CHAPTER 2

REVIEW OF LITERATURE

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Review of literature

2.1 Introduction

Tamarillo (*Solanum beatceum*) is an edible fruit crop native to southern Bolivia and northwest Argentina [65]. This fruit is cultivated and utilized globally in several countries like New Zealand, India, Jamaica, Haiti, Mexico, Costa Rica, East Africa, Southern Europe, Southeast Asia, Australia, and Italy [19]. Tamarillo is a sweet and acidic fruit with juicy pulp and is loaded with phytonutrients such as proteins, vitamins, fibres, and minerals like potassium and phosphorus. Tamarillo's prominent bioactive compounds are organic acids, anthocyanins, carotenoids, flavonoids, and phenolic compounds [12]. Researchers studied the three major varieties of tamarillos and reported that these are distinguished based on the fruit's colour attained by the peel and pulp [64]. Similarly, according to the New Zealand Tamarillo Growers Association, the red, yellow and purple colours are the chief varieties of tamarillo (Fig 2.1) [19].

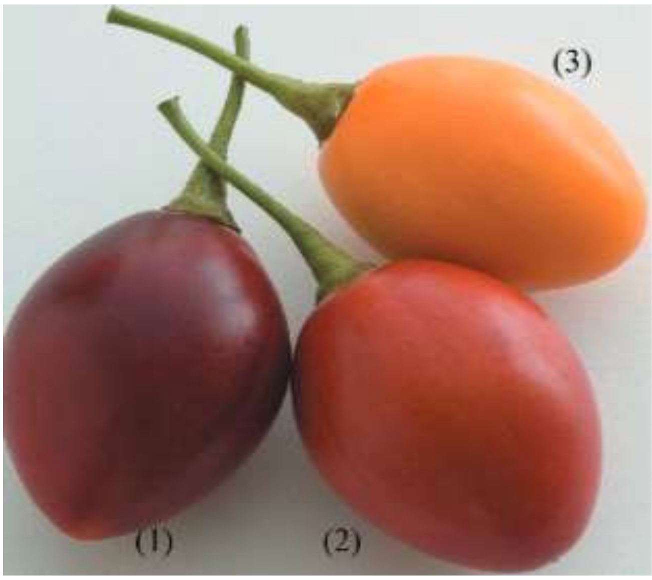

Fig. 2.1. Different varieties of tamarillo, (1) purple, (2) red, (3) and yellow tamarillo [26].

Nowadays, tamarillos as well as their products are in huge demand. In New Zealand, tamarillo is cultivated as a commercial crop and its products are exported to Hong Kong, the USA, Australia, Japan, Singapore, and the Pacific Islands [85]. Consumption of tamarillo is done in many ways. It can be eaten in the raw form or as juice, dessert fruit, ice cream, jellies, liqueurs and in various culinary preparations [4]. Traditionally mature tamarillo fruit is consumed for treating tonsillitis, high cholesterol, and stomach pain [39]. The health benefits of tamarillo are not only because of the essential nutrients like carbohydrates, proteins, and minerals but also the phytochemicals like anthocyanins, carotenoids, vitamin A, vitamin C and phenolic acids that are present. Tamarillo is a functional fruit because of the presence of dietary fiber and hydrocolloids that are known to maintain good health. Tamarillo is divided into three primary parts: seed, pulp, and skin of the fruit, and all these parts are reported to be non-toxic and act as functional foods [64]. Studies on the functional properties possessed by the fractions of the fruit are limited. In the extraction of the bioactive compounds, extraction method plays a vital role in extracting the bioactive compounds from the sample matrix. The efficiency of the extraction methods depends upon factors like bioactivity, yield, extraction time, extraction power, cost, etc. [50]. The main aim of extraction is to bring out from the cell structure the valuable compounds called bioactive compounds, such as phenolic acids, flavonoids, carotenoids, anthocyanins, and alkaloids, that are known to possess numerous functional properties, with a minimum loss [79]. Many novel extraction techniques have been reported for the extraction of bioactive compounds from tamarillo, such as ultrasound [31], supercritical fluid extraction [12], pressured liquid extraction (PLE) [90], different solvent concentrations [59], etc. These extracted phytochemicals have use in pharmaceutical and cosmetics and have immense scope for utilization in the food industries.

Many studies and research articles that have been published on tamarillo have majorly focused on the fruit's phytochemical and physicochemical properties. This review article focuses on the phytochemical composition of purple, red and yellow tamarillo extracts extracted using different novel techniques. We aimed to systematically arrange the overview of available scientific information regarding tamarillo and relate it to health benefits. Therefore, this review chapter emphasizes the health benefits of extracted bioactive compounds and their potential applications in the food industries.

2.1.1 Tamarillo tree overview

Tamarillo fruit belongs to the family of Solanaceae, earlier known as *Cymphomandra betacea* (Cav.) Senden., but in 1995 the fruit's botanical name changed to *Solanum betaceum* (Cav.), and now in many parts of the world, it is popularly known as the tree tomato, tamarillo etc. [4]. The consumption of tamarillo and its value-added products has increased gradually over time in several countries [57]. Earlier, tamarillo was known as the tree tomato, but because of the rapid increase in demand and consumption a specific was required to avoid confusion with ordinary tomato (*Solanum Lycopersicum*). Therefore, tamarillo name was coined and came to market [4]. Tamarillo is a tree that attains 12-14 feet of height, 5-10 cm in width from the base, is a fast-growing tree with shallow roots [25]. The tree starts to bear fruit at 12-18 months and maximum production occurs at the age of 3-4 years and lasts as long as 7-8 years, but if the proper, favorable environmental conditions are provided, then tree survives up to 12 years [4]. Tamarillo leaves are enormous compared to their fruit; they measure 20-30 cm in length and 15-25 cm in width. The leaf colour of tamarillo is also used to distinguish tamarillo varieties, and yellow tamarillo have yellow-green leaf colour, whereas orange-red fruits have purple-red leaf colour [85]. It is a diploid plant tends to germinate itself [4]. The flowering season of this fruit is about six months, specifically from November to April [51]. Tamarillo has different names worldwide; some of them are tomate extranjero syn., tomate de monte syn., tomate cimarron syn., tomate silvestre [31].

2.1.2 Classification of tamarillo varieties

Different varieties of tamarillo are available in the market. All are different in terms of taste, shape, size, nutrients, and phytochemical composition. The yellow type contains a high amount of carotenoids and its presence provides yellow colour to the fruit peel and pulp [57]. The purple variety is known for its high anthocyanins content, and in the red variety, both carotenoids and anthocyanins are present [36]. The phytochemical composition in the tamarillo fruits depends upon the fruits' maturity and variety. The easy and best method for accessing the maturity level of the fruit is the color attained by the fruit and the tenderness of the pulp. Colour of the peel directly affects the internal quality of the pulp, though the firmness of the fruit is directly related to the juice content in the fruit [73].

The most famous tamarillo variety is the purple variety. The peel of purple tamarillo is dark red and the pulp is purple. The weight of this purple variety of this fruit ranges between 60-100 g, and there are vertical green stripes on the skin of this fruit. This variety is the largest and best quality tamarillo. In the United States of America, purple tamarillos are utilized as a commercial variety in tamarillo [94]. The other variety of the tamarillo is the yellow tamarillo, the peel of yellow tamarillos is reported to be bright golden yellow. The weight of this variety of this fruit lies in the range of 50-70 g, and these varieties have brown to green longitudinal vertical stripes on the skin. The tamarillos that are golden yellow (Fig 2.1) are yellow from the outside and inside. The most common variety of tamarillo is the red tamarillo. The peel of the red tamarillo is orange to reddish with brown stripes. The weight of this variety as reported in literature is 50-80 g and the pulp is yellowish-orange in color [51]. The red tamarillo (Fig 2.1) has peel of red color and contains reddish-yellow pulp.

Till now, skin colour has been used to distinguish the tamarillo variety. Two major varieties are reported; purple-red variety (divided into purple and red separately) and yellow (again divided in amber and golden [85]. Among all three varieties of tamarillo, the red tamarillo is the only fruit that contains both polar (water soluble) and water-insoluble (non-soluble) pigments in one fruit [36]. In literature, it is reported that mesocarp of the red tamarillo contains anthocyanins, majorly delphinidin 3-rutinoside and pelargonidin 3-rutinoside and carotenoids, majorly β-cryptoxanthin and β –carotene [21]. No international standards are established to distinguish the tamarillos variety. The only way to categorize the tamarillos is based on the morphological parameters attained by the tamarillo. The ripening index of tamarillo was reported in terms of weight, firmness, and sugar content in the range of 8-10 %, and titratable acidity in the range of 0.25-0.36 % (citric acid). Another method of ripening was investigated in Kenya, where a puncture test was used to check the ripeness and it was reported that the firmness of the fruit decreased from 115.5 to 71.6 N with the increase in ripeness. The sensory values (taste and color) of the fruit increase with ripening but decrease when the fruit starts to over-ripen [61]. Up to 400 seeds are present in mature fruit, and the development of seeds depends upon the maturity [73]. The seed of the tamarillo is whitish in color, thin, circular, nearly flat and a little bit hard compared to the tomato seeds, and tamarillo seeds has similar odour as that of passion fruit seeds [94].

2.2 Composition of tamarillo fruit

The weight percentage occupied by pulp, seed, and skin is 51.5, 39.4, and 9.1 % respectively [8]. The Brix range of the three varieties of tamarillo grown in New Zealand was in the range of 9.9 -12.0 and acidity was in the range of 0.99-1.62 [94]. In Table 2.1, the physical composition of two different varieties of tamarillo cultivated in Ecuador and

Spain are given. There is a significant difference in all the parameters reported and tamarillo from Ecuador region showed higher physical measurements [91].. Fruits from Ecuador were egg-shaped, weighing in the range of 60-170 g/ fruit. The fruit length was 6-10 cm and diameter was 4-7 cm. The edible part of the fruit was 65-85 %, and moisture was 84-88% [91].

The physicochemical and phytochemical composition of tamarillo fruit are reliant on the ripening attained by the fruit. The colour parameters of the tamarillo fruit changed with ripening stages, and it is reported that lightness (L*) decreased from 46.3 to 22.1 for peel and from 64.6 to 36.1for pulp [61], b* value of tamarillo decreased from 28.4 to 4.9 for peel and 40.8 to 13.2 for pulp, but there is an increase in a* value in peel and pulp as ripeness increased from 4.9 to 28.3 and 4.3 to 8.5, respectively [61]. The colour of the pulp of the fruit is directly related to maturity and ultimately depends upon bioactive compounds and the concentration of pigments present, mostly chlorophyll, carotenoids, and anthocyanins [25]. Fruits from Argentina had lower colour values and soluble solid content (L* value of 62.33 ± 1.89, a* value of 15.72 ± 1.81 and b* value of 39.92 ± 2.32, and soluble solid content 9.01± 0.5) than the fruits from Colombia, Ecuador, and Spain [4, 65].

Table 2.1. Physical characteristics of tamarillo varieties cultivated in different regions

Parameter	**Golden-yellow variety**		**Purple-red variety**	
	Ecuador	**Spain**	**Ecuador**	**Spain**
Weight (g)	107 ± 6.0	43 ± 3.0	188 ± 21	63 ± 5.4
Diameter (cm)	5.0 ± 0.1	3.9 ± 0.1	7.0 ± 0.2	4.6 ± 0.2
Length (cm)	7.0 ± 0.5	5.6 ± 0.1	8.0 ± 0.7	5.5 ± 0.2

Source: Romero-Rodriguez et al. [80]

Orqueda et al. [64] studied the toxicity of tamarillo fruit and found that the fruit didn't show any type of acute toxicity or genotoxicity. Ordóñez et al. [63] did not find any type of toxicity or mutagenic effect in standard strains of *Salmonella*.

2.3 Nutritional composition of tamarillo

Tamarillo is a fruit that contains a high amount of moisture, about 80-90 % [1]. The pH of tamarillo is acidic with 3.2-3.8 pH, and ascorbic acid is one of the acids that contribute to acidic behaviour of the fruit. Tamarillo has a high amount of vitamins and minerals, especially phosphorus [94] (Table 2.2). The fiber content in tamarillo is 1.6-6.0 per 100 g which is quite high in amount, and it is believed to be a very important ingredient for the proper functioning of the digestive tract, especially in bowel movement. Tamarillo is rich in other nutrients like vitamin E, vitamin C. vitamin B6, potassium, and iron [91].

Table 2.2. The biochemical and nutritional profile of tamarillo on wet basis

Parameter	**Range**
pH	3.2-3.8
Total acidity (g/100 g)	1.0-2.4
Soluble solids content (°Brix)	10.0-13.5
Moisture (g/100 g)	81.0-87.8
Protein (g/100 g)	1.5-2.5
Fat (g/100 g)	0.05-1.28
Glucose (g/100 g)	0.5-1.0
Fructose (g/100 g)	0.7-1.2
Sucrose (g/100 g)	0.3-2.5
Fiber (g/100 g)	1.4-6.0
Citric acid (g/100 g)	1.27-1.80
Malic acid (g/100 g)	0.05-0.15
Quinic acid (g/100 g)	0.40-0.80
Ash (g/100 g)	0.60-0.83
Vitamin A (I.U.)	540-2475
Ascorbic acid (mg/100 g)	19.7-57.8
Sodium (mg/100 g)	1.3-8.9
Potassium (mg/100 g)	290-347
Calcium (mg/100 g)	3.9-11.3
Magnesium (mg/100 g)	19.7-22.3

Iron (mg/100 g)	0.40-0.94
Copper (mg/100 g)	0.05-0.20
Zinc (mg/100 g)	0.10-0.20
Manganese (mg/100 g)	0.10-0.20
Phosphates (mg/100 g)	33.9-65.5

Source: Vasco et al. [91]

Tamarillo from Taiwan recorded moisture content of 85.73 ± 1.05 g/100 g of edible portion and a good amount of fiber content. The ascorbic acid content was 38.5 ± 0.07 g/100g of edible portion [48]. All the varieties of tamarillo fruit were reported to be low in fat content and calories, whereas the levels of vitamins C, vitamin E, and vitamin B6 were high [25]. A good amount of trace elements such as iron, magnesium, copper, and potassium are present in the tamarillo, therefore, one tamarillo helps in providing 5% (recommended dietary intake) RDI of these nutrients. All the nutrients present in fruit make it exotic among all the fruits [66]. The concentration of vitamins (A and C) in the tamarillo was reported to be high [25]. Vitamin A in tamarillo was reported to be 2475 IU/100 g edible portion and this is an important carotenoid that exhibits pro-vitamin A activity and plays an important role in maintaining biological functions [57].

Tamarillo seed oil was analysed using supercritical fluid extraction and the main fatty acids reported were linolenic, oleic and palmitic acids. Smaller proportions of stearic, linolenic and palmitoleic acids in the oil were also detected with the help of GC-FID (Gas chromatography flame ionization detector). Other minor components that were reported in the oil are squalene, sterols (β-sitosterol, cycloartenol, and dihydrolanosterol) and γ –tocopherol [29]. The nutrients and polyphenols (anthocyanins and carotenoids) present boost immunity and helps to reduce oxidative stress, and therefore, possess antioxidant effects [3].

2.4 Bioactive components of tamarillo

In Malaysia, tamarillo is an underutilized fruit due to its sour and astringent taste [36]. In the region of Andes, the tamarillo fruit is not considered as the main crop [4]. Vasco et al. studied the alkaloids in the tamarillo from Ecuador and reported that alkaloids were either not present or present in very low concentrations [91]. However, researchers from another part of the world reported that alkaloids like tropane, pyrrolidine, solasodine, calystegins and tomatidenol were found in tamarillo [94]. Higher levels of esters and terpenes were reported in a golden–yellow variety of tamarillo and the major volatile compounds that were present were 1,8-cineole, α-terpinol, ethyl octanoate, and methyl hexanoate [38].

2.4.1 Polyphenols in tamarillo

Polyphenol, as the word means chains of phenols, are a complex group of substances that are products produced by plants during their regular metabolic activities like during the growth of plants and when plants respond to ultraviolet (UV) radiation stress [34]. Phenolic compounds are secondary metabolites produced by plants. They possess antioxidant activity that depends upon the concentration and bioavailability, and have radical scavenging properties and antimicrobial, anti-inflammatory and anti-viral properties in plants and humans also [78, 86]. The extracts of tamarillo are rich in anthocyanins and as well as carotenoids, therefore studies have reported that the phenolic compounds from tamarillo are very helpful in treating low-density lipoproteins and preventing radical oxygen species [28]. Antioxidant activities by phenolic acids are related to beneficial health as they reduce the risk of numerous diseases like cardiovascular diseases, cancers, diabetes, and obesity [17]. Espin et al. [31] reported that the purple variety of tamarillo from New Zealand possesses high phenolic activity than other varieties. In yellow tamarillo, collected from the regions of Chaltura and Pelileo, the concentration of total hydroxycinnamoyl derivatives ranged between 60.25 and 110.23 mg/100 g dry weight. However, the concentration of total hydroxycinnamoyl derivatives in purple tamarillo collected from Ambato-Tungurahu and Salcedo-Cotopaxi region of Ecuador, respectively were reported to range between 132.57 and 421.55 mg/100 g dry weight, thus, purple tamarillo is a rich source of hydroxycinnamoyl derivatives in comparison to yellow tamarillo. Orqueda et al. [64] reported that phenolic compounds are more in the peel of the yellow variety than in the pulp and lowest in the seed of the fruit. Phenolic compounds in the whole fruit was reported to be 684.5 ± 22.0 mg/100 g of dry weight whereas the content in the peel was 523.8 ± 3.0, pulp 415.2 ± 4.0 and seed 179.4 ± 3.0 mg/ 100g. In all the varieties of tamarillo samples, the phenolic compounds are the derivatives of hydroxycinnamoyl phenolic acids [57]. In the golden yellow variety of tamarillo, the phenolic concentration in the peel, pulp, and seed jelly portion was found to be 387±8, 78 ± 2 and 94 ± 1, whereas in the purple-red variety the concentration of total soluble polyphenols was 620 ± 14, 113 ± 4 and 152 ± 1 in the peel, pulp and seed jelly, respectively per 100 g of fresh weight [91]. Red tamarillo has a high amount of polyphenols when compared to the yellow variety and all the polyphenols that are identified in the tamarillo are derivates of hydroxycinnamic acids [57]. In tamarillo, all hydrocinnamic acids are reported in both varieties, but the quantity in purple was higher compared to the yellow variety. Kou et al. [48] have studied the effect of different solvents on the phenolic content of tamarillo and found that the maximum extraction of phenolic content was found in ethyl acetate with the value of 61.1 ± 0.1 (mg CE/ g dry weight) followed by ethanol and n-butanol, and least was found in water (13.5±0.1 mg CE/ g dry weight).

2.4.2 Phenolic acids

Researchers have reported that antioxidants in fruits and vegetables are directly related to the total phenolic content of the fruit. Total phenolic content is a group of individual phenolic acids [18]. In tamarillo, major phenolic acids that were reported are caffeoylquinic acids, rosmarinic acid, and their derivatives, and these compounds act as anti-diabetic and anti-obesity compounds and inhibitors of α-glucosidase, amylases, and lipases enzymes [16]. Phenolic acids like caffeic acid and chlorogenic acid tend to prepare quinones which are known as powerful phenolic compounds compared to those that can't form quinones [87]. The pulp and seed jelly portions of the fruit exhibit a wide range of phytochemical activity and major phenolic compounds like hydroxycinnamoyl derivatives (e.g., caffeoylquinic acids, caffeoyl glucose, and feruloyl glucose) have been reported in literature [31].

Phenolic acids reported to be present in tamarillo are caffeoylquinic acid, caffeoyl glucose, and feruloyl glucose and the concentration of all phenolic acids is higher in the red tamarillo than in yellow tamarillo, as given in Table 2.3 [25]. In 1974, Wrolstad et al. [96] studied the phenolic profile of tamarillo pulp and reported the presence of chlorogenic acid [31]. However in 2009, a study reported five hydroxycinnamic acids derivatives, myricetin, and quercetin to be present in golden-yellow and purple-red tamarillos [91]. In the purple variety, twelve hydroxycinnamoyl derivatives were identified and these hydroxycinnamoyl derivatives are caffeoyl glucoside, dehydrodiferulic acid (i), 3-o-caffeoylquinic acid, dehydrodiferulic acid (ii), 5-o-caffeoylquinic acid, feruloyl glucoside, rosmarinic acid glucoside (isomer i) , rosmarinic acid glucoside (isomer ii), rosmarinic acid glucoside (isomer iii), maloyl derivative of rosmarinic acid glucoside, rosmarinic acid glucoside (isomer iv) and rosmarinic acid [31]. The concentration of hydroxycinnamoyl in yellow tamarillo fruits from Chaltura and Pelileo was reported to be 60.25 and 11.23 mg/100 g on dry basis, respectively [31]. Orqueda et al. [64] reported in their study that 12 caffeic acid derivatives and 10 rosmarinic acid derivatives are present in orange tamarillo fruit from Argentina.

Table 2.3. Phenolic compounds in tamarillo.

Phenolic compound	Concentration (mg/100 g dw)			
	Yellow giant cultivar A (Chaltura)	Yellow giant cultivar B (Pelileo)	Giant purple cultivar	New Zealand purple cultivar
Caffeoyl glucoside	1.35 ± 0.317	3.90 ± 1.054	3.64 ± 0.412	29.26 ± 0.471
Dehydrodiferulic acid (I)	0.12 ± 0.068	0.06 ± 0.019	3.27 ± 0.324	21.14 ± 7.309
3-O-Caffeoylquinic acid	25.04 ± 2.463	42.73 ± 7.720	50.33 ± 4.361	163.62 ± 10.227
Dehydrodiferulic acid (II)	7.50 ± 1.084	8.46 ± 1.996	10.36 ± 1.537	22.09 ± 4.957
5-O-Caffeoylquinic acid	1.27 ± 0.180	2.62 ± 0.540	0.51 ± 0.020	1.97 ± 0.659
Feruloyl glucoside	1.44 ± 0.303	3.01 ± 0.680	0.21 ± 0.040	0.40 ± 0.566
Rosmarinic acid glucoside (isomer I)	3.27 ± 0.273	4.49 ± 0.853	9.37 ± 0.240	14.85 ± 2.877
Rosmarinic acid glucoside (isomer II)	2.01 ± 0.214	2.98 ± 0.915	7.50 ± 0.160	14.62 ± 2.317
Rosmarinic acid glucoside (isomer III)	3.56 ± 0.437	5.19 ± 1.125	10.27 ± 0.400	19.71 ± 2.557
Malonyl derivative of rosmarinic acid glucoside	1.61 ± 0.229	2.52 ± 0.660	2.78 ± 0.402	6.30 ± 3.652
Rosmarinic acid glucoside (isomer IV)	0.86 ± 0.100	1.42 ± 0.365	4.76 ± 0.439	5.70 ± 0.559
Rosmarinic acid	12.22 ± 1.956	32.85 ± 6.998	29.57 ± 2.571	121.89 ± 11.067

Source: Espin et al. [31]

Tamarillo peel is not preferred and consumed by consumers because of its thick and unpleasant taste [90]. Researchers reported that due to the presence of a higher concentration of rosmarinic acid, the peel has a bitter taste, although rosmarinic acid is reported to exhibit hepato-protective activities in liver diseases [38]. Caffeoyl ester rosmarinic acids are reported to possess tremendous health benefits for the human body including antiviral, anti-inflammatory, and antioxidant activity [71].

2.4.3 Flavonoids

Flavonoids are a class of secondary metabolites, and just like phenolic acids they are produced by plants to protect themselves from abiotic stress and they possess favourable properties for nutraceutical, pharmaceutical, medicinal, and cosmetic applications. Epidemiological studies reveal that the consumption of flavonoids reduces the risk of chronic diseases, including CVD, diabetes, cancers, Alzheimer's disease, and atherosclerosis [53]. Flavonoids is a huge group of bioactive compounds which is divided into subgroups depending upon the carbon attached to the C ring and B ring and the degree of unsaturation and oxidation of the C ring [68]. The subgroups of flavonoids are flavones, flavanones, flavanols or catechins, anthocyanins, and chalcone. Flavones, flavonols, and leucoanthocyanins were reported in red tamarillo [68]. The ethanol extract of tamarillo had 6.44 ± 0.16 and water extract had 2.22 ± 0.31 mg catechin equivalent/g dry weight [62]. The flavonoids that were reported in the fruit are catechin, epicatechin, quercetin, myricetin and kaempferol [91]. Orqueda et al. [64] reported that 7 flavonoids derivatives were present in the tamarillo from fruits of Argentina. Belovic et al. [8] detected rutin, myricetin, quercetin, kaempferol and enantiomers of naringenin in tamarillo seeds.

2.4.4 Anthocyanins

Anthocyanins are water-soluble secondary metabolites belonging to the parent class of flavonoids and and give attractive colour to a variety of fruits such as berries, grapes, apples, purple cabbage, purple potato, and tamarillo [13]. The highest intensity of anthocyanin was shown in the flavylium cation form, however, the stability of anthocyanin depends upon compounds that are attached to the flaviylum group like sugars, substituents and acyl sugars [43]. Anthocyanins occur in the form of glycosides of anthocyanidins, and it is available in six different forms in most fruits and vegetables and the colour depends upon the position and radical group that attach to the basic structure of flavylium [11]. The main members of anthocyanins are delphinidin (purple), cyanidin (red) and pelargonidin (orange), malvidin (blue-red), petunidin (blue-red), and peonidin (orange-red) [10]. The shade of colour in anthocyanins depends upon the number of hydroxyl and methoxyl groups present in the structure because more hydroxyl group favors bluish color and red color comes when the methoxyl group is dominant in the structure. [24].

In fruits from Peru, six anthocyanins were reported in tamarillo, namely, pelargonidin 3-rutinoside, delphinidin 3-rutinoside, cyanidin 3-rutinoside, cyanidin 3-glucoside, pelargonidin 3-glucoside, and delphinidin 3-glucoside [25]. The pigments that were identified in tamarillo from Brazil were pelargonidin 3-glucosyl-glucose, peonidin 3-glucosyl-glucose, and malvidin 3-glucosyl-glucose [94]. Tamarillo from Columbia were reported to have cyanidin-3-O-rutinoside, pelargonidin-3-O-rutinoside, and delphinidin-3-O-rutinoside [66]. The concentration of anthocyanins reported in purple tamarillo cultivated in Brazil showed 8.5 mg cyanidin-3-glucoside/100g; of which, the HPLC-PDA results revealed that delphinidin 3-rutinoside was the major anthocyanin contributing 62 % of the total anthocyanins followed by pelargonidin 3-glucoside-5-rhamnoside that contributed 31.5 %, and cyanidin 3-rutinoside accounted for 6.5 % [21]. In Table 2.4, anthocyanins and their derivatives in two different varieties of tamarillo identified by HPLC are reported. Mertz et al. investigated the red variety of tamarillo and reported that pelargonidin-3-O-rutinoside (115 mg/100g) and delphinidin-3-O-rutinoside (33 mg/100g) were the predominant anthocyanins present in tamarillo [57]. Espin et al. identified delphinidin 3-O-glucosyl rutinoside, delphinidin 3-O-rutinoside, cyanidin 3-O-rutinoside, and pelargonidin 3-O-rutinoside as the anthocyanins in Ecuadorian tamarillo [31].

Table 2.4. Concentration of anthocyanins in red and yellow varieties of tamarillo.

Anthocyanins	**Yellow giant cultivar A (Chaltura)**	**Yellow giant cultivar B (Pelileo)**	**Giant purple Cultivar (mg/100 g dw)**	**New Zealand purple Cultivar (mg/100 g dw)**
Delphinidin 3-O-rutinoside	N.D	N.D	21.79 ± 0.130	87.43 ± 2.356
Cyanidin 3-O-rutinoside	N.D	N.D	2.49 ± 0.197	4.49 ± 0.526
Pelargonidin 3-O-rutinoside	N.D	N.D	78.07 ± 1.469	76.96 ± 5.094

Source: Espin et al. [31]

2.4.5 Carotenoids

Carotenoids is a group of major nonpolar pigments present in tamarillo. Carotenoids are isoprenoid compounds obtained by the tail to tail C_{20} linkage of geranylgeranyl diphosphate molecules yielding a chain length of C_{40} molecule [30]. These carotenoids are a family of over 600 compounds that give color to fruits and vegetables for example; orange color in carrots, redness in tomatoes, etc. [49]. Colour in fruits and vegetables and its intensity is affected by the conjugated double bonds, functional groups, and esterification with fatty acid during the ripening process [25]. In plants, carotenoids are important for many biological functions such as photosynthesis, phytohormones biosynthesis, photo-protection, etc. [58]. The six carotenoids that were detected in the peel and pulp of Brazilian tamarillo were β-carotene, β-cryptoxanthin, ζ-carotene, 5,6-monoepoxy-β-carotene, lutein and zeaxanthin, and β-carotene and β-cryptoxanthin were predominant [25]. Carotenoids in tamarillo fruits from Australia were identified as α-carotene, β-carotene, and β- cryptoxanthin [94]. De Rosso et al. studied the carotenoids profile of Brazilian tamarillo and found that β-cryptoxanthin is the major carotenoid having 45.3% share followed by β-carotene (26.1%), zeaxanthin (5.1%), and antheraxanthin (4.0%), whereas the total carotenoids content reported was 4.4 mg/100 g on wet basis [21]. Orqueda et al. [64] studied the total carotenoids from tamarillo of Argentina and reported that carotenoids content was 1.41 mg/100g dry powder in the whole tamarillo, while the peel (1.37 ± 0.09 mg/100 g dry powder) contained a higher amount of carotenoids than pulp (0.93 ± 0.05 mg/100 g dry powder) and seed (0.53 ± 0.03 mg/100 g dry powder).

Mertz et al. [57] reported that carotenoids that are available in the tamarillo are all-trans-b-carotene and all-trans-β-cryptoxanthin esters and were the major carotenoids. Xanthophylls that were reported in the tamarillo are esterified with palmitic and meristic acids [56] reported carotenoids in two varieties of tamarillo (red and yellow) after and before saponification. The result was better in the unsaponified sample reported 78 % of the total carotenoids contents. Carotenoid content was higher in the red variety in both cases, i.e., after and before saponification (Table 2.5). In quantification of the carotenoid result showed that β-carotene was dominant (4.6, 5.1 μg/g fresh weight in yellow and red tamarillo) in both varieties. Tamarillo is rich in antioxidants like vitamin C and carotenoids; therefore, they contribute to increasing its antioxidant capacity [6]. Carotenoids have potential health benefits for the body. The primary health benefit of carotenoids is to possess antioxidant activity [33]. It is reported that the consumption of lutein and zeaxanthin helps in visual and cognitive development in infants which is reported in the tamarillo [44]. β-cryptoxanthin is the major carotenoid in tamarillo and helps the in the regulation of bone homeostasis [97]. Carotenoid is very important for maintaining normal health but when it is attached to ascorbic acid it becomes more powerful because of its increased antioxidant availability shows the positive result for control of these life-threatening diseases such as Alzheimer's disease, cancer, heart disease and also linked with chronic inflammation [49].

Table 2.5. Carotenoids content in tamarillo.

Carotenoids	Yellow tamarillo	Red tamarillo
	Unsaponification sample	
Zeaxanthin	0.1 ± 0.02	0.3 ± 0.06
β-Cryptoxanthin	1.1 ± 0.1	1.5 ± 0.08
β-Carotene	4.6 ± 0.3	5.1 ± 0.3
Esters	22.6 ± 1.0	25.7 ± 1.0
	Saponofied samples	
Lutein	0.98 ± 0.05	1.25 ± 0.05
Zeaxanthin	0.59 ± 0.02	1.7 ± 0.06
β-Cryptoxanthin	13.5 ± 0.1	15.8 ± 0.1

Source: Mertz et al. [57]

2.5. Health benefits of tamarillo

In vitro studies have noted the high antioxidant capacity of tamarillo, because of the phenolic compounds present. Researchers have reported that tamarillo is loaded with carotenoids as well as anthocyanins, therefore the presence of these two bioactive compounds in one fruit, clearly indicates the efficiency and their potential health benefits [40]. These bioactive compounds are known to possess anti-inflammatory and anti-edema activities, suppress colon carcinogenesis, prevent atherosclerosis, prevent diabetes, and ameliorate light-induced retinal damage [46]. A detailed health benefits possessed by tamarillo are reported below.

2.5.1. Reduced risk of obesity and diabetes

Obesity is currently a major and common metabolic disorder around the globe. Obesity itself is a treatable disorder, associated with insulin resistance syndrome and if not treated properly at the right time, leads to cardiovascular diseases and other health-related disorders like type-2 diabetes, hypertension, polycystic ovary syndrome, nonalcoholic fatty liver disease, and certain forms of cancer [3]. The main source of phytochemicals in the diet is mainly fruits and vegetable that maintains the level of antioxidants in the body and replenishes them back. Studies revealed that consumption of tamarillo at a particular dose showed a decrease in the level of fat in a rat model and an increase in antioxidant enzymes. The high amount of moisture and fiber content help to prevent obesity [35]. The consumption of tamarillo in the diet shows a positive result in maintaining weight, and controlling obesity in the body and there is an enhancement in the level of the antioxidant enzymes like superoxide dismutase and glutathione peroxidase [3]. Phenolic acids like caffeoylquinic acids, rosmarinic acid, and their derivatives present in tamarillo are known for their anti-obesity effect and reduce the chances of cardiovascular problems [15]. Orqueda et al. [64] observed that a polyphenol-rich extract of tamarillo can control the glycemic index imbalance, glucose intolerance, hypertension, and obesity that ultimately prevents type II diabetes. The phenolic-rich extract shows better activity toward α-glucosidase and lowers α-amylase activity, therefore, the powder of tamarillo was found to be suitable for minimizing glucose absorption by diabetic patients.

2.5.2. Inhibition of P12 cells and LDL oxidation

Low-density lipoproteins (LDL) are also known as bad fat for our body and the oxidation of low-density lipoprotein (LDL) is a critical step and oxidized LDL is believed to promote the pathogenesis of atherosclerosis, the underlying cause of myocardial infarctions and thrombotic stroke [89]. Studies show that atherogenesis is promoted by lipid oxidation of low-density lipoprotein (LDL), ultimately leading to modification of apolipoprotein B such that the LDL particle becomes recognized by the macrophage scavenger receptors and produces massive cholesterol loading and foam cell formation ultimately leading to the formation of atherosclerosis [22, 89]. Kou et al. [48] studied tamarillo and reported that tamarillo contains polyphenolic compounds in different fractions whereas the ethyl acetate fraction of polyphenols was found to be helpful to inhibit the copper-induced LDL oxidation like the same or more than by α-tocopherol, these polyphenols can inhibit the TBARS formation (thiobarbituric acid-reactive substances). Polyphenols from tamarillo are very helpful in preventing oxidative stress-induced cell death in neuronal PC12 cells in a dose-dependent manner via attenuation of reactive oxygen species production with the help of -(4,5-dimethyl-thiazol-2-yl)-2,5-diphenyl tetrazolium (MTT) reduction assay showed that *C. betacea* phenolics in ethyl acetate fraction. Therefore, the phenolic and anthocyanins present in the tamarillo are very important and useful antioxidants that inhibit the LDL oxidation process in in vitro studies and suppress the activity of PC 12 cells. Consumption of tamarillo will be helpful against neurodegenerative diseases and atherosclerosis [48].

2.5.3. Prebiotic activity

Studies have reported that tamarillo contains hydrocolloids that have prebiotic activity in the gut [36]. The two hydrocolloids that are reported in the study are found in the pulp and mucilage. In the seed mucilage of tamarillo, low molecular weight arabinogalactan protein-associated pectin is found and another fraction present in the pulp has high molecular weight hemicellulosic polysaccharide [36]. As per definition, a prebiotic is defined as a selectively fermented ingredient that allows specific changes in the composition and/or activity of the gastrointestinal microbiota that confers benefits upon host wellbeing and health [77]. Researchers worked on the hydrocolloids obtained from the fruit and reported that hydrocolloids were found to be resistant to the digestive enzymes in gastrointestinal conditions and are available for fermentation by gut microbiota [61]. These hydrocolloids are helpful for the body as they allow the growth of beneficial bacteria and suppress the growth of pathogenic bacteria. These hydrocolloids can be used by microbes, and short-chain fatty acids are formed. In a comparative study [36] among inulin, oligosaccharide, and tamarillo hydrocolloids, tamarillo hydrocolloids were noted to be less effective than commercial ones. Tamarillo hydrocolloid also has the capacity of oil holding in the range of 3.3–3.6 g oil/g dry sample and water holding in the range of 25–27 g water/g dry sample [37]. The high water-holding capacity of tamarillo gives high viscosity that has hypoglycaemic and hypocholesterolemic activities [36]. Another group of researchers reported that in mucilage, a good amount of methoxylated homogalacturonan mixed with type I arabinogalactan, a linear (1→5)-linked α-L-arabinan and a linear (1→4)-β-D-xylan was present [27]. However, difference in the length of side chains of pectin and degree of xylans present in pulp and seed mucilage's was reported too [27].

2.5.4. Antioxidant Effect

Antioxidants are those compounds present in the food matrix composed of the heterogeneous category of molecules that inhibit the oxidation reaction by various mechanisms (scavenging free radicals, metal chelation) and protect the molecule before it gets damaged All of them are known for their preventive and protective property for maintaining good health conditions and have diverse biological activities such as anti-inflammatory, anti-carcinogenic and anti-atherosclerotic effects, and help to reduce the incidence of coronary diseases and maintain gut healthy [14]. Polyphenols present in fruits and vegetables are known to possess antioxidant properties having potential inhibitors of LDL oxidation [34].Castro et al. [12] studied the antioxidant potential using supercritical fluid extraction with ethanol as modifier and used to determine the inhibiting effects of lipid oxidation in cooked beef meat and reported that the epicarp tamarillo was a potential source of antioxidants. The total antioxidant activity of 23 tamarillo accessions ranged from 13.2-48.7 µmol TE (Trolox equivalent)/g dry weight, the lowest activity was shown by orange pointed tamarillo, and the highest by red conical tamarillo varieties [5].

A high amount of ascorbic acid is present in tamarillo, and ascorbic acid is known for possessing antioxidant effects [80, 91]. Phenolics from the tamarillo fruit is reported to be potent antioxidants possessing the power to inhibit LDL oxidation and reactive oxygen species in rat adrenal pheochromocytoma cell line study [39]. Phenolics, ascorbic acid and carotenoids are reported to be the major contributors to the antioxidant activity of tamarillo [31].

2.6. Effect of processing on bioactive compounds present in tamarillo

As tamarillo is loaded with plentiful bioactive compounds with proven health beneficial properties, researchers have conducted many scientific studies on the utilization of tamarillo fruit and their by-products in the development of new food products. A concise review of these studies are presented below.

Ramakrishnan et al. [75] studied the effect of different wall materials (maltodextrin, gum Arabic, resistant maltodextrin, n-octenyl succinic anhydride modified starch) in the spray drying of tamarillo juice. Powders prepared using gum arabic and n-octenyl succinic anhydride modified starch has highest encapsulation efficiency for both carotenoids and anthocyanin present in the tamarillo, however reduction in the bioactive compounds was reported during storage period and more degradation was reported at elevated temperature. Garcia et al. [38] with his co-workers developed the carotenoids-rich microencapsulates using tamarillo as the main ingredient along with banana and mango. For spray drying, a range of inlet temperature from 130-180°C was used and found that at 130°C, powder exhibited highest carotenoids retention.

Angelica et al. [6] optimized the composition of tamarillo fruit and sappan wood for developing a beverage and reported that 58.97% tamarillo, 9.83% sappan woood, 29.49% water, and 1.7% stevia powder gave a good product. Castro-Vargas et al. [12]studied the processing of tamarillo extract, for which super critical fluid extraction (SCFE) and Soxhlet extraction methods were used. The extract was used on cooked beef and positive results of minimizing lipid oxidation in cooked beef were observed. The highest antioxidant activity was observed using 50 °C, 30 MPa and 2% of ethyl alcohol. Mertz et al. [57] studied the effect of thermal processing on carotenoids and vitamin C content and they reported that on increasing temperature from 80-90°C, the zeaxanthin and β-carotene was found to be decrease by 22 and 14%, respectively. Tamarillin, a serine protease and an alkaline enzyme found in tamarillo, was used by researchers to study the effect on milk. Tamarillin showed faster and wider caseinolytic activity in comparison to rennet [52].

Diep et al. [25] reported that tamarillo has a high nutritional adequacy score of 7.9 and 7.4 for yellow and red varieties of tamarillo, respectively, and therefore this fruit has a high scope of commercialization and a potential candidate for new product development.

2.6.1. Polyphenol-rich extract

Ultrasound-assisted extraction (UAE) helps in effective extraction with a high yield in a short time [72]. Ferrara et al. [32] made a comparative study of the effect of probe ultrasonication and conventional extraction of the polyphenols from purple eggplant peel and reported that extraction of 30 min gave 29.01 mg GAE/g whereas in UAE technique, whereas only 23.10 mg GAE/g was extracted in 60 min during conventional extraction,. Nowadays, ultrasound has several technological applications in the food processing sector [88]. The supercritical fluid extraction (SCFE) method gives a good yield of phenolic compounds and anthocyanins in the pressure range of 100-162 bar. The pressure of more than 200 bar and an increase in temperature from 40 to 50°C had adverse effect on the yield [55]. The extraction of phenolic compounds and anthocyanins using supercritical fluid extraction was enhanced when acidified solvents were used [92]. Optimization of phenolic compounds and anthocyanins from grape peel showed that the optimal conditions for extraction by SCFE were: temperature of 45-46°C, pressure of 160-165 kg cm^2, ethanol concentration of 6-7% [92].

2.6.2. Carotenoids enriched puree

Localization of carotenoids in the matrix has a direct impact on release and stability during processing, storage,e and digestion. During the processing and disruption phase, oil acts as the extraction medium and the solubility of the carotenoids in oil is high due to their lipophilic behaviour [60]. Homogenization helps to improve the nutritional value because it reduces the cellular structure that enhances the extraction yield of carotenoids and other bioactive compounds from the sample matrix, and hence increases the bioaccessibility [70]. Patrignani et al. [69] studied the effect of HPH on kiwifruit juice and reported a reduction in *S. cerevisiae* load in treated juice, an increase in polyphenols and antioxidant activity, and an increase in shelf life by 15 days at refrigeration temperature. Pressure and the number of passes during homogenization play an important role in the inactivation of microorganisms [28]. Gupta et al. [41] reported that HPH-treated tomato juice samples showed a 12% increase in carotenoid content. Further, combining thermal treatment with HPH had a positive impact on lycopene extractability. There are, however, no reports in literature on the efficacy of high pressure homogenization technique for the extraction of carotenoids present in tamarillo.

2.6.3. Pulp powder

Air drying and freeze-drying are the most common and widely used drying techniques for lowering the moisture content of food which enhances its shelf life [83]. It is reported that more than 85% of driers used in industries are the convective type that uses hot air or combustion gases as the medium for mass transfer [99]. Purkayastha et al. [20] studied thin layer drying of tomato slices at different temperatures (50°C, 60°C, 65°C and 70°C) and reported that drying at 50°C showed a maximum amount of retention of ascorbic acid, sugar/acid ratio and red hue, whereas, drying at higher temperature

(65°C and 70°C) degraded the nutrients and colour quality. Sacilik et al. [82] studied the drying kinetics of apple slices at a temperature range between 40°C and 60°C and reported that apple slices dried perfectly within 240–460 min under these drying conditions. Russo et al. [81] studied the physical properties of dried eggplant and found that a drying temperature of 60°C gave a good product and better rehydration ability.

Freeze drying is the technique to preserve heat-sensitive foods with higher nutrients and product quality. Freeze drying technique gave better quality retention and end product quality of tomato pomace powder for ketchup production [9]. Argyropoulos et al. [7] studied different drying techniques and found that freeze-dried products gave a precise rehydration ratio. Many researchers reported that freeze-dried product has minimal shrinkage (5-15 %) in most food products [45, 47, 95]. Freeze drying method also causes negligible loss of phenolic content [8]. Ratti et al. [76] reported that foam-mat dried samples retain their volatiles whereas in non-foamed samples volatile compounds are lost during drying. Foam porosity (volume of air entrapped in the sample) is an important parameter to determine the quality of foam. It is reported that when the volume of foam is higher, foam stability is more stable because air bubbles are smaller, therefore larger surface area is exposed to the dry air resulting in good product quality [23]. Numerous studies were done on the development and characterization of foam mat dried powder from fruits like mango, sour cherry, tomato, and guava [2, 74]. Ozcelik et al. [67] studied the effect of hydrocolloid on foamed raspberry puree and reported that foamed puree contained more anthocyanins and ascorbic acid than unprocessed puree and retention was increased as the concentration of stabilizer and foaming agent was increased.

2.6.4 Carotenoids encapsulated seed oil nanoemulsion

The emulsion is categorized as a nanoemulsion if the particle size is found below 500nm and that with a size above 500 nm is referred to as a conventional emulsion [93]. Oil in water emulsion is effective in encapsulating and delivering carotenoids and can withstand processing conditions and storage in the development of functional food ingredients. Ha et al. [42] studied the effect of different sizes of nanoemulsion and their effect on antioxidant activity and bioaccessibility, and nanoemulsion size more than 100 nm exhibited more antioxidant property, but nanoemulsion less than 100 nm exhibited better in vitro bioaccessibility. Many authors reported that smaller size of nanoemulsion has higher lipid digestion rate which enhances the bioaccessibility of lipophilic compounds [83, 84]

Yi et al. [98] studied the physicochemical stability and in vitro bioaccessibility of β-carotene using sodium caseinate as an emulsifier and observed that sodium caseinate (food grade emulsifier) can be used to prepare stable emulsions of food oils carrying β-carotene. Ultrasonication is a better method for the fabrication of nanoemulsion because it uses cavitation phenomena for the breakdown of larger droplets into smaller droplets. Researchers reported that ultrasonication provided better results of nanoemulsion than microfluidization and consumed less power input [54].

Bibliography

[1] Abad, J., Valencia-Chamorro, S., Castro, A., and Vasco, C., Studying the effect of combining two nonconventional treatments, gamma irradiation and the application of an edible coating, on the postharvest quality of tamarillo (*Solanum betaceum* Cav.) fruits. *Food Control,* 72:319-323, 2017.

[2] Abbasi, E. and Azizpour, M., Evaluation of physicochemical properties of foam mat dried sour cherry powder. *LWT,* 68:105-110, 2016.

[3] Abdul Kadir, N.A.A., Rahmat, A., and Jaafar, H.Z., Protective effects of tamarillo (*Cyphomandra betacea*) extract against high fat diet induced obesity in Sprague-Dawley rats. *Journal of Obesity,* 2015, 2015.

[4] Acosta-Quezada, P., Riofrío-Cuenca, T., Rojas, J., Vilanova, S., Plazas, M., and Prohens, J., Phenological growth stages of tree tomato (*Solanum betaceum* Cav.), an emerging fruit crop, according to the basic and extended BBCH scales. *Scientia Horticulturae,* 199:216-223, 2016.

[5] Acosta-Quezada, P.G., Raigón, M.D., Riofrío-Cuenca, T., García-Martínez, M.D., Plazas, M., Burneo, J.I., Figueroa, J.G., Vilanova, S., and Prohens, J., Diversity for chemical composition in a collection of different varietal types of tree tomato (*Solanum betaceum* Cav.), an Andean exotic fruit. *Food Chemistry,* 169:327-335, 2015.

[6] Angelica, C., Pangestu, O., Kurniawan, J., Meindrawan, B., and Hutabarat, D. Design formula and product prototype of beverage made from tamarillo (*Solanum betaceum*) fruit and sappan wood (*Caesalpinia sappan*) using Kano method. in

IOP Conference Series: Earth and Environmental Science, Vol. 715. 012070: IOP Publishing, 2021.

[7] Argyropoulos, D., Heindl, A., and Müller, J., Assessment of convection, hot-air combined with microwave-vacuum and freeze-drying methods for mushrooms with regard to product quality. *International Journal of Food Science & Technology,* 46(2):333-342, 2011.

[8] Asami, D.K., Hong, Y.-J., Barrett, D.M., and Mitchell, A.E., Comparison of the total phenolic and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry, and corn grown using conventional, organic, and sustainable agricultural practices. *Journal of Agricultural and Food Chemistry,* 51(5):1237-1241, 2003.

[9] Belović, M., Torbica, A., Lijaković, I.P., Tomić, J., Lončarević, I., and Petrović, J., Tomato pomace powder as a raw material for ketchup production. *Food Bioscience,* 26:193-199, 2018.

[10] Borochov-Neori, H., Judeinstein, S., Harari, M., Bar-Ya'akov, I., Patil, B.S., Lurie, S., and Holland, D., Climate effects on anthocyanin accumulation and composition in the pomegranate (*Punica granatum* L.) fruit arils. *Journal of Agricultural and Food Chemistry,* 59(10):5325-5334, 2011.

[11] Castañeda-Ovando, A., de Lourdes Pacheco-Hernández, M., Páez-Hernández, M.E., Rodríguez, J.A., and Galán-Vidal, C.A., Chemical studies of anthocyanins: A review. *Food Chemistry,* 113(4):859-871, 2009.

[12] Castro-Vargas, H.I., Benelli, P., Ferreira, S.R., and Parada-Alfonso, F., Supercritical fluid extracts from tamarillo (*Solanum betaceum* Sendtn) epicarp and its application as protectors against lipid oxidation of cooked beef meat. *The Journal of Supercritical Fluids,* 76:17-23, 2013.

[13] Cavalcanti, R.N., Santos, D.T., and Meireles, M.A.A., Non-thermal stabilization mechanisms of anthocyanins in model and food systems—An overview. *Food Research International,* 44(2):499-509, 2011.

[14] Chang, S.K., Alasalvar, C., and Shahidi, F., Review of dried fruits: Phytochemicals, antioxidant efficacies, and health benefits. *Journal of Functional Foods,* 21:113-132, 2016.

[15] Chen, J., Mangelinckx, S., Ma, L., Wang, Z., Li, W., and De Kimpe, N., Caffeoylquinic acid derivatives isolated from the aerial parts of *Gynura divaricata*

and their yeast α-glucosidase and PTP1B inhibitory activity. *Fitoterapia,* 99:1-6, 2014.

[16] Chen, M., Zhao, Y., and Yu, S., Optimisation of ultrasonic-assisted extraction of phenolic compounds, antioxidants, and anthocyanins from sugar beet molasses. *Food Chemistry,* 172:543-550, 2015.

[17] Cheng, J.-C., Dai, F., Zhou, B., Yang, L., and Liu, Z.-L., Antioxidant activity of hydroxycinnamic acid derivatives in human low density lipoprotein: mechanism and structure–activity relationship. *Food Chemistry,* 104(1):132-139, 2007.

[18] Corral-Aguayo, R.D., Yahia, E.M., Carrillo-Lopez, A., and Gonzalez-Aguilar, G., Correlation between some nutritional components and the total antioxidant capacity measured with six different assays in eight horticultural crops. *Journal of Agricultural and Food Chemistry,* 56(22):10498-10504, 2008.

[19] Correia, S.I. and Canhoto, J.M., Biotechnology of tamarillo (*Cyphomandra betacea*): From in vitro cloning to genetic transformation. *Scientia Horticulturae,* 148:161-168, 2012.

[20] Das Purkayastha, M., Nath, A., Deka, B.C., and Mahanta, C.L., Thin layer drying of tomato slices. *Journal of Food Science and Technology,* 50(4):642-653, 2013.

[21] de Rosso, V.V. and Mercadante, A.Z., HPLC–PDA–MS/MS of anthocyanins and carotenoids from dovyalis and tamarillo fruits. *Journal of Agricultural and Food Chemistry,* 55(22):9135-9141, 2007.

[22] de Winther, M.P., van Dijk, K.W., Havekes, L.M., and Hofker, M.H., Macrophage scavenger receptor class A: a multifunctional receptor in atherosclerosis. *Arteriosclerosis, Thrombosis, and Vascular Biology,* 20(2):290-297, 2000.

[23] Dehghannya, J., Pourahmad, M., Ghanbarzadeh, B., and Ghaffari, H., Influence of foam thickness on production of lime juice powder during foam-mat drying: Experimental and numerical investigation. *Powder Technology,* 328:470-484, 2018.

[24] Delgado-Vargas, F. and Paredes-López, O., Anthocyanins and betalains. *Natural Colorants for Food and Nutraceutical Uses*:167-219, 2003.

[25] Diep, T., Pook, C., and Yoo, M., Phenolic and anthocyanin compounds and antioxidant activity of tamarillo (*Solanum betaceum* Cav.). *Antioxidants,* 9(2):169, 2020.

[26] Diep, T.T., Rush, E.C., and Yoo, M.J.Y., Tamarillo (*Solanum betaceum* Cav.): A review of physicochemical and bioactive properties and potential applications. *Food Reviews International,* 38(7):1343-1367, 2022.

[27] do Nascimento, G.E., Iacomini, M., and Cordeiro, L.M., A comparative study of mucilage and pulp polysaccharides from tamarillo fruit (*Solanum betaceum* Cav.). *Plant Physiology and Biochemistry,* 104:278-283, 2016.

[28] Donsì, F., Annunziata, M., and Ferrari, G., Microbial inactivation by high pressure homogenization: Effect of the disruption valve geometry. *Journal of Food Engineering,* 115(3):362-370, 2013.

[29] Dorado Achicanoy, D., Hurtado Benavides, A., and Martínez-Correa, H.A., Study of supercritical CO2 extraction of tamarillo (*Cyphomandra betacea*) seed oil containing high added value compounds. *Electrophoresis,* 39(15):1917-1925, 2018.

[30] Dutta, D., Chaudhuri, U.R., and Chakraborty, R., Structure, health benefits, antioxidant property and processing and storage of carotenoids. *African Journal of Biotechnology,* 4(13), 2005.

[31] Espín, S., Gonzalez-Manzano, S., Taco, V., Poveda, C., Ayuda-Durán, B., Gonzalez-Paramas, A.M., and Santos-Buelga, C., Phenolic composition and antioxidant capacity of yellow and purple-red Ecuadorian cultivars of tree tomato (S*olanum betaceum* Cav.). *Food Chemistry,* 194:1073-1080, 2016.

[32] Ferarsa, S., Zhang, W., Moulai-Mostefa, N., Ding, L., Jaffrin, M.Y., and Grimi, N., Recovery of anthocyanins and other phenolic compounds from purple eggplant peels and pulps using ultrasonic-assisted extraction. *Food and Bioproducts Processing,* 109:19-28, 2018.

[33] Fiedor, J. and Burda, K., Potential role of carotenoids as antioxidants in human health and disease. *Nutrients,* 6(2):466-488, 2014.

[34] Frankel, E., German, J., Kinsella, J., Parks, E., and Kanner, J., Inhibition of oxidation of human low-density lipoprotein by phenolic substances in red wine. *The Lancet,* 341(8843):454-457, 1993.

[35] Gannasin, S.P., Adzahan, N.M., Hamzah, M.Y., Mustafa, S., and Muhammad, K., Physicochemical properties of tamarillo (*Solanum betaceum* Cav.) hydrocolloid fractions. *Food Chemistry,* 182:292-301, 2015.

[36] Gannasin, S.P., Mustafa, S., Adzahan, N.M., and Muhammad, K., In vitro prebiotic activities of tamarillo (*Solanum betaceum* Cav.) hydrocolloids. *Journal of Functional Foods,* 19:10-19, 2015.

[37] Gannasin, S.P., Ramakrishnan, Y., Adzahan, N.M., and Muhammad, K., Functional and preliminary characterisation of hydrocolloid from tamarillo (*Solanum betaceum* Cav.) puree. *Molecules,* 17(6):6869-6885, 2012.

[38] García, J.M., Prieto, L.J., Guevara, A., Malagon, D., and Osorio, C., Chemical studies of yellow tamarillo (*Solanum betaceum* Cav.) fruit flavor by using a molecular sensory approach. *Molecules,* 21(12):1729, 2016.

[39] Ghosal, M., Chhetri, P.K., Ghosh, M.K., and Mandal, P., Changes in antioxidant activity of *Cyphomandra betacea* (Cav.) Sendtn. fruits during maturation and senescence. *International Journal of Food Properties,* 16(7):1552-1564, 2013.

[40] Giuffrida, D., Zoccali, M., Arigò, A., Cacciola, F., Roa, C.O., Dugo, P., and Mondello, L., Comparison of different analytical techniques for the analysis of carotenoids in tamarillo (*Solanum betaceum* Cav.). *Archives of Biochemistry and Biophysics,* 646:161-167, 2018.

[41] Gupta, R., Kopec, R.E., Schwartz, S.J., and Balasubramaniam, V., Combined pressure–temperature effects on carotenoid retention and bioaccessibility in tomato juice. *Journal of Agricultural and Food Chemistry,* 59(14):7808-7817, 2011.

[42] Ha, T.V.A., Kim, S., Choi, Y., Kwak, H.-S., Lee, S.J., Wen, J., Oey, I., and Ko, S., Antioxidant activity and bioaccessibility of size-different nanoemulsions for lycopene-enriched tomato extract. *Food Chemistry,* 178:115-121, 2015.

[43] Harborne, J. and Williams, C., Anthocyanins and other flavonoids. *Natural Product Reports,* 12(6):639-657, 1995.

[44] Henriksen, B.S. and Chan, G.M., Importance of carotenoids in optimizing eye and brain development. *Journal of Pediatric Gastroenterology and Nutrition,* 59(5):552, 2014.

[45] Horszwald, A., Julien, H., and Andlauer, W., Characterisation of Aronia powders obtained by different drying processes. *Food Chemistry,* 141(3):2858-2863, 2013.

[46] Jiao, G., Extraction of anthocyanins from haskap berry pulp using supercritical carbon dioxide: Influence of co-solvent composition and pretreatment. *LWT,* 98:237-244, 2018.

[47] Karam, M.C., Petit, J., Zimmer, D., Djantou, E.B., and Scher, J., Effects of drying and grinding in production of fruit and vegetable powders: A review. *Journal of Food Engineering,* 188:32-49, 2016.

[48] Kou, M.-C., Yen, J.-H., Hong, J.-T., Wang, C.-L., Lin, C.-W., and Wu, M.-J., *Cyphomandra betacea* Sendt. phenolics protect LDL from oxidation and PC12 cells from oxidative stress. *LWT,* 42(2):458-463, 2009.

[49] Krinsky, N.I. and Johnson, E.J., Carotenoid actions and their relation to health and disease. *Molecular Aspects of Medicine,* 26(6):459-516, 2005.

[50] Lefebvre, T., Destandau, E., and Lesellier, E., Selective extraction of bioactive compounds from plants using recent extraction techniques: A review. *Journal of Chromatography A,* 1635:461770, 2021.

[51] Lewis, D. and Considine, J., Pollination and fruit set in the tamarillo (*Cyphomandra betacea* (Cav.) Sendt.) 1. Floral biology. *New Zealand Journal of Crop and Horticultural Science,* 27(2):101-112, 1999.

[52] Li, Z., Scott, K., Hemar, Y., and Otter, D., Protease activity of enzyme extracts from tamarillo fruit and their specific hydrolysis of bovine caseins. *Food Research International,* 109:380-386, 2018.

[53] Liu, R.H., Potential synergy of phytochemicals in cancer prevention: mechanism of action. *The Journal of Nutrition,* 134(12):3479S-3485S, 2004.

[54] Mahdi Jafari, S., He, Y., and Bhandari, B., Nano-emulsion production by sonication and microfluidization—a comparison. *International Journal of Food Properties,* 9(3):475-485, 2006.

[55] Maran, J.P., Priya, B., and Manikandan, S., Modeling and optimization of supercritical fluid extraction of anthocyanin and phenolic compounds from *Syzygium cumini* fruit pulp. *Journal of Food Science and Technology,* 51(9):1938-1946, 2014.

[56] Mertz, C., Brat, P., Caris-Veyrat, C., and Gunata, Z., Characterization and thermal lability of carotenoids and vitamin C of tamarillo fruit (*Solanum betaceum* Cav.). *Food Chemistry,* 119(2):653-659, 2010.

[57] Mertz, C., Gancel, A.-L., Gunata, Z., Alter, P., Dhuique-Mayer, C., Vaillant, F., Perez, A.M., Ruales, J., and Brat, P., Phenolic compounds, carotenoids and antioxidant activity of three tropical fruits. *Journal of Food Composition and Analysis,* 22(5):381-387, 2009.

[58] Monego, D.L., da Rosa, M.B., and do Nascimento, P.C., Applications of computational chemistry to the study of the antiradical activity of carotenoids: A review. *Food Chemistry,* 217:37-44, 2017.

[59] Mutalib, M.A., Rahmat, A., Ali, F., Othman, F., and Ramasamy, R., Nutritional compositions and antiproliferative activities of different solvent fractions from ethanol extract of *Cyphomandra betacea* (Tamarillo) fruit. *The Malaysian Journal of Medical Sciences: MJMS,* 24(5):19, 2017.

[60] Mutsokoti, L., Panozzo, A., Musabe, E.T., Van Loey, A., and Hendrickx, M., Carotenoid transfer to oil upon high pressure homogenisation of tomato and carrot based matrices. *Journal of Functional Foods,* 19:775-785, 2015.

[61] Mwithiga, G., Mukolwe, M.I., Shitanda, D., and Karanja, P.N., Evaluation of the effect of ripening on the sensory quality and properties of tamarillo (*Cyphomandra betaceae*) fruits. *Journal of Food Engineering,* 79(1):117-123, 2007.

[62] Noor Atiqah, A., Maisarah, A., and Asmah, R., Comparison of antioxidant properties of tamarillo (*Cyphomandra betacea*), cherry tomato (*Solanumly copersicum* var. *cerasiform*) and tomato (*Lyopersicon esulentum*). *International Food Research Journal,* 21(6), 2014.

[63] Ordóñez-Santos, L.E., Esparza-Estrada, J., and Vanegas-Mahecha, P., Ultrasound-assisted extraction of total carotenoids from mandarin epicarp and application as natural colorant in bakery products. *LWT,* 139:110598, 2021.

[64] Orqueda, M.E., Rivas, M., Zampini, I.C., Alberto, M.R., Torres, S., Cuello, S., Sayago, J., Thomas-Valdes, S., Jiménez-Aspee, F., and Schmeda-Hirschmann, G., Chemical and functional characterization of seed, pulp and skin powder from chilto (*Solanum betaceum*), an Argentine native fruit. Phenolic fractions affect key enzymes involved in metabolic syndrome and oxidative stress. *Food Chemistry,* 216:70-79, 2017.

[65] Orqueda, M.E., Zampini, I.C., Torres, S., Alberto, M.R., Ramos, L.L.P., Schmeda-Hirschmann, G., and Isla, M.I., Chemical and functional characterization of skin, pulp and seed powder from the Argentine native fruit mistol (*Ziziphus mistol*). Effects of phenolic fractions on key enzymes involved in metabolic syndrome and oxidative stress. *Journal of Functional Foods,* 37:531-540, 2017.

[66] Osorio, C., Hurtado, N., Dawid, C., Hofmann, T., Heredia-Mira, F.J., and Morales, A.L., Chemical characterisation of anthocyanins in tamarillo (*Solanum betaceum* Cav.) and Andes berry (*Rubus glaucus* Benth.) fruits. *Food Chemistry,* 132(4):1915-1921, 2012.

[67] Ozcelik, M., Ambros, S., Heigl, A., Dachmann, E., and Kulozik, U., Impact of hydrocolloid addition and microwave processing condition on drying behavior of foamed raspberry puree. *Journal of Food Engineering,* 240:83-91, 2019.

[68] Panche, A.N., Diwan, A.D., and Chandra, S.R., Flavonoids: an overview. *Journal of Nutritional Science,* 5, 2016.

[69] Patrignani, F., Mannozzi, C., Tappi, S., Tylewicz, U., Pasini, F., Castellone, V., Riciputi, Y., Rocculi, P., Romani, S., and Caboni, M.F., (Ultra) high pressure homogenization potential on the shelf-life and functionality of kiwifruit juice. *Frontiers in Microbiology,* 10:246, 2019.

[70] Pérez-Conesa, D., García-Alonso, J., García-Valverde, V., Iniesta, M.-D., Jacob, K., Sánchez-Siles, L.M., Ros, G., and Periago, M.J., Changes in bioactive compounds and antioxidant activity during homogenization and thermal processing of tomato puree. *Innovative Food Science & Emerging Technologies,* 10(2):179-188, 2009.

[71] Petersen, M., Rosmarinic acid: new aspects. *Phytochemistry Reviews,* 12(1):207-227, 2013.

[72] Pradal, D., Vauchel, P., Decossin, S., Dhulster, P., and Dimitrov, K., Kinetics of ultrasound-assisted extraction of antioxidant polyphenols from food by-products: Extraction and energy consumption optimization. *Ultrasonics Sonochemistry,* 32:137-146, 2016.

[73] Pringle, G.J. and Murray, B.G., Reproductive biology of the tamarillo, *Cyphomandra betacea* (Cav.) Sendt.(*Solanaceae*), and some wild relatives. *New Zealand Journal of Crop and Horticultural Science,* 19(3):263-273, 1991.

[74] Qadri, O.S. and Srivastava, A.K., Microwave-assisted foam mat drying of guava pulp: Drying kinetics and effect on quality attributes. *Journal of Food Process Engineering,* 40(1):e12295, 2017.

[75] Ramakrishnan, Y., Adzahan, N.M., Yusof, Y.A., and Muhammad, K., Effect of wall materials on the spray drying efficiency, powder properties and stability of bioactive compounds in tamarillo juice microencapsulation. *Powder Technology,* 328:406-414, 2018.

[76] Ratti, C. and Kudra, T., Drying of foamed biological materials: opportunities and challenges. *Drying Technology,* 24(9):1101-1108, 2006.

[77] Roberfroid, M., Prebiotics: the concept revisited. *The Journal of Nutrition,* 137(3):830S-837S, 2007.

[78] Rodriguez-Mateos, A., Vauzour, D., Krueger, C.G., Shanmuganayagam, D., Reed, J., Calani, L., Mena, P., Del Rio, D., and Crozier, A., Bioavailability, bioactivity and impact on health of dietary flavonoids and related compounds: an update. *Archives of Toxicology,* 88(10):1803-1853, 2014.

[79] Rodriguez Garcia, S.L. and Raghavan, V., Green extraction techniques from fruit and vegetable waste to obtain bioactive compounds—A review. *Critical Reviews in Food Science and Nutrition,* 62(23):6446-6466, 2022.

[80] Romero-Rodriguez, M., Vazquez-Oderiz, M., Lopez-Hernandez, J., and Simal-Lozano, J., Composition of babaco, feijoa, passionfruit and tamarillo produced in Galicia (North-west Spain). *Food Chemistry,* 49(1):23-27, 1994.

[81] Russo, P., Adiletta, G., and Di Matteo, M., The influence of drying air temperature on the physical properties of dried and rehydrated eggplant. *Food and Bioproducts Processing,* 91(3):249-256, 2013.

[82] Sacilik, K. and Elicin, A.K., The thin layer drying characteristics of organic apple slices. *Journal of Food Engineering,* 73(3):281-289, 2006.

[83] Salvia-Trujillo, L., Qian, C., Martín-Belloso, O., and McClements, D.J., Influence of particle size on lipid digestion and β-carotene bioaccessibility in emulsions and nanoemulsions. *Food Chemistry,* 141(2):1472-1480, 2013.

[84] Salvia-Trujillo, L., Soliva-Fortuny, R., Rojas-Graü, M.A., McClements, D.J., and Martín-Belloso, O., Edible nanoemulsions as carriers of active ingredients: A review. *Annual review of Food Science and Technology,* 8:439-466, 2017.

[85] Schotsmans, W., East, A., and Woolf, A., Tamarillo (*Solanum betaceum* (Cav.)), in Postharvest biology and technology of tropical and subtropical fruits. *Elsevier*, 427-442e, 2011.

[86] Siemińska-Kuczer, A., Szymańska-Chargot, M., and Zdunek, A., Recent advances in interactions between polyphenols and plant cell wall polysaccharides as studied using an adsorption technique. *Food Chemistry,* 373:131487, 2022.

[87] Singh, B., Singh, J.P., Kaur, A., and Singh, N., Phenolic composition, antioxidant potential and health benefits of citrus peel. *Food Research International,* 132:109114, 2020.

[88] Soria, A.C. and Villamiel, M., Effect of ultrasound on the technological properties and bioactivity of food: a review. *Trends in Food Science & Technology,* 21(7):323-331, 2010.

[89] Steinberg, D. and Witztum, J.L., Oxidized low-density lipoprotein and atherosclerosis. *Arteriosclerosis, Thrombosis, and Vascular Biology,* 30(12):2311-2316, 2010.

[90] Suárez-Montenegro, Z.J., Ballesteros-Vivas, D., Gallego, R., Valdés, A., Sánchez-Martínez, J.D., Parada-Alfonso, F., Ibáñez, E., and Cifuentes, A., Neuroprotective Potential of Tamarillo (*Cyphomandra betacea*) Epicarp Extracts Obtained by Sustainable Extraction Process. *Frontiers in Nutrition,* 8, 2021.

[91] Vasco, C., Avila, J., Ruales, J., Svanberg, U., and Kamal-Eldin, A., Physical and chemical characteristics of golden-yellow and purple-red varieties of tamarillo fruit (*Solanum betaceum* Cav.). *International Journal of Food Sciences and Nutrition,* 60(sup7):278-288, 2009.

[92] Vatai, T., Škerget, M., and Knez, Ž., Extraction of phenolic compounds from elder berry and different grape marc varieties using organic solvents and/or supercritical carbon dioxide. *Journal of Food Engineering,* 90(2):246-254, 2009.

[93] Walia, N., Zhang, S., Wismer, W., and Chen, L., A low energy approach to develop nanoemulsion by combining pea protein and Tween 80 and its application for vitamin D delivery. *Food Hydrocolloids for Health,* 2:100078, 2022.

[94] Wang, S. and Zhu, F., Tamarillo (*Solanum betaceum*): Chemical composition, biological properties, and product innovation. *Trends in Food Science & Technology,* 95:45-58, 2020.

[95] Witrowa-Rajchert, D. and Rząca, M., Effect of drying method on the microstructure and physical properties of dried apples. *Drying Technology,* 27(7-8):903-909, 2009.

[96] Wrolstad, R.E. and Heatherbell, D.A., Identification of anthocyanins and distribution of flavonoids in tamarillo fruit (*Cyphomandra betaceae* (Cav.) Sendt.). *Journal of the Science of Food and Agriculture,* 25(10):1221-1228, 1974.

[97] Yamaguchi, M. and Uchiyama, S., Effect of carotenoid on calcium content and alkaline phosphatase activity in rat femoral tissues in vitro: the unique anabolic effect of β-cryptoxanthin. *Biological and Pharmaceutical Bulletin,* 26(8):1188-1191, 2003.

[98] Yi, J., Li, Y., Zhong, F., and Yokoyama, W., The physicochemical stability and in vitro bioaccessibility of beta-carotene in oil-in-water sodium caseinate emulsions. *Food Hydrocolloids,* 35:19-27, 2014.

[99] Zarein, M., Samadi, S.H., and Ghobadian, B., Investigation of microwave dryer effect on energy efficiency during drying of apple slices. *Journal of the Saudi Society of Agricultural Sciences,* 14(1):41-47, 2015.