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REVIEW ARTICLE

A review of nutritional properties and health benefits of *Physalis* species

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Abstract
The *Physalis* genus of the *Solanaceae* family is home to many edible food crops including tomatillo, goldenberry, and groundcherry. These *Physalis* members have garnered more attention as consumer interest in novel fruits and vegetables has increased because of increasing awareness of the health benefits of eating a diverse diet. As a result of this interest, several preliminary studies were conducted of these *Physalis* to evaluate their nutritional and chemical profiles associated with health benefits. Results showed these crops contain many essential minerals and vitamins, notably potassium and immune system supporting Vitamin C, also known for its antioxidant activity. Beyond nutritional properties, these crops also contain a class of steroidal lactones called withanolides, which have been recognized for their antitumor, and antinflammatory properties. In some studies, withanolide extract from *Physalis* species have exhibited cytotoxicity towards cancers cells. Overall, this review focuses on the nutritional and physiochemical properties of tomatillo, goldenberry, and groundcherry and how they relate to human health.

Keywords *Physalis* · Tomatillo · Groundcherry · Goldenberry · Nutrition · Health · Functional food

Abbreviations

ABTS	2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonate)
DM	Dry matter
DPPH	2,2-diphenyl-1-picrylhydrazyl
DW	Dry weight
FW	Fresh weight
FRAP	Ferric reducing ability of plasma
GAE	Gallic acid equivalent
ORAC	Oxygen radical absorption capacity
TE	Trolox equivalents

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Introduction

A diverse diet of predominately fruits and vegetables has been shown to be of great benefit for human health and avoidance of chronic conditions. Fruits and vegetables are rich in naturally occurring substances, such as antioxidants, that have health benefits beyond basic nutrition [1]. The well documented benefit has led to increased interest in untapped sources of novel fruits and vegetables, and their potential to provide a source of beneficial compounds and key nutrients as part of a healthy diet. One such underutilized source is the *Physalis* genus in the *Solanaceae* family, which also contains more commonly known food crops such as tomato, pepper, and potato. The *Physalis* genus has gained more interest as a potential source for new food crops because it contains many edible species; however, they are underutilized within the current food production system yielding their nutritional benefits widely unrealized.

The *Physalis* genus contains an estimated 85 species of annual and perennial plants that are grown in temperate regions of the world [2]. The genus is native to South America and originated at least 52 million years ago, during the Eocene Epoch [3]. Members of this genus can be distinguished by the inflated calyx that forms a husk that surrounds the fruit during development. The husk possibly evolved to aid in seed

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dispersal and offers protection against environmental pressures such as pests, diseases [3–5].

Overall, the majority of *Physalis* species grow wild, with only few species cultivated as food crops or ornamentals [6]. Among those cultivated are tomatillo, goldenberry, and groundcherry. These tomato relatives have been cultivated for both dietary and medicinal purposes. Over time, interest in these edible *Physalis* has grown because of their chemical compounds and culinary properties [7–12].

One of the most well-known cultivated food crops of the *Physalis* genus is tomatillo (*P. ixocarpa or P. philadelphica)*, a specialty crop native to Mexico that remains a cultural staple for much of Mexico and Central America. Depending on the cultivar, tomatillo are either green or purple and range from 2.5 to 6.25 cm in diameter [13]. Known for its unique acidic flavor, tomatillo is prominently featured in Mexican cuisine, and is commonly used in sauces, salads, and salsas [9]. The crop is grown best at low altitudes, between 18 and 25 °C on slightly acidic soils in regions receiving between 60 and 120 cm of annual rainfall [14]. Tomatillo is grown year-round in Mexico, which is the largest producer. In 2016, it was estimated that Mexico produced 698,000 tons of tomatillo and exports of the crop were valued at 66.6 million USD, double the value of 2010 exports. The largest importer of tomatillo is the United States [9, 14] .

Another edible *Physalis* species is *P. peruviana,* commonly known as Cape gooseberry or goldenberry. Goldenberry is believed to have originated in the Peruvian and Ecuadorian Andes region of South America [12]. The crop is grown in tropical regions as a perennial and in temperate regions as an annual [13]. Like other members of the genus, the fruit comes wrapped in a husk that turns papery upon maturation. The fruit is a golden-colored globular berry, 1.25–2.50 cm in diameter, weighing 4 to 10 g [15]. It is consumed fresh and used for desserts and preserves, but it is also dried [16]. The biggest producer of goldenberry is Colombia, which produces 11,500 tons of fruit *per* year, which is second only to banana production [12]. International demand for goldenberry has resulted in a large volume of exports. In 2015, Colombian exports of the crop were valued at 30.2 million USD at a volume of 5832 tons, with the main importers being members of the European Union [17].

Goldenberry is rich in nutrients and other bioactive compounds; notably vitamins A, B, C, antioxidants known to benefit human health [12]. In folk medicine, other parts of the plant have been used for their believed medicinal properties in treatment of diseases such as cancer and hepatitis [18]. Specifically, members of the Malayali tribes in the Kolli Hills of India use *P. peruviana* whole plant extract to treat skin diseases, and the Tribes of Thiashola, Manjoor, and Western Ghats use the leaves and seeds to treat jaundice and glaucoma [19, 20].

Beyond medicinal properties, interest in the goldenberry's potential as a health food has continued to grow. In 2018, Nestlé acquired a 60% stake in Terrafertil, the world's largest buyer of goldenberry, citing a desire to expand their plant–based food offerings "known as 'superfoods' due to their high natural nutrient content" [21]. Meanwhile, South African producer Keisie Valley Gooseberries, is hoping to shift the market from decorative garnish to "superfood" in the European Union [22]. Overall, there has been a growing interest in the nutritional profile of goldenberry which has translated into marketability to food producers and consumers.

Groundcherry (Spp. *pruinosa, pubescens, grisea*), which is native to North America, is similar in appearance to goldenberry [23]. Although *P. pruinosa*, *P. pubescens, and P. grisea* are different species, they are commonly confused and are collectively marketed under the name groundcherry [24]. Groundcherry also matures in a husk, however, it drops to the ground at various stages of maturity. The fruit drop, hence the name groundcherry, creates a labor-intensive harvest and also risks the degradation of fruit quality from mechanical damage or infection by soil-borne pathogens. Researchers have proposed solutions to mitigate the fruit drop problem, including net, a trellising technique, and a self-propelled mechanical harvester, however these approaches have not been readily adopted [25, 26]. Groundcherry fruit are smaller than goldenberry, and have milder, yet unique flavor that is described as both sweet and tart. Over time, different cultivars of the groundcherry have been produced, with varieties such as "Aunt Molly's and "Goldie" readily available from United States seed suppliers. Groundcherries are mainly cultivated in home gardens and small farms in North America and Europe, and presently no large-scale commercial production exists. The fruit is predominately eaten fresh, but is also used for pies, jams, and salsas. Groundcherry is used as part of ancient Chinese medicine to treat fevers, coughs, sore throats and abscesses [27]. Similar to its relatives, the groundcherry contains a variety of beneficial compounds that benefit human health.

Nutritional and compositional properties of *Physalis* species

Various studies have been conducted to further investigate the underlying nutritional profiles of tomatillo, goldenberry, and groundcherry. Many factors (*e.g.*, differences in cultivar, growing conditions) can influence the nutritional and physiochemical composition of food. The purpose of this review is to collate research on the chemical properties across these three edible *Physalis* species, to provide a general overview of their nutritional characteristics. A comparison of their nutritional properties between can be found in Tables 1, 2, and 3.

Table 1 Comparison of chemical properties of tomatillo, goldenberry, and groundcherry

	P. ixocarpa[1]	*P. peruviana*	*P. pubescens*[6]	*P. pruinosa*[a]
pH	3.76	3.48[2], 3.92[3]	3.74	–
Total soluble solids	0.54	–	13.46	–
Total titratable acidity (%)	–	0.35[5], 1.85[3], 2.00[4]	1.23	–
°Brix	8.24	6.43–17.3[5], 14.80[3]		–
Moisture content	91.76	76.9–85.9,[2] 79.11[3], 85.4[4]	81.34	–
Protein (% FW)	0.75–1.06	0.3–1.9[2], 1.35[3], 1.9[4]	2.46	–
Fat (% FW)	1.12–2.10	0.0–0.5[2], 0.39[3], 0.7[4]	2.91	–
Ash (% FW)	0.77–1.42	0.7–1.0[2], 0.81[3], 0.8[4]	5.58	–
Total dietary fiber (% FW)	0.085–0.68	0.4–4.9[2], 4.12[3]	–	–
Carbohydrate (% FW)	4.36	11.0–19.6[2], 14.22[3], 11.2[4]	–	–
Kcalories/100 g	31.45	49.0–76.8, 53	49	–

[1] Bock et al. 1995

[2] Puente et al. 2011

[3] Bazalar Pereda et al. 2019

[4] USDA

[5] Singh et al. 2014

[6] El Sheikha et al. 2010

[a] No available data

Nutritional aspects of *Physalis*

The chemical properties of *Physalis* species have been analyzed across many studies, where differences in pH, brix, protein, and other chemical characteristics have been observed (Table 1). The basic nutritional properties of tomatillo were analyzed in a study that used the green-fruited Sero Gordo variety. The average pH was 3.76, which is considered acidic enough for food preservation purposes, and is more acidic than the average tomato [9]. Moisture content had an overall mean of 91.76%, protein ranged from 0.75–1.06% FW, fat ranged from 1.12–2.10%, ash content ranged from 0.77–1.42%. Total dietary fiber content was also variable, ranging from 0.085 – 0.68%. Excluding dietary fiber content, the total carbohydrate content was found to be 4.36% on average. The overall caloric value was calculated at approximately 31.45 kcalories/100 g FW [9]. These values were similar to the composition reported by the USDA, though no cultivar information was provided [28]. In a separate study, total soluble solids and total titratable acidity were reported as 8.24 °Brix and

Table 2 Comparison of mineral content in tomatillo, goldenberry, and groundcherry

	P. ixocarpa[1]	*P. peruviana*	*P. pubescens*[4]	*P. pruinosa*[a]
Potassium	268	210–320[2], 373.25[3]	239.09	–
Phosphorous	39	27–55[2]		–
Magnesium	20	7-19[2], 48.7[3]	34.52	–
Calcium	7.00	8–28[2], 11.17[3]	12.31	–
Sodium	1.00	1–6[2], 8.78[3]	–	–
Iron	0.62	0.03–1.24[2]	2.53	–
Zinc	0.22	0.28–0.40[2]	1.18	–
Manganese	0.153	–	0.27	–
Copper	0.079	0.35[3]	0.035	–
Selenium	0.0005	–	–	–

[1] USDA

[2] Puente et al. 2011

[3] Bazalar Pereda et al. 2019

[4] El Sheikha et al. 2010

[a] No available data

Table 3 Comparison of vitamin content in fruit pulp of tomatillo, goldenberry, and groundcherry

	P. ixocarpa	*P. peruviana*	*P. pubescens**	*P. pruinosa*
Vitamin C (mg 100 g^{-1} FW)	8–15[1], 24.28[2], 11.7[3]	33.4–39.4[4], 20.00–40.00[5]	39.68[2]	24.28[2]
Vitamin A (IU or mg 100 g^{-1} DW)	114[3]		0.04 mg[6]	–
β-carotene		648[5] IU, 1730[5] IU, 720 IU[5], 1460mg[3]		
Thiamin (mg 100 g^{-1} FW)	0.044[3]	0.10–0.18[5], 0.110[3]	23.41[6] (mg 100 g^{-1} DW)	–
Riboflavin (mg 100 g^{-1} FW)	0.035[3]	0.03–0.17[5], 0.04[3]	6.24[6] (mg 100 g^{-1} DW)	–
Niacin (mg 100 g^{-1} FW)	1.850[3]	0.8–1.70[5], 2.80[3]	20.21[6] (mg 100 g^{-1} DW)	–
Pantothenic acid (mg 100 g^{-1} FW)	0.150[3]	–		–
Pyridoxine (mg 100 g^{-1} FW)	0.056[3]		19.73[6] (mg 100 g^{-1} DW	–
Folate (µg 100 g^{-1} FW)	7.00[3]		5.23 (mg100g^{-1} DW)	–
Cobalamin			16.23 (mg 100 g^{-1} DW	
Vitamin E (mg 100 g^{-1} FW)	0.38[3]		0.04 (mg 100 g^{-1} DW)	–
Vitamin K (mg 100 g^{-1} FW)	10.10		2.33 (mg 100 g^{-1} DW)	–

*Contains values reported on a DM basis

[1] Ostrzycka et al. 1988

[2] Singh et al. 2014

[3] USDA

[4] Olivares-Tenorio et al. 2016

[5] Puente et al. 2011

[6] Rashwan and Khalifa 2017

0.54%, respectively [29]. Acidity and Brix properties have been shown to affect tomatillo flavor; in one experiment fruit containing the highest amounts of sugar and acid was rated as the best tasting [30].

In a review of the nutritional profile of goldenberry, Puente et al. [12] compared data from five different studies. The average pH was found to be 3.48, and caloric content ranged from 49 to 76.8 cal *per* 100 g FW. Moisture content ranged from 76.9–85.9%, protein content 0.3–1.9% FW, fat content 0.0 -0.5% FW, and ash content 0.7–1.0% FW. Dietary fiber ranged from 0.4–4.9% FW and total carbohydrate from 11.0–19.6% FW [5, 16, 31–33]. A more recent study determined the pH of goldenberry to be 3.92, slightly higher than average reported by Puente et al. [12], however the rest of the values reported for the above physiochemical fell within the ranges reported [34]. Goldenberry is also listed in the USDA nutritional database, but was erroneously referred as “groundcherries”. It is also listed as cape-gooseberry and poha, two common names for *P. peruviana*. They report moisture content as 85.4%, a caloric value of 53 cal *per* 100 g FW, 1.9% protein, 0.7% fat, 0.8% ash, and 11.2% carbohydrates [35].

Other chemical characteristics of goldenberry have been found to vary across ecotypes. For instance, in an ecotype from India, total soluble solids, measured in °Brix, were found to be 6.43, and total titratable acid was 0.35%, while an ecotype from Colombia had 17.3° Brix and a titratable acid of 2% m/m citric acid [29]. Goldenberry fruit collected from the Argentinean North Andean Region had a total soluble solids of 14.80 °Brix and a titratable acidity of 1.85% m/m citric acid [34]. Differences in sugar content within goldenberry germplasm have been found to be a result of different growing environments as well as underlying genetics [36, 37] . Other reported values from studies in Colombia for °Brix and titratable acidity fell close to those reported for the Colombia ecotype, though it is not explicitly stated the ecotype used [12].

Less popular worldwide than tomatillo and goldenberry is the wild relative known as the groundcherry. Although this species is not yet commercially produced, there have been several reports on the chemical properties of this small fruit. A study by El Sheikha et al. [27] evaluated the chemical properties of *P. pubescens* fruit. The pH was 3.74 and caloric content was listed as 49 cal/100 g DM. Moisture content was 81.34%, protein 2.46% FW, fat 2.91% FW, crude fiber 5.78% DM, ash 5.58% DM, and reducing and non-reducing sugars were 18.16–14.27% DM, respectively. Total soluble solids were found to be 13.46% and total titratable acidity was 1.23%.

Minerals

Many of the macro- and micronutrients needed for human health are found in *Physalis* species (Table 2). According to the USDA, tomatillo contains the following *per* 100 g^{-1} FW: 268 mg potassium, 39 mg phosphorous, 20 mg magnesium, 7 mg calcium, 1 mg sodium, 0.62 iron, 0.22 mg zinc, 0.153 mg manganese, 0.079 mg copper, and 0.5 µg selenium

[28]. Although mineral content may vary depending on the cultivar, interestingly, it appears that in tomatillo mineral content is not greatly influenced. A comparison study examined three different cultivars of tomatillo for mineral content on a DM basis: Rendidora B1, Antocyjanowa, and Bujna. Overall, all three cultivars yielded similar mineral content and were found to have insignificant differences [30].

Mineral content in goldenberry was previously reviewed in Puente et al. [12], where data from four studies was analyzed. *Per* 100 g of pulp, potassium was by far the most abundant ranging from 210 to 320 mg followed by phosphorous 27–55 mg, calcium 8–28 mg, and magnesium 7–19 mg. Other minerals present in smaller amounts based on 100 g^{-1} FW were sodium 1–6 mg, iron 0.03–1.24 mg, and zinc 0.28–0.40 mg [16, 33, 38, 39]. An additional study found higher levels of potassium and magnesium reporting 373.25 and 48.7 mg, respectively [34].

The USDA data for calcium, iron, and phosphorous all fall within the ranges listed reported by Puente et al. [12]. A separate study by Rodrigues et al. [40] analyzed the mineral content of goldenberry on a dry matter basis notably reporting 347 mg of potassium, 34.70 mg magnesium, and 9 mg of calcium.

In a study of fresh fruit of *P. pubescens* by Rashwan et al. [41], the following minerals were found *per* 100 g of FW: 239.09 mg potassium, 12.31 mg calcium, 34.52 mg magnesium, 2.53 mg iron, 0.035 mg copper, 0.27 mg manganese, and 1.18 mg zinc [41]. Interestingly, *P. pubescens* juice was found to have the same mineral content where notably potassium content was 25.4% and phosphorous was 83.6% of the adult daily recommended intake [27].

Vitamins

Physalis species contains most of the essential vitamins needed to promote human metabolism (Table 3). The ascorbic acid (vitamin C) content of tomatillo has been the focus in multiple studies as it functions as an antioxidant and supports important human functions such as the immune system. One study reported the vitamin C content to be 8–15 mg 100 g^{-1} FW across three different cultivars (Rendidora BI, Bujna, and Anotcyjanowa) and noted that lower levels were observed towards the end of the growing season [30]. Another study that analyzed the juice of the fruit reported a higher value of 24.28 mg 100 g^{-1} FW, though no cultivar was specified [29]. The USDA lists vitamin C content to be 11.7 mg 100 g^{-1} FW, which is 7% of the adult recommended daily value (DV) [28].

Tomatillo is also a source of other essential vitamins. According to the USDA tomatillo contains on 100 g^{-1} FW Basis: 114 IU vitamin A, 0.044 mg thiamin (B_1), 0.035 mg riboflavin (B_2), 1.850 mg niacin (B_3), 0.150 mg pantothenic acid (B_5), 0.056 mg vitamin B_6, 7 μg total folate (B_9), 0.38 mg vitamin E, and 10.1 μg vitamin K. These values were obtained from multiple studies, however, cultivar information was not provided [28].

Similar to tomatillo, goldenberry also contains a high amount of vitamin C, with one study reporting 33.4–39.4 mg 100 g^{-1} FW, a value confirmed to be similar in other studies [15, 34, 42]. However, goldenberry is frequently processed before consumption, undergoing pasteurization or drying, all processes that may involve heat, a factor known to degrade vitamin C. Notably, it was found that vitamin C in goldenberry degrades much slower than other vitamin-C containing fruits, and is considered to be approximately 15 times more stable. It was found that vitamin C was still available at relevant levels after heating, indicating that food processing does not greatly decrease content [42].

The vitamin content of goldenberry was also previously reviewed by Puente et al. [12] where a range of values from three separate studies was reported in fruit pulp on a 100 g^{-1} FW basis. Accession information for each study was not provided, and could contribute to some of the variation in the determined values. β-carotene was reported as 648 IU, 1730 IU, and 1460 mg. Thiamine (B_1) ranged from 0.10–0.18 mg, riboflavin (B_2), 0.03–0.17 mg, and Niacin (B_3) 0.8–1.70 mg. Vitamin C values were similar to the previously mentioned study, ranging from 20–40 mg. Furthermore, the USDA has reported similar values of 720 IU vitamin A, 0.110 mg thiamine, 0.04 mg riboflavin, and 2.80 mg niacin [35].

Vitamin content in goldenberry was also specifically analyzed in the oils found in seeds, pulp and skin on a g *per* kg of total lipids basis by Ramadan and Mörsel [43]. They reported that in seed oil there was 0.12 g vitamin K_1, 29.70 g vitamin E, 0.88 g α-tocopherol, 11.30 g β-tocopherol, 9.08 γ-tocopherol, and 8.44 g δ-tocopherols. In pulp and skin oil the following values were reported 2.12 g vitamin K_1, 86.30 vitamin E, 22.50 g α-tocopherol, 13.10 g β-tocopherol, 50.40 γ-tocopherol, and 0.30 g δ-tocopherols.

Values of vitamin content have also been determined for both species of groundcherry. In *P. pubescens*, the vitamin C content was 39.68 mg 100 g^{-1} FW. A similar value of 24.28 mg 100 g^{-1} was reported for *P. pruinosa* [29]. In addition to vitamin C, *P. pubescens* fruit have also been found to contain water-soluble B vitamins and fat-soluble A, E, K, and D vitamins. These values were reported *per* 100 g of DW as 23.41 mg thiamine (B_1), 6.24 mg riboflavin (B_2), 20.21 mg nicotinic acid (B_3), 19.73 mg pyridoxine (B_6), 5.23 mg folic acid (B_9), 16.23 mg cobalamin (B_{12}), 0.01 mg vitamin A, 0.04 mg vitamin E, 2.33 mg vitamin K, and 0.04 mg Vitamin D [41].

Fatty acids

Fatty acids are one of the main compounds that comprise lipids. These molecules provide an energy source for animals and support cellular functions. Excessive consumption of saturated fats has been linked to health risks in humans, particularly certain forms of cardiac disease. However, unsaturated fatty acids have been linked to health benefits, with some fatty acids being considered "Essential" fatty acids. These compounds are required for biological functions related to human health and are not synthesized by the human body, therefore diet is the source. There are two fatty acids considered essential to humans; alpha-linoleic acid (omega-3 fatty acid) and linoleic acid (omega-6 fatty acid).

According to the USDA, the tomatillo fruit contains approximately 41.7% polyunsaturated fats, 15.5% monounsaturated fats, and 13.9% saturated fats. The most abundant fatty acid is linoleic acid at 40.2%, followed by 15.5% oleic, 10.2% palmitic, and 4% stearic acids. In the analyzed fatty acid content of tomatillo seeds alone, linoleic acid continued to be most abundant ranging from 83.7–95.2%, followed by oleic acid 2.8–6.7%, palmitic acid 1.4–7.7%, and stearic acid 0.6–2.2%.

The fatty acid profile of goldenberry was analyzed by Rodrigues et al. [40] it was found that oil comprises 2% of the whole berry on a fresh weight basis. The breakdown of the fatty acid profile was 72.42% linoleic, 10.03% oleic, 9.38% palmitic, 2.67% stearic, 1.36% arachidic, 0.71% palmitoleic, 0.32% α-linolenic, 0.26% behenic, and 0.24% lignoceric acids. Of these fatty acids, 73.78% of them are polyunsaturated, 10.71% are monounsaturated, and 12.87% are saturated. In separate study by Ramadan and Mörsel [43], fatty acid composition was analyzed for whole berry, seed, and pulp oils of goldenberry. It was found that linoleic acid comprised 70.6% of whole berry oil, 76.1% seed oil, and 44.4% pulp oil.

There are no known reports of the fatty acid composition of groundcherry fruit, however data is available for the fatty acid profile of *P. pubescens* juice. In this study by El Sheikha et al. [44] it was found that in *P. pubescens* juice 65.5% of the fatty acids were unsaturated. The study reports that juice was comprised of 26.98% α-linolenic, 23.42% oleic, and 5.47% linoleic acids, with other fatty acids found in smaller amounts.

Phytosterols

Another type of compound important to human health is phytosterols, a naturally occurring compound found in plants. These compounds are known for their antioxidant activity and have been linked to lower LDL cholesterol levels. In a study by Ramadan and Mörsel [43] goldenberry was found to contain a variety of phytosterols. They reported *per* 100 g of whole berry oil 6.70 g campersterol, 5.73 g β-sitosterol, 4.70 g Δ5-avenserol, 2.51 g lanosterol, 1.69 g stigmasterol, 1.21 g Δ7-avenasterol, and 1.16 g of ergosterol. To our knowledge there is no reported phytosterol information for tomatillo or groundcherry.

Phenolic compounds

Phenolic compounds are plant secondary metabolites that contribute to qualities such as fruit color and flavor as well as having antioxidant activity among other functions [45]. Quantification of soluble phenolic compounds can vary based on the solvent and extraction method [46]. In a study of four cultivars of purple tomatillo, the values of soluble phenolic content were found to have differed between cultivars, ranging from 5.3 to 10.08 GAE/100 g FW [47]. The total phenolic compound content of goldenberry was analyzed on a DM basis and found to be 23.86 ± 1.22 mg GAE/100 g when extracted from fruit pulp [48]. In a separate study, the phenolic compound content on FW basis of fruit pulp was found to be 15.20 mg GAE/ 100 g [34].

Total soluble phenolic compound content has not been reported for *P. pruinosa*, however, it has been reported for *P. pubescens*. Of interest, the phenolic compound pyrogallol was present in the highest quantity at 173.5 mg 100 g^{1} DW [41]. The polyphenol pyrogallol is known to have antibacterial properties, has been used as a pesticide, and is used pharmaceutically as an antipsoriactic [49, 50]. The compound has also been investigated for its ability to maintain fruit quality in litchi fruit [51]. It is possible that this compound may also play a role in *P. pubescens* fruit quality.

Antioxidant capacity

Many phytonutrients have antioxidant function, which can be measured in terms of its ability to prevent oxidation. Four cultivars of tomatillo were assessed for radical scavenging activity using the DPPH method. The results were reported as a percentage of DPPH radical scavenging activity and ranged from 28–90% across the cultivars [47].

Antioxidant capacity in goldenberry has been determined in multiple studies. In a study by Bazalar Pereda et al. [34] the results of a DPPH and FRAP assays were compared for both cultivated and wild accessions of goldenberry. In both cases, The FRAP values were consistently higher than the antiradical activity ABTS values, with 11.12 versus 3.76 μmol TE/100 g FW for cultivated accessions and 8.96 versus 2.60 μmol TE/100 g FW for the wild accessions. It was speculated that the difference in values between methods could indicate that antioxidant compounds present in goldenberry are more reactive as reducers of ferric ions [34]. An additional finding was that cultivated lines consistently displayed more free-radical scavenging ability than their wild counterparts. Despite this difference, both cultivated and wild accessions had higher FRAP values than those reported for apple, banana, cherry tomato, grapefruit, mango, nectarine, orange and pitaya [34].

A separate study [48] used the oxygen radical absorbance capacity assay (ORAC) to examine the relationship between storage conditions and antioxidant activity in goldenberry fruit pulp. The study found that goldenberry had antioxidant activity of 6914.10 ± 417.27 μmol TE/100 g DM. However, when fruit pulp was stored under pressurized conditions over a period of 60 days at 4 °C it had significantly greater antioxidant capacity than the control stored under non-pressurized conditions at the same temperature [48]. This suggested that post-harvest conditions may affect the nutritional quality of fruit.

Differences in values across studies on the goldenberry fruit could be attributed to differences in methodology. Previous work has examined the ability of different assays including ABTS, DPPH, FRAP, and ORAC to estimate antioxidant activity in guava fruit extracts [52]. This study found that all four methods had comparable results when determining antioxidant activity, but that the FRAP method had the highest reproducibility. Another potential cause for difference in values is difference in accession and ripeness among fruit samples. A study by Bravo et al. [53] looked at 15 different accessions of goldenberry at different ripeness levels and found that antioxidant activity was strongly influenced by accession and maturity of fruit. Higher ORAC values and LDL oxidation inhibition levels were observed at the earlier fruit maturity stages, and decreased as ripening continued.

Information on the antioxidant activity of groundcherry was not available, however compounds known to have antioxidant activity, such as pyrogallol and vitamin C have been found in groundcherry [29, 51]. Therefore, further research into the antioxidant activity of groundcherry is warranted.

Steroidal structures

Withanolides represent a large group of steroids found in the *Physalis* genus. This group has received considerable attention based on the potential health benefits associated with their biological activity as it relates to properties that include anti-inflammatory, anti-microbial, anti-tumor, antifeedant, and immunosuppressive [54]. Not surprisingly, *Physalis* has been used in traditional medicine as treatment for certain maladies [55].

Numerous withanolides have been isolated from tomatillo, among them physalin B, withaphysacarpin, *ixocarpa*lactone A, *ixocarpa*lactone B, *ixocarpa*nolide, 2,3-dihydro-3-methoxywithaphysacarpin, 24,25dihydrowithanolide D, philadelphicalactone A, philadelphicalactone B, philadelphicalactone C, philadelphicalactone D, 18-hydroxywithanolide D, withanone, 2,3-dihydro-3β-methoxyisocarpalactone B and 4β,7β,20R-trihydroxy-1-oxowitha-2,5-dien-22,26-olide, 16β-hydroxy*ixocarpa*nolide (1), 24,25-dihydroexodeconolide C (2), 16,17-dehydro-24-epi-dioscorolide A(3), 17-epi-philadelphicalactone A (4), 16-deoxyphiladelphicalactone C (5), and 4-deoxy*ixocarpa*lactone A [56]. Withanolides extracted from tomatillo, 17-epi-philadelphicalactone, withaphysacarpin, philadelphicalactone C, and *ixocarpa*lactones A have all exhibited cytotoxicity against human renal carcinoma, kidney carcinoma, and melanoma cancer cell lines [56]. Other withanolides, 2,3-dihydro-3-methoxywithaphysacarpin, withaphysacarpin, 24,25dihydrowithanolide D, have been found to induce quinone reductase, which has been linked to prevention of tumor formation [57].

More than 40 withanolides have been isolated from goldenberry, many of which have also been shown to exhibit cytotoxic activity. Among them, 4β-hydroxywithanolide E has exhibited cytotoxicity to cells of lung cancer, liver carcinoma, breast adenocarcinoma, oral cancer, and colorectal cancer while withanolide E, phyperunolide A, and withanolide C exhibited toxicity to cells of lung cancer, liver carcinomas, and breast adenocarcinomas [55]. Researchers have continued to isolate additional withanolides and assay their cytotoxicity against various cancer cell lines to better understand the mechanism underlying the cytotoxic function. Recent findings suggest that the structure of the compound and side chain orientation may play a role in the cytotoxic activity of the withanolides. In one study, it was found that the α-orientation of the side chain and a β-OH at C17 may increase cytotoxic activity against certain cancer cells. Similar findings were noted in tomatillo [56].

Withanolides isolated from *P. pruinosa* and *P. pubescens* include physapubescin A, physapubescin B, physapubescin C, and physapubescin. Physapruin D, isolated from *P. pubescens,* was shown to induce quinone reductase at a rate of 1.27 to 2.41 times higher than the negative control of DMSO [58]. Two withanolides, physapruin A and physapruin B have been isolated from *P. pruinosa,* however, their specific function has not been characterized [59].

Overall the *Physalis* genus contains over 160 withanolides, many of which have exhibited anti-cancer or antitumor properties [55]. The results of these studies are promising, with widespread cancers such as lung, kidney, and skin showing susceptibility to these compounds. However, more research is needed to fully exploit the benefits that these compounds may provide for human health.

An additional type of steroids, known as physalins, has been isolated from whole plant extract of *P. angulata*, *P. minima*, and *P. alkekgeni* [60–64]. Preliminary findings by Fukushima et al. [65] suggest that physalins are also present in the leaves of *P. peruviana*. In this study [65], liquid chromatography was used to analyze the presence of physalin B, D, and F in the leaves of *P. peruviana* and *P. alkekgeni*. When comparing signal strength, *P. alkekgeni* had a much stronger signal for all three physalin compounds, however there were still detectable levels of physalin B and F in some accessions of *P. peruviana*. Despite being found in *P. alkekgeni,* physalin D was not detected in any of the

P. peruviana samples [65]. These compounds are notable as previous studies have shown that physalins may have anti-tumor and anti-microbial functions [66]. Further research into the possible presence of these compounds in edible species of *Physalis* could elucidate additional health beneficial attributes of the fruit.

Conclusion

As consumers become more health-conscious and begin to look for alternative sources of nutrition in their diets, they should look no farther than the *Physalis* genus, which offers fruit and vegetables rich with vitamins, minerals, and other health-promoting compounds. Many of the vitamins essential to human health are found in these species in addition to minerals known to help regulate systems in the body. In particular, vitamin C was found in high amounts, and is known for its health benefits including its role as an antioxidant and promoting a healthy immune system. Furthermore, phenolic compounds found in these edible *Physalis* also exhibit antioxidant activity, responsible for scavenging harmful free radicals. Notably, tomatillo, goldenberry and groundcherry all contain withanolides, a group of steroidal lactones, of which some exhibit anticancer and antitumor activity.

While there is detailed information related to the nutritional qualities of goldenberry and tomatillo, it is important to note that among the edible species of *Physalis,* there is a considerable lack of research into the species of groundcherry, and more work is needed in that area. Additional studies needed to broaden the knowledge of nutritional content would involve determination of folate content in goldenberry and groundcherry. To expand on research related to nutritional benefits of goldenberry, groundcherry, and tomatillo, studies on bioavailability of the various nutritional components would perhaps reveal some unique attributes of absorption in the gut for added health benefits compared to other fruit. Current research offers a promising outlook on the health benefits derived from the consumption of *Physalis*, and we expect more research to be conducted in the future to better understand the mechanisms underlying these benefits.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights This article does not contain any studies with human participants performed by any of the authors.

References

1. Siró I, Kápolna E, Kápolna B, Lugasi A (2008) Functional food. Product development, marketing and consumer acceptance—a review. Appetite 51:456–467. https://doi.org/10.1016/J.APPET.2008.05.060
2. Vargas O, Martínez M, Dávila AP (2001) Two new species of *Physalis* (*Solanaceae*) endemic to Jalisco, Mexico. Brittonia 53:505–510. https://doi.org/10.1007/BF02809650
3. Wilf P, Carvalho MR, Gandolfo MA, Cúneo NR (2017) Eocene lantern fruits from Gondwanan Patagonia and the early origins of Solanaceae. Science 355:71–75
4. He C, Münster T, Saedler H (2004) On the origin of floral morphological novelties. FEBS Lett 567:147–151. https://doi.org/10.1016/j.febslet.2004.02.090
5. Fischer G, Lüdders P (1997) Developmental changes of carbohydrates in cape goosberry (*Physalis peruviana* L) fruits in relation to the calyx and the leaves. Agron Colomb 14:95–107. https://doi.org/10.1016/J.MSEA.2015.07.007
6. Khan W, Bakht J (2015) Development of efficient and optimized protocol for rapid micropropagation pf *Physalis ixocarpa*, a medicinal herb. Pak J Weed Sci Res 21:381–391
7. Lim TK (2013) *Physalis peruviana*. In: Edible medicinal and non-medicinal plants. Springer Netherlands, Dordrecht, pp 300–309
8. Takimoto T, Kanbayashi Y, Toyoda T, Adachi Y, Furuta C, Suzuki K, Miwa T, Bannai M (2014) 4β-Hydroxywithanolide E isolated from *Physalis pruinosa* calyx decreases inflammatory responses by inhibiting the NF-κB signaling in diabetic mouse adipose tissue. Int J Obes 38:1432–1439. https://doi.org/10.1038/ijo.2014.33
9. Bock MA, Sanchez-Pilcher J, Mckee LJ, Ortiz M (1995) Selected nutritional and quality analyses of tomatillos (Physalis ixocarpa). Plant Foods Hum Nutr 48:127–133
10. Kupska M, Jeleń HH (2017) In-tube extraction for the determination of the main volatile compounds in *Physalis peruviana* L. J Sep Sci 40:532–541. https://doi.org/10.1002/jssc.201600797
11. Zhang C-R, Khan W, Bakht J, Nair MG (2016) New antiinflammatory sucrose esters in the natural sticky coating of tomatillo (*Physalis philadelphica*), an important culinary fruit. Food Chem 196:726–732. https://doi.org/10.1016/j.foodchem.2015.10.007
12. Puente LA, Pinto-Muñoz CA, Castro ES, Cortés M (2011) *Physalis peruviana* Linnaeus, the multiple properties of a highly functional fruit: a review. FRIN 44:1733–1740. https://doi.org/10.1016/j.foodres.2010.09.034
13. Morton, JF (1987) Fruits of warm climates. Julia F. Morton, Miami, pp 430–434
14. SIAP (2017) Atlas Agroalimentario 2017 | Servicio de Información Agroalimentaria y Pesquera https://www.gob.mx/siap/prensa/atlas-agroalimentario-2017. Accessed 20 Sept 2018
15. Olivares-Tenorio M-L, Dekker M, Verkerk R, Van Boekel MAJS (2016) Health-promoting compounds in cape gooseberry (*Physalis peruviana* L.): review from a supply chain perspective. Trends Food Sci Technol 57:83-92. https://doi.org/10.1016/j.tifs.2016.09.009
16. National Research Council (1989) Goldenberry (cape gooseberry). In: Lost crops of the Incas: little-known plants of the Andes with promise for worldwide cultivation. National Academies Press, Washington, DC, pp 241–251
17. Miniagricultura Uchuva colombiana en fresco ya puede ingresar a las mesas de EE.UU. https://www.minagricultura.gov.co/noticias/

Paginas/Uchuva-colombiana-en-fresco-a-EE-UU.aspx. Accessed 15 Nov 2018
18. Wu S-J, Ng L-T, Lin D-L, Huang SN, Wang SS, Lin CC (2004) *Physalis peruviana* extract induces apoptosis in human Hep G2 cells through CD95/CD95L system and the mitochondrial signaling transduction pathway. Cancer Lett 215:199–208. https://doi.org/10.1016/J.CANLET.2004.05.001
19. Sharmila S, Kalaichelvi K, Rajeswari M, Anjanadevi N (2014) Studies on the folklore medicinal uses of some indigenous plants among the tribes of thiashola, manjoor, nilgiris south division, western ghats. Int J Plant, Anim Environ Sci 4:14–22
20. Anjalam A, Kalpana S, Vijai D, Premalatha S (2016) Documentation of medicinal plants used by malayali tribes in Kolli Hills. Int J Adv Res Biol Sci 3:101–107
21. (2018) Nestlé acquires majority interest in Latin American company Terrafertil | Nestlé Global. In: Press Release. https://www.nestle.com/media/news/nestle-acquires-majority-interest-in-terrafertil. Accessed 16 Nov 2018
22. Jansen C (2018) Goldenberries are the real superfood, says South African producer with big European plans Fresh Plaza https://www.freshplaza.com/article/9043074/goldenberries-are-the-real-superfood-says-south-african-producer-with-big-european-plans/. Accessed 16 Nov 2018
23. Plants Profile for *Physalis pubescens* integrifolia (husk tomato). In: USDA. https://plants.usda.gov/core/profile?symbol=PHPUI. Accessed 16 Nov 2018
24. Martínez M (1993) The correct application of *Physalis pruinosa* L. *(Solanaceae)*. Taxon 42:103–104. https://doi.org/10.2307/1223312
25. Garfield L (2015) Final report for FNE15–828: methods for improving quality and conditions of ground cherry production. Sustain Agric Res Educ. https://projects.sare.org/sare_project/fne15-828/. Accessed 16 Nov 2018
26. Jenni S, Chagnon R (2012) Ground cherries: a new crop (pdf). Agric Agri-food Canada. http://publications.gc.ca/collections/collection_2012/agr/A42-114-2012-eng.pdf. Accessed 16 November 2018
27. El Sheikha AF, Zaki M, Bakr A, El Habashy M, Montet D (2008) Physico-chemical properties and biochemical composition of *Physalis* (*Physalis pubescens* L.) Fruits. Food 2:124–130
28. USDA National Nutrient Database for Standard Reference (2018) Full report (all nutrients): 11954, Tomatillos, raw. https://fdc.nal.usda.gov/fdc-app.html#/food-details/168566/nutrients. Accessed 20 November 2018
29. Singh DB, Ahmed N, Lal S, Mirza A, Sharma OC, Pal AA (2014) Variation in growth, production and quality attributes of *Physalis* species under temperate ecosystem. Fruits 69:31–40. https://doi.org/10.1051/fruits/2013099
30. Ostrzycka J, Horbowicz M, Dobrzański W, Jankiewicz LS, Borkowski J (1988) Nutritive value of tomatillo fruit (*Physalis ixocarpa* Brot.). Acta Soc Bot Pol 57:507–521. https://doi.org/10.5586/asbp.1988.049
31. Corporación Colombia Internacional (CCI) Uchuva. Perfil de producto, Sistema de Inteligencia de Mercados, Bogotá (2001), pp. 1–12
32. Osorio Diaz DL, Roldan G (2003) Volvamos al campo: manual de la uchuva (No. C047. 085). Grupo Latino LTDA
33. Repo De Carrasco R, René C, Zelada E (2008) Determinación de la capacidad antioxidante y compuestos bioactivos de frutas nativas peruanas. Rev la Soc Química del Perú 74:108–124
34. Bazalar Pereda MS, Nazareno MA, Viturro CI (2019) Nutritional and antioxidant properties of *Physalis peruviana* L. fruits from the Argentinean northern Andean region. Plant Foods Hum Nutr 74:68–75. https://doi.org/10.1007/s11130-018-0702-1
35. National Nutrient Database for Standard Reference (2018) Full report (all nutrients): 09138, Groundcherries, (cape-gooseberries or poha), raw. https://fdc.nal.usda.gov/fdc-app.html#/food-details/173043/nutrients. Accessed 20 November 2018
36. Maruenda H, Cabrera R, Cañari-Chumpitaz C, Lopez JM, Toubiana D (2018) NMR-based metabolic study of fruits of *Physalis peruviana* L. grown in eight different Peruvian ecosystems. Food Chem 262:94–101. https://doi.org/10.1016/j.foodchem.2018.04.032
37. Wolff XY (1991) Species, cultivar, and soil amendments influence fruit production of 2 *Physalis* species. HortScience 26:1558–1559
38. Leterme P, Buldgen A, Estrada F, Londoño AM (2006) Mineral content of tropical fruits and unconventional foods of the Andes and the rain forest of Colombia. Food Chem 95:644–652. https://doi.org/10.1016/j.foodchem.2005.02.003
39. Musinguzi E, Kikafunda JK, Kiremire BT (2007) Promoting indigenous wild edible fruits to complement roots and tuber crops in alleviating vitamin a deficiencies in Uganda. In: Proceedings of the 13th ISTRC symposium, Kampala, pp 763–769
40. Rodrigues E, Rockenbach II, Cataneo C, Gonzaga LV, Chaves ES, Fett R (2009) Minerals and essential fatty acids of the exotic fruit *Physalis peruviana* L. Ciência e Tecnol Aliment 29:642–645. https://doi.org/10.1590/S0101-20612009000300029
41. Rashwan MRA, Khalifa AH, Zeiad FKA, Mohamed MIA (2017) Nutrient and phytochemical compounds of persimmon and husk tomato. Assiut J Agric Sci 48:102–112
42. Olivares-Tenorio M-L, Verkerk R, van Boekel MAJS, Dekker M (2017) Thermal stability of phytochemicals, HMF and antioxidant activity in cape gooseberry (*Physalis peruviana* L.). J Funct Foods 32:46–57. https://doi.org/10.1016/j.jff.2017.02.021
43. Ramadan MF, Mörsel JT (2003) Oil goldenberry (*Physalis peruviana* L.). J Agric Food Chem 51:969–974. https://doi.org/10.1021/jf020778z
44. El Sheikha AF, Piombo G, Goli T, Montet D (2010) Main composition of *Physalis* (*Physalis pubescens* L.) fruit juice from Egypt. Fruits 65:255–265. https://doi.org/10.1051/fruits/2010021
45. Cheynier V (2012) Phenolic compounds: from plants to foods. Phytochem Rev 11:153–177. https://doi.org/10.1007/s11101-012-9242-8
46. Wu SJ, Tsai JY, Chang SP, Lin DL, Wang SS, Huang SN, Ng LT (2006) Supercritical carbon dioxide extract exhibits enhanced antioxidant and anti-inflammatory activities of *Physalis peruviana*. J Ethnopharmacol 108:407–413. https://doi.org/10.1016/j.jep.2006.05.027
47. González-Mendoza D, Grimaldo-Juárez O, Soto-Ortiz R et al (2013) Evaluation of total phenolics, anthocyanins and antioxidant capacity in purple tomatillo (*Physalis ixocarpa*) genotypes. African J Biotechnol 9:5173–5176. https://doi.org/10.4314/ajb.v9i32
48. Torres-Ossandón MJ, Vega-Gálvez A, López J, Stucken K, Romero J, di Scala K (2018) Effects of high hydrostatic pressure processing and supercritical fluid extraction on bioactive compounds and antioxidant capacity of cape gooseberry pulp (*Physalis peruviana* L.). J Supercrit Fluids 138:215–220. https://doi.org/10.1016/j.supflu.2018.05.005
49. Tinh TH, Nuidate T, Vuddhakul V, Rodkhum C (2016) Antibacterial activity of pyrogallol, a polyphenol compound against *Vibrio parahaemolyticus* isolated from the central region of Thailand. Procedia Chem 18:162–168. https://doi.org/10.1016/j.proche.2016.01.025
50. Beyza S, Sarikaya O (2015) Acethylcholinesterase inhibitory potential and antioxidant properties of pyrogallol. J Enzyme Inhib Med Chem 30:761–766. https://doi.org/10.3109/14756366.2014.965700
51. Jing G, Huang H, Yang B, Li J, Zheng X, Jiang Y (2013) Effect of pyrogallol on the physiology and biochemistry of litchi fruit during storage. Chem Cent J 7:19. https://doi.org/10.1186/1752-153X-7-19

52. Thaipong K, Boonprakob U, Crosby K, Cisneros-Zevallos L, Hawkins Byrne D (2006) Comparison of ABTS, DPPH, FRAP, and ORAC assays for estimating antioxidant activity from guava fruit extracts. J Food Compos Anal 19:669–675. https://doi.org/10.1016/j.jfca.2006.01.003
53. Bravo K, Sepulveda-Ortega S, Lara-Guzman O, Navas-Arboleda AA, Osorio E (2015) Influence of cultivar and ripening time on bioactive compounds and antioxidant properties in cape gooseberry (*Physalis peruviana* L.). J Sci Food Agric 95:1562–1569. https://doi.org/10.1002/jsfa.6866
54. Kennelly EJ, Gerhäuser C, Song LL, Graham JG, Beecher CW, Pezzuto JM, Kinghorn AD (2010) Natural withanolides: an overview. Nat Prod Rep 28:705–740. https://doi.org/10.1039/c0np00045k
55. Xu Y-M, Wijeratne EMK, Babyak AL, Marks HR, Brooks AD, Tewary P, Xuan LJ, Wang WQ, Sayers TJ, Gunatilaka AAL (2017) Withanolides from aeroponically grown *Physalis peruviana* and their selective cytotoxicity to prostate cancer and renal carcinoma cells. J Nat Prod 80:1981–1991. https://doi.org/10.1021/acs.jnatprod.6b01129
56. Xu Y-M, Wijeratne EMK, Brooks AD, Tewary P, Xuan LJ, Wang WQ, Sayers TJ, Gunatilaka AAL (2018) Cytotoxic and other withanolides from aeroponically grown *Physalis* philadelphica. Phytochemistry 152:174–181. https://doi.org/10.1016/j.phytochem.2018.04.018
57. Kennelly EJ, Gerhä C, Song LL et al (1997) Induction of quinone reductase by withanolides isolated from *Physalis philadelphica* (tomatillos). J Agric Food Chem 45:3771–3777
58. Ji L, Yuan Y, Ma Z, Chen Z, Gan L, Ma X, Huang D (2013) Induction of quinone reductase (QR) by withanolides isolated from *Physalis pubescens* L. (Solanaceae). Steroids 78:860–865. https://doi.org/10.1016/j.steroids.2013.05.008
59. Shingu K, Miyagawa M, Yahara S, Nohara T (1993) Studies on the constituents of solanaceous plants. Part 27. Physapruin-A and physapruin-B, 2 new withanolides from *Physalis pruinosa* Bailey. Chem Pharm Bull (Tokyo) 41:1873–1875. https://doi.org/10.1248/cpb.39.1591
60. Choudhary MI, Yousaf S, Ahmed S et al (2005) Antileishmanial physalins from *Physalis* minima. Chem Biodivers 2:1164–1173. https://doi.org/10.1002/cbdv.200590086
61. Silva MTG, Simas SM, Batista TGFM, et al (2005) Studies on antimicrobial activity, *in vitro*, of *Physalis angulata* L. (Solanaceae) fraction and physalin B bringing out the importance of assay determination. Mem Inst Oswaldo Cruz 100:779–782. https://doi.org/10.1590/s0074-02762005000700018
62. Januário AH, Filho ER, Pietro RCLR, Kashima S, Sato DN, França SC (2002) Antimycobacterial physalins from *Physalis angulata* L. (Solanaceae). Phytother Res 16:445–448. https://doi.org/10.1002/ptr.939
63. Matsuura T, Kawai M, Nakashima R, Butsugan Y (1970) Structures of physalin a and physalin B, 13,14-seco-16,24-cyclo-steroids from *Physalis alkekengi* var. Francheti. J Chem Soc C Org 664:664. https://doi.org/10.1039/j39700000664
64. Damu AG, Kuo P-C, Su C-R, Kuo TH, Chen TH, Bastow KF, Lee KH, Wu TS (2007) Isolation, structures, and structure−cytotoxic activity relationships of withanolides and physalins from *Physalis angulata*. J Nat Prod 70:1146–1152. https://doi.org/10.1021/np0701374
65. Fukushima A, Nakamura M, Suzuki H, Yamazaki M, Knoch E, Mori T, Umemoto N, Morita M, Hirai G, Sodeoka M, Saito K (2016) Comparative characterization of the leaf tissue of *Physalis* alkekengi and *Physalis peruviana* using RNA-seq and metabolite profiling. Front Plant Sci 7:1883. https://doi.org/10.3389/fpls.2016.01883
66. Radzali M, Johari R, Azlan GJ, Marziah M (2005) Accumulation of physalin in cells and tissues of *Physalis minima* L. Acta Hortic 676:53–59. https://doi.org/10.17660/ActaHortic.2005.676.5