Food Research International 160 (2022) 111665

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Review

# Purple passion fruit (*Passiflora edulis* f. *edulis*): A comprehensive review on the nutritional value, phytochemical profile and associated health effects

Alexandre M.A. Fonseca [a,b], Marina V. Geraldi [c], Mário R. Maróstica Junior [c], Armando J. D. Silvestre [b], Sílvia M. Rocha [a,*]

[a] LAQV-REQUIMTE & Department of Chemistry, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
[b] CICECO & Department of Chemistry, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
[c] School of Food Engineering, Food Science and Nutrition Department, University of Campinas, Monteiro Lobato Street 80, 13083-862 Campinas, São Paulo, Brazil

ARTICLE INFO

*Keywords:*
Purple passion fruit
Food
Nutritional value
Phytochemical composition
Biological activities
Antioxidant
Safety

ABSTRACT

Passiflora is a highly diverse genus where taxonomic lack of consensus remains. This may be the reason why numerous studies do not specify to the infraspecific level the plant material used or lack consistency in the nomenclature of botanical formae of *Passiflora edulis*. Ultimately, this may contribute to inaccurate chemical composition and health effects attributed to different *Passiflora edulis* species and formae. Hence, this review aims to overcome these challenges by exploring the phytochemical profile, specific nutritional value and potential health benefits of purple passion fruit (PPF). PPF is often consumed fresh for its pulp (including seeds) or juice, either directly or added to food dishes. It is also used industrially to produce a wide range of products, where peels and seeds are abundant by-products, most often discarded or used in low-value applications. Herein, in a perspective of integral valorisation of the fruit, the potential use of all PPF fractions (peel, pulp and seeds) is discussed as a source of important macro and micronutrients, adequate to integrate a balanced and healthy diet. In addition, the phytochemical profile of such fractions is also discussed along with the associated *in vitro* biological activities (antioxidant, anti-inflammatory, antibacterial and antifungal) and *in vivo* beneficial effects in the management of several diseases (asthma, hypertension, osteoarthritis, diabetes and pulmonary fibrosis). In summary, this review gathers the current knowledge on the nutritional and phytochemical composition of PPF and highlights the potential of using all fractions as a source of ingredients in food formulations that promote health and well-being. At the same time, it also contributes to defining sustainable strategies for an integrated valorisation of this natural product.

## 1. Introduction

*Passiflora* encompasses the most abundant and economically relevant species of *Passifloracea* family, including 50–60 species that produce edible passion fruits (Feuillet & MacDougal, 2007; Schotsmans & Fischer, 2011). From these, *Passiflora edulis*, a species native from Brazil, is undoubtedly the most economically relevant and the most widely distributed crop of this type (Bernacci et al., 2008). The botanical forma *P. edulis* f. *flavicarpa* (yellow passion fruit) represents about 95% of the world's passion fruit commercial production, (Carr, 2014). The other main forma, *P. edulis* f. *edulis,* commonly known as purple passion fruit (PPF), is commercially explored at a smaller scale along with other species such as *P. ligularis* (sweet granadilla), *P. quadrangularis* (giant granadilla), *P. alata* (fragrant granadilla) and *P. laurifolia* (water lemon) (Corrêa et al., 2016).

A literature survey carried out in the Web of Science™ database, for the period of 2000–2021 identified a total of 2058 publications related with *Passiflora* genus (Fig. 1). Over this period, a growing research interest in *Passiflora* genus has been observed, with an increase of 6.9 times in the number of publications per year. According to this survey, most studied *Passiflora* species were found to be *P. edulis* f. *flavicarpa*, *P. alata*, *P. incarnata* and *P. edulis* f. *edulis* (Fig. 2).

Aside from *P. incarnata,* which is historically known to be used as an herbal medicine for relieving anxiety, insomnia or hypertension, the remaining species correspond to commercially cultivated species appreciated for their fruits typically consumed in fresh. Such relevance as crop for human consumption is in line with the scientific research as the available studies have been performed mainly in the categories

* Corresponding author at: Department of Chemistry, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal.
*E-mail address:* smrocha@ua.pt (S.M. Rocha).

https://doi.org/10.1016/j.foodres.2022.111665
Received 5 March 2022; Received in revised form 1 July 2022; Accepted 6 July 2022
Available online 9 July 2022

"plant sciences" (23.3%), "horticulture" (12.4%), "agronomy" (12.0%) and "food science" (12.0%). Brazil, the country with the highest diversity of *Passiflora* species and, at the same time, the biggest passion fruit producer, is by far the main origin of the studies related to *Passiflora* genus accounting for 59.2% of the publications found.

A long history of medicinal use is algo associated with different parts of *Passiflora* species plants. This is supported by the fact that 18.7% (corresponding to 385 studies) of the publications found in the literature survey belong to the categories "Pharmacology", "Chemistry Medicinal" and "Integrative Complementary Medicine". Nowadays, those species are widely used in traditional medicine as sedatives and anxiolytics (Dhawan et al., 2004). However, several other biological activities have been reported, namely anti-inflammatory, antioxidant, gastroprotective, antibacterial, analgesic, antidiarrheal, anti-diabetic and antiproliferative, which are certainly related to their specific composition in terms of bioactive composition (Asadujjaman et al., 2014; Carraz et al., 2015; Ferreres et al., 2007; Gupta et al., 2012; Montanher et al., 2007; Siebra et al., 2018; Taïwe & Kuete, 2017; Wasicky et al., 2015). However, comparative studies show that different species and even botanical formae have significantly different genotypes, chemical composition and consequently biological properties (Aukar et al., 2002; Dhawan et al., 2001; Li et al., 2011; Pontes et al., 2009; Zucolotto et al., 2012).

In the case of *Passiflora edulis*, an infraspecific distinction is commonly used for cultivation purposes, but in phytochemical and pharmacological studies of the species, the plant materials are frequently not identified at the infraspecific taxon, with only *Passiflora edulis* being mentioned (Li et al., 2011). This may be one of the reasons for the contradictory results reported for this species, such as their neuropharmacological activity (Coleta et al., 2006; Dhawan et al., 2001).

To tackle these limitations and to allow further exploitation of food applications with beneficial health impacts, the present review aims at presenting a comprehensive review of the nutritional value, bioactive composition and reported health effects of purple passion fruit (*Passiflora edulis* f. *edulis*). Initially, a contextualization of *Passiflora* species origin and taxonomic uncertainties is put forward (Section 2) followed by a brief description of PPF geographical distribution, agricultural practices and fruit morphology (section 3). Section 4 addresses the strategy adopted to compile the chemical composition and bioactivities specific to PPF while in Section 5, a detailed discussion of PPF nutritional value and bioactive composition is presented, with a special emphasis on the most abundant and promising compounds or families in a perspective of food products formulation. Section 6 summarizes the current scientific evidence of the putative biological activities of PPF fractions (peels, pulp, epicarp or seeds) extracts while pointing out the animal and human clinical trials available and discussing the most relevant health benefits of those fractions extracts. The safety concerns related to the consumption of the PPF fractions are also discussed (Section 7).

## 2. Origin and taxonomy

Although passion flowers were already known by natives of North and South America, Europeans only found them after the discovery of the Americas and during the Spanish colonial period in South America. The first known reference to a *Passiflora* plant dates back to 1553 and is attributed to Pedro Cieza de León (Bernacci et al., 2008; Yockteng R. et al., 2011). Since then, passion flower descriptions were tightly associated with the belief that their morphology depicted Christ's crucifixion. This symbolism became so embedded at the time that led Linnaeus to adopt *Passiflora* (*passio* meaning "suffering" and *flora* meaning "flower") as the definitive name for the genus in 1753 when he laid the foundations for the botanical nomenclature (Bernacci et al., 2008).

Nowadays, *Passifloraceae* family, to which *Passiflora* genus belongs, is usually reported as containing between 500 and 700 species (Cerqueira-Silva et al., 2014; Nyanzi et al., 2005; Rodriguez-Amaya, 2012; Zerbini et al., 2008). However, the Global Biodiversity Information Facility (GBIF), the largest online database of biological data, indicates the existence of 1407 species belonging to this family (Passifloraceae in GBIF Secretariat, 2021). Lack of consensus on the number of *Passifloraceae* species is usually attributed to taxonomic uncertainties, the use of synonyms, and ongoing description of new species (Cerqueira-Silva et al., 2014; Muschner et al., 2006). Moreover, the number of genera is also a matter of debate, varying between 18 and 23 (Corrêa et al., 2016). Despite this divergence, it is clear that *Passiflora* is by far, the most important and diverse genus of *Passifloraceae* (Feuillet & MacDougal,

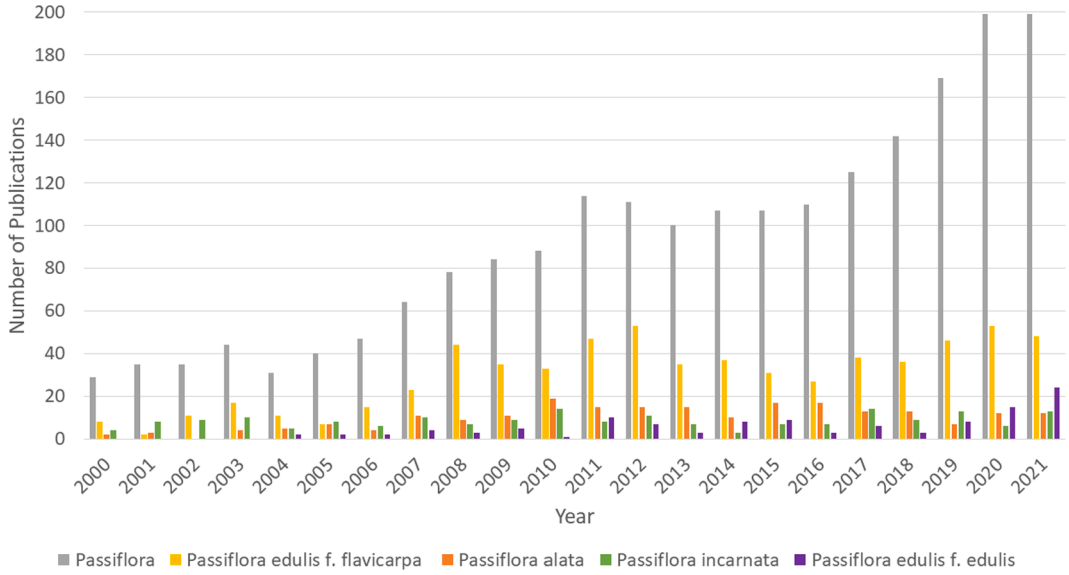


**Fig. 1.** Literature survey, via Web of Science™, of papers published between 2000 and 2021 regarding *Passiflora* genus (search query: "TS = passiflora AND DOCUMENT TYPES: (Article)") and the most studied species and varieties: *P. edulis* f. *flavicarpa* (search query: "TS=(*passiflora* AND (*flavicarpa* OR yellow)) AND DOCUMENT TYPES: (Article)"); *P. alata* (search query: "TS=(*passiflora* AND *alata*) AND DOCUMENT TYPES: (Article)"); *P. incarnata* (search query: "TS=(*passiflora* AND *incarnata*) AND DOCUMENT TYPES: (Article)"); and *P. edulis* f. *edulis* (search query: "TS=(*passiflora* AND (purple OR "f. *edulis*" OR "var. *edulis*")) AND DOCUMENT TYPES: (Article)").

2007). *Passiflora* taxonomic hierarchy is rather complex as its infrageneric classification is divided into subgenus, supersections, sections and series, and in some cases, an infraspecific classification is also required (Feuillet & MacDougal, 2003). Although being an active area of research, nowadays, the infrageneric classification of *Passiflora* genus suggested by Feuillet and MacDougal in 2004 into four subgenera (*Astrophea*, *Deidamioides*, *Decaloba* and *Passiflora*) is commonly accepted. Although this classification system is purely based on morphological and ecological characteristics, later studies on phylogenetic systematics using molecular markers and sequencing techniques, have partially corroborated this classification (Feuillet & MacDougal, 2003; Muschner et al., 2003, 2012).

## 3. Purple passion fruit geographical distribution, production and morphology

After its discovery, passion fruit spread rapidly to Europe and elsewhere, and, by the end of the nineteenth century, it was widely distributed throughout many tropical and subtropical regions of both the New and Old World (Carr, 2014). Nowadays, even though the passion flower species are distributed across the globe, the pantropical region of the Americas still holds the higher abundance and diversity, with Brazil and Colombia being particularly rich with an estimate of 150 and 170 species, respectively (Bernacci et al., 2015; Feuillet & MacDougal, 2007; Ocampo et al., 2010). *P. edulis* Sims is assumed to be native from this region, more specifically, from the edges of the tropical rainforests in South America (Brazil). Existing data on the current distribution of *P. edulis* Sims rarely differentiates between its botanical formae, thus the exact regions that each of those occupies are not completely known. GBIF provides this geographic distribution at the infraspecific level, but the number of records (66 georeferenced records for the purple forma) is still scarce when compared with the records for the species (6459 georeferenced records for *Passiflora edulis* Sims). Nonetheless, one as to take into consideration that despite being the largest initiative aiming to mobilize biodiversity data from museums, surveys, and other data sources into an online data search portal, GBIF data usage has been criticized because of its inherent biases (Beck et al., 2014). That might result from the fact that GBIF collects and provides data from "sources spanning from museum specimens collected in the 18th and 19th centuries to recently geotagged smartphone photos shared by amateur naturalists." (GBIF.org, 2022). Fig. 3 presents a comparison of available geographical occurrences available on GBIF database for *Passiflora edulis* f. *edulis* and *Passiflora edulis* Sims.

Despite some lack of reliable distribution data, PPF is the most cold-tolerant forma of *Passiflora edulis* and thrives at elevations of 600–2000 m. It prefers a cool, frost-free climate and performs poorly in intense summer heat. It will grow in areas with 900 mm annual precipitation well distributed throughout the year. It is mainly produced in Colombia, Australia, South Africa, Kenya, Papua-New Guinea, New Zealand, Sri Lanka, and India. Production of PPF is also possible in frost-free areas of temperate zones, although fruiting is generally more limited than in tropical regions. Seedlings are usually planted 3–4 m apart and the first harvest is obtained in the following year. Plants continue to grow during the next 5–6 years, after which the crop yield starts to gradually diminish. Although plants can live much longer, after this period, the plantation is usually renewed for economic reasons. On average, a modern plantation has a life span of 7 years. In comparison to yellow passion fruit which yields up to 50 tonnes per hectare, PPF productivity is relatively low: 10–15 tonnes per hectare (Ulmer & MacDougal, 2004).

According to the FAO "Food Outlook - Biannual report on Global Food Markets", global production of passion fruit reached an average of 1.5 million tonnes between 2015 and 2017 (FAO, 2018). Brazil is the main producer, being responsible for approximately 65% of the global production, followed by Colombia and Indonesia (FAO, 2018). Brazil, is the country is the world's biggest consumer of passion fruit, and domestic supply struggles to meet demand. In terms of international suppliers, Ecuador is ranked as the largest exporter, followed by Australia and New Zealand (FAO, 2018). Most of the current passion fruit production is directed for consumption in fresh. To this end, the fruit is cut into halves and the pulp is spooned out of the skin and eaten directly or used as dressing in salads, ice creams, and other sweets. Other culinary uses include juices, liqueurs, tropical punches, yogurts, jams, jellies and confectioneries (Ulmer & MacDougal, 2004). The peels have been also used to produce wine or tea, as source of pectin and medicinal ingredients, or to incorporate in animal feed. (He et al., 2020). Additionally, the cold-pressed seeds yield a pale-yellow oil with a mild, pleasant taste that is used both in cooking and as a raw material in the paint and varnish industry.

In terms of morphology, PPF presents a globular to ovoid shape with 4–5 cm in diameter (Fig. 4) and an average weight of 35 g (Ulmer & MacDougal, 2004). It is enclosed by a smooth leathery peel that becomes wrinkled when the fruit becomes fully ripe. This peel (corresponding to the pericarp) is composed of three different tissues: a hard, waxy, deep purple epicarp (the external epidermis); a white and spongy

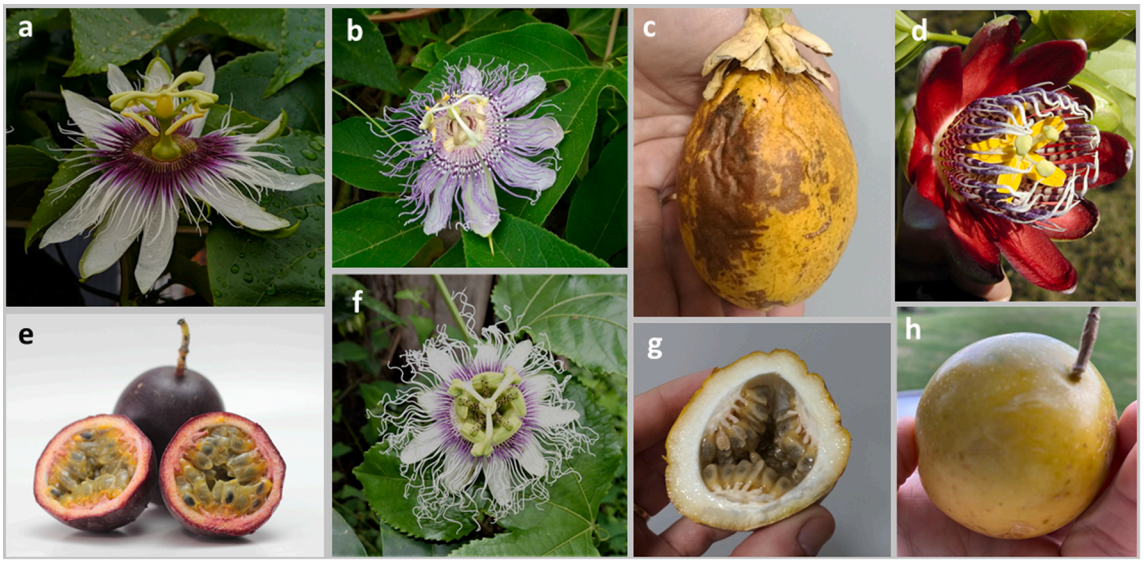


**Fig. 2.** Characteristic flowers and fruits from the most studied species of Passiflora plants: *P. edulis* f. *flavicarpa* (a) (h); *P. alata* (d) (c) (g); *P. incarnata* (b); and *P. edulis* f. *edulis* (f) (e). Adapted from (iNaturalist contributors, 2021).

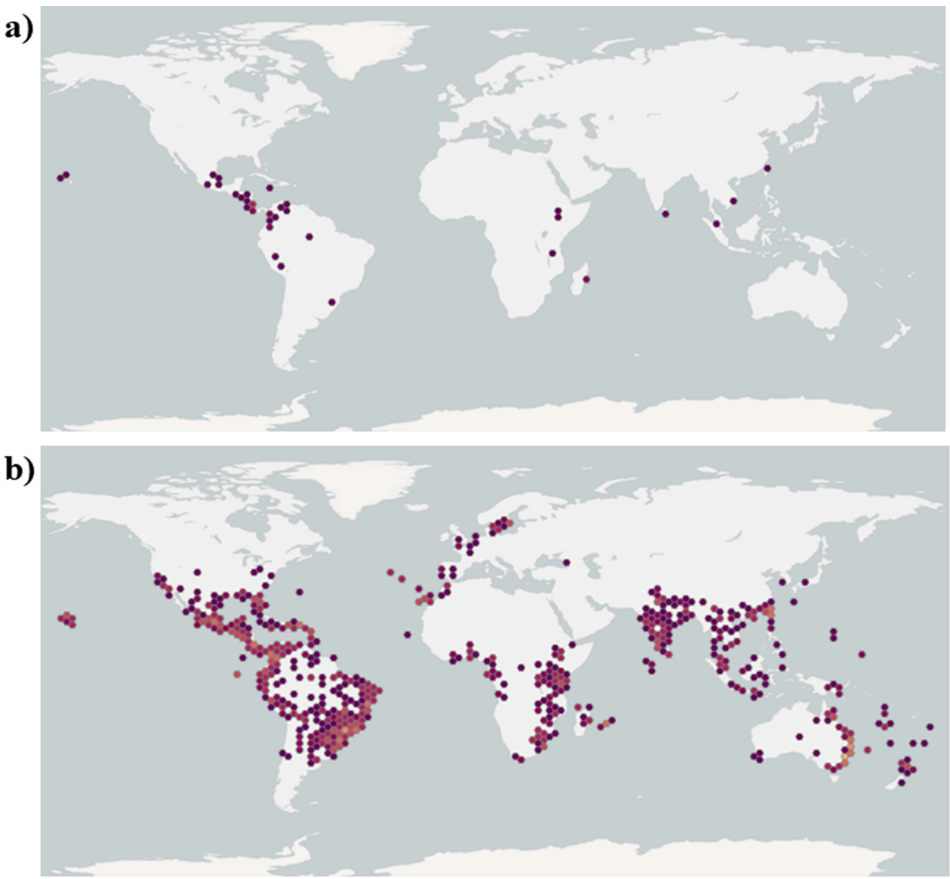


**Fig. 3.** Global occurrences of a) *Passiflora edulis* f. *edulis* and b) *Passiflora edulis* Sims according to Global Biodiversity Information Facility (GBIF) for the period 1827–2020 using the query "*passiflora edulis* f. *edulis*" and "*passiflora edulis* sims", respectively (Passifloraceae in GBIF Secretariat, 2021). Colour scale from purple to yellow represents lower to higher occurrences, respectively.

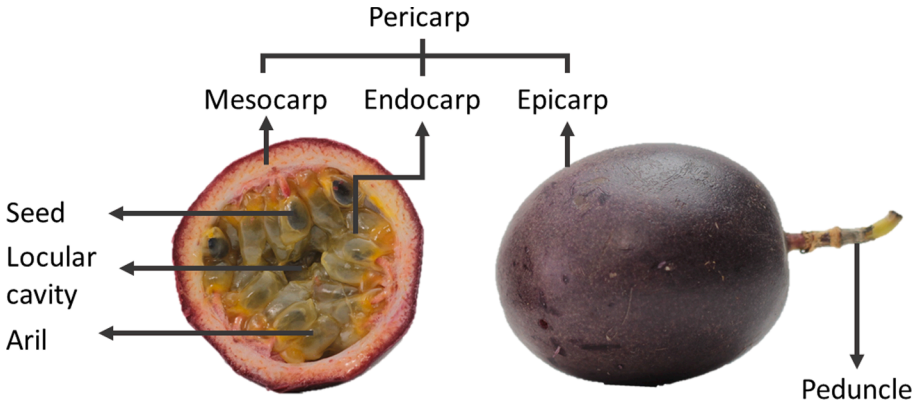


**Fig. 4.** Purple passion fruit (*Passiflora edulis* f. *edulis*) morphology. PPF peel (or pericarp) is composed by the epicarp (outermost deep purple leathery layer), mesocarp (white and spongy parenchyma layer) and endocarp (innermost peel layer that encompasses a placental region from which numerous funiculi are directed towards the locular cavity). Pulp is formed by numerous seeds enclosed in gelatinous arils.

parenchyma corresponding to mesocarp, which thickness varies with maturity; and the endocarp (placental region) from which numerous funiculi are directed towards the locular cavity (Florez et al., 2003). When PPF is either consumed fresh or used in juice and pulp production, this peel is usually discarded or used as a by-product for low-value applications. The inside of the fruit, which corresponds to the part normally consumed, is filled with a gelatinous, translucent and intensely fragrant yellow-orange pulp composed of arils that represent about 35% of fruit weight (Ulmer & MacDougal, 2004). Embedded in arils, numerous small, flattened, oval, black seeds are present, which are often consumed with the pulp. The juice recovery from the fruit varies between 31.0 and 35.0% of total weight (Thokchom & Mandal, 2017). The total percentage of each fraction varies widely within PPF. Four different accessions of PPF from India registered a percentage of total weight between 37.8% and 63.0% for peel; 23.9 % to 46.5% for juice and 9.8% to 18.5% in seeds (Charan et al., 2018).

## 4. Bibliographic research method

To compile relevant data on the chemical composition and biological

activities specific to PPF, a bibliographic search on the Web of science™ database, was carried out using appropriate keywords to select relevant studies. Some criteria of inclusion were established for each of the read publications such as the relevance for the particular aspects focused on each of the following sections and a publication date as recent as possible. Due to the lack of specification or the ambiguity in the identification of the forma of *P. edulis* used in some articles, only works that clearly stated the use of *P. edulis* f. *edulis* or *P. edulis* with purple peel coloration were selected.

The strategy for literature analysis was based on the use of VOSviewer software (van Eck & Waltman, 2010) which allows the visualization of bibliometric networks through the analysis of co-occurrence of links between keywords, which occurred at least twice. The circles and label size are proportional to the number of a specific keyword occurrence, while their proximity is determined according to the number of sources in which the keywords occur together. In the present study, a set of 48 references that specify the use of PPF were selected. The diagram obtained using this software is shown in Fig. 5. Besides the species and fruit names, that are expected to appear as the most frequent keywords, terms such as "flavonoids", "anthocyanins", "phenolic compounds" and "antioxidant" are also recurring. This suggests that the antioxidant activity is the most studied biological activity in PPF which can be associated with their high content in phenolic compounds such as flavonoids or anthocyanins. The presence of methodologies keywords such as high performance liquid chromatography ("HPLC"), "gas chromatography", "mass spectrometry" and "solid-phase microextraction" are also suggesting their use in the chemical characterization of PPF.

To compile and help to visualize the PPF phytochemical composition, a network graph was built using the software Cytoscape v3.5.1 (The Cytoscape Consortium, San Diego, CA, USA) (Fig. 6). This graph shows the bioactive compounds found in PPF (Carmona-Hernandez et al., 2019; Chan et al., 1972; Chassagne et al., 1996, 1999; Chassagne & Crouzet, 1998; Conde-Martínez et al., 2013; Domínguez-Rodríguez et al., 2019; dos Reis et al., 2018; Ghada et al., 2020; Giuffré, 2007; Herderich & Winterhalter, 1991; Herrera-Ramirez et al., 2020; M. Hu et al., 2020; Y. Hu et al., 2018; Ichimura et al., 2006; Jiménez et al., 2011; KidØy et al., 1997; Krambeck et al., 2020; Lee et al., 2015; Lourith & Kanlayavattanakul, 2013; Medina et al., 2017; Nyanzi et al., 2005; Piombo et al., 2006; Pontes et al., 2009; Porto-Figueira et al., 2015; Ramaiya et al., 2019; Shiomi et al., 1996; U.S. Department of Agriculture, 2019; Winterhalter, 1990; Wondracek et al., 2011; Yepes et al., 2021; Zibadi et al., 2007) according to their number of citations and organizes such compounds in phytochemical families depending on their association with each fruit fraction: peel, pulp, juice, seeds and epicarp. A detailed analysis of Fig. 6 is performed in the next sections.

## 5. Chemical composition and nutritional value of purple passion fruit

The systematization of the chemical composition of plant materials always faces several challenges. Namely, considerable variation is often observed within the same matrix even in the case of the same forma. Factors such as cultivar, climate and agricultural management practices can greatly impact the phytochemical composition of the plant material used for analysis (Ramaiya et al., 2013; Rodriguez-Amaya, 2003). Additionally, the lack of standardization of the analytical methods used by different research groups can also explain some of the variations observed. Due to this lack of standardization, the use of different units in quantitative analysis also hampers the comparison of results across different studies.

*P. edulis* f. *flavicarpa* and PPF present distinct chemical compositions and also genotype as it has been shown for example, by the distinct profiles of volatile compounds obtained by headspace solid-phase microextraction (HS-SPME) followed by gas chromatography-quadrupole mass spectrometry analysis (GC-qMS) or high genetic diversity (34,4% similarity) estimated by random amplified polymorphic DNA products (RAPD) (Aukar et al., 2002; Pontes et al., 2009). This distinction evidences the need to characterize the chemical composition of the two formae independently. Table 1 comprises the nutritional value of the several fractions (peel, pulp, juice and seeds) of ripe PPF including the proximate and micronutrient (minerals, vitamins and amino acids) composition.

Aside from the water content, which can reach up to 85.5% in the pulp, 87.0% in the peel and 45.9% in the seeds, carbohydrates comprise the second largest family in fractions of PPF, reaching a content of 80.7%, 89.4% and 69.9% on a dry weight basis on the peel, pulp and seeds, respectively. Seeds are the richest fraction of the fruit in terms of protein (13.2% of DW) and lipids (14.9% of DW) contents while peels contain the highest amount of fiber (61.7% of DW).

Regarding micronutrients, PPF pulp and juice are naturally rich in

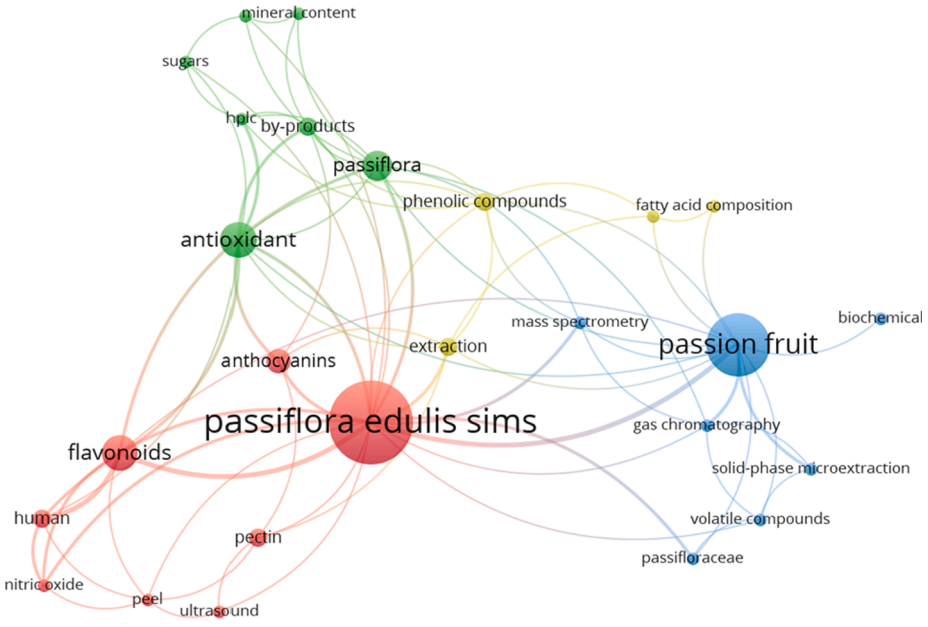


**Fig. 5.** Analysis of co-occurrence links between keywords that occur at least twice in the selected articles (research articles that specify the composition of PPF), constructed using the software VOSviewer (version 1.6.17) (van Eck & Waltman, 2010)..

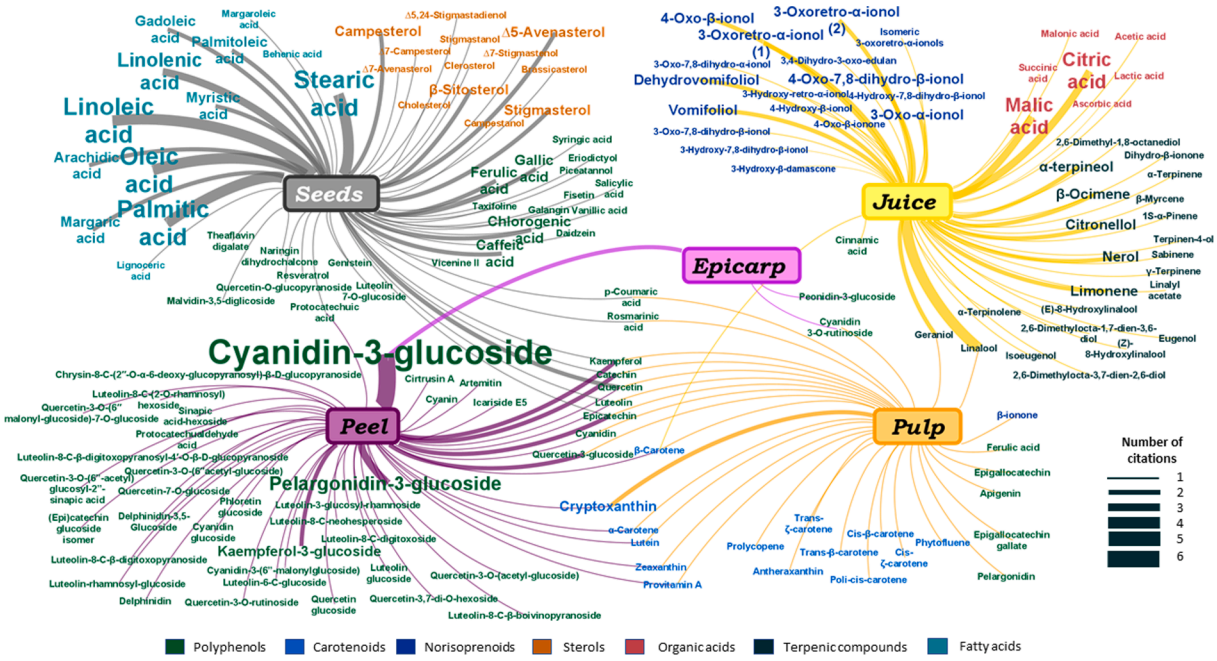


**Fig. 6.** Visual representation of the phytochemical compounds reported in the literature for purple passion fruit (*Passiflora edulis* f. *edulis*) peel, seeds, juice, epicarp and pulp (Carmona-Hernandez et al., 2019; Chan et al., 1972; Chassagne et al., 1996, 1999; Chassagne & Crouzet, 1998; Conde-Martínez et al., 2013; Domínguez-Rodríguez et al., 2019; dos Reis et al., 2018; Ghada et al., 2020; Giuffré, 2007; Herderich & Winterhalter, 1991; Herrera-Ramirez et al., 2020; M. Hu et al., 2020; Y. Hu et al., 2018; Ichimura et al., 2006; Jiménez et al., 2011; KidØy et al., 1997; Krambeck et al., 2020; Lee et al., 2015; Lourith & Kanlayavattanakul, 2013; Medina et al., 2017; Nyanzi et al., 2005; Piombo et al., 2006; Pontes et al., 2009; Porto-Figueira et al., 2015; Ramaiya et al., 2019; Shiomi et al., 1996; U.S. Department of Agriculture, 2019; Winterhalter, 1990; Wondracek et al., 2011; Yepes et al., 2021; Zibadi et al., 2007). Nodes represent the PPF fractions and lines connect compounds to the fruit fraction where they have been identified. Line thickness and compound font size is correlated with the number of studies that identified each compound. Compounds are colour coded by chemical family.

vitamin C (up to 40.0% and 93.2 % of recommended dietary intake (RDI) per 100 g of FW, respectively) while peels and seeds provide considerable amounts of potassium, copper, magnesium, zinc and iron. Although peels are not usually consumed fresh and generally need to be further processed (drying and milling), the nutritional value of the several fractions of PPF shows that they all can positively contribute to diet as they provide significant amounts of dietary fiber and vitamin C as well as several important minerals. At the same time, it also hints at the compounds targeted with a greater research interest within each fruit fraction such as fiber in peel or lipids in seeds.

Plant secondary metabolites are often bioactive compounds that can be used in traditional medicine, industrial applications and as part of human diet when consumed directly or as supplements (Tiwari & Rana, 2015). Phytochemical composition (including potential bioactive compounds) of PPF fruit fractions along with the respective quantification (when available) are listed in Table 2. A visual overview of this phytochemical composition is also shown in Fig. 6, which allows the identification of the most frequently studied compounds/chemical families in each fruit fraction. This kind of representation allows us to make some observations regarding the research interest shown in each PPF fraction composition: The PPF peel has been mainly studied for its phenolic composition and cyanidin-3-glucoside stands out as the most frequently reported compound. Besides phenolic compounds, only carotenoids have been reported in PPF peel. Phenolic compounds have been also reported in seeds, but the most frequent source of interest in this fruit fraction is the lipidic composition, in which most frequently, the presence of linoleic, linolenic, oleic, palmitic and stearic acids is highlighted. Studies on the chemical characterization of pulp have been mainly focused on phenolic compounds and carotenoids while terpenic compounds, norisoprenoids and organic acids have also been reported in juice.

### 5.1. Carbohydrates composition

As seen in Table 1, PPF peel carbohydrates are mainly composed by dietary fiber (617 $mg.g^{-1}$ of DW, representing 76.4% of total carbohydrate content) (dos Reis et al., 2018). A similar dietary fiber content has been found in other passion fruit peels, such as *P. edulis* f. *flavicarpa* and *Passiflora caerulea* (612 and 621 $mg.g^{-1}$ of DW, respectively). In PPF, cellulose and hemicelluloses (306 and 119 $mg.g^{-1}$ DW, respectively) have been determined to account for a significant portion of dietary fiber found in the peel, while the remaining content has been reported as pectin (Delvar et al., 2019). However, the reported pectin PPF contents are quite variable (73.0–329 $mg.g^{-1}$ DW) which is probably due to the different extraction methodologies applied (Dam & Nguyen, 2013; Delvar et al., 2019; dos Reis et al., 2018; Thu Dao et al., 2020). In a comparative study, *P. edulis* f. *flavicarpa* was found to have the highest pectin content (377 $mg.g^{-1}$ DW) followed by PPF (329 $mg.g^{-1}$ DW) and *Passiflora caerulea* (216 $mg.g^{-1}$ DW) (dos Reis et al., 2018).

The detailed characterization of a polysaccharide optimally extracted (yield of 10.05%) from PPF peel via ultrasonic-aided aqueous ammonium oxalate extraction was recently reported (Guo et al., 2020). Monosaccharide composition of the extracted polysaccharide revealed an estimated content of galacturonic acid and glucuronic acid of 51.8 ± 1.66% (w/w) and 2.16 ± 0.07% (w/w), respectively, which confirms its pectic nature (Guo et al., 2020).

Due to their content in dietary fiber, PPF peel may be used in the development of new fiber-rich healthy food products and also as a potential alternative source of pectin to incorporate in different food formulations. With that perspective in mind, an optimized microwave-assisted extraction methodology achieved a maximum pectin yield of 18.7%. At optimized extraction conditions (12 min, 218 W, pH of 2.9 and liquid:solid ratio of 57:1 $mL.g^{-1}$), this pectin yield was higher when compared to conventional heating method under the same operating conditions (13.58%), which highlights the potential of PPF peel wastes

**Table 1**
Nutritional composition of purple passion fruit (*Passiflora edulis* f. *edulis*) peel, pulp, juice and seeds.

| Composition | Peel [a] | | Pulp [b] | | Juice | Seeds | |
|---|---|---|---|---|---|---|---|
| | per 1 g DW | per 1 g FW | per 1 g DW | per 1 g FW | per 1 g FW | per 1 g DW | per 1 g FW |
| Proximate | | | | | | | |
| Water (mg) | – | 870[1] | – | 720 – 860[1,2,3] | 770 – 860[3,4] | – | 460[1] |
| Energy (kcal) | – | – | – | 0.97[3] | 0.51[3] | – | – |
| Protein (mg) | 64.7 – 75.0[1,5] | – | 65.3 – 77.0[1,5] | 22.0 – 30.0[2,3] | 3.9 – 12.0[3,4,6] | 122 – 132[1,5,7] | – |
| Total lipid (mg) | 4.0 – 48.9[1,5] | – | 7.0 – 10.9[1,5] | 4.8 – 7.0[2,3] | 0.0 – 0.5[3,6] | 149 – 301[1,5,7] | – |
| Total carbohydrates (mg) | 807[1] | – | 894[1] | 55.4 – 234[2,3] | 132 – 165[3,6] | 699[1] | – |
| Sugars (mg) | – | – | – | 112[3] | 74.0 – 143[3,4,8] | – | – |
| Dietary fiber (mg) | 617[1] | – | 14.0[1] | 39.2 – 104[2,3] | 1.0 – 2.0[3,6] | 438 – 551[1,7] | – |
| Ash (mg) | 79.3[1] | – | 29.5[1,2] | 10.2 – 12.9[2] | 3.4 – 6.0[3,6] | 13.4 – 18.5[1,7] | – |
| Micronutrients | | | | | | | |
| Minerals | | | | | | | |
| Calcium (mg) | 3.10[1] | – | 0.20 – 0.567[1,2] | 0.12[3] | 0.04 – 0.18[3,4] | 0.06 – 1.73[1,7] | – |
| Iron (mg) | 0.046[1] | – | 0.029 – 0.034[1,2] | 0.016[3] | 0.0024 – 0.040[3,4] | 0.043 – 0.062[1,7] | – |
| Magnesium (mg) | 1.30[1] | – | 1.00 – 1.28[1,2] | 0.29[3] | 0.17 [3] | 1.38 – 2.90[1,7] | – |
| Phosphorus (mg) | 0.70[1] | – | 1.00 – 1.50[1,2] | 0.68[3] | 0.63 – 1.15[1,7] | – | – |
| Potassium (mg) | 28.0[1] | – | 4.13 – 16.0[1,2] | 3.48[3] | 2.78[3] | 1.12 – 3.55[1,7] | – |
| Sodium (mg) | 0.073[1] | – | 0.053 – 0.40[1,2] | 0.28[3] | 0.06[3] | 0.048 – 2.41[1,7] | – |
| Zinc (μg) | 9.0[1] | – | 3.0 – 21.0[1,2] | 1.0[3] | 0.5[3] | 4.6 – 56[1,7] | – |
| Copper (μg) | 2.0[1] | – | 1.1 – 3.4[1,2] | 0.9[3] | 0.5[3] | 7.0 – 14.0[1,7] | – |
| Selenium (μg) | – | – | – | 0.0060[3] | 0.0010[3] | – | – |
| Boron (μg) | 14.0[1] | – | 2.0[1] | – | – | 5.0[1] | – |
| Manganese (μg) | 7.0[1] | – | 4.0[1,2] | – | – | 23[1]; nd[7] | – |
| Sulfur (mg) | 16.0[1] | – | 0.90[1] | – | – | 0.32[1] | – |
| Nitrogen (mg) | 9.20[1] | – | 11.0[1] | – | – | 3.80[1] | – |
| Vitamins | | | | | | | |
| Vitamin A (μg) | – | – | – | 0.64[3] | 0.36[3] | – | – |
| Vitamin E (μg α-tocopherol equivalents) | – | – | – | 0.2[3] | 0.1[3] | – | – |
| Riboflavin (μg) | – | – | – | 1.3[3] | 1.2 – 1.9[3,4] | – | – |
| Niacin (μg) | – | – | – | 15.0[3] | 15.0[3] | – | – |
| Vitamin $B_6$ (μg) | – | – | – | 1.0[3] | 0.5[3] | – | – |
| Folate (μg) | – | – | – | 0.14[3] | 0.07[3] | – | – |
| Vitamin C, total ascorbic acid (mg) | – | – | – | 0.30[3] | 0.22 – 0.70[3,4,8] | – | – |
| Choline (μg) | – | – | – | 76.0[3] | 40.0[3] | – | – |
| Vitamin K (μg) | – | – | – | 0.0070[3] | 0.0040[3] | – | – |
| Amino acids | | | | | | | |
| γ-aminobutyric acid (mg) | 2.40 – 4.40[10] | – | – | – | – | – | |
| Arginine | ✓[9] | | – | – | ✓[9] | ✓[9] | |
| Aspartic acid | ✓[9] | | – | – | ✓[9] | ✓[9] | |
| Glycine | ✓[9] | | – | – | ✓[9] | ✓[9] | |
| Leucine | ✓[9] | | – | – | ✓[9] | ✓[9] | |
| Lysine | ✓[9] | | – | – | ✓[9] | ✓[9] | |
| Proline | ✓[9] | | – | – | ✓[9] | ✓[9] | |
| Threonin | ✓[9] | | – | – | ✓[9] | ✓[9] | |
| Tyrosine | ✓[9] | | – | – | ✓[9] | ✓[9] | |
| Valine | ✓[9] | | – | – | ✓[9] | ✓[9] | |

DW: Dry weight; FW: Fresh weight; ✓: Detected but not quantified; nd: Not detected; –: Data not available.
[a] Epicarp + mesocarp; [b] Without seeds.
[1] (dos Reis et al., 2018); [2] (Ramaiya et al., 2019); [3] (U.S. Department of Agriculture, 2019); [4] (Pruthi & Lal, 1959); [5] (Delvar et al., 2019); [6] (Jiménez et al., 2011); [7] (Ramaiya et al., 2018); [8] (Ramaiya et al., 2013); [9] (Pruthi, 1963); [10] (Ichimura et al., 2006).

to be used as a source of pectin that can be extracted by quicker and simple methods (Thu Dao et al., 2020). This potential was also corroborated by structural assessment by fourier-transform infrared spectroscopy (FTIR), which confirmed that the isolated pectin was very similar to commercially available citrus pectin and thus suitable to meet market requirements (Thu Dao et al., 2020). A different study also evaluated the use of PPF peel as a potential alternative source of pectin (Dam & Nguyen, 2013). Optimized pectin extraction from PPF (extracted with HCl at 96 °C, pH 1.96 and extraction time of 83.5 min to achieve a yield of 13.5%) revealed similar quality to commercial pectins, due to a good gel-forming capacity, high gel stability, good quality in acid environment, and a two times higher viscosity. Authors proposed the suitability of PPF pectin to be commercially produced not only as a solution to the peels waste disposal but also to meet the requirement of pectin in the market (Dam & Nguyen, 2013).

Similarly to peel, PPF seed dietary fiber accounts for up to 78.8% (551 $mg.g^{-1}$ DW) of the total carbohydrate content (699 $mg.g^{-1}$ DW) (dos Reis et al., 2018). Cellulose has been found to account for 521 $mg.g^{-1}$ DW while hemicellulose and lignin were determined in lower amounts (24 and 22 $mg.g^{-1}$ DW, respectively) meaning that the dietary fiber present in seeds is mainly insoluble (Delvar et al., 2019). Insoluble dietary fiber consumption can be beneficial to weight management and gut health by preventing constipation and hemorrhoids (Ramaiya et al., 2018).

In PPF juice, carbohydrate fraction was found to be mainly composed of glucose, fructose, and sucrose (Fig. 7) accounting for up to 86.0% of the total carbohydrates followed by smaller amounts of starch (mainly amylopectin) (Chan & Kwok, 1975; Rodriguez-Amaya, 2012). With a total sugar content between 74.0 and 143 $mg.g^{-1}$ FW (Table 1), PPF juice compares to other tropical fruit juices such as papaya (90.0 $mg.g^{-1}$ FW), pineapple (123 $mg.g^{-1}$ FW) and mango (140 $mg.g^{-1}$ FW) (Yahia et al., 2018). The content of the 3 main sugars in PPF juice range between 14.7 and 15.4 $mg.g^{-1}$ FW for sucrose; 64.5–67.4 $mg.g^{-1}$ FW for glucose; and 63.8–65.4 $mg.g^{-1}$ FW for fructose (Ramaiya et al., 2013). Glucose values were accompanied by fructose content as shown by a G/F ratio of 1.03. However, smaller differences between fructose and glucose content in comparison to sucrose have been also reported (Chan & Kwok, 1975).

**Table 2**
Phytochemical composition of purple passion fruit (*Passiflora edulis* f. *edulis*) peel, epicarp, pulp, juice and seeds.

| Compound | Peel [a] | Epicarp | Pulp [b] | Juice | Seeds |
|---|---|---|---|---|---|
| **Flavonoids** | | | | | |
| **Flavonols** | | | | | |
| Artemitin | ✓[1] | -[c] | – | – | – |
| Fisetin | – | – | – | – | 25.0 μg.g$^{-1}$ DW[2] |
| Galangin | – | – | – | – | 74.0 μg.g$^{-1}$ DW[2] |
| Kaempferol | 0.74 mg.g$^{-1}$ DW[3]; ✓[4] | – | 0.12 mg.g$^{-1}$ DW[3] | – | 7.8 μg.g$^{-1}$ DW[2] |
| Kaempferol-3-glucoside | 0.33 mg.g$^{-1}$ DW[5]; ✓[4] | – | – | – | – |
| Quercetin | ✓[4] | – | 2.30 mg.g$^{-1}$ DW[3] | – | 0.20 – 0.30 mg.g$^{-1}$ DW[6]; ✓[2] |
| Quercetin-3-glucoside | 1.67 mg.g$^{-1}$ DW[5]; ✓[4] | – | <LOQ[c,7] | – | – |
| Quercetin glucoside | ✓[1] | – | – | – | – |
| Quercetin-3,7-di-*O*-hexoside | 0.58 mg.g$^{-1}$ DW[5] | – | – | – | – |
| Quercetin-3- *O* -(6″-acetyl-glucoside) | ✓[1] | – | – | – | – |
| Quercetin-3- *O* -(6″-malonyl-glucoside)-7-O -glucoside | ✓[1] | – | – | – | – |
| Quercetin-3- *O* -(acetyl-glucoside) | tr[5] | – | – | – | – |
| Quercetin-3- *O* -rutinoside | tr[5] | – | – | – | – |
| Quercetin-7- *O* -glucoside | 0.33 mg.g$^{-1}$ DW[5] | – | – | – | – |
| Quercetin- *O* -glucopyranoside | – | – | – | – | 5.2 μg.g$^{-1}$ DW[2] |
| **Flavanols** | | | | | |
| Catechin | ✓[1,4] | – | 0.28 μg. mL$^{-1}$ FW[7] | – | ✓[2] |
| (Epi)catechin glucoside isomer | ✓[1] | – | – | – | – |
| Epicatechin | ✓[1,4] | – | 0.22 μg. mL$^{-1}$ FW[7] | – | ✓[2] |
| Epigallocatechin | – | – | <LOQ[c,7] | – | – |
| Epigallocatechin gallate | – | – | <LOQ[c,7] | – | – |
| Theaflavin digallate | – | – | – | – | 6.7 μg.g$^{-1}$ DW[2] |
| **Flavones** | | | | | |
| Apigenin | – | – | <LOQ[c,7] | – | – |
| Chrysin-8-C-(2″-*O*-α-6-deoxy-glucopyranosyl)-β-D-glucopyranoside | ✓[8] | – | – | – | – |
| Luteolin | 20.0 μg.g$^{-1}$ DW[9] | – | <LOQ[c,7] | – | 4.3 μg.g$^{-1}$ DW[2] |
| Luteolin glucoside | ✓[1] | – | – | – | – |
| Luteolin-3-glucosyl-rhamnoside | ✓[1] | – | – | – | – |
| Luteolin-6-*C*-glucoside | 41.0 μg.g$^{-1}$DW[9] | – | – | – | – |
| Luteolin-7- *O* -glucoside | – | – | – | – | 60.1 μg.g$^{-1}$ DW[2] |
| Luteolin-8-*C*-(2-*O*-rhamnosyl) hexoside | 0.44 mg.g$^{-1}$ DW[5] | – | – | – | – |
| Luteolin-8-*C*-digitoxoside | ✓[4] | – | – | – | – |
| Luteolin-8-*C*-neohesperoside | ✓[4] | – | – | – | – |
| Luteolin-8-*C*-β-boivinopyranoside | ✓[9] | – | – | – | – |
| Luteolin-8-*C*-β-digitoxopyranoside | ✓[9] | – | – | – | – |
| Luteolin-8-*C*-β-digitoxopyranosyl-4′-*O*-β-D-glucopyranoside | ✓[9] | – | – | – | – |
| Luteolin-rhamnosyl-glucoside | ✓[1] | – | – | – | – |
| Vicenine II | – | – | – | – | 0.01 μg.g$^{-1}$ DW[2] |
| **Anthocyanins** | | | | | |
| Cyanin | 14.8 μg.g$^{-1}$ DW[3] | – | – | – | – |
| Cyanidin | 12.4 μg.g$^{-1}$ DW[3] | – | <LOQ[c,7] | – | – |
| Cyanidin glucoside | ✓[1] | – | – | – | – |
| Cyanidin-3-(6″-malonylglucoside) | 2.00 %[d,10] | – | – | – | – |
| Cyanidin-3-glucoside | 97.0 %[d,10]; 0.029 –5.78 mg.g$^{-1}$ DW[3,5,11]; ✓[4,12] | 2.82 mg.g$^{-1}$ DW[13]; ✓[14] | – | – | – |
| Cyanidin-3-*O*-rutinoside | – | ✓[14] | <LOQ[c,7] | – | – |
| Delphinidin | 0.91 mg.g$^{-1}$ DW[3] | – | – | – | – |
| Delphinidin-3,5-glucoside | 86.8 μg.g$^{-1}$ DW[3] | – | – | – | – |
| Malvidin-3,5-diglicoside | – | – | – | – | 82.3 μg.g$^{-1}$ DW[3] |
| Pelargonidin | – | – | <LOQ[c,7] | – | – |
| Pelargonidin-3-glucoside | 15.5 μg.g$^{-1}$ DW[3]; 1.00 %[d,10]; tr[5] | – | – | – | – |
| Peonidin-3-*O*-glucoside | – | ✓[14] | – | – | – |
| **Other Flavonoids** | | | | | |
| Daidzein | – | – | – | – | 0.01 μg.g$^{-1}$ DW[2] |
| Eriodictyol | – | – | – | – | 68.0 μg.g$^{-1}$ DW[2] |

(*continued on next page*)

**Table 2** (*continued*)

| Compound | Peel [a] | | Epicarp | Pulp [b] | Juice | Seeds |
|---|---|---|---|---|---|---|
| Genistein | – | – | – | – | | 0.70 mg.g$^{-1}$ DW[2] |
| Naringin dihydrochalcone | – | – | – | – | | 6.5 μg.g$^{-1}$ DW[2] |
| Phloretin glucoside | ✓[1] | – | – | – | | – |
| Quercetin-3-*O*-(6″-acetyl) glucosyl-2″-sinapic acid | 0.42 mg.g$^{-1}$ DW[5] | – | – | – | | – |
| Taxifoline | – | – | – | – | | 1.9 μg.g$^{-1}$ DW[2] |
| **Phenolic acids** | | | | | | |
| **Hydroxybenzoic acids** | | | | | | |
| Gallic acid | – | – | – | – | | 10.4–400 μg.g$^{-1}$ DW[2,6] |
| Protocatechualdehyde acid | ✓[1] | – | – | – | | – |
| Protocatechuic acid | ✓[4] | – | – | – | | 0.18 mg.g$^{-1}$ DW[2] |
| Salicylic acid | – | – | – | – | | 85.8 μg.g$^{-1}$ DW[2] |
| Syringic acid | | | | | | 1.4 μg.g$^{-1}$ DW[2] |
| Vanillic acid | – | – | – | – | | 90.1 μg.g$^{-1}$ DW[2] |
| **Hydroxycinnamic acids** | | | | | | |
| Caffeic acid | – | – | – | – | | tr – 48.5 μg.g$^{-1}$ DW[6] |
| Chlorogenic acid | – | – | – | – | | 2.2 – 100 μg.g$^{-1}$ DW[2,6] |
| Cinnamic acid | – | – | – | 0.91 μg.g$^{-1}$DW[15] | | – |
| Ferulic acid | – | – | <LOQ[c,7] | – | | 2.6 μg.g$^{-1}$DW[2]; nd – tr[6] |
| *p*-Coumaric acid | – | – | <LOQ[c,7] | – | | 15.0 μg.g$^{-1}$ DW[2] |
| Rosmarinic acid | – | – | 0.13 μg.mL$^{-1}$ FW[7] | – | | nd – 200 μg.g$^{-1}$DW[6] |
| Sinapic acid-hexoside | tr[5] | – | – | – | | – |
| **Stilbenes** | | | | | | |
| Piceatannol | – | – | – | – | | ✓[16] |
| Resveratrol | – | – | – | – | | ✓[16] |
| **Other polyphenols** | | | | | | |
| Cirtrusin A | ✓[8] | – | – | – | | – |
| Icariside $E_5$ | ✓[8] | – | – | – | | – |
| **Carotenoids** | | | | | | |
| Antheraxanthin | – | – | ✓[17] | – | | – |
| Cis- ζ-carotene | – | – | 12.1 μg.g$^{-1}$ DW[17] | – | | – |
| Cis-β-carotene | – | – | tr[17] | – | | – |
| Cryptoxanthin | 0.75 μg.g$^{1}$DW[3] | – | 0.20 – 0.31 μg.g$^{-1}$DW[3,17] | – | | – |
| Lutein | 3.67 μg.g$^{-1}$DW[3] | – | 0.11 μg.g$^{-1}$ DW[3] | – | | – |
| Phytofluene | – | – | ✓[17] | – | | – |
| Poli-*cis*-carotene | – | – | 3.40 μg.g$^{-1}$DW[17] | – | | – |
| Prolycopene | – | – | 5.90 μg.g$^{-1}$DW[17] | – | | – |
| Provitamin A | 0.60 μg.g$^{-1}$ DW[3] | – | 0.14 μg.g$^{-1}$ DW REA[3] | – | | – |
| Trans- ζ-carotene | – | – | 11.0 μg.g$^{-1}$ DW[17] | – | | – |
| Trans-β-carotene | – | – | 2.60 μg.g$^{-1}$ DW[17] | – | | – |
| Zeaxanthin | 0.49 μg.g$^{-1}$ DW[3] | – | 0.075 μg.g$^{-1}$DW[3] | – | | – |
| α-Carotene | 0.37 μg.g$^{-1}$DW[3] | – | 0.68 μg.g$^{-1}$ DW[3] | – | | – |
| β-Carotene | 7.16 μg.g$^{-1}$ DW[3] | – | 1.72 μg.g$^{-1}$DW[3] | 4.19 μg.g$^{-1}$ FW[18] | | – |
| **Cyanogenic glycosides** | | | | | | |
| Amygdalin | 19.6 μg.g$^{-1}$ FW[19] | – | – | 31.3 μg.g$^{-1}$ FW[19] | | – |
| (R)-mandelonitrile α -L -rhamnopyranosyl- β -D-glucopyranoside | – | – | – | ✓[20] | | – |
| Mandelonitrile rutinoside (1) | 17.7 μg.g$^{-1}$ FW[19] | – | – | 40.4 μg.g$^{-1}$ FW[19] | | – |
| Mandelonitrile rutinoside (2) | 11.4 μg.g$^{-1}$ FW[19] | – | – | 10.4 μg.g$^{-1}$ FW[19] | | – |
| Prunasin | 231 μg.g$^{-1}$ FW[19]; ✓[4,8] | – | – | 43.1 μg.g$^{-1}$ FW[19] | | – |
| Sambunigrin | 5.6 μg.g$^{-1}$ FW[19] | – | – | 0.4 μg.g$^{-1}$ FW[19] | | – |

(*continued on next page*)

**Table 2** (*continued*)

| Compound | Peel [a] | | Epicarp | Pulp [b] | Juice | Seeds |
|---|---|---|---|---|---|---|
| **Organic acids** | | | | | | |
| Citric acid | – | – | – | 0.13 meq.g$^{-1}$ FW[21]; 14.87 mg. g$^{-1}$ FW[22]; ✓[23] | – | |
| Lactic acid | – | – | – | 0.074 meq.g$^{-1}$ FW[21]; nd[22] | – | |
| Malic acid | – | – | – | 0.038 meq.g$^{-1}$ FW[21]; 2.58 mg.g$^{-1}$ FW[22]; ✓[23] | – | |
| Malonic acid | – | – | – | 0.049 meq.g$^{-1}$ FW[21] | – | |
| Succinic acid | – | – | – | 0.024 meq.g$^{-1}$ FW[21] | – | |
| **Mono and sesquiterpenic compounds** | | | | | | |
| (1S)-α-Pinene | – | – | – | ✓[24] | – | |
| (*E*)-8-Hydroxylinalool | – | – | – | 0.12 μg. g$^{-1}$ DW[15] | – | |
| (Z)-8-Hydroxylinalool | – | – | – | 0.78 μg. g$^{-1}$ DW[15] | – | |
| 2,6-Dimethyl-1,8-octanediol | – | – | – | 0.31 μg. g$^{-1}$ DW[15] | – | |
| 2,6-Dimethylocta-1,7-dien-3,6-diol | – | – | – | 0.13 μg. g$^{-1}$ DW[15] | – | |
| 2,6-Dimethylocta-3,7-dien-2,6-diol | – | – | – | 0.16 μg. g$^{-1}$ DW[15] | – | |
| Citronellol | – | – | – | 0.11 μg. g$^{-1}$ DW[15]; ✓[25] | – | |
| Geraniol | – | – | 0.092 μg.g$^{-1}$ FW[26] | 0.37 μg. g$^{-1}$ DW[15]; ✓[25] | – | |
| Limonene | – | – | – | ✓[24,27] | – | |
| Linalool | – | – | ✓[26] | 1.44 μg. g$^{-1}$ DW[15]; 0.25 μg. g$^{-1}$ FW[25]; ✓[24,26,27] | – | |
| Linalyl acetate | – | – | – | ✓[27] | – | |
| Nerol | – | – | – | 0.11 μg. g$^{-1}$ DW[15]; ✓[25] | – | |
| Sabinene | – | – | – | ✓[24] | – | |
| Terpinen-4-ol | – | – | – | ✓[24] | – | |
| α-Terpinene | – | – | – | ✓[24] | – | |
| α-Terpineol | – | – | – | 0.078 μg.g$^{-1}$ DW[15]; ✓[25] | – | |
| α-Terpinolene | – | – | – | ✓[24] | – | |
| β-Myrcene | – | – | – | ✓[24] | – | |
| β-Ocimene | – | – | – | ✓[24,27] | – | |
| γ-Terpinene | – | – | – | ✓[24] | – | |
| **Norisoprenoids** | | | | | | |
| 3-Oxo-7,8-dihydro-β-ionol | – | – | – | | – | |

(*continued on next page*)

**Table 2** (*continued*)

| Compound | Peel [a] | Epicarp | Pulp [b] | Juice | Seeds |
|---|---|---|---|---|---|
| | | | 0.44 μg. $g^{-1}$ DW[15] | | |
| 3,4-Dihydro-3-oxo-edulan | – | – | 0.19 μg. $g^{-1}$ DW[15] | – | |
| 3-Hydroxy-*retro*-α-ionol | – | – | ✓[28] | – | |
| 3-Oxo-7,8-dihydro-α-ionol | – | – | ✓[25] | – | |
| 3-Oxoretro-α-ionol (1) | – | – | 0.60 μg. $g^{-1}$ DW[15]; ✓[25] | – | |
| 3-Oxoretro-α-ionol (2) | – | – | 0.24 μg. $g^{-1}$ DW[15]; ✓[25] | – | |
| 3-Oxo-α-ionol | – | – | 0.60 μg. $g^{-1}$ DW[15]; ✓[25] | – | |
| 4-Hydroxy-7,8-dihydro-β-ionol | – | – | ✓[25] | – | |
| 4-Hydroxy-β-ionol | – | – | ✓[25] | – | |
| 4-Oxo-7,8-dihydro-β-ionol | – | – | 0.16 μg. $g^{-1}$ DW[15]; ✓[25] | – | |
| 4-Oxo-β-ionol | – | – | 0.71 μg. $g^{-1}$ DW[15]; ✓[25] | – | |
| 4-Oxo-β-ionone | – | – | 0.092 μg.$g^{-1}$ DW[15] | – | |
| Dehydrovomifoliol | – | – | 0.069 μg.$g^{-1}$ DW[15]; ✓[25] | – | |
| Dihydro-β-ionone | – | – | ✓[27] | | |
| Isomeric 3-oxoretro-α-ionols | – | – | ✓[25] | – | |
| Vomifoliol | – | – | 0.045 μg.$g^{-1}$ DW[15]; ✓[25] | – | |
| β-ionone | – | 0.59 μg. $g^{-1}$ FW[26] | – | – | |
| **Fatty acids** | | | | | |
| Myristic acid (C14:0) | – | – | – | 0.06–0.10 %[e,29,30] | |
| Palmitic acid (C16:0) | – | – | – | 8.73 –11.6 %[e,29,30,31,32] | |
| Palmitoleic acid (C16:1) | – | – | – | 0.20–0.24 %[e,29,30] | |
| Margaric acid (C17:0) | – | – | – | 0.07–0.10 %[e,29,30] | |
| Margaroleic (C17:1) | – | – | – | 0.05 %[e,29] | |
| Stearic acid (C18:0) | – | – | – | 1.90 –4.23 %[e,29,30,31,32] | |
| Oleic acid (C18:1) | – | – | – | 13.6 –31.2 %[e,29,30,31,32] | |
| Linoleic acid (C18:2) | – | – | – | 52.9 –75.1 %[e,29,30,31,32] | |
| Linolenic acid (C18:3) | – | – | – | 0.34 –0.40 %[e,29,30,32] | |
| Arachidic acid (20:0) | – | – | – | 0.11 –0.20 %[e,29,30] | |
| Gadoleic acid (C20:1) | – | – | – | 0.10 %[e,29,30] | |
| Behenic acid (C22:0) | – | – | – | 0.06 %[e,29] | |
| Lignoceric acid (C24:0) | – | – | – | 0.03 %[e,29] | |
| **Sterols** | | | | | |
| $^{\Delta 5}$-Avenasterol | – | – | – | 3.30 –3.69 %[f,29,30] | |
| $^{\Delta 5,24}$-Stigmastadienol | – | – | – | 0.33 %[f,29] | |
| $^{\Delta 7}$-Avenasterol | – | – | – | 2.44 %[f,29] nd[30] | |
| $^{\Delta\Delta 7}$-Campesterol | – | – | – | 0.39 %[f,29] | |
| $^{\Delta 7}$-Stigmastenol | – | – | – | 2.60 %[f,29] | |
| Brassicasterol | – | – | – | 1.67 %[f,29] | |
| Campestanol | – | – | – | 1.36 %[f,29] | |
| Campesterol | – | – | – | 11.1 –13.5 %[f,29,30] | |
| Cholesterol | – | – | – | 0.34 %[f,29] | |
| Clerosterol | – | – | – | 0.53 %[f,29] | |
| Stigmastanol | – | – | – | 1.18 %[f,29] | |
| Stigmasterol | – | – | – | 30.9 –41.7 %[f,29,30] | |
| β-Sitosterol | – | – | – | 41.5 –42.5 %[f,29,30] | |

DW: Dry weight; FW: Fresh weight; tr: Trace amount; RAE: Retinol activity equivalent; ✓: Detected but not determined; nd: Not detected; -: Data not available.

[a] Epicarp + mesocarp; [b] Pulp without seeds; [c] LOQ = 0.05 μg.mL$^{-1}$; [d] Relative amounts of the total anthocyanin content; [e] Percentage of total fatty acid content in seed oil; [f] Percentage of total sterol content in seed oil.

[1] (Domínguez-Rodríguez et al., 2019); [2] (Yepes et al., 2021); [3] (dos Reis et al., 2018); [4] (Zibadi et al., 2007); [5] (Medina et al., 2017); [6] (Lourith & Kanlayavattanakul, 2013); [7] (Carmona-Hernandez et al., 2019); [8] (Y. Hu et al., 2018); [9] (Ichimura et al., 2006); [10] (KidØy et al., 1997); [11] (Herrera-Ramirez et al., 2020); [12] (Jiménez et al., 2011); [13] (Ghada et al., 2020); [14] (M. Hu et al., 2020); [15] (Chassagne et al., 1999); [16] (Krambeck et al., 2020); [17] (Wondracek et al., 2011); [18] (U.S. Department of Agriculture, 2019); [19] (Chassagne et al., 1996); [20] (Chassagne & Crouzet, 1998); [21] (Chan et al., 1972); [22] (Ramaiya et al., 2019); [23] (Shiomi et al., 1996); [24] (Porto-Figueira et al., 2015); [25] (Winterhalter, 1990); [26] (Conde-Martínez et al., 2013); [27] (Pontes et al., 2009); [28] (Herderich & Winterhalter, 1991); [29] (Giuffré, 2007); [30] (Piombo et al., 2006); [31] (Lee et al., 2015); [32] (Nyanzi et al., 2005).

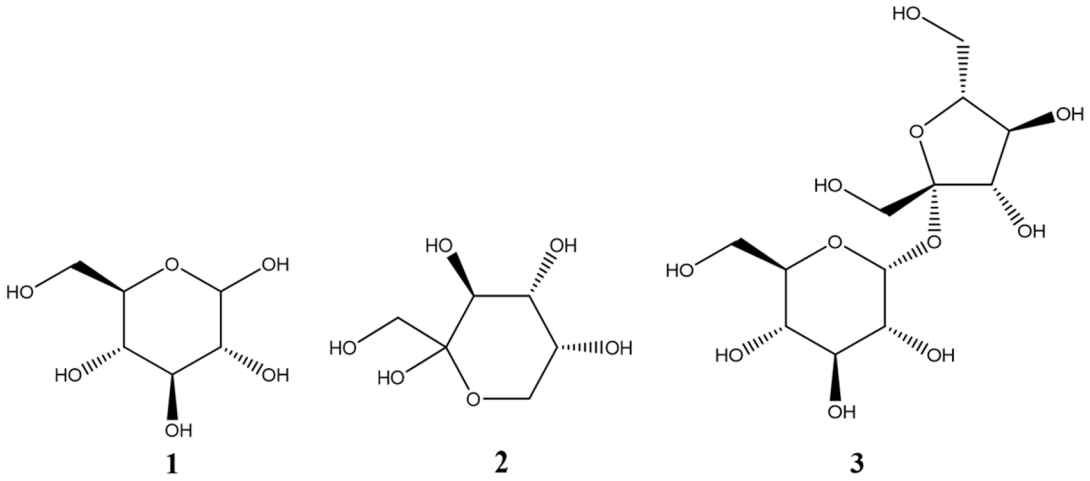


**Fig. 7.** Chemical structures of the main carbohydrate constituents of PPF juice: glucose (1), fructose (2) and sucrose (3).

### 5.2. Protein and amino acids composition

Similarly to most plants, protein content in PPF is low and remains little explored, especially in the purple variety, in which only total protein content has been determined and free amino acids identified. As seen in Table 1, PPF peel and pulp display similar amounts of protein (64.7 – 75.0 mg.g$^{-1}$ DW and 65.3 – 77.0 mg.g$^{-1}$ DW, respectively) while seeds are the richest fraction of PPF (122 – 132 mg.g$^{-1}$ DW), a range comparable to other seeds such as maize and oats (Ramaiya et al., 2018). Free amino acids have been identified (but not quantified) in PPF peel, juice and seeds. These included leucine, valine, tyrosine, proline, threonine, glycine, aspartic acid, arginine, and lysine, glutamic acid, serine and γ-aminobutyric acid (GABA) (Ichimura et al., 2006; Pruthi, 1963; Shiomi et al., 1996).

Proteins play an important role in human nutrition not only as an energy source but also as a source of amino acids. In particular, essential amino acids (the ones that humans cannot synthesize), can only be obtained through diet and thus, their sources are of special interest. GABA, which has been associated with antihypertensive activities, was detected in a PPF peel methanol extract in concentrations higher enough (2.40 – 4.40 mg.g$^{-1}$ DW) to be associated with the decrease blood pressure in spontaneously hypertensive rats (Ichimura et al., 2006).

### 5.3. Lipophilic compounds composition

As observed in Fig. 6, the lipidic composition in PPF has been explored almost exclusively in seeds where they account for 14.9% up to 30.1% of seeds DW (Table 1) (Delvar et al., 2019; dos Reis et al., 2018; Ramaiya et al., 2018). This content is comparable to other fruit seeds, as in most cases, oil content is close to one-third of their DW (Alves et al., 2021). In other PPF fractions the lipophilic content is quite low (0.40 – 4.89% and 0.70 – 1.09% DW, in peel and pulp respectively).

PPF seed oil has shown to be predominantly composed of unsaturated fatty acids (UFA) (Table 2) with a UFA/SFA ratio of 8.12. These include linoleic acid (53.0 – 75.1% (w/w) of total FA content) as the most abundant component among the UFA, followed by oleic acid (13.6 – 31.2% (w/w) of total FA content) and smaller amounts of linolenic, palmitoleic, gadoleic, and margaroleic acids (Fig. 8). Saturated fatty acids (SFA) include palmitic acid (8.73 – 11.6% (w/w) of total FA content) (Fig. 8) followed by minor amounts of stearic, arachidic, margaric, myristic, behenic and lignoceric acids.

A very high linoleic acid/oleic acid ratio (4.50) has been reported and a low free fatty acid content of the PPF seed oil, expressed as a percentage of oleic acid (0.60%), which is quite acceptable for a non-refined oil (Giuffré, 2007; Piombo et al., 2006).

Seed oils represent a very interesting raw material for several industries (i.e., cosmetics, human nutrition, pharmaceuticals) due to their composition in essential FA and bioactive lipids and lipophilic compounds (Alves et al., 2021). Existing studies on PPF seed lipids, besides exploring their FA composition, have evaluated the potential of the oil to be used in food and industrial applications. Due to its high content of linoleic acid and oleic acid, PPF seed oil is comparable to other premium oils (e.g., sunflower oil) (Giuffré, 2007; Lee et al., 2015; Nyanzi et al., 2005). Furthermore, their polyunsaturated essential fatty acids also present excellent bioavailability due to their preferential localization at the *sn2* position of the triacylglycerols backbone (Piombo et al., 2006).

Besides FA, other minor components, namely sterols and tocopherols, have been identified in PPF seeds oils (Table 2). A total sterol content of 2.09 – 3.33 mg.g$^{-1}$ in seed oil has been reported (Giuffré, 2007; Piombo et al., 2006). PPF seed oil contains mainly β-sitosterol (41.5 – 42.5% of total phytosterol content), stigmasterol (30.9 – 41.7% of total phytosterol content) and campesterol (11.1 – 13.5% of total phytosterol content) (Fig. 8) (Giuffré, 2007; Piombo et al., 2006) while other sterols (Table 2) are present in smaller amounts. Phytosterols are known for their hypocholesterolemic properties, however, several authors suggest that phytosterols, namely β-sitosterol, can also have a protective effect against oxidative stress through the modulation of antioxidant enzymes (Vivancos & Moreno, 2005; Yoshida & Niki, 2003).

Regarding tocopherols, a total content of 0.47 mg.g$^{-1}$ have been reported with γ-tocopherol and δ-tocopherol as the main constituents (Table 2), found in comparable amounts (0.22 and 0.24 mg.g$^{-1}$, respectively) (Giuffré, 2007; Piombo et al., 2006). Tocopherols are also natural antioxidants, well recognized for their effective inhibition of lipid oxidation in foods and biological systems. Therefore, their content

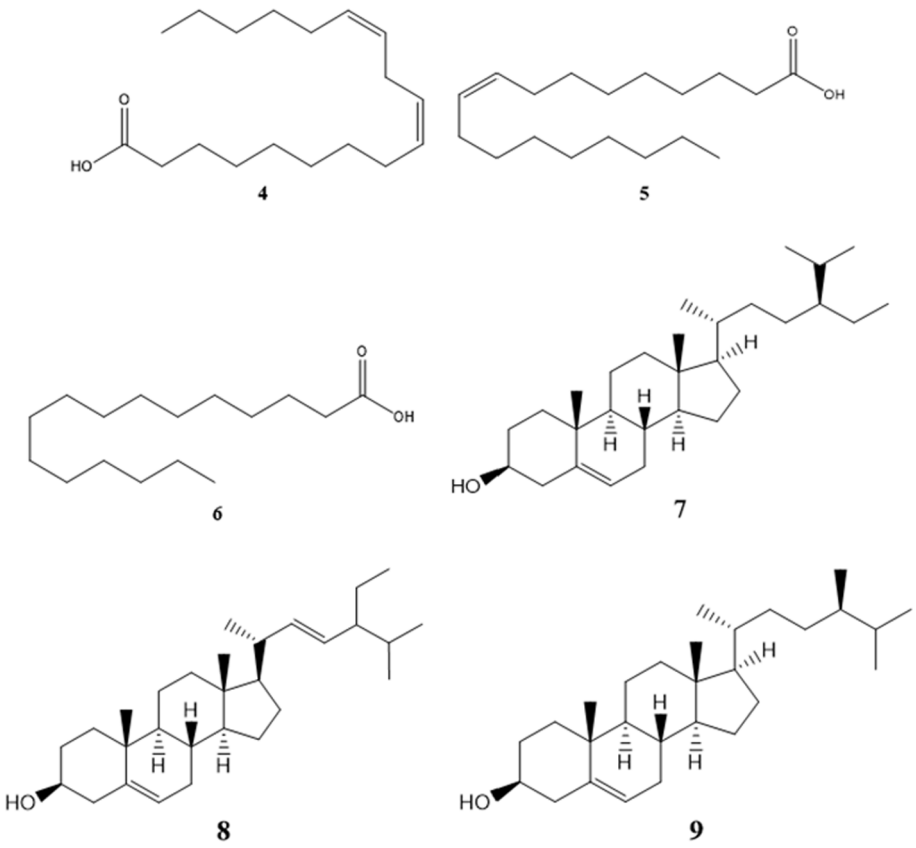


**Fig. 8.** Chemical structures of most abundant fatty acids and phytosterols in PPF seeds: linoleic acid (4), oleic acid (5), palmitic acid (6), β-sitosterol (7), stigmasterol (8), campesterol (9).

is important to protect against autoxidation and, thereby, increase the shelf life of food products.

Thus, considering the PPF seed oil's significant amounts of sterols and tocopherols, it may be worth to exploring its use in the food industry.

### 5.4. Vitamins and minerals composition

PPF is mostly consumed *in natura* as pulp or as a juice. Either way, PPF is a substantial source of vitamin C (Fig. 9) with up to 40.0% and 93.2% of RDI per 100 g of fresh pulp and juice, respectively (Table 1). These values compare to other vitamin C rich fruits like oranges and kiwi (70.9% and 99.6% of RDI per 100 g, respectively) (U.S. Department of Agriculture, 2019). Considerable amounts of riboflavin (11.8% and 16.8% of RDI per 100 g of PPF pulp and juice, respectively) and niacin (12.5% and 12.5% of RDI per 100 g of PPF pulp and juice, respectively) are also present (Fig. 9) (Pruthi & Lal, 1959; Ramaiya et al., 2013; U.S. Department of Agriculture, 2019).

Besides vitamins, PPF also provides several minerals in relevant amounts (Table 1). Considering minerals RDI, 100 g of fresh pulp contains significant amounts of Fe (20.0% of RDI), Cu (10.0% of RDI), P (9.71% of RDI), K (7.40% of RDI) and Mg (6.90% of RDI), while juice provides up to 50.4%, 8.63%, 5.91%, 5.56% and 4% of RDI of Fe, P, K, Cu and Mg, respectively (dos Reis et al., 2018; Ramaiya et al., 2019; U.S. Department of Agriculture, 2019). Mineral contents per dry matter of PPF peels and seeds have also been reported (Table 1). Peels contain up

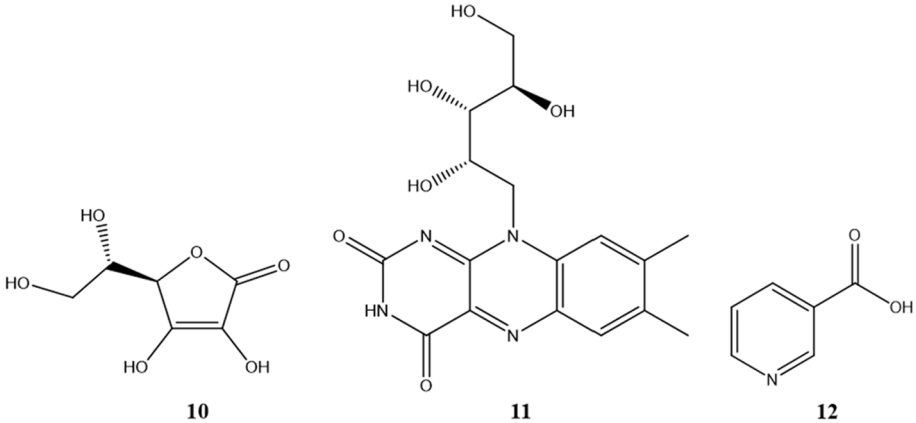


**Fig. 9.** Chemical structures of the vitamins present in PPF pulp and juice that have the highest percentage of the dietary recommended intake: vitamin C (10), Riboflavin (11) and Niacin (12).

to 59.6%, 57.5%, 31.0%,31.0%, 30.4%, and 22.2% of the RDI of K, Fe, Mg, Ca, Mn, and Cu, respectively, while seeds contain up to 155.6%, 77.5%, 69.0% and 50.9%, of Cu, Fe, Mg and Zn, respectively (dos Reis et al., 2018; Ramaiya et al., 2018).

Although required in lower amounts when compared to macronutrients, vitamins and minerals intervene in numerous body functions. Thus, a healthy and balanced diet should provide enough amounts of these micronutrients for our bodies to function and develop normally. As seen above, PPF fractions can provide several micronutrients, thus making it appropriate to incorporate a healthy diet and significantly contribute to meet the RDI of these micronutrients.

### 5.5. Phenolic compounds composition

Phenolic compounds have been a target of research in all PPF fractions with exception of juice (Fig. 6). A particular diversity of such compounds has been reported in peel although only a few compounds were identified in more than one study (cyanidin-3-glucoside, pelargonidin-3-glucoside, kaempferol-3-glucoside, kaempferol, catechin, epicatechin and quercetin-3-glucoside). While phenolic composition of peels consists mainly of flavonoids, a considerable amount of the phenolic compounds reported in seeds are phenolic acids from which ferulic acid, gallic acid, chlorogenic acid and caffeic acid stand out as the most frequently reported. Comparatively to peel and seeds, phenolic compounds on PPF pulp have been studied to a lesser extent and identified compounds are mostly flavonoids.

In terms of total phenolic content (TPC) in *Passiflora* species, Folin-Ciocalteu method was applied to compare the ethanolic extracts of seeds and pulps and peels of PPF, yellow passion fruit (*P. edulis* f. *flavicarpa*) and orange passion fruit (*P. caerulea*) (dos Reis et al., 2018). In the case of PPF, pulp, peel and seeds revealed a TPC of 7.89, 15.70 and 3.26 mg of gallic acid equivalent (GAE).$g^{-1}$ of DW, respectively, while yellow passion fruit and orange passion fruit contained 12.97, 10.61 and 3.46 mg GAE.$g^{-1}$ of DW and 15.59, 25.84 and 4.29 mg GAE.$g^{-1}$ of DW, respectively (dos Reis et al., 2018). Although PPF TPC content was shown to be lower than the other passion fruits evaluated in most of the fruit fractions, the assay used is not specific for phenolic compounds and compounds such as tryptophan, ascorbic acid, thiols, redox-active metal ions, and nucleotide bases can all inflate the TPC values obtained through the Folin-Ciocalteu method (Everette et al., 2010). In a different study focused on peels of *P. ligularis*, PPF, *P. edulis* f. *flavicarpa*, and *P. mollissima*, extracts obtained by pressurized hot water extraction, TPC values of 5.08, 24.96, 8.34 and 30.19 mg GAE.$g^{-1}$ of dried extract, respectively, were determined (Domínguez-Rodríguez et al., 2019).

The data available on the qualitative and quantitative composition of phenolic compounds in each PPF fruit fraction is shown in Table 2. Several studies have been performed in the characterization of phenolic compounds of PPF peel. A purified hot water extract of PPF peel was obtained and characterized by HPLC (Zibadi et al., 2007) and although only about 20% of the extract mass was identified, the major phenolic compounds identified were cyanidin-3-*O*-glucoside, quercetin-3-*O*-glucoside, and edulilic acid (Fig. 10). Minor phenolic compounds identified included catechin, epicatechin, kaempferol 3-*O*-glucoside, kamepferol, luteolin-8-*C*-neohesperoside, luteolin-8-*C*-digitoxoside, protocatechuic acid and quercetin. Cyanidin-3-*O*-glucoside and quercetin-3-*O*-glucoside were also reported as the major phenolic compounds identified in a methanolic extract of PPF peel (Medina et al., 2017). A different study performed a detailed chemical characterization of PPF peel extracted with pressurized hot water using HPLC coupled with a diode array detector and a quadrupole-time of flight mass spectrometer (HPLC-DAD-QTOF/MS), which allowed the tentative identification of 14 compounds (belonging to the flavanols, flavonols, flavones, hydroxybenzoic acids, anthocyanidins families) (Domínguez-Rodríguez et al., 2019). Although no quantification of identified compounds was

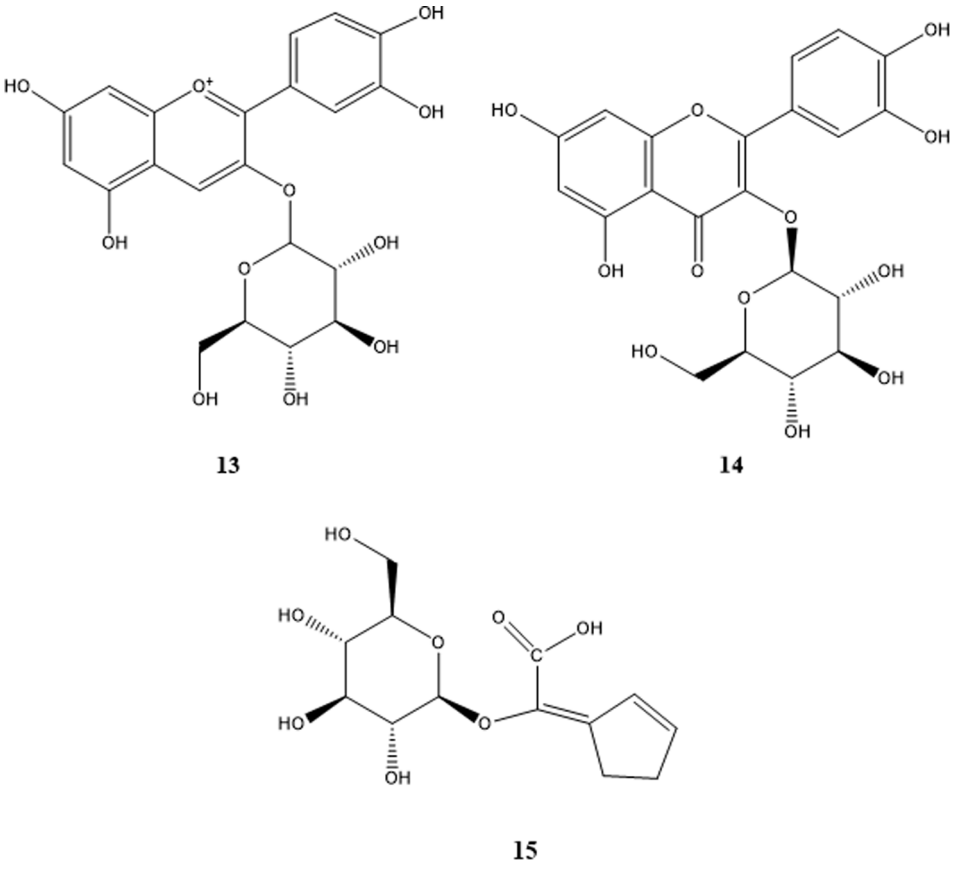


**Fig. 10.** Chemical structures of abundant phenolic compounds reported in PPF peel: cyanidin-3-*O*-glucoside (13), quercetin-3-*O*-glucoside (14), delphinidin (15).

performed, the predominant peak was tentatively identified as a cyanidin glucoside which corroborates the results obtained in the previous studies (Domínguez-Rodríguez et al., 2019; Medina et al., 2017).

The total anthocyanins content in PPF peels acidified (HCl 1%) methanol extract was quantified by HPLC and achieved 1.04 mg.g$^{-1}$ DW (dos Reis et al., 2018). Anthocyanins present in the extract included cyanin (14.8 μg.g$^{-1}$ DW), delphinidin-3,5-glucoside (86.8 μg.g$^{-1}$ DW), cyanidin-3-glucoside (0.029 mg.g$^{-1}$ DW), pelargonidin-3-glucoside (15.5 μg.g$^{-1}$ DW), delphinidin aglycone (0.91 mg.g$^{-1}$ DW) and a cyanidin aglycone (12.4 μg.g$^{-1}$ DW). Anthocyanins in PPF peel were also quantified in other studies (Herrera-Ramirez et al., 2020; Jiménez et al., 2011). Extraction with methanol–acetic acid (19:1 v/v) yielded an anthocyanin content of 1.73 mg of cyanidin-3-*O*-glucoside equivalent. g$^{-1}$ of DW while optimized ethanolic extraction conditions for anthocyanins from PPF peel yielded 5.78 mg of cyanidin-3-*O*-glucoside equivalent.g$^{-1}$ of DW (Herrera-Ramirez et al., 2020; Jiménez et al., 2011).

The anthocyanins composition was also evaluated in epicarp of PPF, the outermost layer of PPF peel. The solid–liquid extraction of anthocyanins from this fraction was optimized recently using acidified ethanol resulting in a maximum content of 3.40 mg of cyanidin-3-*O*-glucoside equivalent.g$^{-1}$ of dried epicarp (Ghada et al., 2020). A different study evaluated the composition of purified PPF epicarp anthocyanins (M. Hu et al., 2020). Three major anthocyanins identified, namely cyanidin 3-*O*-glucoside (639 mg.g$^{-1}$ extract), cyanidin 3-*O*-rutinoside (30.6 mg.g$^{-1}$ extract) and peonidin 3-*O*-glucoside (40.5 mg.g$^{-1}$ extract).

Studies dealing with the phenolic compounds in PPF pulp and seeds are less frequent (Table 2). A comparative study determined that the methanolic PPF pulp extracts contain the highest TPC (1.62 mg GAE.g$^{-1}$ DW) when compared to *P. edulis* f. *flavicarpa* (1.18 mg GAE.g$^{-1}$ DW) and *P. ligularis* (1.55 mg GAE.g$^{-1}$ DW). The most abundant phenolic compounds detected in that PPF extract were (+)-catechin (0.28 μg.mL$^{-1}$), (−)-epicatechin (0.22 μg.mL$^{-1}$), and rosmarinic acid (0.13 μg.mL$^{-1}$) (Carmona-Hernandez et al., 2019). A TPC of 583 mg GAE.g$^{-1}$ was reported for the ethyl acetate PPF seed extract in which gallic acid, chlorogenic acid, rosmarinic acid and quercetin were identified as main constituents (Lourith & Kanlayavattanakul, 2013).

Phenolic compounds are naturally found in plants and are responsible for several roles such as sensorial properties (colour, aroma, taste and astringency), structure, pollination, resistance to pests and predators, germinative processes of seed after harvesting and growth as well as development and reproduction, among others (Reis Giada, 2013). However, the major interest in these compounds from a nutritional point of view lies in their antioxidant potential. Epidemiological studies and associated meta-analysis, strongly suggest that long-term diets rich in plant phenolic compounds promote human health through the prevention of several diseases (Pandey & Rizvi, 2009). However, the antioxidant activity of phenolic compounds depends largely on the chemical structure of these substances and their bioavailability, but also on the amount in which they are ingested (Scalbert & Williamson, 2000).

In the case of PPF, the peel is described above as the fruit fraction with the highest amount of phenolic compounds and thus the most promising to be explored in terms of antioxidant properties of the extracts obtained thereof. Furthermore, cyanidin-3-*O*-glucoside, which is the main phenolic compound in peel extracts and the main responsible for the purple colour of the peel, with well-known antioxidant and anti-inflammatory properties (Tan et al., 2019). It is thought that these effects are exerted through metabolites resulting from the catabolism of cyanidin-3-*O*-glucoside in the gastrointestinal tract that generate other bioactive phenolic metabolites, such as protocatechuic acid, phloroglucinaldehyde, vanillic acid, and ferulic acid (Tan et al., 2019).

### 5.6. Carotenoids composition

The carotenoid composition in PPF (Fig. 6) has been evaluated solely in pulp and peel (Wondracek et al., 2011; dos Reis et al., 2018). It was reported that the PPF pulp and peel total carotenoid content was significantly lower (2.88 and 12.4 μg.g$^{-1}$ DW, respectively) than in orange passion fruit (53.5 and 255 μg.g$^{-1}$ DW, respectively) and lower than in yellow passion fruit pulp (17.9 μg.g$^{-1}$ DW) but higher in yellow passion fruit peel (9.18 μg.g$^{-1}$ DW) (dos Reis et al., 2018). Table 2 presents the carotenoid composition of both PPF peel and pulp showing that β-carotene (Fig. 11) is the main component of this family found in both fractions (7.16 μg.g$^{-1}$ DW in the peel and 1.72 μg.g$^{-1}$ DW in the pulp), although lutein (Fig. 11) was also present in significant amounts in the peel (3.67 μg.g$^{-1}$ DW) (dos Reis et al., 2018). Another study that evaluated the carotenoid composition, reported a similar content of β-carotene (2.60 μg.g$^{-1}$) in PPF pulp of several native accessions from "Cerrado" region of Brazil, but ζ-carotene (Fig. 11) was reported as the main constituent (23.15 μg.g$^{-1}$) of these extracts (Wondracek et al., 2011).

Consumption of carotenoids is thought to provide health benefits by decreasing the risk of some diseases (namely cancer and eye disease) in part, due to their role as antioxidants and the ability of some (e.g. β-carotene) to be converted to vitamin A (Johnson, 2002). Most studied carotenoids in this context are β-carotene, lycopene, lutein, and zeaxanthin. β-carotene in particular, which is a carotenoid with provitamin A activity, appears in considerable amounts on PPF peel, making this fraction an important source of this vitamin.

### 5.7. Monoterpenic, sesquiterpenic and norisoprenoid composition

Terpenic compounds and norisoprenoids have been studied almost exclusively in PPF juice. Most frequently reported terpenic compounds are linalool, citronellol, geraniol, limonene, nerol, α-terpineol and β-ocimene, whereas 3-oxoretro-α-ionol (1), 3-oxoretro-α-ionol (2), 3-oxo-α-ionol, 4-oxo-7,8-dihydro-β-ionol, 4-oxo-β-ionol and vomifoliol are the most abundant norisoprenoids (Fig. 6). These compounds have been identified e in free form or released through enzymatic hydrolysis of glycosylated derivatives (Chassagne et al., 1999; Pontes et al., 2009; Porto-Figueira et al., 2015; Winterhalter, 1990). Terpenic compounds found in free form of PPF juice using HS-SPME coupled with gas chromatography-mass spectrometry (GC–MS) consisted mainly of mono and sesquiterpenes and represented 4.32% of total volatile compounds peak area (Porto-Figueira et al., 2015). The most abundant terpenes identified were *cis*-β-ocimene, β-myrcene, α-terpinolene and limonene (Fig. 12), although in a previous study using HS-SPME only *cis*-β-ocimene, linalool and linalyl acetate were identified (Pontes et al., 2009). To elucidate the occurrence of glycosylated terpenoids, fractions of PPF juice were incubated with β-glucosidase to liberate the corresponding aglycons (Winterhalter, 1990), allowing to identify linalool (0.25 μg.g$^{-1}$ of FW) followed by smaller amounts of α-terpineol, citronellol and geraniol (Winterhalter, 1990). Similar monoterpenoids were identified in a later study using a combined action of Hemicellulase REG 2 and sweet almond glucosidase (emulsin) (Chassagne et al., 1999). The amount of linalool liberated in this study was considerably higher (1.44 μg.g$^{-1}$) which can be attributed to a higher hydrolysis yield obtained in this study (Chassagne et al., 1999).

The enzymatic hydrolysis of PPF juice also allowed to identify a wide range of glycosylated $C_{13}$ norisoprenoid (Table 2) (Chassagne et al., 1999; Winterhalter, 1990). β-glucosidase treatment of the juice allowed the release of a total of 15 norisoprenoid aglycones of which eleven were identified in passion fruit for the first time. Two groups of norisoprenoids prevailed in the PPF juice: β-ionol derivatives with an oxygen function in position 4; and α-ionol derivatives, oxygenated in position 3 (Table 2) (Winterhalter, 1990). The results of the study of Chassagne et al. (1999), dealing also with the analysis of enzymatic hydrolysis of PPF juice, confirmed the norisoprenoid aglycones composition reported above and provided valuable quantification data of such compounds (Table 2). It was also found that α-ionol derivatives oxygenated in position 3 seem to be characteristic of PPF (Chassagne et al., 1999).

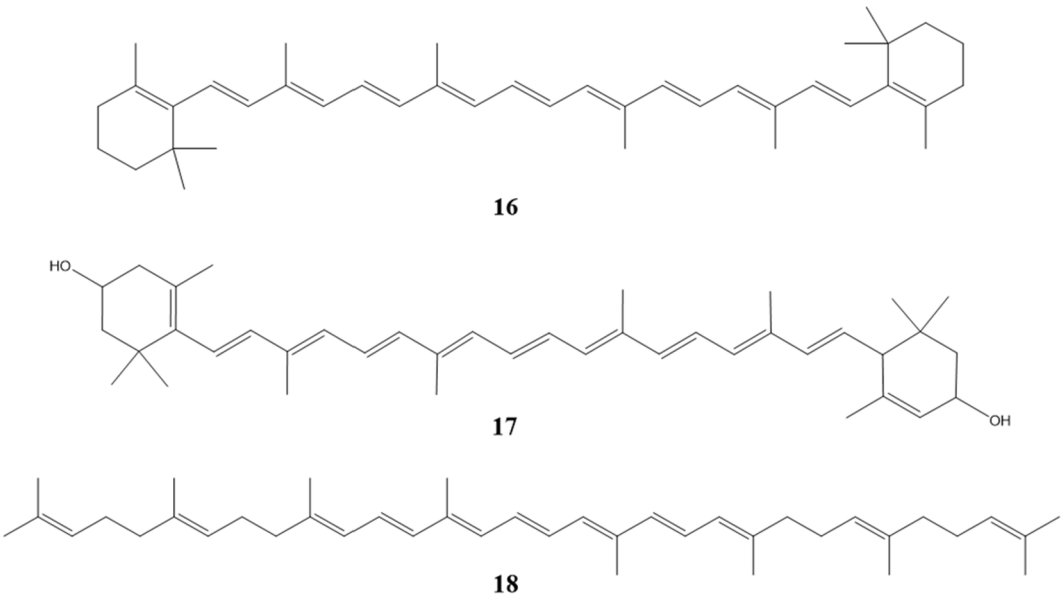


**Fig. 11.** Chemical structures of the most abundant carotenoids found in PPF pulp and peel: β-carotene (16), lutein (17) and ζ-carotene (18).

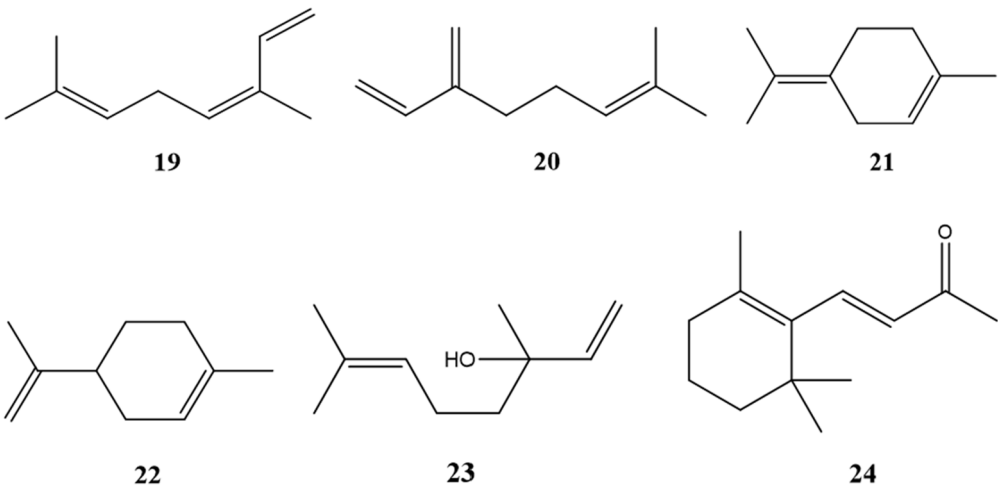


**Fig. 12.** Chemical structures of most abundant volatile terpenic compounds found in PPF juice (*cis*-β-ocimene (19), β-myrcene (20), α-terpinolene (21), limonene (22)) and most abundant bound monoterpenoid (linalool (23)). β-ionone (24), a key aroma compound in PPF pulp is also displayed.

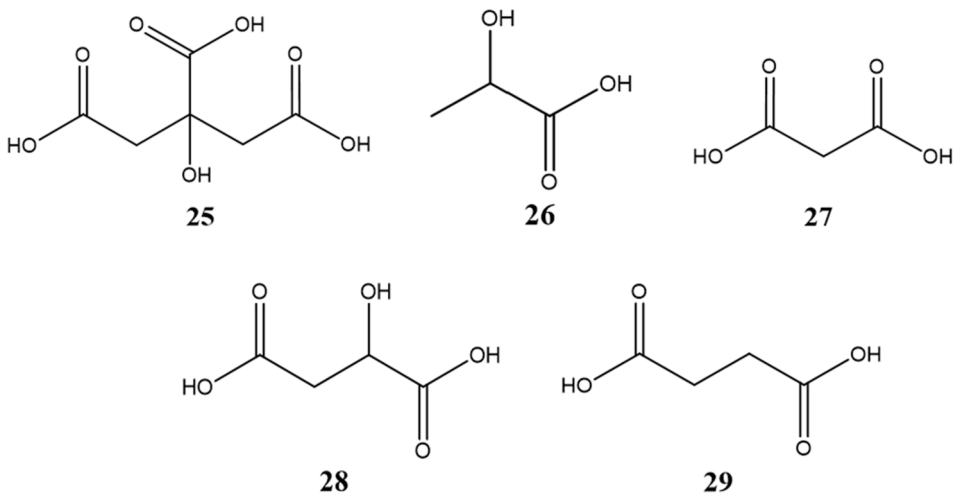


**Fig. 13.** Chemical structures of the organic acids identified in PPF juice: citric acid (25), lactic acid (26), malonic acid (27), malic (28) and succinic acid (29).

In plants, terpenic compounds and norisoprenoids contribute to the flavour and aroma of their leaves, flowers, and fruits but are also essential for their growth and development by protecting against insects, herbivores and fungal diseases (Tetali, 2018).

A study regarding the odour-active compounds of PPF pulp identified nineteen compounds in a solvent-assisted flavour evaporation extract from which only linalool, geraniol and β-ionone (Fig. 12) were terpenoids (Conde-Martínez et al., 2013). After calculation of odour activity values, β-ionone was identified as key aroma compound in PPF, contributing to the fruity and floral odour notes of pulp (Conde-Martínez et al., 2013).

### 5.8. Organic acids composition

The organic acid composition is only available for PPF juice (Fig. 6), and its quantification is presented in Table 2**.** In both available studies, citric acid (Fig. 13) was found to be the most abundant acid (14.89 mg.$g^{-1}$ FW and 0.13 meq.$g^{-1}$ FW) representing 41% of the total acids (Chan et al., 1972; Ramaiya et al., 2019), but significant differences in the relative abundance of remaining organic acids was observed. While in the most recent study, malic acid was the second most abundant acid (2.58 mg.$g^{-1}$ FW) and lactic acid was not detected, in the previous one lactic (23.4%), malonic (15.5%), malic (12.1%), and succinic acid (7.60%) (Fig. 13) were reported in considerable amounts (Chan et al., 1972; Ramaiya et al., 2019).

Compared to other passion fruits, namely *P. edulis* f. *flavicarpa*, PPF, is known to be more pleasant for raw consumption because of its higher sweetness and lower acidity (Pontes et al., 2009). This is confirmed by the total acid content in their juice (determined both by gas–liquid chromatography and titration), which was found to be 0.66 meq.$g^{-1}$ FW and 0.32 meq.$g^{-1}$ FW for *P. edulis* f. *flavicarpa* and PPF, respectively (Chan et al., 1972).

Each fruit usually has a unique pattern of organic acids and their qualitative and quantitative analysis is considered essential for authenticity testing of several fruit juices (Ehling & Cole, 2011). The organic acids are also known to exert a significant influence on the organoleptic properties (flavor, colour and aroma) of passion fruit juices as well as on their stability (Hasib et al., 2002).

## 6. Purple passion fruit potential health benefits

*Passiflora* species fruits and leaves have been used in traditional medicine to treat numerous illnesses and symptoms across different geographies (Dhawan et al., 2004). The most popular pharmacological application of *Passiflora* genus is the use of *Passiflora incarnata* aerial parts as well as its preparations, to help in the treatment of insomnia, anxiety, and depression. A recent systematic review showed the potential of this species to alleviate some symptoms of neuropsychiatric origin, namely anti-anxiety effect comparable to drugs such as oxazepam or midazolam (Janda et al., 2020). However, the studies reporting these effects usually don't mention the part of the plant used, which is a clear limitation (Janda et al., 2020). Contrary to the extensive literature regarding *P. incarnata* neuropsychiatric effects, it was only recently that biochemical and pharmacological studies have confirmed that PPF fractions and their extracts present a wide range of *in vitro* and *in vivo* bioactivities: antioxidant (Domínguez-Rodríguez et al., 2019; dos Reis et al., 2018; Herrera-Ramirez et al., 2020; Lourith & Kanlayavattanakul, 2013; Montoya Yepes et al., 2021; Ramaiya et al., 2013), antibacterial (Ghada et al., 2020; Jusuf et al., 2020), antifungal (Ghada et al., 2020), anti-asthmatic (Watson et al., 2008), anti-hipertensive (Ichimura et al., 2006; Zibadi et al., 2007), anti-inflammatory (Carmona-Hernandez et al., 2019; Chilakapati et al., 2014; Dewi et al., 2020; Farid et al., 2010), hepaprotective and nephroprotective (Nerdy & Ritarwan, 2019) and anti-fatigue (M. Hu et al., 2020); a detailed description of these bioactivities will be discussed here, according to the nature of the studies in which they have been reported. Further health benefits, such as emollient (Guzmán et al., 2020) and anti-aging activity (Nazliniwaty et al., 2020) have been demonstrated for peel and seeds, but since their use is outside the scope of food products formulation in which this review is focused, these will not be explored in detail.

### 6.1. In-vitro biological activities of purple passion fruit

The *in vitro* antioxidant, anti-inflammatory, antimicrobial and antifungal activities reported for PPF are summarized in Table 3.

Studies on PPF peel used mainly aqueous and ethanolic extracts to evaluate the antioxidant, antibacterial and antifungal activities (Domínguez-Rodríguez et al., 2019; dos Reis et al., 2018; Ghada et al., 2020; Herrera-Ramirez et al., 2020) while pulp ethanolic and methanolic extracts have been tested for their antioxidant and anti-inflammatory potential (Carmona-Hernandez et al., 2019; dos Reis et al., 2018; Ramaiya et al., 2013) and seeds water, ethanolic and ethyl acetate extracts for their antioxidant activity (dos Reis et al., 2018; Lourith & Kanlayavattanakul, 2013; Yepes et al., 2021). It is worth mentioning in the available studies that report these biological activities usually do not demonstrate the relationship between those activities and the chemical composition of the PPF as well as the underlying mechanisms in action, which would be essential for better understanding these activities.

a) Antioxidant activity.

PPF peel extracts antioxidant activity has been tested *in vitro* using several methods. Using 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, the $IC_{50}$ values obtained were 32.93 μg of extract.$mL^{-1}$ and 69.8 mg of peel.$mL^{-1}$ for hot water or ethanol extracts respectively (Domínguez-Rodríguez et al., 2019; dos Reis et al., 2018).

A comparison with other *Passiflora* species peels pressurized hot water extracts revealed that PPF extracts presented higher DPPH activity than *P. ligularis* and *P. edulis* f. *flavicarpa* extracts (298.6 and 718.9 μg of extract.$mL^{-1}$) but lower than *P. mollissima* extracts (10.6 mg of extract.$mL^{-1}$) (Domínguez-Rodríguez et al., 2019). However, when ethanol extracts were used, DPPH activity was the lowest for PPF extracts (69.8 mg of peel.$mL^{-1}$) when compared to *P. edulis* f. *flavicarpa* (16.9 mg of peel.$mL^{-1}$) and *Passiflora caerulea* (24.5 mg of peel.$mL^{-1}$) extracts (dos Reis et al., 2018). Furthermore, an optimized extract for anthocyanin recovery with a content of 5.77 mg.$g^{-1}$ of dry PPF peel of cyanidin-3-*O*-glucoside, showed antioxidant capacity measured by DPPH and ferric reducing antioxidant power (FRAP) assays of 4.90 and 5.29 μmol of Trolox.$g^{-1}$ of extract respectively, which exceeded the radical scavenging values reported for oat oil, white and red wines (Herrera-Ramirez et al., 2020).

The 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical cation-based assay $IC_{50}$ determined in the same study, also corroborates the lowest antioxidant activity of ethanolic extract of PPF peel (93.7 mg of peel.$mL^{-1}$) when compared with the other species (22.2 and 29.5 mg of peel.$mL^{-1}$ for *P. edulis* f. *flavicarpa* and *Passiflora caerulea*, respectively*)* (dos Reis et al., 2018).

The antioxidant activity through the prevention of intracellular reactive oxygen species (ROS) formation in HeLa cell cultures using a PPF pressurized hot water peel extract was also accessed (Domínguez-Rodríguez et al., 2019). This extract was able to reduce the intracellular ROS production to 43.8 ± 2.00% with an extract concentration of 400 μg.$mL^{-1}$, which was found to be close to the inhibition values obtained with the synthetic antioxidant Trolox (50.0 ± 5.6% at 1 mg.$mL^{-1}$) (Domínguez-Rodríguez et al., 2019).

Finally, the antioxidant activity of an optimized PPF peel anthocyanin extract was also evaluated through its capacity to prevent the formation of thiobarbituric acid reactive substances (TBARS) and the oxidative hemolysis (OXHLIA) (Ghada et al., 2020): that extract showed high potential to inhibit the TBARS formation ($IC_{50}$: 115 μg of extract.$mL^{-1}$) and oxidative hemolysis ($IC_{50}$: 78.0 μg of extract.$mL^{-1}$), thus being suitable for lipid peroxidation inhibition in food products. The same authors also demonstrated that optimized conditions for anthocyanins extraction (t = 38 min, T = 20 °C, S = 0% ethanol/water (v/v)

**Table 3**
*In vitro* biological activities reported for purple passion fruit (*Passiflora edulis* f. *edulis)* fractions.

| Experimental model/Method | Fruit fraction | Extraction (solvent) | Main results | Reference |
|---|---|---|---|---|
| **DPPH** | Peel | Pressurized hot water | 32.9 μg dried extract.mL$^{-1}$ ($IC_{50}$) | (Domínguez-Rodríguez et al., 2019) |
| | Peel | Ethanol | 69.8 mg of peel.mL$^{-1}$ ($IC_{50}$) | (dos Reis et al., 2018) |
| | Peel | Ethanol | 4.90 μmol Trolox.g$^{-1}$ of extract | (Herrera-Ramirez et al., 2020) |
| | Pulp | Methanol | 0.55 μmol Trolox.mL$^{-1}$ of pulp ($IC_{50}$) | (Ramaiya et al., 2013) |
| | Pulp | Ethanol | 33.2 mg of pulp.mL$^{-1}$ ($IC_{50}$) | (dos Reis et al., 2018) |
| | Seeds | Ethyl Acetate | $2.70 \times 10^{-3}$ mg of seeds.mL$^{-1}$ ($IC_{50}$) | (Lourith & Kanlayavattanakul, 2013) |
| | Seeds | Water | 0.18 mg of seeds.mL$^{-1}$ ($IC_{50}$) | (Lourith & Kanlayavattanakul, 2013) |
| | Seeds | Ethanol | 132 mg of extract.mL$^{-1}$ (SC50)[b] | (Yepes et al., 2021) |
| | Seeds | Ethanol | 63.0 mg of seeds.mL$^{-1}$ ($IC_{50}$) | (dos Reis et al., 2018) |
| **ABTS** | Peel | Pressurized hot water | 2.01 mmol Trolox.g$^{-1}$ of dried extract | (Domínguez-Rodríguez et al., 2019) |
| | Peel | Ethanol | 93.7 mg of peel.mL$^{-1}$ ($IC_{50}$) | (dos Reis et al., 2018) |
| | Pulp | Ethanol | 45.9 mg of pulp.mL$^{-1}$ ($IC_{50}$) | (dos Reis et al., 2018) |
| | Seeds | Ethanol | 47.6 mg of seeds.mL$^{-1}$ ($IC_{50}$) | (dos Reis et al., 2018) |
| | Seeds | Ethyl Acetate | 9.0 μg of seeds.mL$^{-1}$ ($IC_{50}$) | (Lourith & Kanlayavattanakul, 2013) |
| | Seeds | Water | 15.4 μg of seeds.mL$^{-1}$ ($IC_{50}$) | (Lourith & Kanlayavattanakul, 2013) |
| **FRAP** | Peel | Ethanol | 5.29 μmol Trolox.g$^{-1}$ of extract | (Herrera-Ramirez et al., 2020) |
| | Seeds | Ethyl Acetate | 2.81 mg of seeds.mL$^{-1}$ ($EC_{1mM\ FeSO4}$) | (Lourith & Kanlayavattanakul, 2013) |
| | Seeds | Water | 0.13 mg of seeds.mL$^{-1}$ ($EC_{1mM\ FeSO4}$) | (Lourith & Kanlayavattanakul, 2013) |
| | Seeds | Ethanol | 14.2 μmol TE.g$^{-1}$ extract | (Yepes et al., 2021) |
| **ORAC** | Seeds | Ethanol | 18.3 μmol TE.g$^{-1}$ extract | (Yepes et al., 2021) |
| **TBARS** | Peel | Water | 115 μg of extract.mL$^{-1}$ ($EC_{50}$) | (Ghada et al., 2020) |
| **OXHLIA ($IC_{50}$)** | Peel | Water | 78 μg of extract.mL$^{-1}$ ($IC_{50}$) | (Ghada et al., 2020) |
| **Intracellular ROS formation/Flow cytometry** | Peel | Pressurized hot water | Peel extract (400 μg.mL$^{-1}$) reduced the intracellular ROS production by 43.8 ± 2.0% | (Domínguez-Rodríguez et al., 2019) |
| **Caco-2 cells/Transepithelial electrical resistance (TEER)** | Pulp | Methanol | Pulp extract prevented loss of TEER in Caco-2 cells treated with an inflammatory cocktail after 48 h:<br>- Residues after extraction: 83.7 ± 6.90%.<br>- Lyophilized extract(0.10 mg.mL$^{-1}$): 59.5 ± 6.60%. | (Carmona-Hernandez et al., 2019) |
| **Antibacterial activity:** | | | MIC[b]; MBC[c] | |
| - *Staphylococcus aureus* | Peel | Water | 8.00 mg.mL$^{-1}$; 8.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |
| - *Listeria monocytogenes* | Peel | Water | 4.00 mg.mL$^{-1}$; 8.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |
| - *Escherichia coli* | Peel | Water | 4.00 mg.mL$^{-1}$; 8.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |
| - *Enterobacter cloacae* | Peel | Water | 8.00 mg.mL$^{-1}$; 8.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |
| - *Salmonella typhimurium* | Peel | Water | 8.00 mg.mL$^{-1}$; 8.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |
| - *Propionibacterium acnes* | Seeds | Ethanol | antibacterial activity in a concentration dependent manner:<br>- MIZ[d] (1.25%) = 6.00 mm<br>- MIZ (2.5%) = 6.83 mm<br>- MIZ (5%) = 8.50 mm<br>- MIZ (10%) = 10.1 mm<br>- MIZ (20%) = 14.0 mm<br>- MIZ (40%) = 16.0 mm<br>MIC; MFC[e] | (Jusuf et al., 2020) |
| **Antifungal activity:** | | | | |
| - *Aspergillus fumigatus* | Peel | Water | 8.00 mg.mL$^{-1}$; >8.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |
| - *Aspergillus versicolor* | Peel | Water | 8.00 mg.mL$^{-1}$; 8.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |
| - *Aspergillus niger* | Peel | Water | 4.00 mg.mL$^{-1}$; 8.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |
| - *Penicillium funiculosum* | Peel | Water | 8.00 mg.mL$^{-1}$; 8.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |
| - *Penicillium ochrochloron* | Peel | Water | 1.00 mg.mL$^{-1}$; 1.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |
| - *Trichoderma viride* | Peel | Water | 4.00 mg.mL$^{-1}$; 8.00 mg.mL$^{-1}$ | (Ghada et al., 2020) |

[a] mean inhibition zone; [b] Minimal inhibitory concentration; [c] Minimal bactericidal concentration; [d] 50% DPPH stabilization concentration; [e] Minimal fungicidal concentration.

acidified with citric acid to pH 3, and $R_{S/L}$ = 50.0 g.L$^{-1}$) promoted the recovery of 2.82 mg of cyanidin-3-*O*-glucoside.g$^{-1}$ of PPF dried peel. It was found that the higher the cyanidin-3-*O*-glucoside, the higher the antioxidant activity in the TBARS and OXHLIA assays (Ghada et al., 2020).

PPF pulp has also been evaluated for its *in vitro* antioxidant activity in comparative studies through DPPH and ABTS assays (dos Reis et al., 2018; Ramaiya et al., 2013). DPPH assay was performed on pulp

methanolic extracts of seven passion fruit cultivars (Purple, Frederick, Yellow, Pink, *P. edulis* f. *flavicarpa, P. maliformis,* and *P. quadrangularis*) showing that purple and yellow cultivars extracts exhibit the higher antioxidant activity (0.55 and 0.52 μmol Trolox.mL$^{-1}$ of FW pulp, respectively) (Ramaiya et al., 2013). Authors also found a strong correlation between the TPC and antioxidant activity in the pulp extracts of these cultivars (Ramaiya et al., 2013).

A different study evaluated the scavenging power of yellow, purple, and orange passion fruit pulp towards DPPH and ABTS free radicals, concluding that yellow passion fruit pulp extracts scavenging power ($IC_{50}$ of 2.0 and 8.2 mg of pulp.mL$^{-1}$) is higher than purple ($IC_{50}$ of 33.2 and 45.9 mg of pulp.mL$^{-1}$) and orange ($IC_{50}$ of 24.1 and 37.2 mg of pulp.mL$^{-1}$) passion fruit pulp extracts scavenging activity (dos Reis et al., 2018).

The antioxidant *in vitro* activity has been also investigated in PPF seeds extracts through DPPH, ABTS, FRAP and oxygen radical absorbance capacity (ORAC) assays in extracts obtained with ethanol, water and ethyl acetate, reporting the following $IC_{50}$ values: 2.70 × 10$^{-3}$- 0.18 mg of seeds.mL$^{-1}$ for DPPH assay; and 9.0 – 47.6 μg of seeds.mL$^{-1}$ for ABTS assay (dos Reis et al., 2018; Lourith & Kanlayavattanakul, 2013; Yepes et al., 2021). The ferric reducing antioxidant power of PPF seeds has been determined as 0.13 – 2.81 mg of seeds.mL$^{-1}$ ($EC_{1mM\ FeSO4}$) and 14.2 μmol TE.g$^{-1}$- extract while the ORAC assay applied to seeds resulted in 18.3 μmol TE.g$^{-1}$ extract (dos Reis et al., 2018; Lourith & Kanlayavattanakul, 2013; Yepes et al., 2021).

The lack of standardization of the different methods applied to evaluate the antioxidant potential as well as the different extraction conditions turns it difficult to compare the results between the fractions of PPF. According to the chemical composition previously shown (Table 2 and Fig. 6), it would be expected that the antioxidant activity of peels would be superior when compared to pulp and seeds considering their higher TPC content. However, *in vitro* assays do not corroborate that hypothesis. Although a correlation between TPC and antioxidant capacity is frequently observed, other kinds of compounds can also impact such biological activity, namely carotenoids or sterols which can be the case in PPF.

b) Anti-inflammatory activity.

The Anti-inflammatory activity of PPF pulp has been evaluated through its efficacy in the prevention of the loss of transepithelial electrical resistance (TEER) in Caco-2 cells treated with an inflammatory cocktail (Carmona-Hernandez et al., 2019). Caco-2 cell models from human adenocarcinoma are commonly used to evaluate potential inhibitors of inflammation-induced intestinal barrier dysfunction. The maintenance of the intestinal barrier homeostasis is important to prevent bacterial translocation, leakage of pro-inflammatory compounds from the gut, and chronic inflammation (Hossen et al., 2020). It was demonstrated that a methanolic PPF pulp extract was able to improve TEER results (83.7% and 59.5% for residues after extraction and lyophilized extract (0.10 mg.mL$^{-1}$), respectively. This effect was associated with phenolic compounds profile of the extract, with ferulic acid and epigallocatechins being suggested as the most effective inhibitors (Carmona-Hernandez et al., 2019). Further investigation is needed to determine the mechanism(s) of action to improve TEER, although the inhibitory action of phenolic compounds on inflammatory routes related to cyclooxygenases (COX) type COX-1 and COX-2, nuclear factor kappa B (NF-κB), and by the increasing tight junction proteins ZO-1 and occludin have been proposed (Carmona-Hernandez et al., 2019).

c) Antibacterial and antifungal activity.

The antimicrobial activity of PPF has been demonstrated with an optimized anthocyanin peel aqueous extract (Ghada et al., 2020). The optimized extract was able to inhibit and kill all the tested bacteria (*Staphylococcus aureus, Listeria monocytogenes, Escherichia coli, Enterobacter cloacae, Salmonella typhimurium*) and fungi (*Aspergillus fumigatus, Aspergillus versicolor, Aspergillus niger, Penicillium funiculosum, Penicillium ochrochloron, Trichoderma viride*). An extract concentration of 8 mg.mL$^{-1}$ was enough to inhibit and kill all bacteria and all the fungi, with the exception of *Aspergillus fumigatus*.

A different study used a PPF seed ethanolic extract to demonstrate its antimicrobial activity against *Propionibacterium acnes* and found that the inhibitory activity increased with the extract concentration (Jusuf et al., 2020). The minimum concentration of the extract to reach an antibacterial effect was 5.00% (w/v), with a mean inhibition zone (MIZ) of 8.50 mm, followed by 10.0% (w/v) with MIZ 10.1 mm, 20.0% (w/v) 14.0 mm, and 40.0% (w/v) 16.0 mm. *P. acnes* is usually found in human skin and promotes bacterially induced inflammation, sebum accumulation, and acne vulgaris development (Jusuf et al., 2020). The PPF seed extract inhibitory effect is comparable to clindamycin and erythromycin, demonstrating its potential in the management of acne vulgaris (Jusuf et al., 2020).

### 6.2. *In-vivo biological activities of purple passion fruit*

The *in vivo* biological activities reported for PPF fractions extracts are summarized in Table 4**.** Almost all available studies have been carried out with peels extracts (with the exception of a single study with an epicarp extract), either in mice or humans, regarding chronic conditions such as asthma, hypertension, osteoarthritis or diabetes (Farid et al., 2010; Ichimura et al., 2006; Raju et al., 2013; Watson et al., 2008; Zibadi et al., 2007). While studies involving humans only used PPF peel aqueous extracts, animal studies also tested the efficacy of methanolic and ethanolic peel extracts.

Oxidative stress plays an important role in cardiovascular diseases, and diet supplementation of with antioxidant compounds or antioxidant rich extractives has been shown a protective effect against oxidative damage of nucleic acids, lipids, proteins and other biomolecules (Manzoor et al., 2021; Miller et al., 2017)).

The antioxidant effects of PPF peel extracts have been reported to have a positive impact on conditions such as asthma, pulmonary fibrosis and osteoarthritis (Chilakapati et al., 2014; Farid et al., 2010; Watson et al., 2008). In the case of asthma, a 4-week, randomized, placebo-controlled, double-blind trial was performed with oral administration of an aqueous PPF peel extract (150 mg.day$^{-1}$) or placebo pills to 43 adult patients with asthma (Watson et al., 2008). Compared to a control group, the prevalence of wheeze, cough, and shortness of breath was reduced significantly in the group treated with PFP extract (Watson et al., 2008). Spirometry tests were able to show a significant increase in the forced vital capacity of the treated patients, but no improvement was observed in the forced expiratory volume at 1 s (Watson et al., 2008). HPLC analysis of the used extract revealed that among a complex composition, the most abundant compounds identified were edulilic acid, quercetin-3-*O*-glucoside, and cyanidin-3-*O*-glucoside. The anti-asthmatic effect of the PPF peel extract can be associated with the protection of endogenous antioxidant defenses, inactivation of reactive oxygen species from environmental exposure to air pollution and reduction of asthmatic inflammation induced by the phenolic compounds present in the extracts (Watson et al., 2008).

The same PPF peel extract was also evaluated, through diet supplementation (0.1 mg.g$^{-1}$), in a mouse model of bleomycin-induced pulmonary fibrosis (Chilakapati et al., 2014). Besides significantly reducing loss of body weight and mortality rate compared to a control, PPF peel extract administration significantly attenuated inflammatory cell numbers, like macrophages, lymphocytes, and neutrophils in bronchoalveolar lavage fluid after 7 and 21 days of treatment (Chilakapati et al., 2014). Furthermore, diet supplementation with PPF peel extract also restored the decrease in superoxide dismutase and decreased myeloperoxidase activities, suppressed hydroxyproline deposition and attenuated inflammatory cell infiltration and accumulation of collagen in lung tissue (Chilakapati et al., 2014).

Inflammation and oxidative stress also play an important role in osteoarthritis, a degenerative disorder involving cartilage degradation, and inflammation is associated with accelerating joint destruction. A PPF aqueous peel extract was tested in thirty-three patients suffering

**Table 4**
*In vivo* biological activities reported for purple passion fruit (*Passiflora edulis* f. *edulis)* fractions.

| Fraction | Extract | Experimental model | Administration; dosage | Main results | Reference |
|---|---|---|---|---|---|
| Peel | Hot water | Ashtmatic patients (double-blind, placebo-controlled trial) | Oral; 150 mg.day$^{-1}$ | • Reduction of the prevalence of wheeze, cough, shortness of breath and forced vital capacity. | (Watson et al., 2008) |
| Peel | Hot water | Hypertensive rats | Oral; 0.05 mg.g$^{-1}$ | • Reduction of systolic blood pressure by 12.3 mm Hg and decrease of serum nitric oxide level by 65.0%. | (Zibadi et al., 2007) |
| | | Hypertensive patients (randomized, double-blind placebo-controlled trial) | Oral; 400 mg.day$^{-1}$ | • Decrease of systolic and diastolic blood pressure by 30.9 and 24.6 mm Hg, respectively. | |
| Peel | Hot water | Mouse with bleomycin induced pulmonary fibrosis | Oral; 0.10 mg.g$^{-1}$ | • Reduction of body weight loss and mortality rate;· Attenuation of the increase of inflammatory cells, macrophages, lymphocytes and neutrophils;<br>Attenuation of the increase of inflammatory cells, macrophages, lymphocytes and neutrophils;<br>Decrease of superoxide dismutase and myeloperoxidase activities (7days);<br>Suppression of enhanced hydroxyproline deposition (21 days);<br>Attenuation of extensive inflammatory cell infiltration (7 days) and accumulation of collagen in lung tissue sections (21 days). | (Chilakapati et al., 2014) |
| Peel | Ethanolic | Albino rat (*Rattus norvegicus)* | Oral; 0.13 – 0.50 mg.g$^{-1}$ | • Hepatoprotective activity and nephroprotective activity in a dose-dependent activity. | (Nerdy & Ritarwan, 2019) |
| Peel | Methanolic | Spontaneously hypertensive rats | Oral; 0.010 or 0.050 mg.g$^{-1}$ | • Reduction of systolic blood pressure in spontaneously hypertensive rats. | (Ichimura et al., 2006) |
| Peel | Hot water | Patients with knee osteoarthritis (randomized, double-blind, placebo-controlled trial with parallel-group design) | Oral; 150 mg.day$^{-1}$ | • Amelioration of osteoarthritis symptoms (pain, stiffness, physical function, and composite WOMAC score). | (Farid et al., 2010) |
| Peel | Hot water | Type 2 diabetics (randomized, placebo-controlled, double-blind trial) | Oral; 220 mg.day$^{-1}$ | • Reduction in systolic blood pressure and fasting blood glucose. | (Raju et al., 2013) |
| Epicarp | Ethanolic | Mice | Oral; 0.20 – 0.60 mg.g$^{-1}$ | • Anti-fatigue effect by enhancing weight-loaded forced swimming time, reducing the LDH activity, retarding the accumulation of blood lactate and blood urea nitrogen level, and increasing the liver glycogen content. | (M. Hu et al., 2020) |

from knee osteoarthritis enrolled in a randomized, double-blind, placebo-controlled, parallel-group design trial (Farid et al., 2010). Western Ontario and McMaster Universities (WOMAC) Osteoarthritis Index score was used to evaluate the efficacy of treatment with PPF peel extract oral supplementation (150 mg.day$^{-1}$). After 60 days, reductions of 18.6%, 18%, 19.6%, and 19.2% in pain, stiffness, physical function, and composite WOMAC score, respectively, were self-reported in the treated group (Farid et al., 2010).

The observed effect in both pulmonary fibrosis and knee osteoarthritis was attributed to the ability of the extract to act as an antioxidant and anti-inflammatory agent due to the flavonoid composition of the extract (Chilakapati et al., 2014; Farid et al., 2010). Regarding osteoarthritis, the ability of passion fruit peel to inhibit matrix metalloproteinases, enzymes that contribute to cartilage destruction and further development of osteoarthritis and joint degradation, had been previously reported and thus thought to contribute to the observed effect (Farid et al., 2010; Puricelli et al., 2003).

The same antioxidant and anti-inflammatory effects have been observed in mice using a anthocyanin-rich PPF epicarp ethanolic extract, that, when orally administered, was able to delay physical fatigue, regulate energy metabolism, and ameliorate oxidative stress biomarkers, antioxidant enzymes, and inflammatory cytokines (TNF-α, IL-1β, IL-6) in exercise-induced mice (M. Hu et al., 2020). These anti-fatigue effects were attributed to the presence of cyanidin-3-*O*-glucoside, cyanidin-3-*O*-rutinoside, and peonidin-3-*O*-glucoside (M. Hu et al., 2020).

Extracts of PPF peel, have also demonstrated antihypertensive effect in humans and rats (Ichimura et al., 2006; Raju et al., 2013; Zibadi et al., 2007). Hypertensive rats diet was supplemented with PPF peel aqueous extract (0.05 mg.g$^{-1}$) for 8 weeks significantly lowered systolic blood pressure by 12.3 mm Hg and decreased serum nitric oxide level by 65.0% compared with the control group (Zibadi et al., 2007). The same study also performed a randomized, double-blind placebo-controlled trial, in which oral supplementation of PPF peel extract (400 mg.day$^{-1}$) for 4 weeks in hypertensive patients decreased the systolic and diastolic blood pressure by 30.9 ± 6.30 and 24.6 ± 3.30 mm Hg, respectively, compared with the placebo (Zibadi et al., 2007). A different study also observed a significant reduction in systolic blood pressure in spontaneously hypertensive rats through oral administration of a PPF peel methanolic extract (0.01 or 0.05 mg.g$^{-1}$) (Ichimura et al., 2006). The clinical efficacy of PPF aqueous peel extract in reducing cardiovascular risk factors in adult type 2 diabetic subjects was also evaluated in a randomized, double-blind, placebo-controlled trial (Raju et al., 2013). In this case, the regular dietary supplementation with PPF peel extract (220 mg.day$^{-1}$) for 16 weeks promoted a significant reduction in systolic blood pressure and fasting blood glucose (Raju et al., 2013).

The antihypertensive effect of PPF peel may, in part, be mediated through the downregulation of iNOS expression by phenolic compounds such as quercetin, luteolin, cyanidin 3-*O*-glucoside (Zibadi et al., 2007). These compounds may also inhibit the peroxynitrite anion generation, affecting the endogenous antioxidant system, which in turn should modify the vascular tone and peripheral vascular resistance, and thus lower blood pressure (López-López et al., 2004; Raju et al., 2013). Furthermore, GABA, which has shown antihypertensive activity, has been found in substantial amounts in methanolic extract of PPF peel (2.4–4.4 mg.g$^{-1}$ DW), and may also be responsible for the observed effect (Hayakawa et al., 2002; Ichimura et al., 2006).

Besides the above-mentioned activities, an uncharacterized ethanolic PPF peel extract has demonstrated both hepato- and nephroprotective effects (Nerdy & Ritarwan, 2019). These effects were tested for three varieties of the passion fruit (purple, red, and yellow) peel extracts administered in a daily dosage between 0.13 and 0.50 mg.g$^{-1}$ to albino rats. While all passion fruit extracts were able to promote hepatoprotective and nephroprotective activity in a dose-dependent manner, PPF peel showed the best protective effect compared to red and yellow passion fruit peel extracts (Nerdy & Ritarwan, 2019).

In summary, PPF has shown *in vivo* potential to be used as an alternative or complementary therapy for the treatment of asthma (Watson

et al., 2008), pulmonary fibrosis (Chilakapati et al., 2014), knee osteoarthritis (Farid et al., 2010), fatigue (M. Hu et al., 2020) and hypertension (Ichimura et al., 2006; Zibadi et al., 2007). The peel remains, almost exclusively, as the fruit fraction with health benefits demonstrated *in vivo* and all these effects have been demonstrated through the administration of the respective extract orally. In human studies, only aqueous peel extracts have been used (in the range of 150–400 mg.day$^{-1}$) while in animal studies, aqueous, ethanolic and methanolic peel extracts have been supplemented to their diets in concentrations from 0.01 mg.g$^{-1}$ up to 0.6 mg.g$^{-1}$.

Most of the beneficial effects observed are attributed to the antioxidant and anti-inflammatory activities of such extracts thought to be mainly conferred by their high content in flavonoids. However, it should be kept in mind that in some cases this cause-effect association has not been proven and the underlying molecular mechanisms of the observed effects are not clear. Thus, a more comprehensive characterization of these extracts and the molecular targets of their components should be further studied. Furthermore, reported human studies present limitations regarding small sample size, short follow-up periods and in some cases concerns over the accuracy of self-report of disease symptoms.

## 7. Safety precautions

Passion fruit consumption is generally regarded as safe. However, cyanogenic compounds content is usually considered as the biggest concern in terms of toxicity as they have been found in all PPF fractions (mainly when immature) except for seeds (Spencer & Seigler, 1983). Compared to juice (8.91 × 10$^{-3}$ mg.g$^{-1}$ FW), the PPF peel has been found to present higher amount (24.6 × 10$^{-3}$ mg.g$^{-1}$ FW) of hydrogen cyanide (HCN) equivalence released by enzymatic treatment (Chassagne et al., 1996).

As shown in Table 2, several cyanogenic glycosides have been identified on PPF peels and juice: sambunigrin, prunasin, mandelonitrile rutinoside (1), mandelonitrile rutinoside (2) and amygdalin (Chassagne et al., 1996). PPF peel cyanogenic glycosides are mainly composed of prunasin (231 μg.g$^{-1}$ FW) representing 80% of the total amount, while in juice, prunasin (43.1 μg.g$^{-1}$ FW) along with mandelonitrile rutinoside (1) (40.4 μg.g$^{-1}$ FW) were the most abundant (Chassagne et al., 1996). Prunasin has also been identified in other studies in PPF peel ethanolic and hot water extracts (Y. Hu et al., 2018; Zibadi et al., 2007). Compared to PPF, yellow passion fruit contains a higher HCN amount in both peel (31.5 μg.g$^{-1}$ FW) and juice (15.3 μg.g$^{-1}$ FW) with prunasin (290 μg.g$^{-1}$ FW) as the main cyanogenic component in peel and mandelonitrile rutinoside (1) (99.6 μg.g$^{-1}$ FW) in juice (Chassagne et al., 1996).

These cyanogenic compounds are not toxic *per se*, but their hydrolysis produces HCN that may cause nausea, vomiting, diarrhea, weakness, and dizziness. A dose in the range of 5.0 × 10$^{-4}$ to 3.50 × 10$^{-3}$ mg.g$^{-1}$ body weight (between 25.0 and 175 mg for a person with 50 kg) can cause acute cyanide toxicity in humans (Bolarinwa et al., 2014). For instance, a typical glass of juice (200 mL) allows an intake of 1.78 mg of HCN, which is considerably below the inferior value of the interval that can cause toxicity in a 50 kg person (25.0 mg). This allows to infer that consumption of PPF juice within reasonable amounts is regarded as safe and does not represent a danger in terms of HCN toxicity.

*In vitro* assessment of PPF toxicity has found that *Passiflora* pressurized water peel extracts (0.025 – 1 mg.mL$^{-1}$), including PPF, did not show cytotoxicity in human cervical cancer HeLa cell cultures as the cell viability was not significantly altered (Domínguez-Rodríguez et al., 2019). Furthermore, in a rat liver slice toxicity assay, PPF peel aqueous extract (0.020 mg.mL$^{-1}$) did not show hepatotoxicity after 9 h of incubation (Zibadi et al., 2007). Available *in vivo* studies involving the oral administration of PPF peel aqueous extracts to humans have reported the absence of adverse effects in the participants with doses ranging between 150 and 400 mg.day$^{-1}$ (3.0 × 10$^{-3}$ mg.g$^{-1}$ – 8.0 × 10$^{-3}$ mg.g$^{-1}$ a day for a person with 50 kg) and study duration between 4 and 16 weeks (Farid et al., 2010; Raju et al., 2013; Watson et al., 2008; Zibadi et al., 2007).

## 8. Concluding remarks and future perspectives

PPF is often consumed directly in fresh for its pulp and juice or added to food dishes such as desserts or salads for its fragrant and pleasant pulp flavour. The pulp and juice are good sources of carbohydrates, several minerals (Fe, Cu, P, K and Mg), riboflavin and niacin while providing low amounts of fat, making them low-energy foods. They also provide considerable amounts of vitamin C, which is a powerful antioxidant and a compound associated with many body functions like proper functioning of the immune system. Otherwise, peels and seeds, by-products resulting from the consumption *in natura* or industrial processing, are usually discarded or used in low-value applications. However, their nutritional value and phytochemical profiles unveil that these by-products have also the potential to contribute to a healthy and balanced diet by providing significant amounts of several macro (lipids, fiber) and micronutrients (K, Fe, Mg, Cu, Mn, Ca and Zn). Chemical characterization of these by-products has revealed that peels may be used in the development of new fiber-rich healthy food products as well as a potential alternative source of pectin to be commercially produced. On the other hand, lipidic fraction extracted from seeds also demonstrate potential to be used in food and industrial applications due to its high content in unsaturated fatty acids with a regio-distribution that confers a high bioavailability.

The phytochemical characterization of the different parts of the fruit unveils their diverse potential. Phenolic compounds, namely flavonoids in the case of pulp and peel and phenolic acid in the seeds have been reported. Carotenoids are present in the pulp and peels (mainly as β-carotene), while sterols (mostly β-sitosterol and stigmasterol) and tocopherols (predominantly γ-tocopherol and δ-tocopherol) have been characterized in seeds. These compounds can act as natural antioxidants thus their incorporation in food products may be considered in that perspective.

A growing interest in the study of the phytochemical composition of this fruit has led to the evaluation of *in vitro* bioactivities and *in vivo* efficacy of the use of PPF in several diseases' treatment and prevention. The most frequently reported *in vitro* biological effect of PPF is its antioxidant activity (peel, pulp and seeds), although anti-inflammatory (pulp), antibacterial (peel and seeds) and antifungal (peel) activities have been also reported. Reported *in vivo* studies were performed exclusively with peels whose beneficial effects are usually attributed to the antioxidant and anti-inflammatory activities of these extracts found to be rich in flavonoids. *In vivo* studies in animals allowed to demonstrate a dose-dependent effect of the PPF peel extracts in the case of antihypertensive, anti-fatigue and hepato and nephroprotective effects. Human studies, on the other hand, showed positive effects on the management of diabetes, osteoarthritis, hypertension and asthma when performed through oral supplementation of PPF peel extracts with a single dosage in the range of 150–400 mg.day$^{-1}$.

To confirm the efficacy of these extracts, further investigation of these effects should be undertaken in clinical setting using larger cohorts and longer follow-up periods. A more extensive characterization of extracts would be also advisable and further investigation of the underlying mechanisms involved in the reported health promotion effects should be further explored. Considering PPF chemical composition and the health-promoting benefits demonstrated, all fruit fractions should be considered in the production of food supplements, nutraceuticals or functional foods. The development of such products targeting chronic and lifestyle associated diseases should be seen with particular interest when using PPF as ingredient, due to the role of oxidative stress in the pathogenesis of such conditions. Such use in food formulations should ideally incorporate all fruit fractions, thus allowing the integral valorisation of the whole fruit.

Considering the nutritional value and phytochemical profiles of the different parts of the fruit, it is possible to foresee several lines of

valorisation of these plant-based materials. Also, consumers increasingly value products obtained in a sustainable way that can promote health, well-being, and beauty. Recently, a growing trend in cosmetics industry is the convergence of food and cosmetics in the development of the so-called food-based cosmetics or nutricosmetics. These products aim to provide "beauty from within" through the consumption of food or oral supplements to produce an appearance benefit. To achieve that purpose, bioactive ingredients with properties such as antioxidant, antimicrobial and antiaging are sourced from natural materials or their by-products to substitute synthetic chemicals that are currently in use. These can include vitamins, carotenoids, polyphenols, minerals, essential fatty acids or amino acids and peptides (Faria-Silva et al., 2020). As seen before, among all PPF fractions considerable amounts of such compounds can be found. Pulp contains considerable amounts of vitamin C, minerals and carotenoids; peels are rich in polyphenols; and seeds can provide essential fatty acids (mainly linoleic acid). Thus, PPF can be also considered as a source of ingredients in the context of "Green Beauty" in which the use of natural and organic ingredients and the sustainability of the products are a growing demand from the consumers.

Funding.

Thanks are due to FCT (Fundação para a Ciência e Tecnologia) /MEC for the financial support of LAQV-REQUIMTE (UIDB/50006/2020) and CICECO-Aveiro Institute of Materials (UIDB/50011/2020 & UIDP/50011/20209, through national funds and when applicable co-financed by the FEDER, within the PT2020 Partnership Agreement. Alexandre M. A. Fonseca thanks FCT and ESF (European Social Fund) through POCH (Programa Operacional Capital Humano) for his PhD grant (SFRH/BD/146391/2019). Marina V. Geraldi thanks the FAPESP for her PhD grant (2019/12244–8). This study was also financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES, Finance Code 001) e Conselho Nacional de Desenvolvimento Científico e Tecnológico. Mário R. Maróstica Juniór acknowledges Red Iberomericana de Alimentos Autoctonos Subutilizados [ALSUB-CYTED, 118RT0543].

## CRediT authorship contribution statement

**Alexandre M.A. Fonseca:** Conceptualization, Methodology, Investigation, Data curation, Writing – original draft, Visualization. **Marina V. Geraldi:** Writing – review & editing. **Mário R. Maróstica Junior:** Writing – review & editing. **Armando J.D. Silvestre:** Conceptualization, Methodology, Data curation, Writing – review & editing, Supervision. **Sílvia M. Rocha:** Conceptualization, Methodology, Data curation, Writing – review & editing, Supervision.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## References

Alves, E., Simoes, A., & Domingues, M. R. (2021). Fruit seeds and their oils as promising sources of value-added lipids from agro-industrial byproducts: Oil content, lipid composition, lipid analysis, biological activity and potential biotechnological applications. *Critical Reviews in Food Science and Nutrition, 61*(8), 1305–1339. https://doi.org/10.1080/10408398.2020.1757617

Asadujjaman, M., Mishuk, A. U., Hossain, M. A., & Karmakar, U. K. (2014). Medicinal potential of Passiflora foetida L. plant extracts: Biological and pharmacological activities. *Journal of. Integrative Medicine, 12*(2), 121–126. https://doi.org/10.1016/S2095-4964(14)60017-0

Aukar, A. P. de A., Lemos, E. G. de M., & Oliveira, J. C. (2002). Genetic variations among passion fruit species using rapd markers. *Revista Brasileira de Fruticultura, 24*(3), 738–740. 10.1590/s0100-29452002000300044.

Beck, J., Böller, M., Erhardt, A., & Schwanghart, W. (2014). Spatial bias in the GBIF database and its effect on modeling species' geographic distributions. *Ecological Informatics, 19*, 10–15. https://doi.org/10.1016/j.ecoinf.2013.11.002

Bernacci, L. C., Cervi, A. C., Milward-de-Azevedo, M. A., Nunes, T. S., Imig, D. C., & Mezzonato, A. C. (2015). *Passifloraceae*. Lista de Espécies Da Flora Do Brasil; Jardim Botânico do Rio de Janeiro. http://floradobrasil.jbrj.gov.br/jabot/floradobrasil/FB182. Accessed on 30/04/2021.

Bernacci, L. C., Soares-Scott, M. D., Junqueira, N. T. V., Passos, I. R. da S., & Meletti, L. M. M. (2008). Passiflora edulis Sims: the correct taxonomic way to cite the yellow passion fruit (and of others colors). *Revista Brasileira de Fruticultura, 30*(2), 566–576. 10.1590/s0100-29452008000200053.

Bolarinwa, I. F., Orfila, C., & Morgan, M. R. A. (2014). Amygdalin content of seeds, kernels and food products commercially-available in the UK. *Food Chemistry, 152*, 133–139. https://doi.org/10.1016/j.foodchem.2013.11.002

Carmona-Hernandez, J. C., Taborda-Ocampo, G., Valdez, J. C., Bolling, B. W., & González-Correa, C. H. (2019). Polyphenol extracts from three Colombian passifloras (passion fruits) prevent inflammation-induced barrier dysfunction of Caco-2 cells. *Molecules, 24*(24). https://doi.org/10.3390/molecules24244614

Carr, M. K. V. (2014). Passion fruit. In *Advances in Irrigation Agronomy* (pp. 252–264). Cambridge University Press. https://doi.org/10.1017/cbo9781139584012.014.

Carraz, M., Lavergne, C., Jullian, V., Wright, M., Gairin, J. E., Gonzales De La Cruz, M., & Bourdy, G. (2015). Antiproliferative activity and phenotypic modification induced by selected Peruvian medicinal plants on human hepatocellular carcinoma Hep3B cells. *Journal of Ethnopharmacology, 166*, 185–199. https://doi.org/10.1016/j.jep.2015.02.028

Cerqueira-Silva, C., Jesus, O., Santos, E., Corrêa, R., & Souza, A. (2014). Genetic Breeding and Diversity of the Genus Passiflora: Progress and Perspectives in Molecular and Genetic Studies. *International Journal of Molecular Sciences, 15*(8), 14122–14152. https://doi.org/10.3390/ijms150814122

Chan, H. T., Chang, T. S. K., & Chenchin, E. (1972). Nonvolatile acids of passion fruit juice. *Journal of Agricultural and Food Chemistry, 20*(1), 110–112. https://doi.org/10.1021/jf60179a012

Chan, H. T., & Kwok, S. C. M. (1975). Identification and Determination of Sugars in Some Tropical Fruit Products. *Journal of Food Science, 40*(2), 419–420. https://doi.org/10.1111/j.1365-2621.1975.tb02218.x

Charan, S. M., Gomez, S., Sheela, K. B., Meagle Joseph, P., & Sruthi, C. v. (2018). Quality characteristics and antioxidant activity of passion fruit (Passiflora edulis sims) accessions. *Indian Journal of Horticulture*, *75*(2), 185–190. 10.5958/0974-0112.2018.00034.8.

Chassagne, D., Boulanger, R., & Crouzet, J. (1999). Enzymatic hydrolysis of edible Passiflora fruit glycosides. *Food Chemistry, 66*(3), 281–288. https://doi.org/10.1016/S0308-8146(99)00044-8

Chassagne, D., & Crouzet, J. (1998). A cyanogenic glycoside from Passiflora edulis fruits. *Phytochemistry, 49*(3), 757–759. https://doi.org/10.1016/S0031-9422(98)00130-7

Chassagne, D., Crouzet, J. C., Bayonove, C. L., & Baumes, R. L. (1996). Identification and Quantification of Passion Fruit Cyanogenic Glycosides. *Journal of Agricultural and Food Chemistry, 44*(12), 3817–3820. https://doi.org/10.1021/jf960381t

Chilakapati, S. R., Serasanambati, M., Manikonda, P. K., Chilakapati, D. R., & Watson, R. R. (2014). Passion fruit peel extract attenuates bleomycin-induced pulmonary fibrosis in mice. *Canadian Journal of Physiology and Pharmacology, 92*(8), 631–639. https://doi.org/10.1139/cjpp-2014-0006

Coleta, M., Batista, M. T., Campos, M. G., Carvalho, R., Cotrim, M. D., de Lima, T. C. M., & da Cunha, A. P. (2006). Neuropharmacological evaluation of the putative anxiolytic effects of Passiflora edulis Sims, its sub-fractions and flavonoid constituents. *Phytotherapy Research: PTR, 20*(12), 1067–1073. https://doi.org/10.1002/ptr.1997

Conde-Martínez, N., Jiménez, A., Steinhaus, M., Schieberle, P., Sinuco, D., & Osorio, C. (2013). Key aroma volatile compounds of gulupa (Passiflora edulis Sims fo edulis) fruit. *European Food Research and Technology, 236*(6), 1085–1091. https://doi.org/10.1007/s00217-013-1979-9

Corrêa, R. C. G., Peralta, R. M., Haminiuk, C. W. I., Maciel, G. M., Bracht, A., & Ferreira, I. C. F. R. (2016). The past decade findings related with nutritional composition, bioactive molecules and biotechnological applications of Passiflora spp. (passion fruit). *Trends in Food Science and Technology, 58*, 79–95. https://doi.org/10.1016/j.tifs.2016.10.006

Dam, S. M., & Nguyen, D. V. (2013). Optimization of pectin extraction from fruit peel of purple passion fruit (Passiflora edulis Sims) in Vietnam. *Acta Horticulturae*, *989*, 279–284. 10.17660/ActaHortic.2013.989.36.

Delvar, A., de Caro, P., Candy, L., Caro, Y., Cheong Sing, A. S., & Raynaud, C. (2019). Integrated process for extraction and formulation in emulsions of active molecules from fresh passion fruits (Passiflora edulis Sims). *Journal of Food Engineering, 263*, 388–397. https://doi.org/10.1016/j.jfoodeng.2019.07.014

Dhawan, K., Dhawan, S., & Sharma, A. (2004). Passiflora: A review update. *Journal of Ethnopharmacology, 94*(1), 1–23. https://doi.org/10.1016/j.jep.2004.02.023

Dhawan, K., Kumar, S., & Sharma, A. (2001). Comparative biological activity study on Passiflora incarnata and P. edulis. *Fitoterapia, 72*(6), 698–702. https://doi.org/10.1016/S0367-326X(01)00306-9

Domínguez-Rodríguez, G., García, M. C., Plaza, M., & Marina, M. L. (2019). Revalorization of Passiflora species peels as a sustainable source of antioxidant phenolic compounds. *Science of the Total Environment, 696*, Article 134030. https://doi.org/10.1016/j.scitotenv.2019.134030

dos Reis, L. C. R., Facco, E. M. P., Salvador, M., Flôres, S. H., & Rios, A. de O. (2018). Antioxidant potential and physicochemical characterization of yellow, purple and orange passion fruit. *Journal of Food Science and Technology, 55*(7), 2679–2691. https://doi.org/10.1007/s13197-018-3190-2

Ehling, S., & Cole, S. (2011). Analysis of organic acids in fruit juices by liquid chromatography-mass spectrometry: An enhanced tool for authenticity testing. *Journal of Agricultural and Food Chemistry, 59*(6), 2229–2234. https://doi.org/10.1021/jf104527e

Everette, J. D., Bryant, Q. M., Green, A. M., Abbey, Y. A., Wangila, G. W., & Walker, R. B. (2010). Thorough study of reactivity of various compound classes toward the Folin-

Ciocalteu reagent. *Journal of Agricultural and Food Chemistry, 58*(14), 8139–8144. https://doi.org/10.1021/jf1005935
FAO. (2018). *Food Outlook: Biannual Report on Global Food Markets*. www.fao.org/publications. Accessed on 13/04/2020.
Faria-Silva, C., Ascenso, A., Costa, A. M., Marto, J., Carvalheiro, M., Ribeiro, H. M., & Simões, S. (2020). Feeding the skin: A new trend in food and cosmetics convergence. *Trends in Food Science & Technology, 95*, 21–32. https://doi.org/10.1016/J.TIFS.2019.11.015
Farid, R., Rezaieyazdi, Z., Mirfeizi, Z., Hatef, M. R., Mirheidari, M., Mansouri, H., Esmaelli, H., Bentley, G., Lu, Y., Foo, Y., & Watson, R. R. (2010). Oral intake of purple passion fruit peel extract reduces pain and stiffness and improves physical function in adult patients with knee osteoarthritis. *Nutrition Research, 30*(9), 601–606. https://doi.org/10.1016/j.nutres.2010.08.010
Ferreres, F., Sousa, C., Valentão, P., Andrade, P. B., Seabra, R. M., & Gil-Izquierdo, Á. (2007). New C-Deoxyhexosyl flavones and antioxidant properties of Passiflora edulis leaf extract. *Journal of Agricultural and Food Chemistry, 55*(25), 10187–10193. https://doi.org/10.1021/jf072119y
Feuillet, C., & MacDougal, J. M. (2003). A new infrageneric classification of Passiflora L. (Passifloraceae). *The Journal & Newsletter of Passiflora Society. International, 13*(2), 34–35.
Feuillet, C., & MacDougal, J. M. (2007). Passifloraceae. In Kubitzki K. (Ed.), *Flowering Plants · Eudicots. The Families and Genera of Vascular Plants* (Vol. 9, pp. 270–281). Springer. 10.1007/978-3-540-32219-1_35.
Florez, L. M., Vaillant, F., Hollander, H., & Ariza-Nieto, M. (2003). Passion fruit juice sacs: Biochemical characterization and enzymatic treatment. *Tropical Science, 43*(1), 28–34. https://doi.org/10.1002/ts.84
GBIF.org. (2022). *What is GBIF?* https://www.gbif.org/what-is-gbif. Accessed on 22/01/2022.
Ghada, B., Pereira, E., Pinela, J., Prieto, M. A., Pereira, C., Calhelha, R. C., Stojković, D., Sokóvić, M., Zaghdoudi, K., Barros, L., & Ferreira, I. C. F. R. (2020). Recovery of Anthocyanins from Passion Fruit Epicarp for Food Colorants: Extraction Process Optimization and Evaluation of Bioactive Properties. *Molecules, 25*(14), 3203. https://doi.org/10.3390/molecules25143203
Giuffré, A. M. (2007). Chemical composition of purple passion fruit (Passiflora edulis Sims var. edulis) seed oil. *La Rivista Italiana Delle Sostanze Grasse, 84*, 87–93.
Guo, R., Tian, S., Li, X., Wu, X., Liu, X., Li, D., Liu, Y., Ai, L., Song, Z., & Wu, Y. (2020). Pectic polysaccharides from purple passion fruit peel: A comprehensive study in macromolecular and conformational characterizations. *Carbohydrate Polymers, 229*, Article 115406. https://doi.org/10.1016/j.carbpol.2019.115406
Gupta, R. K., Kumar, D., Chaudhary, A. K., Maithani, M., & Singh, R. (2012). Antidiabetic activity of Passiflora incarnata Linn. in streptozotocin-induced diabetes in mice. *Journal of Ethnopharmacology, 139*(3), 801–806. https://doi.org/10.1016/j.jep.2011.12.021
Hasib, A., Jaouad, A., Mahrouz, M., & Khouili, M. (2002). HPLC Determination of Organic Acids in Moroccan Apricot. *Ciencia y Tecnologia Alimentaria, 3*(4), 207–211. https://doi.org/10.1080/11358120209487729
Hayakawa, K., Kimura, M., & Kamata, K. (2002). Mechanism underlying γ-aminobutyric acid-induced antihypertensive effect in spontaneously hypertensive rats. *European Journal of Pharmacology, 438*(1–2), 107–113. https://doi.org/10.1016/s0014-2999(02)01294-3
He, X., Luan, F., Yang, Y., Wang, Z., Zhao, Z., Fang, J., Wang, M., Zuo, M., & Li, Y. (2020). Passiflora edulis: An Insight Into Current Researches on Phytochemistry and Pharmacology. *Frontiers in Pharmacology, 11*, 1–16. https://doi.org/10.3389/fphar.2020.00617
Herderich, M., & Winterhalter, P. (1991). 3-Hydroxy-retro-alpha-ionol: A natural precursor of isomeric edulans in purple passion fruit (Passiflora edulis Sims). *Journal of Agricultural and Food Chemistry, 39*(7), 1270–1274. https://doi.org/10.1021/jf00007a015
Herrera-Ramirez, J., Meneses-Marentes, N., & Tarazona Díaz, M. P. (2020). Optimizing the extraction of anthocyanins from purple passion fruit peel using response surface methodology. *Journal of Food Measurement and Characterization, 14*(1), 185–193. https://doi.org/10.1007/s11694-019-00280-8
Hossen, I., Hua, W., Ting, L., Mehmood, A., Jingyi, S., Duoxia, X., Yanping, C., Hongqing, W., Zhipeng, G., Kaiqi, Z., Fang, Y., & Junsong, X. (2020). Phytochemicals and inflammatory bowel disease: A review. *Critical Reviews in Food Science and Nutrition, 60*(8), 1321–1345. https://doi.org/10.1080/10408398.2019.1570913
Hu, M., Du, J., Du, L., Luo, Q., & Xiong, J. (2020). Anti-fatigue activity of purified anthocyanins prepared from purple passion fruit (P. edulis Sim) epicarp in mice. *Journal of Functional Foods, 65*, Article 103725. https://doi.org/10.1016/j.jff.2019.103725
Hu, Y., Jiao, L., Jiang, M. H., Yin, S., Dong, P., Zhao, Z. M., Yang, D. P., Ho, P. T., & Wang, D. M. (2018). A new C-glycosyl flavone and a new neolignan glycoside from Passiflora edulis Sims peel. *Natural Product Research, 32*(19), 2312–2318. https://doi.org/10.1080/14786419.2017.1410809
Ichimura, T., Yamanaka, A., Ichiba, T., Toyokawa, T., Kamada, Y., Tamamura, T., & Maruyama, S. (2006). Antihypertensive Effect of an Extract of Passiflora edulis Rind in Spontaneously Hypertensive Rats. *Bioscience, Biotechnology, and Biochemistry, 70*(3), 718–721. https://doi.org/10.1271/bbb.70.718
iNaturalist contributors, iNaturalist. (2021). *iNaturalist Research-grade Observations*. Occurrence Dataset 10.15468/ab3s5x. Accessed on 22/01/2022.
Janda, Katarzyna, Wojtkowska, Karolina, Jakubczyk, Karolina, Antoniewicz, Justyna, & Skonieczna-Żydecka, Karolina (2020). *Passiflora incarnata* in Neuropsychiatric Disorders—A Systematic Review. *Nutrients, 12*(12). https://doi.org/10.3390/nu12123894
Jiménez, A. M., Sierra, C. A., Rodríguez-Pulido, F. J., González-Miret, M. L., Heredia, F. J., & Osorio, C. (2011). Physicochemical characterisation of gulupa (Passiflora edulis Sims. fo edulis) fruit from Colombia during the ripening. *Food Research International, 44*(7), 1912–1918. https://doi.org/10.1016/j.foodres.2010.11.007
Johnson, E. J. (2002). The Role of Carotenoids in Human Health. *Nutrition in Clinical Care, 5*(2), 56–65. https://doi.org/10.1046/J.1523-5408.2002.00004.x
Jusuf, N. K., Putra, I. B., & Dewi, N. K. (2020). Antibacterial Activity of Passion Fruit Purple Variant (Passiflora edulis Sims var. edulis) Seeds Extract Against Propionibacterium acnes. *Clinical, Cosmetic and Investigational Dermatology, 13*, 99–104. https://doi.org/10.2147/ccid.s229743
KidØy, L., Nygård, A. M., Andersen, Ø. M., Pedersen, A. T., Aksnes, D. W., & Kiremire, B. T. (1997). Anthocyanins in fruits of Passiflora edulis and P. suberosa. *Journal of Food Composition and Analysis, 10*(1), 49–54. https://doi.org/10.1006/jfca.1996.0514
Krambeck, K., Oliveira, A., Santos, D., Pintado, M. M., Baptista Silva, J., Sousa Lobo, J. M., & Amaral, M. H. (2020). Identification and Quantification of Stilbenes (Piceatannol and Resveratrol) in Passiflora edulis By-Products. *Pharmaceuticals, 13*(4), 73. https://doi.org/10.3390/ph13040073
Lee, S. Y., Fu, S. Y., & Chong, G. H. (2015). Ultrasound-assisted extraction kinetics, fatty acid profile, total phenolic content and antioxidant activity of green solvents extracted passion fruit oil. *International Journal of Food Science and Technology, 50*(8), 1831–1838. https://doi.org/10.1111/ijfs.12844
Li, H., Zhou, P., Yang, Q., Shen, Y., Deng, J., Li, L., & Zhao, D. (2011). Comparative studies on anxiolytic activities and flavonoid compositions of Passiflora edulis "edulis" and Passiflora edulis "flavicarpa". *Journal of Ethnopharmacology, 133*(3), 1085–1090. https://doi.org/10.1016/j.jep.2010.11.039
López-López, G., Moreno, L., Cogolludo, A., Galisteo, M., Ibarra, M., Duarte, J., Lodi, F., Tamargo, J., & Perez-Vizcaino, F. (2004). Nitric Oxide (NO) Scavenging and NO Protecting Effects of Quercetin and Their Biological Significance in Vascular Smooth Muscle. *Molecular Pharmacology, 65*(4), 851–859. https://doi.org/10.1124/mol.65.4.851
Lourith, N., & Kanlayavattanakul, M. (2013). Antioxidant Activities and Phenolics of Passiflora edulis Seed Recovered from Juice Production Residue. *Journal of Oleo Science, 62*(4), 235–240. https://doi.org/10.5650/jos.62.235
Manzoor, M., Singh, J., Gani, A., & Noor, N. (2021). Valorization of natural colors as health-promoting bioactive compounds: Phytochemical profile, extraction techniques, and pharmacological perspectives. *Food Chemistry, 362*, Article 130141. https://doi.org/10.1016/j.foodchem.2021.130141
Medina, S., Collado-González, J., Ferreres, F., Londoño-Londoño, J., Jiménez-Cartagena, C., Guy, A., Durand, T., Galano, J. M., & Gil-Izquierdo, A. (2017). Quantification of phytoprostanes – bioactive oxylipins – and phenolic compounds of Passiflora edulis Sims shell using UHPLC-QqQ-MS/MS and LC-IT-DAD-MS/MS. *Food Chemistry, 229*, 1–8. https://doi.org/10.1016/j.foodchem.2017.02.049
Miller, V., Mente, A., Dehghan, M., Rangarajan, S., Zhang, X., Swaminathan, S., … Yusuf, S. (2017). Fruit, vegetable, and legume intake, and cardiovascular disease and deaths in 18 countries (PURE): A prospective cohort study. *The Lancet, 390*(10107), 2037–2049. https://doi.org/10.1016/S0140-6736(17)32253-5
Montanher, A. B., Zucolotto, S. M., Schenkel, E. P., & Fröde, T. S. (2007). Evidence of anti-inflammatory effects of Passiflora edulis in an inflammation model. *Journal of Ethnopharmacology, 109*(2), 281–288. https://doi.org/10.1016/j.jep.2006.07.031
Muschner, V. C., Lorenz, A. P., Cervi, A. C., Bonatto, S. L., Souza-Chies, T. T., Salzano, F. M., & Freitas, L. B. (2003). A first molecular phylogenetic analysis of Passiflora (Passifloraceae). *American Journal of Botany, 90*(8), 1229–1238. https://doi.org/10.3732/ajb.90.8.1229
Muschner, V. C., Lorenz-Lemke, A. P., Vecchia, M., Bonatto, S. L., Salzano, F. M., & Freitas, L. B. (2006). Differential organellar inheritance in Passiflora's (Passifloraceae) subgenera. *Genetica, 128*(1–3), 449–453. https://doi.org/10.1007/s10709-006-7726-4
Muschner, V. C., Zamberlan, P. M., Bonatto, S. L., & Freitas, L. B. (2012). Phylogeny, biogeography and divergence times in Passiflora (Passifloraceae). *Genetics and Molecular Biology, 35*(4), 1036–1043. https://doi.org/10.1590/S1415-47572012000600019
Nerdy, N., & Ritarwan, K. (2019). Hepatoprotective activity and nephroprotective activity of peel extract from three varieties of the passion fruit (Passiflora sp.) in the albino rat. *Open Access Macedonian. Journal of Medical Sciences, 7*(4), 536–542. https://doi.org/10.3889/oamjms.2019.153
Nyanzi, S. A., Carstensen, B., & Schwack, W. (2005). A comparative study of fatty acid profiles of Passiflora seed oils from Uganda. *Journal of the American Oil Chemists' Society, 82*(1), 41–44. https://doi.org/10.1007/s11746-005-1040-2
Ocampo, J., Coppens D'Eeckenbrugge, G., & Jarvis, A. (2010). Distribution of the Genus Passiflora L. Diversity in Colombia and Its Potential as an Indicator for Biodiversity Management in the Coffee Growing Zone. *Diversity, 2*(11), 1158–1180. https://doi.org/10.3390/d2111158
Pandey, K. B., & Rizvi, S. I. (2009). Plant polyphenols as dietary antioxidants in human health and disease. *Oxidative Medicine and Cellular Longevity, 2*(5), 270–278. https://doi.org/10.4161/oxim.2.5.9498
Passifloraceae in GBIF Secretariat. (2021). *GBIF Backbone Taxonomy*. https://doi.org/10.15468/39omei. Accessed on 22/01/2022.
Piombo, G., Barouh, N., Barea, B., Boulanger, R., Brat, P., Pina, M., & Villeneuve, P. (2006). Characterization of the seed oils from kiwi (Actinidia chinensis), passion fruit (Passiflora edulis) and guava (Psidium guajava). *OCL - Oleagineux Corps Gras Lipides, 13*(2–3), 195–199. https://doi.org/10.1684/ocl.2006.0026
Pontes, M., Marques, J. C., & Câmara, J. S. (2009). Headspace solid-phase microextraction-gas chromatography-quadrupole mass spectrometric methodology for the establishment of the volatile composition of Passiflora fruit species. *Microchemical Journal, 93*(1), 1–11. https://doi.org/10.1016/j.microc.2009.03.010

Porto-Figueira, P., Freitas, A., Cruz, C. J., Figueira, J., & Câmara, J. S. (2015). Profiling of passion fruit volatiles: An effective tool to discriminate between species and varieties. *Food Research International, 77*, 408–418. https://doi.org/10.1016/j.foodres.2015.09.007

Pruthi, J. S. (1963). Physiology, Chemistry, and Technology of Passion Fruit. *Advances in Food Research, 12*, 203–282. https://doi.org/10.1016/s0065-2628(08)60009-9

Pruthi, J. S., & Lal, G. (1959). Chemical composition of passion fruit (Passiflora Edulis, Sims.). *Journal of the Science of Food and Agriculture, 10*(3), 188–192. https://doi.org/10.1002/jsfa.2740100308

Puricelli, L., Dell'Aica, I., Sartor, L., Garbisa, S., & Caniato, R. (2003). Preliminary evaluation of inhibition of matrix-metalloprotease MMP-2 and MMP-9 by Passiflora edulis and P. foetida aqueous extracts. *Fitoterapia, 74*(3), 302–304. https://doi.org/10.1016/s0367-326x(03)00023-6

Raju, I. N., Reddy, K. K., Kumari, C. K., Reddy, E. B., Dattatreya Rao, S., Reddy, C. D., & Watson, R. R. (2013). Efficacy of Purple Passion Fruit Peel Extract in Lowering Cardiovascular Risk Factors in Type 2 Diabetic Subjects. *Journal of Evidence-Based Complementary & Alternative Medicine*. https://doi.org/10.1177/2156587213475627

Ramaiya, S. D., Bujang, J. S., & Zakaria, M. H. (2018). Nutritive Values of Passion Fruit (Passiflora Species) Seeds and Its Role in Human Health. *Journal of Agriculture Food and Development, 4*(1), 23–30. https://doi.org/10.30635/2415-0142.2018.04.4

Ramaiya, S. D., Bujang, J. S., Zakaria, M. H., King, W. S., & Sahrir, M. A. S. (2013). Sugars, ascorbic acid, total phenolic content and total antioxidant activity in passion fruit (Passiflora) cultivars. *Journal of the Science of Food and Agriculture, 93*(5), 1198–1205. https://doi.org/10.1002/jsfa.5876

Ramaiya, S. D., Bujang, J. S., Zakaria, M. H., & Saupi, N. (2019). Nutritional, mineral and organic acid composition of passion fruit (Passiflora species). *Food Research, 3*(3), 231–240. https://doi.org/10.26656/fr.2017.3(3).233

Reis Giada, M. de L. (2013). Food Phenolic Compounds: Main Classes, Sources and Their Antioxidant Power. In J. A. Morales-Gonzalez (Ed.), *Oxidative Stress and Chronic Degenerative Diseases - A Role for Antioxidants*. InTech. 10.5772/51687.

Rodriguez-Amaya, D. B. (2003). Passion Fruits. In B. Caballero (Ed.), *Encyclopedia of Food Sciences and Nutrition* (pp. 4368–4373). Elsevier. https://doi.org/10.1016/b0-12-227055-x/00885-3.

Rodriguez-Amaya, D. B. (2012). Passion Fruit. In M. Siddiq (Ed.), *Tropical and Subtropical Fruits: Postharvest Physiology, Processing and Packaging* (pp. 321–332). Wiley-Blackwell. 10.1002/9781118324097.ch17.

Scalbert, A., & Williamson, G. (2000). Dietary Intake and Bioavailability of Polyphenols. *The Journal of Nutrition, 130*(8), 2073S–2085S. https://doi.org/10.1093/jn/130.8.2073s

Schotsmans, W. C., & Fischer, G. (2011). Passion fruit (Passiflora edulis Sim.). In E. M. Yahia (Ed.), *Postharvest Biology and Technology of Tropical and Subtropical Fruits* (Vol. 4, pp. 125–143e). Woodhead Publishing. https://doi.org/10.1533/9780857092618.125.

Shiomi, S., Kubo, Y., Wamocho, L. S., Koaze, H., Nakamura, R., & Inaba, A. (1996). Postharvest ripening and ethylene biosynthesis in purple passion fruit. *Postharvest Biology and Technology, 8*(3), 199–207. https://doi.org/10.1016/0925-5214(95)00073-9

Siebra, A. L. A., Oliveira, L. R., Martins, A. O. B. P. B., Siebra, D. C., Albuquerque, R. S., Lemos, I. C. S., Delmondes, G. A., Tintino, S. R., Figueredo, F. G., da Costa, J. G. M., Coutinho, H. D. M., Menezes, I. R. A., Felipe, C. F. B., & Kerntopf, M. R. (2018). Potentiation of antibiotic activity by Passiflora cincinnata Mast. front of strains Staphylococcus aureus and Escherichia coli. *Saudi Journal of Biological Sciences, 25*(1), 37–43. https://doi.org/10.1016/j.sjbs.2016.01.019

Spencer, K. C., & Seigler, D. S. (1983). Cyanogenesis of Passiflora edulis. *Journal of Agricultural and Food Chemistry, 31*(4), 794–796. https://doi.org/10.1021/jf00118a028

Taïwe, G. S., & Kuete, V. (2017). Passiflora edulis. In V. Kuete (Ed.), *Medicinal Spices and Vegetables from Africa* (pp. 513–526). Elsevier Inc.. https://doi.org/10.1016/B978-0-12-809286-6.00024-8

Tan, J., Li, Y., Hou, D. X., & Wu, S. (2019). The effects and mechanisms of cyanidin-3-glucoside and its phenolic metabolites in maintaining intestinal integrity. *Antioxidants, 8*(10), 1–16. https://doi.org/10.3390/antiox8100479

Tetali, S. D. (2018). Terpenes and isoprenoids: A wealth of compounds for global use. *Planta, 249*(1), 1–8. https://doi.org/10.1007/S00425-018-3056-x

Thokchom, R., & Mandal, G. (2017). Production Preference and Importance of Passion Fruit (Passiflora Edulis): A Review. *Journal of Agricultural Engineering and Food Technology, 4*(1), 27–30.

Thu Dao, T. A., Webb, H. K., & Malherbe, F. (2020). Optimisation of pectin extraction from fruit peels by response surface method: Conventional versus microwave-assisted heating. *Food Hydrocolloids, 113*, Article 106475. https://doi.org/10.1016/j.foodhyd.2020.106475

Tiwari, R., & Rana, C. S. (2015). Plant secondary metabolites: A review. *International Journal of Engineering Research and General Science, 3*(5), 661–670.

Ulmer, T., & MacDougal, J. M. (2004). *Passiflora: Passionflowers of the world*. Timber Press, Inc.

U.S. Department of Agriculture. (2019). *FoodData Central*. Agricultural Research Service. http://fdc.nal.usda.gov. Accessed on 26/04/2020.

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics, 84*(2), 523–538. https://doi.org/10.1007/S11192-009-0146-3/figures/7

Vivancos, M., & Moreno, J. J. (2005). β-Sitosterol modulates antioxidant enzyme response in RAW 264.7 macrophages. *Free Radical Biology and Medicine, 39*(1), 91–97. https://doi.org/10.1016/j.freeradbiomed.2005.02.025

Wasicky, A., Hernandes, L. S., Vetore-Neto, A., Moreno, P. R. H., Bacchi, E. M., Kato, E. T. M., & Yoshida, M. (2015). Evaluation of gastroprotective activity of Passiflora alata. *Brazilian Journal of Pharmacognosy, 25*(4), 407–412. https://doi.org/10.1016/j.bjp.2015.07.011

Watson, R. R., Zibadi, S., Rafatpanah, H., Jabbari, F., Ghasemi, R., Ghafari, J., Afrasiabi, H., Foo, L. Y., & Faridhosseini, R. (2008). Oral administration of the purple passion fruit peel extract reduces wheeze and cough and improves shortness of breath in adults with asthma. *Nutrition Research, 28*(3), 166–171. https://doi.org/10.1016/j.nutres.2008.01.003

Winterhalter, P. (1990). Bound Terpenoids in the Juice of the Purple Passion Fruit (Passiflora Edulis Sims). *Journal of Agricultural and Food Chemistry, 38*(2), 452–455. https://doi.org/10.1021/jf00092a026

Wondracek, D. C., Faleiro, F. G., Sano, S. M., Vieira, R. F., & Agostini-Costa, T. da S. (2011). Composição de carotenoides em passifloras do Cerrado. *Revista Brasileira de Fruticultura, 33*(4), 1222–1228. https://doi.org/10.1590/S0100-29452011000400022

Yahia, E. M., Carrillo-López, A., & Bello-Perez, L. A. (2018). Carbohydrates. In E. M. Yahia (Ed.), *Postharvest Physiology and Biochemistry of Fruits and Vegetables* (pp. 175–205). Elsevier Inc.. https://doi.org/10.1016/B978-0-12-813278-4.00009-9

Yepes, A., Ochoa-Bautista, D., Murillo-Arango, W., Quintero-Saumeth, J., Bravo, K., & Osorio, E. (2021). Purple passion fruit seeds (Passiflora edulis f. edulis Sims) as a promising source of skin anti-aging agents: Enzymatic, antioxidant and multi-level computational studies. *Arabian Journal of Chemistry, 14*(1), Article 102905. https://doi.org/10.1016/j.arabjc.2020.11.011

Yockteng, R., d'Eeckenbrugge, G. C., & Souza-Chies, T. T. (2011). Passsiflora. In C. Kole (Ed.), *Wild Crop Relatives: Genomic and Breeding Resources* (pp. 97–107). Berlin Heidelberg: Springer. https://doi.org/10.1007/978-3-642-20447-0_7.

Yoshida, Y., & Niki, E. (2003). Antioxidant Effects of Phytosterol and Its Components. *Journal of Nutritional Science and Vitaminology, 49*(4), 277–280. https://doi.org/10.3177/jnsv.49.277

Zerbini, F. M., Otoni, W. C., & Vieira, M. L. C. (2008). Passionfruit. In C. Kole, & T. C. Hall (Eds.), *Compendium of Transgenic Crop Plants: Transgenic Tropical and Subtropical Fruits and Nuts* (pp. 213–233). Blackwell Publishing Ltd.

Zibadi, S., Farid, R., Moriguchi, S., Lu, Y., Foo, L. Y., Tehrani, P. M., Ulreich, J. B., & Watson, R. R. (2007). Oral administration of purple passion fruit peel extract attenuates blood pressure in female spontaneously hypertensive rats and humans. *Nutrition Research, 27*(7), 408–416. https://doi.org/10.1016/j.nutres.2007.05.004

Zucolotto, S. M., Fagundes, C., Reginatto, F. H., Ramos, F. A., Castellanos, L., Duque, C., & Schenkel, E. P. (2012). Analysis of C-glycosyl Flavonoids from South American Passiflora Species by HPLC-DAD and HPLC-MS. *Phytochemical Analysis, 23*(3), 232–239. https://doi.org/10.1002/pca.1348