polyphenols (68.17–83.40 mg gallic acid eq per 100 g), total carotenoids (1.12–1.73 mg per 100 g), and antioxidant capacity determined by the DPPH (290–309 µM Trolox per 100 g) and ABTS (896.00–1033 µM Trolox per 100 g) methods were high. The results demonstrate that the *Physalis* fruit grown in the Andean region of Peru is a potential candidate for the development of new functional foods due to its nutritional and bioactive properties. Finally, the fruits of *P. peruviana* grown in the Calca region presented higher contents of proteins, potassium, vitamin C, total carotenoids, and total polyphenols.

Conflicts of interest

The Authors declare no conflict of interest.

REFERENCES

1. *Ajila C.M., Leelavathi K., Prasada Raoa U.J.S.*: Improvement of dietary fiber content and antioxidant properties in soft dough biscuits with the incorporation of mango peel powder. J Cereal Sci 2008;48:319-326.
2. *Albalasmeh A.A., Berhe A.A., Ghezzehei T.A.*: 2013. A new method for rapid determination of carbohydrate and total carbon concentrations using UV spectrophotometry. Carbohydr Polym 2013;97:253-261.
3. AOAC. Official methods of analysis of AOAC International, 18th edition. Gaithersburg, Maryland, 2010.

4. AOAC. Official methods of analysis of AOAC International, 19th edition. Gaithersburg, Maryland, 2012.
5. *Balasundram N., Sundram K., Samman S.*: Phenolic compounds in plants and agri-industrial by-products: Antioxidant activity, occurrence, and potential uses. Food Chem 2006;99:191-203.
6. *Bazalar Pereda M.S., Nazareno M.A., Viturro C.I.*: Optimized formulation of a Physalis peruviana L. fruit nectar: physicochemical characterization, sensorial traits and antioxidant properties. J Food Sci Technol 2020;57:3267-3277.
7. *Benassi M.T., Antunes A.J.*: A comparison of meta-phosphoric and oxalic acids as extractant solutions for determination of vitamin C in selected vegetables. Arq Biol Tecnol 1988;31:507-513.
8. *Brand-Williams W., Cuvelier M.E., Berset C.*: Use of a free radical method to evaluate antioxidant activity. LWT-Food Sci Technol 1995;28:25-30.
9. *Carbajal Y, Bonilla H., Siles-Vallejos M., López A.*: Citogenética comparativa de *Physalis peruviana* en tres poblaciones cultivadas de Cajamarca, Perú [Comparative cytogenetics of Physalis peruviana from cultivated populations from Cajamarca, Peru]. Revista Peruana de Biologia 2021, doi:10.15381/rpb.v28i2.20462 (in Spanish).
10. *Carvalho C.M., Gross L.A., Azevedo M.J., Viana L.V.*: 2019. Dietary fiber intake (supplemental or dietary pattern rich in fiber) and diabetic kidney disease: a systematic review of clinical trials. Nutrients 2019;11:347.
11. *Castro A., Davila C., Laura W., Cubas Saucedo F., Ávalos G., López Ocaña C., Villena D., Valdez M., Urbiola J., Trebejo I., Menis L.*: Climas del Perú: mapa de clasificación climática nacional [Cimates of Peru: National climate classification map]. https://repositorio.senamhi.gob.pe/handle/20.500.12542/923 (accessed 01.11.2021).
12. *Curi P.N., Carvalho C.S., Salgado D.L., Pio R., Silva, D.F., Pinheiro A.C.M., Souza V.R.*: Characterization of different native American physalis species and evaluation of their processing potential as jelly in combination with brie-type cheese. Food Sci. Technol. Campinas, 2018;38:112-119.
13. *Fernández-Condori R., Ramos-Escudero F.*: Efecto de la ingesta de frutas nativas como guanábana, sachatomate, aguaymanto y tumbo serrano sobre la glicemia a través del índice glicémico [Effect of the intake of native fruits such as soursop, sachatomate, goldenberry, and tumbo serrano on glycemia througt glycemic index]. Revista Española de Nutricion Comunitaria 2021;27(2).
14. *Fischer G., Almanza-Merchán P.J., Miranda D.*: Importancia y cultivo de la uchuva (*Physalis peruviana* L.) [Importance and cultivation of cape gooseberry (*Physalis peruviana* L.)]. Rev Bras Frutic 2014;36:1-15.
15. *Grosso G., Bei R., Mistretta A., Marventano S., Calabrese G., Masuelli L., Giganti M.G., Modesti A., Galvano F., Gazzolo D.*: Effects of vitamin C on health: a review of evidence. Front Biosci 2013;18:1017-1029.
16. *Guiné, R.P.F., Gonçalves F.J.A., Oliveira S.F., Correia P.M.R.*: Evaluation of phenolic compounds, antioxidant activity and bioaccessibility in *Physalis peruviana* L. Int J Fruit Sci 2020;2:S470-S490.
17. *Häkkinen S.H., Kärenlampi S.O., Heinonen I.M., Mykkänen H.M., Törrönen A.R.*: Content of the flavonols quercetin, myricetin, and kaempferol in 25 edible berries. J Agric Food Chem 1999;47:2274-2279.
18. Institute of Medicine. Panel on micronutrients. dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Washington (DC): National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK222318/ (accessed 05.11.2021).
19. *Jiménez-Escrig A., Jiménez-Jiménez I., Pulido R., Saura-Calixto F.*: Antioxidant activity of fresh and processed edible seaweeds. J Sci Food Agric 2001;81:530-534.
20. *Jurado Teixeira B., Aparcana Ataurima I.M., Villarreal Inca L.S., Ramos Llica E., Calixto Cotos M.R., Hurtado Manrique P.E., Acosta Alfaro K.M.C.*: Evaluación del contenido de polifenoles totales y la capacidad antioxidante de los extractos etanólicos de los frutos de aguaymanto (*Physalis peruviana* L.) de diferentes lugares del Perú. Rev Soc Quím Perú 2016;82:272-279.
21. *Leterme P., Buldgen A., Estrada F., Londono A.M.*: Mineral content of tropical fruits and unconventional foods of the Andes and the rain forest of Colombia. Food Chem 2006;95:644-652.
22. *Licodiedoff S., Koslowski L.A.D., Hoffmann Ribani R.*: Flavonols and antioxidant activity of *Physalis peruviana* L. fruit at two maturity stages. Acta Sci Technol 2013;35:393-399.
23. *Miller N.J., Rice-Evans C.A.*: Factors influencing the antioxidant activity determined by the $ABTS^{+}$ radical cation assay. Free Radic Res 1997;26:195-199.
24. *Nocetti D., Núñez H., Puente L., Espinosa A., Romero F.*: Composition and biological effects of goldenberry byproducts: an overview. J Sci Food Agric 2020;100:4335-4346.
25. *Obregón-La Rosa A.J., Elías-Peñafiel C.C.A., Contreras-López E., Constanza Arias-Arroyo G., Bracamonte-Romero M.*: Physicochemical, nutritional, and morphological characteristics of native fruits. Rev Investig Altoandin 2021;23:17-25.
26. *Olivares-Tenorio M-L., Dekker M., Verkerk R., van Boekel M.A.J.S.*: Health-promoting compounds in cape gooseberry (*Physalis peruviana* L.): Review from a supply chain perspective. Trends Food Sci Technol 2016;57:83-92.
27. *Oliveira S.F., Gonçalves F.J.A., Correia P.M.R., Guiné R.P.F.*: Physical properties of *Physalis peruviana* L. Open Agric 2016;1:55-59.
28. *Ozturk A., Özdemir Y., Albayrak B., Simşek M., Yildirim K.C.*: Some nutrient characteristics of goldenberry (*Physalis peruviana* L.) cultivar candidate from Turkey. Sci Papers Ser B Hortic 2017;61:293-297.
29. *Petkova N.T., Popova V.T., Ivanova T.A., Mazova N.N., Panayotov N.D., Stoyanova A.*: Nutritional composition of different cape gooseberry genotypes (*Physalis peruviana* L.) – a comparative study. Food Res 2021;5:191-202.

30. *Puente L.A., Pinto-Muñoz C.A., Castro E. S., Cortés M.*: *Physalis peruviana* Linnaeus, the multiple properties of a highly functional fruit: A review. Food Res Int 2011;44:1733-1740.
31. *Ramadan M., El-Ghorab A.H., Ghanem K.Z.*: Volatile compounds, antioxidants, and anticancer activities of cape gooseberry fruit (*Physalis peruviana* L.): An in-vitro study. J Arab Soc Med Res 2015;10:56-64.
32. *Ramadan M.F.*: Bioactive phytochemicals, nutritional value, and functional properties of cape gooseberry (*Physalis peruviana*): An overview. Food Res Int 2011;44:1830-1836.
33. *Rapisarda P., Tomaino, A., Lo Cascio, R., Bonina, F., De Pasquale, A., Saija, A.*: Antioxidant effectiveness as influenced by phenolic content of fresh orange juices. J Agric Food Chem 1999;47:4718-4723.
34. *Re R., Pellegrini N., Proteggente A., Pannala A., Yang M., Rice-Evans C.*: Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radic Biol Med 1999;26:1231-1237.
35. *Reyes M., Gómez-Sánchez I., Espinoza C.*: Tablas peruanas de composición de alimentos. Instituto Nacional de Salud, Lima, Perú. 2017.
36. *Sharoba M.A., Ramadan M.F.*: Rheological behavior and physicochemical characteristics of goldenberry (*Physalis peruviana*) juice as affected by enzymatic treatment. J Food Process Preserv 2011;35:201-219.
37. SIICEX. Aguaymanto. Sistema Integrado de información de Comercio Exterior. https://www.siicex.gob.pe/siicex/portal5ES.asp?_page_=172.17100&_portletid_=sfichaproductoinit&scriptdo=cc_fp_init&pproducto=229&pnomproducto=Aguaymanto (accessed 01.12.2021).
38. *Siles-Vallejos M., Bracamonte-Guevara O., García-Paitán M., López-Sotomayor A.*: Primer reporte sobre identificación del locus 5s rADN en cromosomas de *Physalis peruviana* L. Sci Agropecu 2021;12:149-153.
39. *Singleton V.L., Rossi, J.A.*: Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Am J Enol Vitic 1965;16:144-158.
40. *Talcott S.T., Howard L.R.*: Chemical and sensory quality of processed carrot puree as influenced by stress-induced phenolic compounds. J Agric Food Chem 1999;47:1362-1366.
41. *Thuy N.M., Phuong N.P., Suong C.T.D., Tai N.V.*: Physical and chemical characteristics of goldenberry (*Physalis peruviana*) grown in Lam Dong province, Vietnam. Food Res 2020;4;1217-1225.
42. *Carr A.C., Lykkesfeldt J.*: Discrepancies in global vitamin C recommendations: a review of RDA criteria and underlying health perspectives. Crit Rev Food Sci Nutr 2021;61;742-755.

Received: 06.11.2023
Accepted: 07.02.2023