Compositional differences in pulp and peel of brebas and figs (Ficus carica L.): implications for nutritional quality and functional value

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Abstract

This study investigated the nutritional profile and range of bioactive compound composition of pulp and peel from brebas and figs (*Ficus carica* L.) from several cultivars, with emphasis on compounds relevant to the functional value of plant foods for human nutrition. Carotenoids, tocols, amino acids, phenolic compounds, anthocyanins, and antioxidant capacity were determined using UPLC-PDA, UPLC-FL, and spectrophotometric assays. Seven carotenoids were identified, with β-carotene as the predominant compound and significantly higher levels in peel than in pulp. Among the cultivars, SANT variety showed the highest total carotenoid content in both fruit tissues. Among tocols, δ-tocotrienol and α-tocopherol were the dominant, and both occurred at higher levels in peel. Twenty free amino acids were found covering essential, conditionally essential, and non-essential groups, and among essentials, threonine and valine were the dominant ones in both brebas and figs. Phenolic composition varied markedly among varieties and fruit tissues. Breba pulp contained higher total polyphenol levels than fig pulp, whereas anthocyanins were predominantly in the peel, where the CDN variety reached the highest concentrations. Antioxidant capacity (ORAC, FRAP, and ABTS) was systematically higher in peel than in pulp and attained its maximum in the CDN cultivar. The results demonstrate substantial varietal and tissue-dependent differences in the distribution of nutritional and bioactive compounds in F. carica, indicating that both developmental stage and anatomical part influence the nutritional and functional value of figs as plant foods for human consumption.

1. INTRODUCTION

Brebas and figs are fruits of *Ficus carica*, a small tree of the *Moraceae* familly, originating from the Mediterranean basin and parts of western and southern Asia (Zohary et al., 2012). Although domesticated in antiquity, *F. carica* is today cultivated in many regions worldwide (Bandelj et al., 2023). Humans have consumed its fruits since antiquity, enjoying them fresh, dried, as jams, juices, and in other forms (Harzallah et al., 2016). These fruits are seasonal and can be harvested twice annually in some varieties, once in spring crop (brebas) and a later summer crop (figs) (Ramadan, 2023). Due to their short shelf life, a surplus of figs often arises in European countries, creating the need to mitigate environmental impacts and achieve zero waste (Teruel-Andreu et al., 2021; Wojdyło et al., 2016).

In the last decade, attention has increasingly focused on naturally occurring phytochemicals in foods that can function as antioxidants in the human body (Kotha et al., 2022). Within this group, carotenoids are recognized for their antioxidant effects and their antioxidant properties and their ability to protect cells against oxidative damage, while selected compounds such as β-carotene also function as vitamin A precursors, essential for normal vision, immune competence and skin integrity (Rao & Rao, 2007). Another important class is formed by tocols (tocopherols and tocotrienols), collectively referred to as vitamin E, are essential antioxidants that regulate free radical production in the body. While tocopherols have been extensively studied, tocotrienols remain relatively less explored but are thought to offer protective effects against cancer, diabetes, and cardiovascular and neurodegenerative diseases (Singh et al., 2013).

Amino acids are fundamental to metabolism, as they are required for protein synthesis and for the production of many small bioactive molecules. Some amino acids also display bioactive properties and may contribute to the management of metabolic diseases, infertility, as well as intestinal and neurological dysfunction (Wu, 2013). Moreover, numerous preclinical and clinical research reports indicate that diets providing high amounts of polyphenols are associated with a lower incidence of chronic diseases, including neurodegenerative and cardiovascular disorders, cancers, diabetes, inflammatory conditions and infections (Khan et al., 2021). It has also been proposed that inhibition digestive enzymes such as α-amylase and α-glucosidase, which are involved in carbohydrate breakdown, represents a useful strategy for controlling type 2 diabetes by limiting postprandial glucose uptake (Awosika & Aluko, 2019).

Recent investigations have described the general nutritional traits of several *Ficus carica* cultivars (San Antonio, Colar, Cuello Dama Negro, and Superfig), with detailed evaluation of fruit (pulp and peel) and leaves (Teruel-Andreu et al., 2025; Teruel-Andreu et al., 2024a; Teruel-Andreu et al., 2023a, b). These works reported data on sugars, organic acids, minerals, volatile compounds and overall antioxidant properties. However, information on other health-relevant phytochemicals, particularly carotenoids, tocopherols, amino acids, and polyphenolic compounds, is still fragmentary, and their antidiabetic activity has not yet been evaluated in relation to harvest type and fruit tissue. Addressing this gap is essential, as increasing awareness of their health-promoting properties could support their incorporation into novel food matrices. Indeed, previous work has already demonstrated the successful integration of *F. carica* extracts into fermented milk products, enhancing antioxidant capacity and functional value (Teruel-Andreu et al., 2024b; Teruel-Andreu et al., 2024c), reinforcing the potential for broader applications in food innovation and nutraceutical development.

This study provides a comprehensive characterization of bioactive compounds in brebas and figs (*Ficus carica* L.), focusing on the peel and pulp of commercially significant Spanish varieties. It identifies and quantifies a wide range of compounds, evaluates their antioxidant capacity, and assesses their ability to inhibit key enzymes linked to health-related functions. The research aims to differentiate anatomical parts and harvest types based on their profiles of health-promoting compounds. The main novelty of this work lies in the simultaneous, multi-class profiling of carotenoids, tocols, amino acid, and polyphenolics across fruit tissues and harvest types, combined with functional bioactivity assays, which has not been previously reported. Unlike previous studies that examined phenolic content in isolated tissues or compared brebas and figs, this work offers a holistic analysis of both fruiting phases and their distinct components. The findings not only reveal antioxidant capacity and potential therapeutic functions but also support innovative applications in food and nutraceutical development, contributing to sustainable valorization strategies for surplus fig production.

2. MATERIAL AND METHODS

2.1. Ficus carica as a *plant material*

The plant material analysed in this work consisted of brebas and figs of four *Ficus carica* cultivars, and the orchard conditions, sampling procedure and fruit maturity stage have been described in detail previously by Teruel-Andreu et al. (2023b).

2.2. Extraction of carotenoids and tocols

Carotenoids and tocols were extracted following a previously described procedure by Tkacz et al. (2024). Briefly, Three-hundred fifty milligrams of lyophilized powdered sample were weighed into a tube and 5 mL of ethanol containing 0.05% butylated hydroxytoluene (BHT) was added. The suspension was kept at 4°C overnight and subsequently mixed with a 60% KOH solution, after which the samples were saponified at 80°C for 1 hour in a shaking water bath (GFL 1083, GFL Gesellschaft für Labortechnik mbH, Burgwedel, Germany). After saponification, 10 mL of 1% NaCl were added, and the mixture was cooled in an ice bath, followed by extraction with 10 mL of hexane/ethyl acetate (9:1, *v/v*) containing 0.05% BHT, shaking at 500 rpm for 30 min (Orbital shaker ELMI DOS-10L, ELMI, Riga, Latvia). Next, 1 mL of saturated NaCl was added, and the upper organic phase was collected and evaporated to dryness using an automated concentration / evaporation system (Horizon Technology, Inc. – XcelVap, Biotage, Sweden). The dried residue was redissolved in 1 mL of gradient grade methanol containing 5 mg/100g BHT and filtered by using 0.20 µm polytetrafluoroethylene (PTFE) filters prior to UPLC analysis.

2.3. Identification and quantification of carotenoids by UPLC-PDA

The determination of carotenoids was carried out according to the approach described by Tkacz et al. (2024). Analyses was performed using an Acquity UPLC System equipped (Waters Corp., Milford, MA, USA) with a binary solvent manager, a photodiode array (PDA) detector and coupled to a G2 Q/TOF mass spectrometer fitted with an electrospray ionization (ESI) source operating in acting in positive ion mode. Chromatographic separation of carotenoids was achieved on an ACQUITY UPLC BEH Shield reversed phase (RP) C18 column (1.7 µm, 2.1 mm × 100 mm) protected by a C18 guard column, with the column temperature maintained at 32°C. Results were expressed as mg / 100 g of dry matter (dm) for each individual carotenoid and for the total carotenoid content.

2.4. Identification and quantification of tocopherols and tocotrienols by UPLC-FL

Tocols (tocopherols and tocotrienols) were analysed using an UPLC system with fluorescence detection, following the procedure reported by Tkacz et al. (2024).Measurements were carried out on an Acquity UPLC system equipped with a binary solvent manager and a fluorescence detector. Separation was performed on an BEH RP C18 column (1.7 µm, 2.1 mm × 100 mm, Waters Corp., Milford, MA, USA) The content of tocols were expressed as mg / 100 g of dm.

2.5. *Estimation of free amino acids by* UPLC-PDA

Free amono acids were quantified according to the protocol of Tkacz et al. (2022), adapted for the present samples. Sample (3 µL) was injected onto an AccQ Tag Ultra BEH column (2.1 × 100 mm, 1.7 µm, Waters Corp).The content of amino acids were expressed as mg / 100 g of dry matter (dm).

2.6. Extraction and analysis of phenolic compounds by UPLC-PDA

Extraction and analysis of polyphenol (flavan-3-ols, phenolic acid, flavonols, anthocyanins) and polymeric procyanidins were performed the basis of the method proposed by Wojdyło et al. (2020) with slight modifications to fit the present material. All measurements were conducted in n = 3, and the results was reported as mg / 100 g of dm.

2.7. Analysis of in vitro biological Activity

The solvent system used for antioxidant capacity assays was prepared according to the procedure reported by Tkacz et al. (2019), with minor adjustments for the present samples. Antioxidant capacity was tested as three complementary methods: ORAC (oxygen radical absorbance capacity) previously described by Ou et al. (2002), FRAP (ferric reducing ability of plasma) described by Benzie and Strain (1996)and the ABTS radical cation decolorization assays described by, Re et al. (1999). For all three methods, results were calculated and expressed as mmoL Trolox per 100 g of dm.

The inhibitory of α: -amylase and -glucosidase activities were determined using procedures reported by Tkacz et al. (2019). In brief, inhibition of α-amylase was assessed spectrophotometrically at 600 nm, whereas α-glucosidase inhibition was monitored at an absorbance of 405 nm. In both assays, positive control (acarbose) was used, and enzyme inhibition was expressed as % inhibition of the corresponding enzyme activity under the assay conditions.

2.8. Statistical Analysis

Results of n = 3 measurements are reported as mean for each cultivar and fruit part. XLSTAT 2016: Data Analysis and Statistical Solution for Microsoft Excel (Addinsoft; Paris, France) used for statistical treatment of the data was performed using -one-way and two-way analysis of variance (ANOVA), followed by Tukey's multiple range test, to compare mean values. All calculations, additionally Pearson’s correlation coefficients and principal component analysis (PCA). Differences were considered statistically significant when $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1. Carotenoids: identification and quantification

Carotenoids are organic pigments synthesized within the plastids of plants, as well as in various other photosynthetic organisms such as algae, bacteria and fungi (Zhu et al., 2010). Seven carotenoids were detected (Table 1) in both the pulp and peel of brebas, and figs. Lutein and β-carotene were identified as the predominant carotenoids across all fruit sections analyzed, with β-carotene being particularly abundant. In breba peel, β-carotene concentrations ranged from 532.99 to 1076.12 mg/100 g dm in CALB and SANT, respectively. Conversely, β-carotene content in fig pulp varied from 49.02 to 87.79 mg/100 g dm for CUMH and SANT, respectively, demonstrating consistently higher levels in the peel compared to the pulp, with breba peel exhibiting the highest values. A comparative analysis of carotenoid concentrations between pulp and peel revealed no consistent trend among the different fruit types. In breba fruits, β-

carotene levels were 6.14 times higher in the peel than in the pulp. However, in fig fruits, the β-carotene concentration in the peel was 2.72 times greater than in the pulp.

Table 1
Content of carotenoids (mg/ 100 g dm) in pulp and peel of breba and figs of studied varieties.

	Violaxanthin	Lutein	Zeaxhatin	β-Crypoxanthin	Lycopene	α-Cartotene	β-Carotene
Breba pulp							
SANT	0.25 a	18.44 a	1.65 a	3.68 a	1.63 a	3.75 a	189.46 a
CALB	0.11 b	4.89 b	0.53 b	1.01 b	0.72 b	2.66 b	126.94 b
CUMH	0.15 b	4.30 b	0.20 c	0.80 b	0.69 b	2.60 bc	111.33 bc
CDN	0.14 b	4.93 b	0.46 b	0.95 b	0.65 b	1.94 cd	85.73 cd
SF	0.12 b	2.80 b	0.59 b	0.72 b	0.35 c	1.41 d	75.27 d
Breba peel							
SANT	1.10 a	141.38 b	16.34 a	24.13 b	5.34 a	32.90 a	1,076.12 a
CALB	0.64 c	92.19 c	10.71 b	15.51 c	1.98 c	8.90 b	532.99 b
CUMH	0.87 b	139.34 b	13.22 ab	26.03 b	3.09 b	9.34 b	663.40 b
CDN	0.77 bc	185.97 a	13.38 ab	33.85 a	2.71 bc	8.29 b	728.05 b
SF	0.77 bc	138.64 b	12.57 b	26.19 b	3.49 b	6.53 b	612.02 b
Fig pulp							
SANT	0.19 a	6.83 a	0.56 a	1.41 a	1.49 a	1.67 ab	81.79 a
CALB	0.16 ab	3.01 c	0.28 b	0.63 c	0.55 b	1.36 b	60.21 bc
CUMH	0.07 c	1.78 d	0.12 c	0.32 d	0.50 b	0.84 c	49.02 c
CDN	0.14 b	4.94 b	0.32 b	0.93 b	0.55 b	1.80 a	79.94 a
SF	0.10 c	3.16 c	0.47 a	0.66 c	0.61 b	1.46 ab	71.45 ab
Fig peel							
SANT	0.53 a	61.89 a	8.06 a	12.35 a	3.92 a	5.48 a	211.54 a
CALB	0.28 bc	56.91 a	5.67 b	10.50 a	1.21 d	2.61 b	208.74 ab
CUMH	0.35 b	29.87 b	4.02 c	5.54 b	2.21 b	3.07 b	159.16 bc
CDN	0.25 c	65.29 a	6.89 ab	10.16 a	1.35 cd	2.50 b	203.02 ab
SF	0.32 bc	27.94 b	3.64 c	4.94 b	1.83 bc	2.88 b	148.97 c
Breba (pulp x peel)							
Pulp	0.15 b	7.07 b	0.69 b	1.43 b	0.81 b	2.47 b	117.75 b
Peel	0.83 a	139.50 a	13.24 a	25.14 a	3.32 a	13.19 a	722.51 a
Fig (pulp x peel)							
Pulp	0.13 b	3.95 b	0.35 b	0.79 b	0.74 b	1.42 b	68.48 b
Peel	0.34 a	48.38 a	5.66 a	8.70 a	2.10 a	3.31 a	186.28 a

Value in the same columns followed by different letters is significantly different at $p \leq 0.05$ according to Tukey's test. Legend_ SANT: San Antonio; CALB: Colar Albatera; CUMH: Colar UMH; CDN: Cuello Dama Negra; SF: Superfig.

For breba pulp the values of total content in carotenoids (Fig. 1A) ranged from 81.26 to 218.86 mg/ 100 g dm, with the highest values recorded for SANT variety. For breba peel the highest value of total carotenoids was detected for SANT variety (1297.31 mg/100 g dm) and the lowest value was detected for CALB (662.90 mg/100 g dm). The content of carotenoids in figs pulp ranged from 52.65 to 93.93 mg/ 100 g dm and decreased in the following variety order: SANT > CDN > SF > CALB> CUMH. The contents of carotenoids in figs peel ranged from 190.51 to 303.78 mg/100 g dm, being SANT variety, which showed the highest value following for CDN (289.45 mg/100 g dm) and CALB (285.92 mg/100 g dm).

Our results are consistent with those reported in the literature, indicating that brebas and figs are moderate sources of carotenoids. In contrast to the findings by Yemiş et al. (2012) on two cultivars of *Ficus carica* ('Sarizeybek' and 'Sarilop'), which identified lutein as the primary carotenoid followed by zeaxanthin, β-cryptoxanthin, and β-carotene, the main carotenoid found in our study (both in pulp and peel) was β-carotene. Notably, the

β-carotene content in the peel was approximately five times higher than in the pulp.

According to Lara-Abia et al. (2021), papaya fruits are also considered moderate sources of carotenoids, with concentrations of 205.5 µg/g dm in the pulp and 213.8 µg/g dm in the peel. β-carotene, identified as the dominant carotenoid in our fig samples, is a precursor to vitamin A. Within the human body, β-carotene is metabolized by the enzyme β-carotene dioxygenase in the mucosal layer of the small intestine. This enzymatic process converts

β-carotene into two retinyl molecules, which are then reduced to form vitamin A (During et al., 2001). Vitamin A is essential for normal retinal function and various cellular processes. Deficiency in vitamin A can lead to a spectrum of disorders, including night blindness, metaplasia, and keratinization of epithelial linings, resulting in conditions such as conjunctival and corneal xerosis and mucosal defects. Furthermore, vitamin A deficiency during embryonic and fetal development may cause lasting epigenetic changes, affecting lung function, immune response, and other organ systems, potentially leading to long-term health complications (West, 2013).

In summary, we can conclude that the concentration of carotenoids in fig fruits varies by variety, with the peel serving as a significantly richer source of carotenoids compared to the pulp. The predominance of β-carotene in our samples highlights the nutritional relevance of fig peel, particularly in relation to vitamin A biosynthesis and its associated health benefits.

3.2. Tocols: identification and quantification

Tocols, which include tocopherols and tocotrienols are lipid-associated compounds found in vegetable-based foods such as oils, nuts and animal-based foods like dairy (Delgado et al., 2020). Tocols (α-, β-, γ-, and δ-) are characterized by the number and position of methyl groups (– CH_3) attached at the 5- and 7-positions on the chromanol ring (Saini & Keum, 2016). Table 2 shows the content of tocols in breba (pulp and peel) and fig (pulp and peel) samples.

Table 2
Content of tocotrienols and tocopherols (mg/ 100 g dm) in pulp and peel of breba and figs of studied varieties.

	δ-TT	β-TT	γ-TT	α-TT	δ-TF	β-TF	γ-TF	α-TT
Breba pulp								
SANT	4.62 a	0.20 a	0.01 b	0.59 a	0.09 a	0.07 a	0.34 a	1.37 a
CALB	4.76 a	0.21 a	0.00 c	0.60 a	0.10 a	0.04 bc	0.09 b	0.72 b
CUMH	4.78 a	0.21 a	0.02 a	0.57 a	0.09 a	0.05 b	0.14 b	0.91 b
CDN	5.18 a	0.21 a	0.02 a	0.61 a	0.11 a	0.03 c	0.11 b	0.74 b
SF	5.03 a	0.18 a	0.01 b	0.59 a	0.09 a	0.05 b	0.10 b	0.67 b
Breba peel								
SANT	5.22 a	0.20 ab	0.01 c	0.71 a	0.10 a	0.87 a	1.67 a	7.27 a
CALB	5.60 a	0.20 ab	0.01 c	0.76 a	0.11 a	0.33 b	0.46 c	2.45 c
CUMH	4.97 a	0.18 b	0.02 b	0.63 a	0.09 a	0.33 b	1.24 b	4.72 b
CDN	5.24 a	0.23 a	0.03 a	0.77 a	0.11 a	0.15 c	0.60 c	3.11 c
SF	4.94 a	0.17 b	0.01 c	0.73 a	0.09 a	0.26 bc	1.60 a	5.17 b
Fig pulp								
SANT	4.85 a	0.23 a	0.01 d	0.69 a	0.11 a	0.04 a	0.14 b	0.97 a
CALB	4.99 a	0.24 a	0.01 cd	0.69 a	0.11 a	0.02 b	0.08 cd	0.70 b
CUMH	4.96 a	0.23 a	0.02 b	0.67 a	0.11 a	0.03 a	0.06 d	0.83 ab
CDN	4.60 a	0.22 a	0.02 c	0.66 a	0.10 a	0.02 b	0.22 a	0.70 b
SF	4.80 a	0.21 a	0.03 a	0.62 a	0.10 a	0.02 b	0.12 bc	0.74 b
Fig peel								
SANT	6.30 a	0.25 a	0.02 b	0.71 a	0.11 a	0.28 a	1.22 a	3.51 a
CALB	5.96 a	0.25 a	0.02 ab	0.69 a	0.11 a	0.09 c	0.36 c	1.52 c
CUMH	5.92 a	0.25 a	0.02 a	0.72 a	0.12 a	0.20 b	0.58 b	3.06 a
CDN	5.61 ab	0.24 a	0.02 b	0.66 a	0.11 a	0.06 c	0.43 bc	1.44 c
SF	4.39 b	0.19 a	0.01 c	0.60 a	0.08 b	0.17 b	0.48 bc	2.27 b
Breba (pulp x peel)								
Pulp	4.87 a	0.20 a	0.01 b	0.59 b	0.10 a	0.05 b	0.16 b	0.88 b
Peel	5.19 a	0.20 a	0.02 a	0.72 a	0.10 a	0.39 a	1.11 a	4.55 a
Fig (pulp x peel)								
Pulp	4.84 b	0.23 a	0.02 a	0.67 a	0.11 a	0.03 b	0.12 b	0.79 b
Peel	5.64 a	0.24 a	0.02 a	0.68 a	0.11 a	0.16 a	0.61 a	2.36 a

Value in the same columns followed by different letters is significantly different at $p \leq 0.05$ according to Tukey's test. Legend_ TT: Tocotrienols; TF: Tocopherols; SANT: San Antonio; CALB: Colar Albatera; CUMH: Colar UMH; CDN: Cuello Dama Negra; SF: Superfig.

Between varieties no significant differences were found for δ-TT across all fruit parts analysed. In contrast, the SANT variety consistently showed the highest levels of α-TF in all fruit parts studied. Furthermore, a comparison of tocols concentrations in the pulp and peel revealed a consistent trend, with higher levels consistently found in the peel than in the pulp. Examining the relationship between breba fruits (pulp and peel), the concentrations of β-TF, γ-TF, and α-TF were 7.8, 7.1, and 5.2 times higher, respectively, in the peel than in the pulp. In fig fruits, the pulp-to-peel comparison indicated similar trends, with β-TF, and α-TF concentrations being 6.1, 5.0, and 3.0 times higher, respectively, in the peel compared to the pulp. In addition, Fig. 1B showed significant ($p < 0.05$) differences among studied varieties in breba pulp, being SANT variety, which showed the highest value for the ∑TF (1.87 mg/100 g dm). For fig pulp also was found significant differences in the case of ∑TF, the results ranged from 0.90 to 1.25 (mg/100 g dm), for CALB and SANT varieties, respectively. For fig peel SANT variety highlight attend the content in ∑TT (7.30 mg/100 g) and ∑TF (5.12 mg/100 g). Breba peel (Fig. 1A) exhibited the highest ∑TT + TF content among all fruit parts analyzed, with values ranging from 9.91 to 16.06 mg/100 g dm, decreasing in the following order of varieties: SANT > SF > CUMH > CDN > CALB. In general, tocopherols are more prevalent than tocotrienols, which are present only in the fruits and seeds of certain plant species (Mène-Saffrané & DellaPenna, 2010). α-tocopherol is particularly important because it exhibits the highest vitamin E activity among all tocols (DellaPenna & Pogson, 2006). According to EFSA (2015), the average α-tocopherol absorption from a usual diet is about 75%. The Panel defines adequate intakes (AI) for α-tocopherol, based on observed intakes in healthy populations, as 13 mg/day for men, 11 mg/day for women, 9 mg/day for children aged 3 to < 10 years, and 6 mg/day

for children aged < 3 years. For children aged 10 to < 18 years, the AI is set at 13 mg/day for boys and 11 mg/day for girls. These recommendations are made considering that no vitamin E deficiencies have been reported in Europe, and the Panel considers vitamin E as α-tocopherol only.

In recent years, tocols are linked to numerous health benefits and are vital in preventing certain types of cancer and cardiovascular diseases (Shahidi & De Camargo, 2016). For example, Abraham et al. (2019) investigated anticancer effects of vitamin E and confirming evidence on anticancer properties of tocotrienol in preclinical models. Other interesting article (Ramanathan et al., 2018) associating tocotrienol with cardioprotective effect due its superior antioxidant and anti-inflammatory activity.

Moreover, one of the most interesting applications of tocols as to protect the oxidative deterioration of fat-rich food. Delgado et al. (2020) highlights the significance of tocopherols in preserving the sensory properties of foods and their effectiveness as antioxidants and confirm that their physicochemical properties, low volatility, and excellent solubility in fats and oils provide the necessary resilience to withstand high-temperature processes.

In summary, considering our results for tocopherol and the recommended intake of α-TF by EFSA, the peel of brebas and figs could be considered a moderate source of tocopherol.

3.3. Free amino acid: identification and quantification

Twenty free amino acids (AA) were identified as shown in Table 3, of which eight are essential, five are conditionally essential, and seven are non-essential.

Table 3
Content of free amino acids (mg/100 g dm) in pulp and peel of breba and figs of studied varieties.

	Essential Amino Acids								Conditionally Essential Amino Acids					Non-Essential Amino Acids				
	Thr	Lys	Met	Val	Ile	Leu	Phe	Trp	Gln	Gly	Glu	Pro	Tyr	Sep	Asn	Ser	Asp	Al
	Breba pulp																	
SANT	21.7 b	0.9 b	6.6 b	14.9 b	9.5 b	8.8 cd	5.5 c	1.2 c	170.8 ab	8.5 b	17.0 b	176.5 a	4.1 d	563.4 a	701.9 a	67.1 b	57.7 a	22 a
CALB	6.3 c	0.4 c	3.6 c	5.4 d	3.5 c	6.5 d	5.6 c	1.2 c	40.9 c	4.7 c	9.2 c	148.9 a	3.3 d	133.7 d	145.2 c	20.7 d	29.6 b	52 b
CUMH	28.1 a	1.1 ab	9.7 a	20.3 a	13.4 a	12.4 b	8.7 b	2.4 b	184.0 a	9.7 ab	24.5 a	106.3 b	8.9 b	464.7 b	598.8 ab	84.8 a	60.7 a	20 a
CDN	9.5 c	1.1 ab	7.4 b	9.6 c	6.2 c	11.5 bc	9.7 b	1.9 b	55.2 c	9.1 b	7.1 c	167.1 a	6.7 c	169.4 d	163.8 c	37.4 c	27.6 b	75 b
SF	26.5 ab	1.2 a	10.2 a	20.4 a	13.5 a	17.5 a	14.3 a	3.8 a	142.9 b	11.9 a	8.3 c	85.3 b	12.8 a	293.9 c	495.9 b	69.4 ab	61.8 a	20 a
	Breba peel																	
SANT	14.5 a	0.7 b	6.1 c	11.9 ab	9.0 bc	9.4 b	8.5 ab	2.5 b	99.2 a	8.2 a	9.6 a	57.4 b	4.9 a	322.1 b	436.9 a	45.3 a	22.1 bc	16 a
CALB	6.3 b	0.7 b	11.8 a	6.4 c	5.7 d	9.8 b	6.5 b	1.6 b	36.5 c	7.7 a	2.8 c	74.3 a	4.1 ab	40.2 d	48.9 c	18.2 c	10.7 d	45 c
CUMH	12.0 a	0.5 c	8.9 b	10.5 b	9.8 b	11.7 ab	9.2 a	4.4 a	59.7 b	6.7 a	5.8 b	26.8 c	4.4 a	457.4 a	502.4 a	27.8 b	28.4 a	71 b
CDN	7.0 b	0.9 a	9.0 b	7.5 c	6.8 cd	12.0 ab	8.4 ab	2.1 b	45.5 bc	2.8 b	10.4 a	49.2 b	4.6 a	124.3 c	148.5 b	22.9 bc	17.4 c	55 bc
SF	13.7 a	0.1 d	7.5 bc	14.2 a	13.5 a	14.3 a	9.4 a	5.3 a	62.5 b	6.6 a	12.0 a	31.4 c	2.9 b	366.8 b	457.8 a	26.9 b	25.3 ab	80 b
	Fig pulp																	
SANT	23.1 b	0.8 bc	4.9 b	13.6 bc	9.6 cd	8.1 cd	6.3 c	1.4 c	90.2 ab	7.0 b	10.9 a	159.2 cd	4.3 c	330.6 a	410.7 a	54.0 a	59.8 a	19 a
CALB	42.1 a	1.5 a	8.6 a	37.0 a	27.4 a	13.5 ab	14.0 a	7.7 a	101.5 a	13.1 a	7.6 b	344.9 a	6.8 b	252.0 b	283.1 b	29.6 b	34.4 b	11 b
CUMH	19.4 bc	1.0 b	8.4 a	13.4 bc	10.4 bc	10.8 bc	9.0 b	2.5 b	78.6 b	8.0 b	8.7 ab	207.8 bc	8.7 a	240.1 b	235.8 bc	40.0 b	33.6 b	16 a
CDN	13.1 c	0.7 c	5.0 b	10.7 c	5.7 d	5.4 d	5.3 c	1.1 c	45.3 c	5.6 b	10.0 ab	116.9 d	2.9 c	213.4 bc	195.9 c	31.7 b	37.2 b	79 b
SF	25.6 b	1.6 a	7.3 a	18.2 b	14.1 b	14.0 a	10.8 b	2.5 b	89.1 ab	13.2 a	9.1 ab	255.6 b	9.5 a	164.8 c	228.6 bc	37.3 b	32.0 b	19 a
	Fig peel																	
SANT	16.7 a	0.6 b	4.5 c	11.0 b	8.8 ab	8.5 b	8.4 ab	1.7 b	62.0 a	6.4 c	7.2 c	124.7 ab	4.1 b	145.0 b	147.0 b	28.1 b	19.3 bc	87 bc
CALB	11.2 b	1.0 a	4.9 c	11.0 b	10.1 a	5.9 b	5.4 c	1.7 b	33.2 b	1.3 d	6.5 c	150.3 a	0.1 c	60.1 c	82.7 c	17.6 c	9.6 d	35 d
CUMH	17.4 a	0.9 a	10.4 a	15.8 a	10.8 a	13.5 a	9.5 a	3.1 a	66.8 a	10.2 a	14.4 a	102.2 b	7.9 a	197.6 a	191.8 a	26.7 b	24.5 a	11 a
CDN	11.8 b	0.4 c	5.2 c	10.6 b	7.4 b	7.6 b	6.6 bc	1.0 c	43.9 b	6.9 bc	7.5 bc	117.8 ab	3.8 b	160.1 ab	156.7 ab	26.0 b	14.4 cd	70 c
SF	17.0 a	0.6 b	8.0 b	15.2 a	9.7 ab	12.1 a	7.2 bc	2.1 b	45.0 b	8.7 ab	10.0 b	126.1 ab	6.7 a	137.3 b	118.6 bc	40.1 a	20.8 ab	10 ab
	Breba (pulp x peel)																	
Pulp	18.4 a	1.0 a	7.5 a	14.1 a	9.2 a	11.4 a	8.8 a	2.1 b	118.8 a	8.8 a	13.2 a	136.8 a	7.1 a	325.0 a	421.1 a	55.9 a	47.5 a	15 a
Peel	10.7 b	0.6 b	8.7 a	10.1 b	9.0 a	11.4 a	8.4 a	3.2 a	60.7 b	6.4 b	8.1 b	47.8 b	4.2 b	262.1 a	318.9 a	28.2 b	20.8 b	82 b

Value in the same columns followed by different letters is significantly different at $p \leq 0.05$ according to Tukey's test. Legend_ Thr: Threonine; Lys: Lysine; Me Valine; Ile: Isoleucine; Leu: Leucine; Phe: Phenylalanine; Trp: Tryptophan; Arg: Arginine; Gln: Glutamine; Gly : Glycine; Glu: Glutamic acid; Pro: Proline; Tyr: Tyro Phospho-L-serine; Asn: Asparagine; Ser: Serine; Asp: Aspartic acid; Ala :Alanine; GABA: γ-Aminobutyric acid; Hcy: Homocysteine; SANT: San Antonio; CALB: CUMH: Colar UMH; CDN: Cuello Dama Negra; SF: Superfig.

	Essential Amino Acids								Conditionally Essential Amino Acids					Non-Essential Amino Acids				
	Thr	**Lys**	**Met**	**Val**	**Ile**	**Leu**	**Phe**	**Trp**	**Gln**	**Gly**	**Glu**	**Pro**	**Tyr**	**Sep**	**Asn**	**Ser**	**Asp**	**Al**
	Fig (pulp x peel)																	
Pulp	24.7 a	1.1 a	6.9 a	18.6 a	13.4 a	10.4 a	9.1 a	3.0 a	80.9 a	9.4 a	9.3 a	216.9 a	6.5 a	240.2 a	270.8 a	38.5 a	39.4 a	14 a
Peel	14.8 b	0.7 b	6.6 a	12.7 b	9.3 a	9.5 a	7.4 a	1.9 a	50.2 b	6.7 b	9.1 a	124.2 b	4.5 a	140.0 b	139.4 b	27.7 b	17.7 b	82 b

Value in the same columns followed by different letters is significantly different at $p \leq 0.05$ according to Tukey's test. Legend_ Thr: Threonine; Lys: Lysine; Me Valine; Ile: Isoleucine; Leu: Leucine; Phe: Phenylalanine; Trp: Tryptophan; Arg: Arginine; Gln: Glutamine; Gly : Glycine; Glu: Glutamic acid; Pro: Proline; Tyr: Tyro Phospho-L-serine; Asn: Asparagine; Ser: Serine; Asp: Aspartic acid; Ala :Alanine; GABA: γ-Aminobutyric acid; Hcy: Homocysteine; SANT: San Antonio; CALB: CUMH: Colar UMH; CDN: Cuello Dama Negra; SF: Superfig.

Table 4
Antioxidant activity (mmol Trolox/100 g dm) and antidiabetic activity (% inhibition) in pulp and peel of breba and figs of studied varieties.

	Antioxidant capacity			**Antidiabetic activity**	
	ABTS	**FRAP**	**ORAC**	**α-amylase**	**α- glucosidase**
Breba Pulp					
SANT	0.43 c	0.38 b	4.20 b	47.57 a	10.89 a
CALB	0.62 bc	0.54 b	4.09 b	47.34 a	15.54 a
CUMH	0.93 a	0.88 a	6.02 a	45.15 a	15.29 a
CDN	0.74 ab	0.51 b	6.06 a	44.35 a	12.47 a
SF	0.70 ab	0.66 ab	5.75 a	48.63 a	7.30 a
Breba Peel					
SANT	2.48 c	2.02 e	14.45 b	43.29 a	17.33 a
CALB	5.59 b	4.53 c	14.20 b	45.42 a	26.15 a
CUMH	5.10 b	4.75 b	17.91 b	53.42 a	10.12 a
CDN	18.87 a	15.33 a	60.35 a	58.46 a	8.23 a
SF	4.14 b	3.61 d	16.63 b	56.86 a	12.87 a
Fig pulp					
SANT	0.51 ab	0.47 ab	2.03 c	67.71 a	26.18 a
CALB	0.61 a	0.61 a	4.58 b	65.19 a	15.96 a
CUMH	0.48 ab	0.45 ab	3.98 b	66.80 a	12.79 a
CDN	0.48 ab	0.50 ab	5.75 a	49.82 a	16.37 a
SF	0.36 b	0.31 b	1.47 c	49.51 a	11.14 a
Fig Peel					
SANT	2.69 b	2.08 b	15.91 a	48.26 a	6.14 a
CALB	2.18 c	1.59 c	7.63 b	53.71 a	-1.07 a
CUMH	2.73 b	2.05 b	5.84 b	54.82 a	-1.65 a
CDN	11.79 a	8.25 a	18.03 a	50.88 a	3.89 a
SF	2.05 c	1.46 c	2.32 c	54.52 a	4.65 a
Breba (pulp x peel)					
Pulp	0.68 b	0.59 b	5.22 b	46.61 a	12.30 a
Peel	7.24 a	6.05 a	24.71 a	51.49 a	14.94 a
Fig (pulp x peel)					
Pulp	0.49 b	0.47 b	3.56 b	59.81 a	16.49 a
Peel	4.29 a	3.09 a	9.94 a	52.44 a	2.39 b

Value in the same columns followed by different letters is significantly different at $p \leq 0.05$ according to Tukey's test. Legend_ SANT: San Antonio; CALB: Colar Albatera; CUMH: Colar UMH; CDN: Cuello Dama Negra; SF: Superfig.

Two of the most abundant essential amino acids (eAA) in breba pulp were threonine (Thr) and valine (Val), with the CUMH and SF varieties showing the highest values (28.1 and 20.3 mg/100 g dm, respectively). Additionally, two of the most abundant conditionally essential amino acids in breba pulp were glutamine (Gln) and proline (Pro), with concentrations ranging from 40.9 to 184.0 mg/100 g dm and 85.3 to 176.5 mg/100 g dm, respectively. Asparagine (Asn), a non-essential AA, was the most abundant AA detected in breba pulp, particularly in the SANT variety, with a concentration of 701.9 mg/100 g dm. eAA in breba peel were detected in the following decreasing order: Thr > Val > Ile > Leu > Phe > Met > Trp > Lys. For conditionally essential amino acids, Gln was the most abundant, with the SANT variety displaying the highest concentration at 99.2 mg/100 g dm. The highest concentrations of non-essential AA in breba peel were observed for Asn, followed by Sep. The CUMH variety exhibited the highest levels of both AA, with values of 502.4 mg/100 g dm (Asn) and 457.4 mg/100 g dm (Sep), respectively. In figs pulp Thr and Val were two of the most abundant eAA, with the CALB variety showing the highest values (42.1 and 37.0 mg/100 g dm, respectively). Proline (Pro) was the main conditionally eAA in fig pulp, with concentrations ranging from 116.9 to 344.9 mg/100 g dm. Additionally, Asn and Sep highlighted between non-essential AA in figs pulp, especially for SANT variety (410.7 and 330.6 mg/100 g dm, respectively). Regarding figs peel, Thr was the main eAA in figs peel and ranged from 11.2 to 17.4 mg/100 g dm. Pro was the main conditionally eAA, and the CALB variety presented the highest amount (150.3 mg/100 g dm). Non-essential AA were detected in the following decreasing order: Sep > Asn > Ala > GABA > Ser > Asp >

Hcy. Two of the most abundant non-eAA in figs peel were Sep and Asn. The CUMH variety exhibited the highest concentrations of these AA, at 197.6 mg/100 g dm and 191.8 mg/100 g dm, respectively.

Regarding the differences between the peel and pulp for the primary AA detected in breba, the concentrations of Gln, Pro, Sep, Asn, and Ala in the pulp were 2-fold, 2.9-fold, 1.2-fold, 1.3-fold, and 1.8-fold higher than in the peel, respectively. When comparing the pulp and peel of figs, significant differences were observed across all detected amino acids except for Met, Ile, Leu, Phe, Trp, Glu, and Tyr. For the remaining AA, the detected content was higher in the pulp than in the peel, except for Hcy, which was 8.7 times higher in the peel than in the pulp.

The AA groups (Fig. 1A) detected in the samples, ranked in ascending order of concentration, followed the trend: essential > conditionally essential > non-essential, which was consistently observed across all analyzed samples. In the pulp, these groups comprised 6%, 23%, and 71% of the total amino acid content, respectively, while in the peel, a similar distribution was observed, accounting for 7%, 19%, and 74%, respectively. Among the varieties analyzed, BSA exhibited the highest non-essential amino acids content in the pulp, while FCA had the highest total of essential and conditionally eAA in the pulp. Overall, the pulp displayed substantially higher AA levels than the peel, with values ranging from 1.17 to 2.81 times higher in the pulp compared to the peel for FCDN and FCA, respectively (Fig. 1C).

Regarding literature data, no previous results have been found on the presence of AA in extracts from the peel and pulp of *F. carica* fruits. Other studies (Prakash et al., 2022) found that the peel of different parts of the *Garcinia xanthochymus* fruit was rich in histidine and tyrosine, while the pulp was rich in leucine and lysine. According to Li et al. (2022), aspartic acid and glutamic acid had the highest content in different parts (seed, pulp, flesh, and peel) of spaghetti squash. For comparison, Grygorieva et al. (2021) determined the amino acids composition in pulp and peel of quince (*Cydonia oblonga* Miller) fruits, finding concentrations ranging from approximately 316 to 1357 mg/kg for quince pulp and from 512 to 1820 mg/kg for quince peel. Thus, the results obtained in our study are higher than those for the peel and pulp of quince. Other authors Abdul-Mumeen et al. (2024), analysed the AA profile of *Vitellaria paradoxa* fruit pulp. The study showed that shea nut pulp is a good source of eAA, with arginine being the most concentrated (41.02 g/100 g) among the eAA in the pulp. In addition to protein intake recommendations, the WHO (2007) also provides guidelines for the estimated requirements of essential amino acids. It is recommended that adults consume 184 mg of these indispensable amino acids per kilogram of body weight daily. Insufficient intake of amino acids can be associated with depression, anxiety, insomnia, fatigue, weakness, and growth stunting in the young. In addition, eAA play a key role in stimulating muscle protein anabolism in healthy elderly adults (Volpi et al., 2003).

3.4. Phenolic compounds: identification and quantification

The results from UPLC-PDA analysis of the methanolic extracts of breba and figs present in Table 5. Phenolic profiles varied significantly across varieties, with notable differences in the major phenolic components.

Table 5
Content of Polyphenols (mg/100 g dm) in pulp and peel of breba and figs of studied varieties.

	Phenolic acids								Flavonols				Anthocyanins		
	NEO	CHL	CA	FA	DHCA-Hex	Syr-Hex	GA-diPent	SA	Ap-C-Hex-Pen	Q-Rut	Q-Glc	Q-MalGlc	Cy-3,5-diGlc	Pg-Rut	Cy-Rut
Breba pulp															
SANT	0.77 b	0.34 b	0.00 b	0.00 a	nd	nd	nd	nd	nd	nd	nd	nd	8.91 b	nd	nd
CALB	4.32 ab	0.97 ab	0.36 ab	0.57 a	nd	nd	nd	nd	nd	nd	nd	nd	45.33 ab	nd	nd
CUMH	3.36 ab	0.74 ab	0.06 ab	0.43 a	nd	nd	nd	nd	nd	nd	nd	nd	46.07 ab	nd	nd
CDN	6.21 a	1.54 a	0.51 a	0.43 a	nd	nd	nd	nd	nd	nd	nd	nd	27.12 ab	nd	nd
SF	4.56 a	1.05 ab	0.16 ab	0.22 a	nd	nd	nd	nd	nd	nd	nd	nd	57.24 a	nd	nd
Breba peel															
SANT	5.81 b	2.63 a	4.52 a	1.67 a	1.27 b	6.09 a	1.55 a	0.74 a	32.51 b	3.55 a	5.76 b	10.15 a	9.45 b	103.10 b	16.4 b
CALB	28.14 a	6.34 a	7.67 a	2.60 a	3.98 ab	7.06 a	1.65 a	0.47 a	50.48 ab	4.40 a	9.18 ab	11.37 a	49.23 b	581.28 b	81.1 ab
CUMH	13.40 ab	4.72 a	4.79 a	1.22 a	4.87 ab	11.18 a	3.56 a	0.83 a	89.00 ab	6.40 a	16.29 ab	17.66 a	16.57 b	232.24 b	34.6 b
CDN	21.34 ab	6.35 a	11.64 a	3.68 a	5.25 ab	11.33 a	3.36 a	0.63 a	93.88 ab	8.62 a	17.40 ab	18.15 a	174.21 a	1,244.59 a	178 a
SF	22.12 ab	7.42 a	5.12 a	4.50 a	8.78 a	9.70 a	2.63 a	0.68 a	125.17 a	8.66 a	19.32 a	15.72 a	20.78 b	378.07 b	54.4 b
Fig pulp															
SANT	1.43 a	1.14 a	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	18.10 a	nd	nd
CALB	1.40 ab	2.24 a	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	17.04 a	nd	nd
CUMH	0.91 b	2.65 a	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	18.84 a	nd	nd
CDN	1.46 a	1.26 a	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	21.40 a	nd	nd
SF	1.05 ab	1.58 a	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	19.08 a	nd	nd
Fig peel															
SANT	12.28 a	15.47 a	5.38 a	3.52 a	6.27 a	4.52 a	6.20 a	0.83 a	79.32 a	7.60 a	17.10 a	17.29 a	230.68 a	596.28 ab	118 ab
CALB	9.87 ab	12.18 a	4.53 ab	2.74 a	7.56 a	4.04 a	2.05 b	0.47 a	27.03 b	11.01 a	11.21 ab	4.71 b	206.26 a	424.96 ab	111 ab
CUMH	8.73 abc	6.17 a	2.09 b	2.60 a	5.74 a	4.33 a	0.71 b	0.76 a	14.69 b	13.19 a	9.25 b	5.19 b	35.96 a	196.44 b	38.7 b
CDN	5.18 c	19.49 a	1.99 b	2.59 a	4.25 a	2.18 a	0.70 b	0.64 a	7.52 b	16.72 a	7.86 b	3.46 b	238.01 a	840.09 a	185 a
SF	8.54 bc	6.04 a	2.50 b	4.35 a	7.27 a	2.82 a	2.38 b	0.49 a	16.23 b	12.66 a	7.35 b	4.46 b	16.62 a	208.44 b	36.5 b
Breba (pulp x peel)															

Value in the same columns followed by different letters is significantly different at $p \leq 0.05$ according to Tukey's test. Legend_ SANT: San Antonio; CALB: Col Albatera; CUMH: Colar UMH; CDN: Cuello Dama Negra; SF: Superfig; NEO: Neochlorogenic acid; CHL: Chlorogenic acid; CA: Caffeic acid; FA: Ferulic acid; DHCA-Hex: Dihydrocaffeic acid hexoside; Syr-Hex: Syringic acid hexoside; GA-diPent: Gallic acid di-pentoside ; SA: Sinapic acid; Ap-C-Hex-Pen: Apigenin-*C*-hexoside-pentoside; Q-Rut: Quercetin-3-*O*-rutinoside; Q-Glc: Quercetin-3-*O*-glucoside; Q-MalGlc: Quercetin-3-*O*-(malonyl)-glucoside; Cy-3,5-diGlc: Cyanidin-3,5-diglucoside; Pg-Rut: Pelargonidin-3-rutinoside; Cy-Rut: Cyanidin-3-rutinoside; nd: not detected.

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Phenolic acids									Flavonols				Anthocyanins		
	NEO	CHL	CA	FA	DHCA-Hex	Syr-Hex	GA-diPent	SA	Ap-C-Hex-Pen	Q-Rut	Q-Glc	Q-MalGlc	Cy-3,5-diGlc	Pg-Rut	Cy-Rut
Pulp	3.84 b	0.93 b	0.22 b	0.33 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	36.93 a	0.00 b	0.00
Peel	18.16 a	5.49 a	6.75 a	2.73 a	4.83 a	9.07 a	2.55 a	0.67 a	78.21 a	6.33 a	13.59 a	14.61 a	54.05 a	507.86 a	73.1 a
Fig (pulp x peel)															
Pulp	1.25 b	1.78 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	0.00 b	18.89 b	0.00 b	0.00
Peel	8.92 a	11.87 a	3.30 a	3.16 a	6.21 a	3.58 a	2.41 a	0.64 a	28.96 a	12.24 a	10.55 a	7.02 a	145.51 a	453.24 a	98.2 a

Value in the same columns followed by different letters is significantly different at $p \leq 0.05$ according to Tukey's test. Legend_ SANT: San Antonio; CALB: Col Albatera; CUMH: Colar UMH; CDN: Cuello Dama Negra; SF: Superfig; NEO: Neochlorogenic acid; CHL: Chlorogenic acid; CA: Caffeic acid; FA: Ferulic acid; DHCA-Hex: Dihydrocaffeic acid hexoside; Syr-Hex: Syringic acid hexoside; GA-diPent: Gallic acid di-pentoside ; SA: Sinapic acid; Ap-C-Hex-Pen: Apigenin-*C*-hexoside-pentoside; Q-Rut: Quercetin-3-*O*-rutinoside; Q-Glc: Quercetin-3-*O*-glucoside; Q-MalGlc: Quercetin-3-*O*-(malonyl)-glucoside; Cy-3,5-diGlc: Cyanidin-3,5-diglucoside; Pg-Rut: Pelargonidin-3-rutinoside; Cy-Rut: Cyanidin-3-rutinoside; nd: not detected.

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Table 6
Statistically significant pearson's correlation coefficients among carotenoids, tocols, free amino acids, polyphenolic compounds, and antioxidant and antidiabetic activities in the pulp and peel of breba and figs of studied *Ficus carica* varieties.

Compounds	**ABTS**	**FRAP**	**ORAC**	**α-amylase**	**α-glucosidase**
Breba pulp					
Zeaxhatin	-0.90*				
β-TT					0.94*
Breba peel					
CA	0.95*	0.93*	0.89*		
DGA-Hex				0.92*	
Ap-C-Hex-Pen				0.92*	
Q-Rut				0.99*	
Q-Glc				0.97**	
Q-MalGlc				0.93*	
Cy-3,5-diGlc	0.99***	0.98**	0.97**		
Pg-Rut	0.96**	0.95**	0.91*		
Cy-Rut	0.96**	0.96**	0.92*		
Lutein					-0.88*
β-Crypoxanthin					-0.94*
γ-TT		0.89*	0.89*		
Gly	-0.96**	-0.97**	-0.97**		
Hcy	0.99**	0.98**	0.97**		
Fig pulp					
Lutein					0.88*
β-Crypoxanthin					0.89*
Lycopene					0.91*
β-TT	0.89*			0.91*	
γ-TT					-0.90*
α-TT	0.90*				
Sep					0.90*
Asp					0.97**
Ala			-0.96**		
Fig peel					
CHL			0.95**		
Pg-Rut			0.95**		
Cy-Rut			0.90*		
Lutein			0.88*		
Zeaxhatin			0.92*	-0.95**	
Hcy			0.88*	-0.94*	

Differences of the estimated correlations presented as *, **, ***, significant at $p < 0.05$, 0.01, and 0.001, respectively. Legend_ TT: Tocotrienols; CA: Caffeic acid; DGA-Hex: Dyringic acid hexoside; Ap-C-Hex-Pen: Apigenin-*C*-hexoside-pentoside; Q-Rut: Quercetin-3-*O*-rutinoside; Q-Glc: Quercetin-3-*O*-glucoside; Q-MalGlc: Quercetin-3-*O*-(malonyl)-glucoside; Cy-3,5-diGlc: Cyanidin-3,5-diglucoside; Pg-Rut: Pelargonidin-3-rutinoside; Cy-Rut: Cyanidin-3-rutinoside; Gly: Glycine; Hcy: Homocysteine; Sep: *O*-Phospho-L-serine; Asp: Aspartic acid; Ala: Alanine; CHL: Chlorogenic acid.

A total of fifteen phenolic compounds were identified in the peel of both brebas and figs, belonging to three major groups: phenolic acids (hydroxycinnamic and hydroxybenzoic acids), flavonoids (flavones and flavonols), and anthocyanins. In contrast, only five compounds were detected in breba pulp, all corresponding to phenolic acids and anthocyanins: neochlorogenic, chlorogenic, caffeic and ferulic acids, and cyanidin-3,5-*O*-diglucoside. Fig pulp contained three compounds, also classified as phenolic acids and anthocyanins: neochlorogenic and chlorogenic acids, and cyanidin-3,5-*O*-diglucoside. All samples

contained phenolic acids (chlorogenic derivatives) and anthocyanins (cyanidin derivatives). Some peel samples also contained flavonols, mainly quercetin derivatives. These findings are consistent with previous studies analysing fig peel (Hssaini et al., 2021; Vallejo et al., 2012).

Firstly, the results of the breba will be discussed. Regarding cyanidin-3,5-*O*-diglucoside, the SF variety showed the highest value among breba pulps (57.24 mg/100 g dm), while the SANT variety had the lowest value (8.91 mg/100 g dm). On the other hand, breba peel was rich in anthocyanins, with pelargonidin-3-*O*-rutinoside being the compound with the highest content, particularly in the CDN variety (1244.59 mg/100 g dm). Fig pulp showed fewer polyphenolic compounds than breba pulp. Caffeic acid and ferulic acid were not detected in fig pulp. Regarding fig peel, the CDN variety exhibited the highest values for all anthocyanins compounds detected: cyanidin-3,5-*O*-diglucoside (238.01 mg/100 g dm), pelargonidin-3-*O*-rutinoside (840.09 mg/100 g dm) and cyanidin-3-*O*-rutinoside (185.63 mg/100 g dm). For comparison, Hssaini et al. (2021) analyzed phenolic compounds in figs from different varieties cultivated at the National Institute for Agricultural Research of Meknes (INRA) and detected cyanidin-3,5-*O*-diglucoside in a range of 0.83-494.08 (µg/g dm) in peel and 0.82–20.83 µg/g dm in pulp. Our results are consistent with those found in the literature.

To examine the relationship between pulp and peel in breba fruits, the contents of compounds neochlorogenic acid, chlorogenic acid and ferulic acid were 4.7, 5.9 and 8.3 times higher in the peel than in the pulp, respectively. In contrast, cyanidin-3,5-*O*-diglucoside showed no significant differences between pulp and peel. A similar trend was observed in figs, where neochlorogenic and chlorogenic acid concentrations were 7.1 and 6.7 times higher in the peel than in the pulp. However, for cyanidin-3,5-*O*-diglucoside, the concentration was 7.7 times higher in the peel than in the pulp.

As shown in Fig. 1A, breba peel exhibited the highest total polyphenolic content, with values ranging from 24.28 to 63.57 mg/100 g dm. Figure 1D presents the total sum of polyphenolic groups detected in the analyzed samples. Polymeric procyanidins were the predominant type of polyphenol in breba pulp, with concentrations ranging from 103.70 to 161.62 mg/100 g dm, with the CALB variety exhibiting the highest levels. Similarly, in fig pulp, polymeric procyanidins were notably high, with the CALB variety again demonstrating the greatest concentration at 146.97 mg/100 g dm.

This study identified significant differences in polyphenolic compound content among the fig tree varieties analyzed. The specific fruit part examined also influenced polyphenol levels, with higher concentrations observed in peels compared to the pulps. Additionally, it was concluded that breba peels contain higher levels of phenolic compounds than fig peels.

3.5. Principal component analysis of bioactive compounds

In Fig. 2A the first two principal components accounted for 69.15% of the total variation in the physicochemical properties of the pulp and peel of breba fruit, with the first component (F1) contributing 45.35% and the second component (F2) contributing 23.80%. The biplot reveals two distinct groups: on the left side, the breba peel from all analyzed varieties clusters with tocols and carotenoids, while on the right side, the breba pulp from all varieties clusters with amino acids. Figure 2B presents the correlation of the principal components along two axes for pulp and peel of figs fruits. In this analysis, the first two principal components explain 66.94% of the total variance, with F1 accounting for 49.12% and F2 for 17.81%. These principal component analysis results are similar to the previous analysis. Two groups are identified: one consisting of pulps and most amino acids, and the other consisting of peels, along with all tocols and carotenoids.

3.6. Biological activity: antioxidant and antidiabetic activity

Antioxidant properties (mmol Trolox/100 g dm) were assessed using the ability to capture synthetic radicals (ABTS), ferric reducing ability of plasma (FRAP), and oxygen radical absorbance capacity (ORAC) assays. In breba pulp, the CUMH variety demonstrated the strongest antioxidant potential measured by ABTS (0.93), FRAP (0.88), and ORAC (6.02). Additionally, for breba peel the CDN variety accumulated significantly higher amounts of antioxidant properties with ABTS (18.87), FRAP (15.33), and ORAC (60.35) values. In fig pulp, the CALB variety showed significantly higher antioxidant properties, with ABTS (0.61), and FRAP (0.61). For fig peel, the CDN variety exhibited the strongest antioxidant potential with ABTS (11.79), FRAP (8.25), and ORAC (18.03) values.

In summary, the 'Colar' varieties (CALB and CUMH) demonstrated notable antioxidant activity in the pulp parts of both brebas and figs, while the CDN variety exhibited the highest antioxidant activity in the peel of both fruit types. Moreover, the results showed that antioxidant activity in the peel was significantly higher than in the pulp, with values exceeding those of the pulp by 10.57-fold for ABTS, 10.24-fold for FRAP, and 4.73-fold for ORAC in brebas, and by 8.81-fold for ABTS, 6.59-fold for FRAP, and 2.79-fold for ORAC in figs. Previous research has examined the antioxidant activity in different parts of figs (peel and pulp); however, varying methodologies make it difficult to compare the results (Hssaini et al., 2021; Teruel-Andreu et al., 2023b). It is worth noting that, in general, the antioxidant capacity of brebas was higher than that of figs. Similar findings have been reported in other studies. For instance, Sadowska et al. (2023) found that White mustard plants showed the highest antioxidant activity at 38 days (second harvest) after sowing, but this activity decreased by 21–29% by day 45 (third harvest).

Pearson's correlation coefficients (Table 7) revealed a significant association between antioxidant activity and anthocyanin compounds. In breba peel, ABTS exhibited strong positive correlations ($p < 0.01$) with cyanidin-3,5-*O*-diglucoside ($r = 0.99$), pelargonidin-3-*O*-rutinoside ($r = 0.96$), and cyanidin-3-*O*-rutinoside ($r = 0.96$). Similarly, FRAP was correlated with anthocyanins ($p < 0.01$): cyanidin-3,5-*O*-diglucoside ($r = 0.98$), pelargonidin-3-*O*-rutinoside ($r = 0.95$), and cyanidin-3-*O*-rutinoside ($r = 0.96$). Comparable correlations were observed for ORAC with cyanidin-3,5-*O*-diglucoside ($r = 0.97$, $p < 0.01$), pelargonidin-3-*O*-rutinoside ($r = 0.91$, $p < 0.05$), and cyanidin-3-*O*-rutinoside ($r = 0.92$, $p < 0.05$). In contrast, for fig peel, significant positive correlations were exclusively observed between ORAC values and select bioactive compounds, notably certain polyphenols, carotenoids, and amino acids. Among these, chlorogenic acid and pelargonidin-3-*O*-rutinoside showed particularly strong associations with pelargonidin-3-*O*-rutinoside ($r = 0.95$, $p < 0.01$) and cyanidin-3-*O*-rutinoside ($r = 0.90$, $p < 0.05$) being most prominently linked to antioxidant activity.

The *in vitro* antihyperglycemic potential of breba and fig samples was evaluated by assessing their ability to inhibit the enzymes α-amylase and α-glucosidase. No significant differences were observed in the α-amylase and α-glucosidase inhibitory activities in the peel and pulp extracts of breba samples,

as well as those of fig samples. Besides, when comparing the pulp and peel of breba, no significant differences were detected, with average α-amylase inhibitory activities of 46.61% and 51.49%, respectively. Similar results were reported by Yao et al. (2024), who evaluated different fermentation methods affect the chemical composition, antioxidant activity, and enzymatic inhibition of fermented fig juice. They observed an inhibition rate of 44.33% for α-amylase in unfermented (control sample) fig pulp juice. However, significant differences were noted in the α-glucosidase inhibitory activities between the pulp and peel of figs. The highest inhibition was found in the pulp (16.49%), while the peel exhibited the lowest activity (2.39%). Furthermore, no correlation was found between compounds of fig peel and α-glucosidase inhibitory activity. The highest correlation for α-glucosidase inhibition was associated with aspartic acid ($r = 0.97$, $p < 0.01$) in fig pulp. Some studies have suggested that α-glucosidase inhibition may be linked to the methoxy group of certain hydroxycinnamic derivatives (Adisakwattana et al., 2004). Ferulic and caffeic acids were found in both brebas and figs, but no correlation was found between these phenolic acids and the inhibition against α-glucosidase. This suggests that other, yet undetected conjugated forms of soluble phenolic compounds may be involved. Additionally, Mopuri et al. (2018) analyzed the effects of an ethanolic extract derived from *F. carica* (fruits, leaves, and stembark) on enzymes activity. Their results revealed that extract from *F. carica* fruits exhibited significant inhibitory effects on both α-amylase and α-glucosidase, outperforming all other tested extracts. Furthermore, and Sedaghat and Rahemi (2018) suggest that the ripening of fig fruit largely results from enzyme mediated hydrolysis of cell wall components, particularly polysaccharides. Interestingly, research has shown that plant-based inhibitors of α-glucosidase and α-amylase can help manage hyperglycaemia by reducing postprandial blood glucose levels, offering a potential strategy for controlling type 2 diabetes (Tundis et al., 2010). Therefore, utilizing fruit and vegetable processing waste, such as brebas and figs, for enzyme production may present a valuable opportunity.

4. CONCLUSIONS

Notable distinctions were observed between the pulp and peel in terms of their carotenoids, tocols, amino acids, phenolic compounds, and antioxidant profiles. Seven carotenoids were identified, with β-carotene being the most abundant, particularly in the peel. The SANT variety exhibited the highest carotenoid concentrations in both breba and mature fig samples, whereas the CALB variety showed the highest total tocotrienol (∑TT) content. Among amino acids, threonine (Thr) and valine (Val) were the most prevalent essential amino acids across samples. Polyphenol analysis revealed that breba pulp contained a higher total polyphenol content than fig pulp, with anthocyanins predominating in the peel. The peel of the CDN variety demonstrated the highest levels of anthocyanin and antioxidant activity, as evidenced by results from ABTS, FRAP, and ORAC assays. Overall, this study underscores functional diversity of *F. carica* varieties, emphasizing their potential health benefits and suitability for applications in functional foods and nutraceutical development.

Declarations

Author Contributions: Candela Teruel-Andreu: formal analysis and Writing. **Marina Cano-Lamadrid:** conceptualization, review and editing. **Francisca Hernández:** conceptualization, visualization and supervision. **Karolina Tkacz**: methodology, formal analysis. **Igor Piotr Turkiewicz:** methodology, formal analysis.**Aneta Wojdyło:** Conceptualization, methodology, visualization and supervision.

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Figures

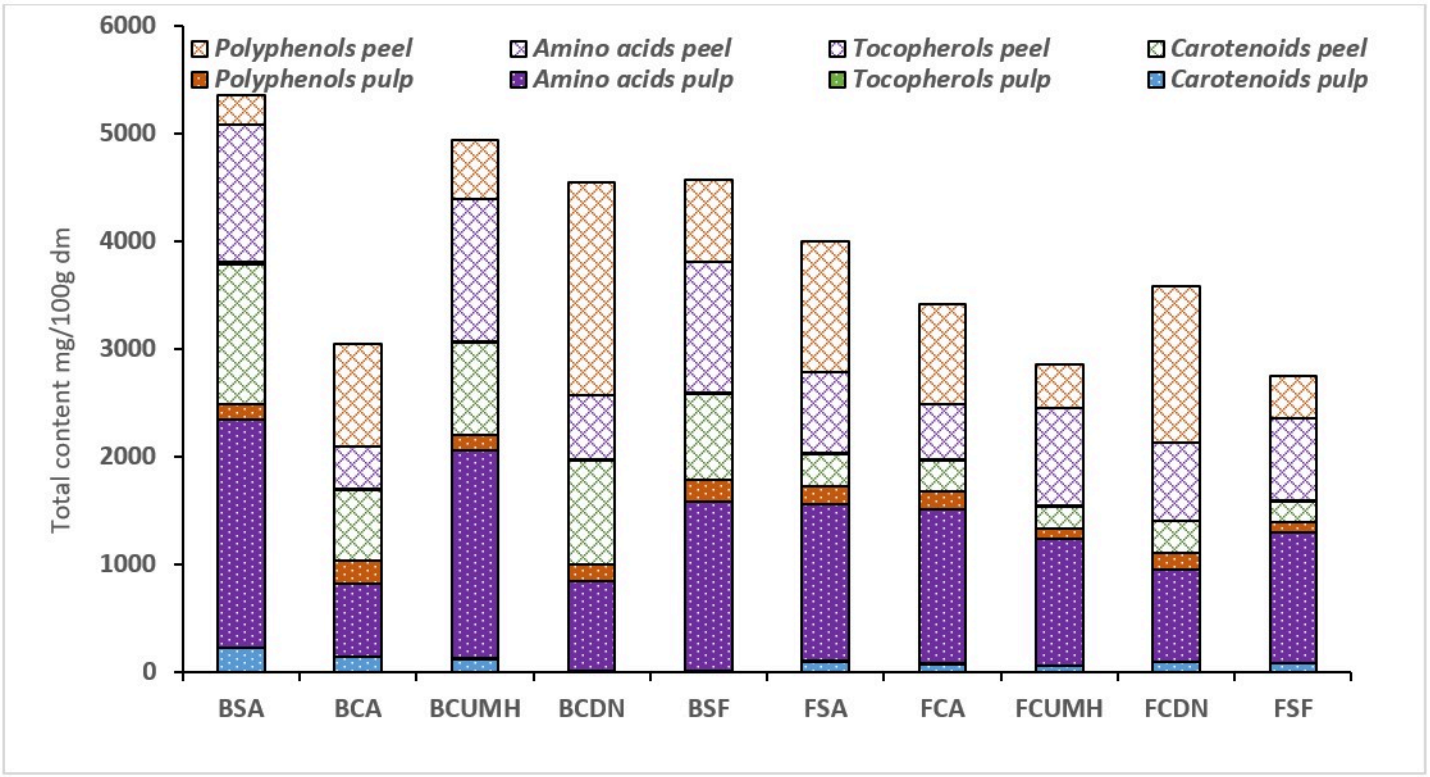

Figure 1

Figure 1 A. Concentration (mg/ 100 g dm) of the total content in main bioactive compounds identified in pulp (bars filled with white dots) and peel (bars filled with squares) in pulp and peel of breba and figs of studied varieties. Legend_ BSA: Breba San Antonio; BCA: Breba Colar Albatera; BCUMH: Breba Colar UMH; BCDN: Breba Cuello Dama Negra; BSF: Breba Superfig; FSA: Fig San Antonio; FCA: Fig Colar Albatera; FCUMH: Fig Colar UMH; FCDN: Fig Cuello Dama Negra; FSF: Fig Superfig.

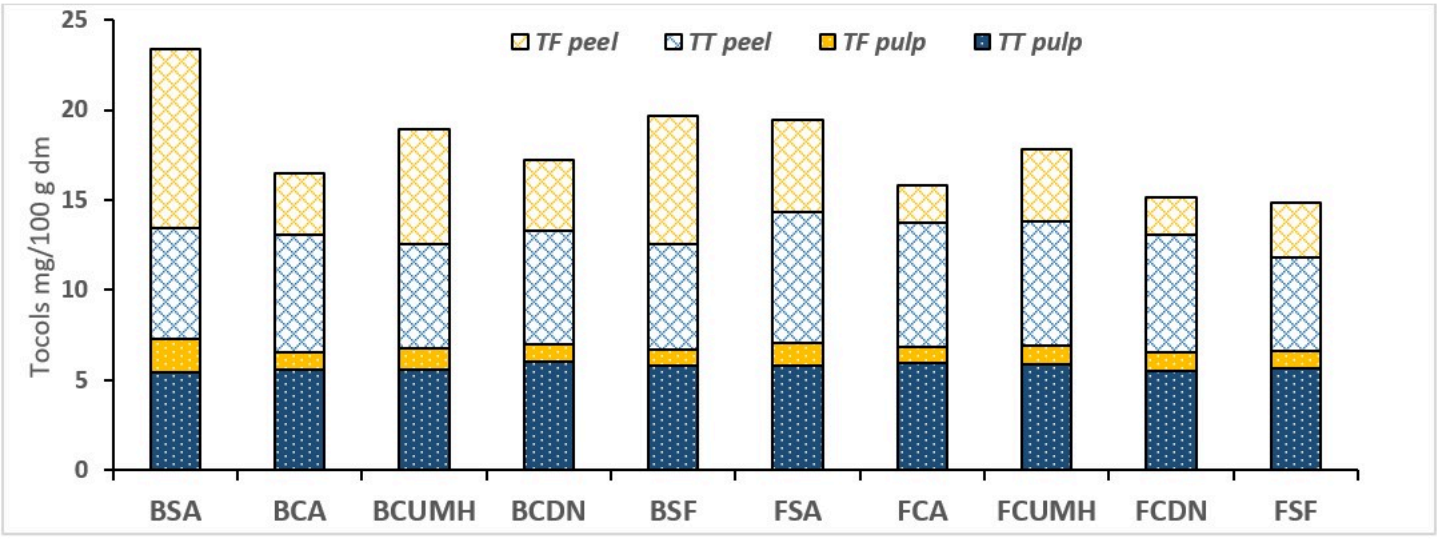

Figure 2

Figure 1B. Concentration (mg/ 100 g dm) of the main tocopherols and tocotrienols families identified in pulp (bars filled with white dots) and peel (bars filled with squares) in pulp and peel of breba and figs of studied varieties. Legend_ BSA: Breba San Antonio; BCA: Breba Colar Albatera; BCUMH: Breba Colar UMH; BCDN: Breba Cuello Dama Negra; BSF: Breba Superfig; FSA: Fig San Antonio; FCA: Fig Colar Albatera; FCUMH: Fig Colar UMH; FCDN: Fig Cuello Dama Negra; FSF: Fig Superfig; TF: Tocopherols; TF: Tocotrienols.

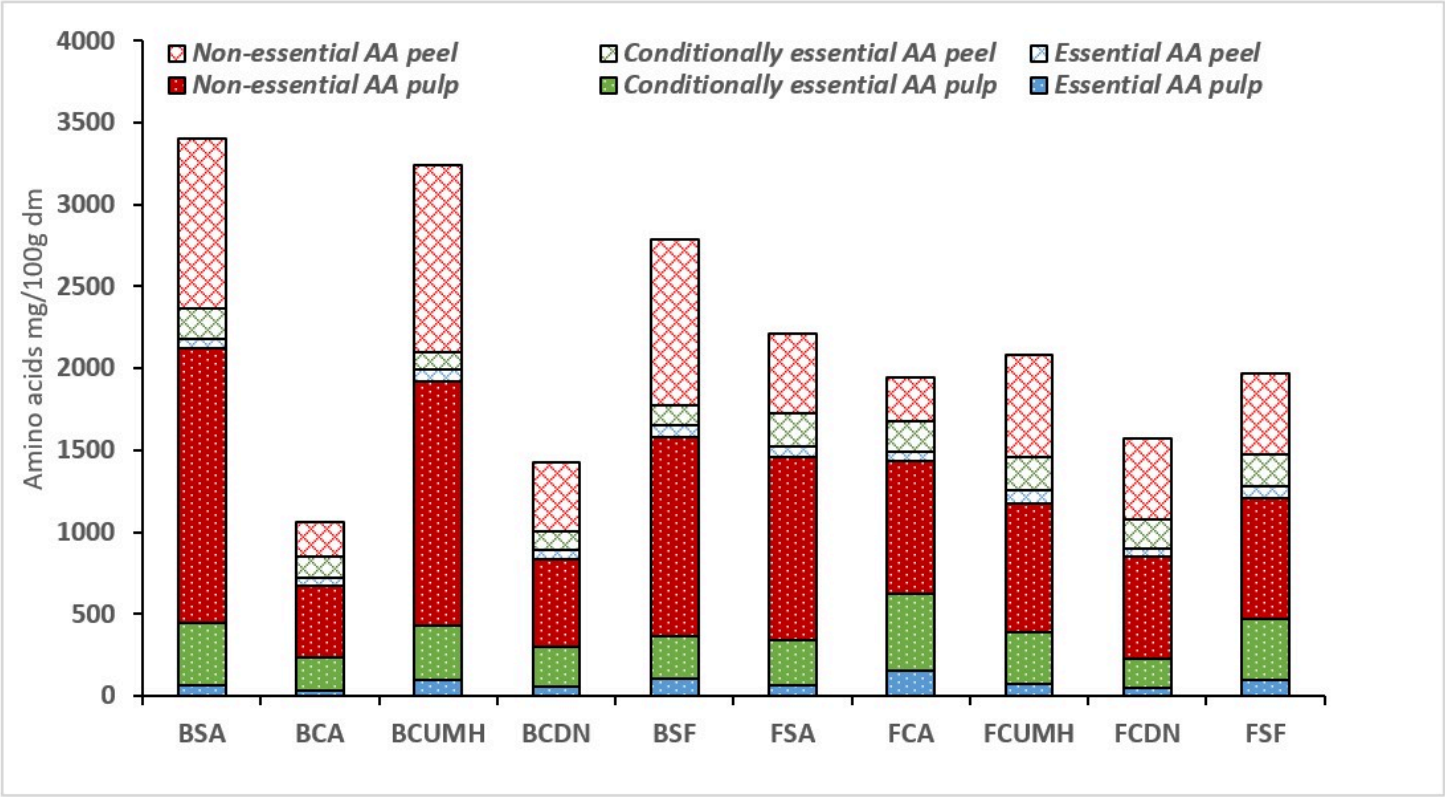

Figure 3

Figure 1C. Concentration (mg/ 100 g dm) of the main amino acids families identified in pulp (bars filled with white dots) and peel (bars filled with squares) in pulp and peel of breba and figs of studied varieties. Legend_ BSA: Breba San Antonio; BCA: Breba Colar Albatera; BCUMH: Breba Colar UMH; BCDN: Breba Cuello Dama Negra; BSF: Breba Superfig; FSA: Fig San Antonio; FCA: Fig Colar Albatera; FCUMH: Fig Colar UMH; FCDN: Fig Cuello Dama Negra; FSF: Fig Superfig; AA: Amino acids.

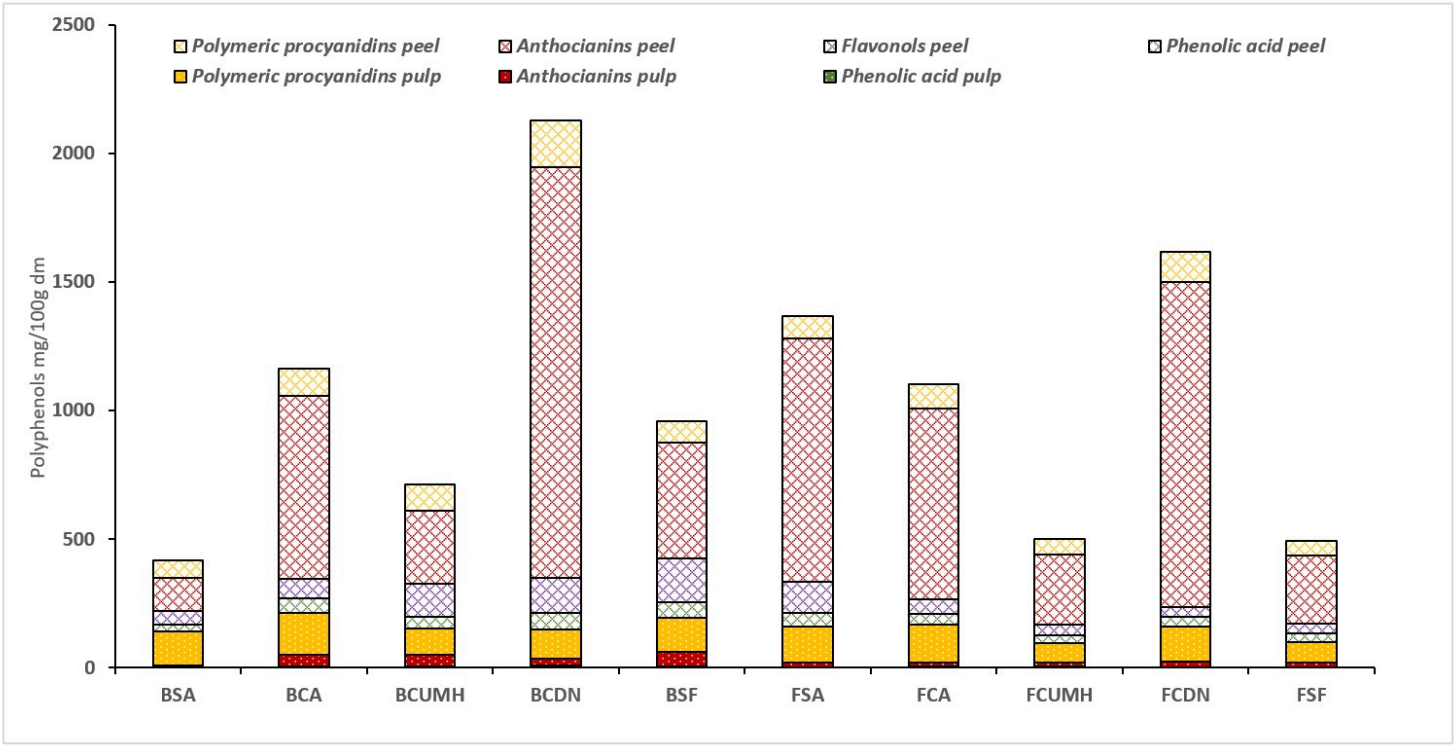

Figure 4

Figure 1D. Concentration (mg/ 100 g dm) of the main polyphenols families identified in pulp (bars filled with white dots) and peel (bars filled with squares) in pulp and peel of breba and figs of studied varieties. Legend_ BSA: Breba San Antonio; BCA: Breba Colar Albatera; BCUMH: Breba Colar UMH; BCDN: Breba Cuello Dama Negra; BSF: Breba Superfig; FSA: Fig San Antonio; FCA: Fig Colar Albatera; FCUMH: Fig Colar UMH; FCDN: Fig Cuello Dama Negra; FSF: Fig Superfig.

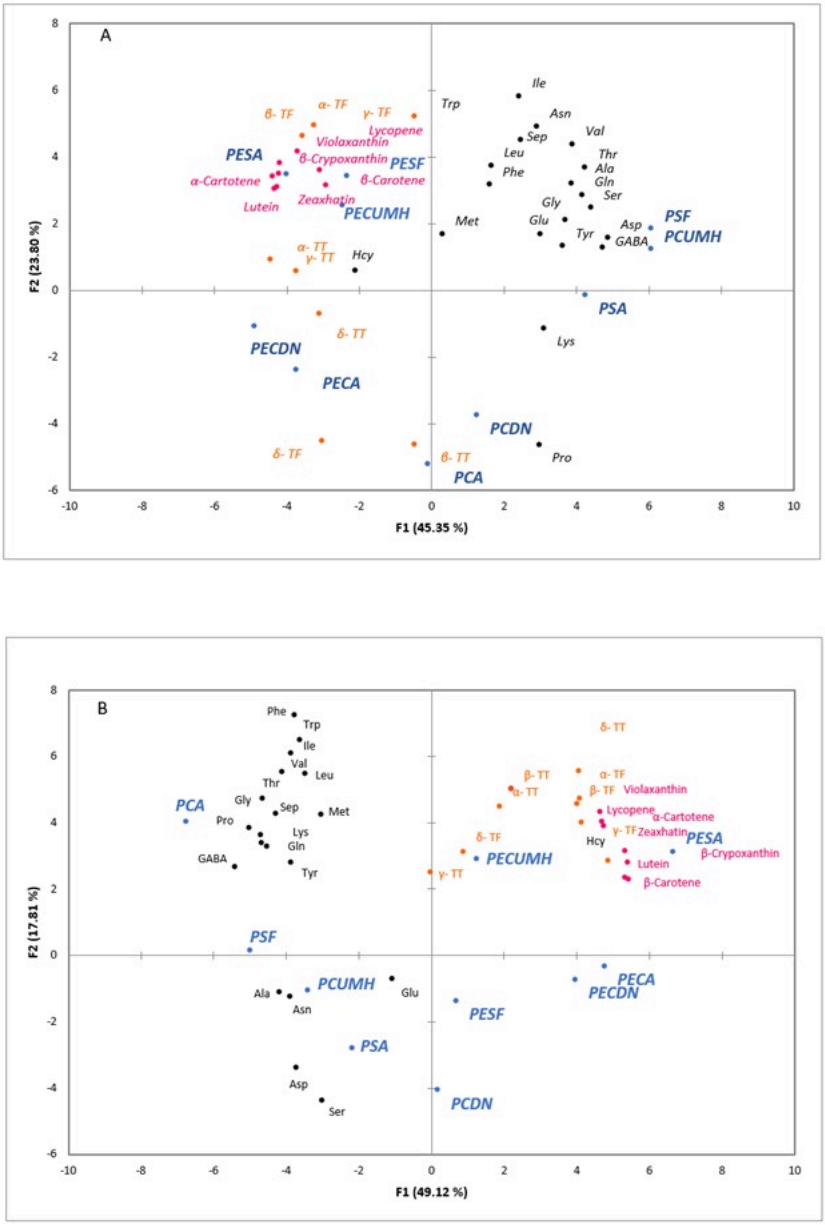

Figure 5

Fig. 2. Principal component analysis of breba (above) and fig samples (below). Legend_ PSA: pulp San Antonio; PCA: pulp Colar Albatera; PCUMH: pulp Colar UMH; PCDN: pulp Cuello Dama Negra; PSF: pulp Superfig; PESA: peel San Antonio; PECA: peel Colar Albatera; PECUMH: peel colar UMH; PECDN: peel Cuello Dama Negra; PESF: peel Superfigf; Thr: Threonine; Lys: Lysine; Met: Methionine; Val: Valine; Ile: Isoleucine; Leu: Leucine; Phe: Phenylalanine; Trp: Tryptophan; Arg: Arginine; Gln: Glutamine; Gly: Glycine; Glu: Glutamic acid; Pro: Proline; Tyr: Tyrosine; Sep: *O*-Phospho-L-serine; Asn: Asparagine; Ser: Serine; Asp: Aspartic acid; Ala: Alanine; GABA: γ-Aminobutyric acid; Hcy: Homocysteine; TT: Tocotrienols; TF: Tocopherols .