Received: 12 December 2022 | Revised: 3 March 2023 | Accepted: 4 April 2023

DOI: 10.1002/efd2.85

RESEARCH ARTICLE

eFood WILEY

Valorization of pomace from craft cider: Nutritional value, chemical composition, and phenolic and mineral profiles

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Funding information

European Regional Development Fund, Grant/Award Numbers: 0627_INBEC_6_E, Norte-01-0145-FEDER-000042; Fundação para a Ciência e a Tecnologia, Grant/Award Number: UIDB/00690/2020

Abstract

Waste recovery, in a circular economy context, is associated with clear economic and environmental benefits. Although apple pomace has been extensively studied for many applications, the valorization of pomace from emerging craft cider production is a novelty. This work is intended to determine the nutritional value, chemical composition, and phenolic and mineral profiles of pomace from craft cider waste. Levels of moisture (79.3%) and sugar contents (54.0%) stand out in their composition. Ethanol (1.56%) has been identified. Also, malic acid (2.94%), as well as α-tocopherols (0.4 mg/100 g) were detected. The phenolic profile showed six flavonoid compounds identified mainly quercetin derivatives. The mineral analysis revealed potassium as the major constituent (58.5 mg/g). In conclusion, it is envisaged that cider pomace could be an ideal substrate for biotechnological purposes, particularly as a sustainable and alternative, cheap source to produce glycerol for application in various industries such as food, cosmetics, and pharmaceuticals.

KEYWORDS

apple pomace, cider, circular bioeconomy, food industry, industrial residue, waste valorization

1 | INTRODUCTION

Apple trees (*Malus* × *domestica* Borkh), with their wide diversity of climatic adaptation, made the apple a universally cultivated fruit, with a production volume of around 87 million tonnes in 2019 (FAOSTAT, 2019). In Portugal, the productive sector recorded 2019 the highest value in the last 30 years, with around 354,000 tons translating into a turnover of nearly 75 million euros (AGROTEC, 2021; Statistics Portugal, 2019). Of the total apples produced in the world about 35% are processed, with juice and cider as the main products (Bortolini et al., 2020). Cider is one of the world's oldest low-alcohol beverages that continues to be widely consumed, especially in regions with long traditions of cider-making such as Western Europe and North America (Merwin et al., 2008). Ciders have been playing an important role in Portugal, with great potential growth in the national market. In 2017 it remained in the top three of the categories FMCG (fast-moving consumer goods) that grew the most, having practically doubled its turnover (Consultant Nielsen Portugal, 2017) and reaching 1.6 million cider consumers in 2018, a value that represents about 19.3% of the population (Marktest, 2019).

Typically, the modern cider-making process is based on the fermentation of pressed apple juice (Figure 1). Throughout the process, some chemicals and nutrients are added for proper control of the fermentation, and to prevent off-flavor compounds or other defects. Further ingredients such as preservatives, sweeteners, carbonation, or colorants are also added in the final bottling (Merwin et al., 2008). Currently, there is concern about making the production process more ecological, simple, and cheap without sacrificing flavor. For example, the brand Vadia, a pioneer in the production of craft beer and cider in Portugal, uses apple pomace (AP) as the main ingredient in its cider-making process (Fernandes et al., 2022). A key aspect of this new approach is the retention of the pomace during alcoholic fermentation to improve the antioxidant activity or the sensory quality of the cider, dispensing the addition of aromas (Bortolini et al., 2020). At the same time, the global issue of food waste is addressed by recycling AP, which would otherwise be discarded (Figure 1).

AP is the main waste generated by the apple processing industries. It represents up to a quarter of the fresh fruit weight, being composed of apple parts such as skins (exocarp), leftover pulp material (mesocarp), seeds (endocarp), and stalks (Barreira et al., 2019). Due to its high biodegradability, AP may cause environmental damage if not disposed of properly. The traditional discharging ways (e.g., landfilling, incineration, composting, or low-quality animal feed and land spreading) are frequently associated with greenhouse gas emissions, smell, or underground water pollution, which have negative repercussions on human health (Ghinea & Leahu, 2022). Consequently, several works have focused on alternative ways to recover AP through a wide range of potential applications (Perussello et al., 2017), either in the food industry or for non-health purposes (Ghinea & Leahu, 2022). Enzymes, organic acids, and biofuels are some examples of high-value bio-products that can be obtained from AP. Several companies around the world already explore this approach, promoting the use of AP as part of bakery products or by exploring purified components (e.g., pectin and phenolic compounds) as food additives (Ghinea & Leahu, 2022).

Although the chemical composition of AP has been extensively investigated and its richness in components well known (Fernandes et al., 2022), the same is not true

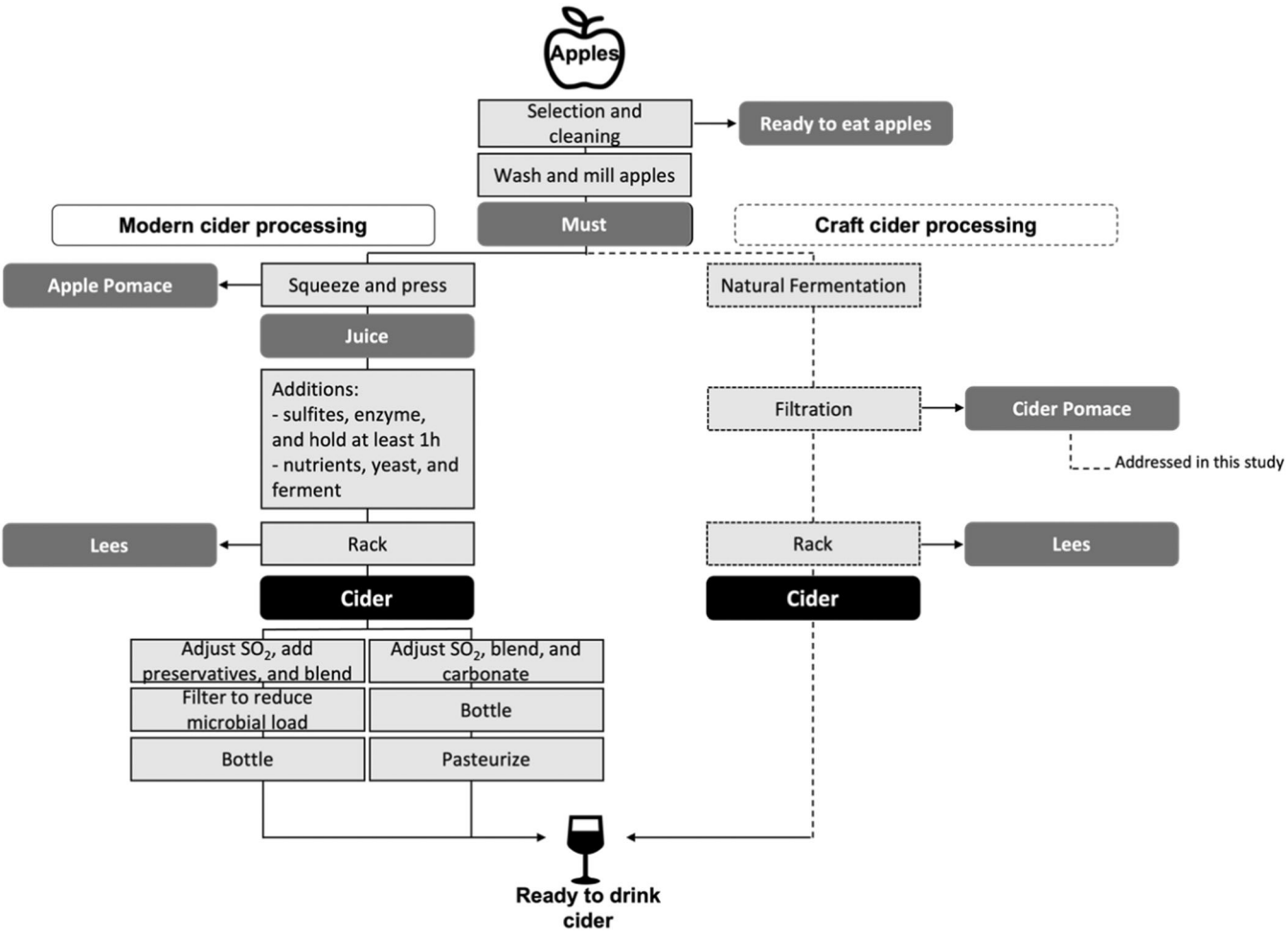

FIGURE 1 Flowchart of typical steps and procedures in different cider-making styles.

for the pomace resulting from craft cider or the emerging techniques of ecofriendly cider production. In these cases, the production process involves apple must-alcoholic fermentation instead of juice fermentation (Figure 1). Thus, it is expected that cider pomace (CP), that is, the residue resulting from the alcoholic fermentation of the must (Figure 1), presents differences in its composition compared to AP, since the fermentative process to which it has been exposed may add some new characteristics to it (Lorenz et al., 2019). In this sense, this work intends to make a comprehensive analysis of the nutritional value, chemical composition, and phenolic and mineral profiles of CP from craft cider, as a prior step to search for novel applications for an increasing valorization of CP and its value chains. To the best of our knowledge, this is the first study on characterization of CP from craft cider. Moreover, this approach is in line with current circular bioeconomy principles by using industrial waste as a matrix for the extraction of high value-added compounds (Brandão et al., 2021), de-stressing the environment and the economy.

2 | MATERIALS AND METHODS

2.1 | Samples

The organic cider was produced according to the flowchart shown in Figure 1. After choosing and washing the apples were crushed and left to ferment spontaneously. Next, the blend was filtered to save the juice and clarify it. The solid fraction was immediately frozen, lyophilized (FreeZone 4.5; Labconco) and kept in a desiccator at room temperature (ca. 25°C) and shielded from light, pending further analysis. To ensure the feasibility of the study, all tests were performed in triplicate.

2.2 | Standards and reagents

HPLC grade ethyl acetate (99.8%), *n*-hexane (95%), and acetonitrile (99.9%) were acquired from Fisher Scientific. The fatty acid methyl ester reference standard mixture 37 (standard 47885-U), Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), other individual fatty acid isomers, tocopherol, L-ascorbic acid, sugar, and organic acid standards were purchased from Sigma. Phenolic standards were acquired from Extrasynthèse. A Milli-Q water purification system (TGI Pure Water Systems) was used.

2.3 | Nutritional value

Nutritional value (ash, carbohydrates, fat, and protein content) was evaluated according to AOAC procedures (AOAC, 2016), following the procedures reported by (Melgar et al., 2017). A macro-Kjeldahl method ($N \times 6.25$) was used for protein content determination; a Soxhlet apparatus was used for evaluating the crude fat, through extraction of the sample with petroleum ether; incineration for 5 h at 600 ± 15°C was used for estimating the ash content; a rough estimate of carbohydrates was calculated by difference.

2.4 | Chemical composition

Organic acids, fatty acids, tocopherols and free sugars were determined following a previously reported procedure (Barros et al., 2013). Ethanol was quantified by injection in a HPLC system fitted with a binary pump (Varian Prostar 220), an infrared detector (Varian RI-4) and an injector (Rheodyne 7725i; Loop 20 µL). A prepacked HPLC analysis column Aminex HPX-87H (Bio Rad; 300 × 7.8 mm, 9 µm particle size, hydrogen form, pH range 1–3, 8% cross linkage), running at 30°C (Jones Chromatography 7981 oven) was used for isocratic elution. The mobile phase comprised an isocratic program of sulfuric acid 0.004 M, pumped at 0.6 mL/min during 30 min. The injection volume was set to 20 µL. A Varian Chromatography Workstation software (version 4.5) was used for data analysis. The results were computed as percentage of dry weight (% dw). To that end, a 7-level (0.044%–3.5%) calibration curve was used ($y = 6{,}341{,}413.7899x + 8209.9366$; $R^2 = 0.9997$; limit of detection [LOD] = 0.07%; limit of quantification [LOQ] = 0.24%).

2.5 | Phenolic profile

2.5.1 | Hydroethanolic extracts preparation

The extract was prepared by adding 2 g of dried sample to 50 mL of ethanol/water (80:20 vol/vol) and left under stirring for 1 h at room temperature. After filtration (Whatman No. 4 paper) the residue was re-extracted with an additional 50 mL of the same solution for 1 h under the same conditions. The combined extracts were then evaporated at 40°C in a rotary evaporator (Büchi R-210) to remove the organic solvent. The aqueous phase was further frozen and lyophilized to obtain a dry extract, stored under controlled light and humidity conditions until further analysis.

2.5.2 | Identification and quantification of phenolic compounds

Phenolic compounds were determined by HPLC (Hewlett–Packard 1100; Agilent Technologies) as previously described by the authors (Bessada et al., 2016). Double online detection was achieved using a Dionex

TABLE 1 Nutrient, chemical, and mineral profile of pomace from craft cider (concentrations are presented as mean ± SE).

Constituent	Mean ± SE
Nutritional value % (g/100 g dw)	
Moisture	79.3 ± 0.14
Ash	0.43 ± 0.00
Protein	1.41 ± 0.01
Fat	0.66 ± 0.03
Carbohydrates	18.2 ± 0.13
Energy	353.2 ± 3.2 kJ/g
Chemical composition % (g/100 g dw)	
Free sugars	
Fructose	29.01 ± 0.75
Glucose	19.82 ± 0.22
Sucrose	5.21 ± 0.33
Total free sugars	54.04 ± 0.65
Ethanol	1.56 ± 0.00 (fw)
Organic acids	
Oxalic	0.24 ± 0.00
Malic	2.94 ± 0.09
Total organic acids	3.18 ± 0.05
Fatty acids	n.d.
Tocopherols (mg/100 g dw)	
α-tocopherol	0.4 ± 0.0
β-tocopherol	n.d.
γ-tocopherol	n.d.
δ-tocopherol	n.d.
Total tocopherols	0.4 ± 0.0
Mineral profile (mg/g dw)	
Potassium (K)	58.5 ± 4.3
Sodium (Na)	4.6 ± 0.6
Calcium (Ca)	8.6 ± 0.1
Magnesium (Mg)	5.9 ± 0.1

Abbreviation: n.d., not detected.

Ultimate 3000 UPLC system (Thermo Fisher Scientific) coupled to a diode array detector (using 280 and 370 nm as preferred wavelengths) and a mass spectrometer Linear Ion Trap LTQ XL (ThermoFinnigan), equipped with an ESI source (electrospray ionization source) working in negative mode. The separation of the compounds was achieved using a Waters Spherisorb S3 ODS-2 reverse phase C18 column (4.6 × 150 mm, 3 μm; Waters) and an elution gradient using as mobile phase formic acid/water (0.1%) and acetonitrile. The compounds identification was performed taking into account the retention time (Rt), UV–Vis spectra (λ_{max}), pseudo-molecular ion ($[M-H]^-$), and molecular ion fragmentation (MS^2), and further comparison with available commercial standards and information present in literature. For quantitative analysis, seven-level calibration curves were used: caffeic acid ($y = 388{,}345x + 406{,}369$, $R^2 = 0.9939$, LOD = 0.78 μg/mL and LOQ = 1.97 μg/mL) and quercetin-3-*O*-glucoside ($y = 34.843x - 160.173$, $R^2 = 0.9998$, LOD = 0.21 μg/mL; LOQ = 0.71 μg/mL). The results were expressed in mg per g of hydroethanolic extract.

2.6 | Mineral profile

Atomic absorption spectrophotometry (AAS) was used for minerals determination. Sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca) were determined using a Pye Unicam PU9100X spectrophotometer. Zinc (Zn), manganese (Mn), copper (Cu), and iron (Fe) were determined using a Perkin Elmer PinAAcle 900 spectrophotometer. For that purpose, the sample (1 g) was weighed and digested with 10 mL of nitric acid, using microwaves and heat (1200 W, 200°C, 15 min). When cooled down, the samples were examined by AAS, after preceding treatment for particular elements. Sodium and potassium were determined by diluting the sample in a cesium buffer (Thermo Fisher Scientific Co.) (1:10 mL). For magnesium and calcium, dilution in a lanthanum solution (Thermo Fisher Scientific Co.) (10 g/L) was used. For copper and manganese, a magnesium nitrate solution was employed as a matrix modifier. By comparing the absorbance responses with pure analytical solutions, the mentioned elements were detected and computed as mg/g dw.

3 | RESULTS AND DISCUSSION

3.1 | Nutritional value

The results regarding the nutritional value of CP are presented in Table 1. Regarding nutritional value, the macronutrients (ash, proteins, fat, and carbohydrates), as well as water content and energy were assessed. The water content is high (cf. Table 1). This value is considerably higher than those of Bortolini et al. (2020) (3.00 ± 0.04%), Alayat et al. (2019) (5.38 ± 0.05%), or Cerda-Tapia et al. (2015) (10.32 ± 0.18%) obtained for AP. The ash obtained is directly proportional to the mineral content of the food. Analyses of this parameter also showed values quite low (cf. Table 1) comparatively to those of AP determined by the same authors cited above, namely 1.52 ± 0.02% dw (Alayat et al., 2019), 1.83 ± 0.02% dw (Bortolini et al., 2020), or 3.49 ± 0.03%

dw (Cerda-Tapia et al., 2015). A low ashes content could be an asset for potential applications of CP in food. This is because, under these conditions, the amount of metal ions would not be favored which lowers the chances of oxidation of the product in which they are embody. In addition, it was also low in two of the main nutritional groups, namely protein and fat (cf. Table 1). Again, these results are considerably lower than those of AP documented by Dhillon, Kaur, Sarma, et al. (2013), with protein ranging from 2.9% dw to 5.7% dw and fat ranging from 1.2% dw to 3.9% dw. Considering that CP results from the alcoholic fermentation of must, which yeasts naturally grow on the fruit mediate, we would expect substantial content of protein because of the spread of microorganisms. For example, in cider lees, high protein levels have been reported (19.4% dw), which have been associated precisely with the strong presence of living or dead populations of microorganisms (Rodríguez Madrera et al., 2019). However, in our case, the lees were not analyzed. Our sample is the solid product of the filtration step, with the lees being formed afterward. Also, in defatted apple seeds selected from AP, the protein was the main component, with an average value of 37.5 ± 1.8% dw (Rodríguez Madrera & Suárez Valles, 2018). This may lead us to speculate about the pressing process efficiency, which in our case might not have been efficient enough to break the apple seeds. In any case, these low levels for both, proteins, and fat, confirmed the CP as a poor option for animal feed. The total carbohydrate content of the dried CP was the main constituent (cf. Table 1) right after the water content, and about half or less of the reported values for AP (Alayat et al., 2019; Dhillon, Kaur, & Brar, 2013). Nevertheless, it is important to note that there are variations in the quantification methods, as well as in the apple cultivars varieties analyzed.

3.2 | Chemical composition

The chemical composition of CP analyzed included free sugars, ethanol, organic acids, fatty acids, and tocopherols, and are presented in Table 1. Characterization in terms of sugar content showed that free sugars remain in CP in relatively high amounts, namely fructose, glucose, and to a lesser extent sucrose (cf. Table 1). The same is supported by other authors, who obtained sugars-rich extracts from AP, containing mainly fructose and glucose (Bortolini et al., 2020; Dhillon, Kaur, & Brar, 2013; Sette et al., 2020). Fructose shows in all cases higher levels in CP than those reported in AP (Bortolini et al., 2020; Dhillon, Kaur, & Brar, 2013; Queji et al., 2010; Sette et al., 2020). The higher amounts of fructose and glucose over sucrose in CP are a result of incomplete alcoholic fermentation halted by technological reasons. During fermentation, the available sucrose is extracellularly hydrolyzed into glucose and fructose by the yeast's invertase, and the hexoses are then used by the yeast as carbon and energy source. When present as a mixture (as in apple juice and pomace), there is a preferential use of sucrose, followed by the uptake of glucose and only then fructose (D'Amore et al., 1988; Marques et al., 2016).

The presence of this considerable amount of sugar makes the CP a promising cheap growth substrate for other downstream fermentation processes under the biorefinery concept, for example, to produce several industrially important products such as citric acid (CA) (D'Amore et al., 1988). In this case, the ethanol content (although low [cf. Table 1]) could bring an advantage to CP over AP, because the presence of ethanol (or methanol) is a requirement for the proper development of the fermentative process for CA production using *Aspergillus niger* (Dhillon et al., 2011; Dhillon, Kaur, Sarma, et al., 2013). In nonalcoholic substrates (such as AP) ethanol must be added, which results in increased costs. On this basis, the authors of the present study also evaluated the potential of CP to produce CA through solid-state fermentation by different *A. niger* strains (unpublished data). For this, several natural *A. niger* strains and several variations of the fermentation substrates (AP, CP, mixtures of AP + CP, supplemented with several nutrients, and non-supplemented) were tested. Contrary to expectations, there was no advantage in the use of CP over AP to produce CA, whose concentrations obtained were lower whenever CP was used as substrate. However, a promising glycerol yield was achieved with non-supplemented CP (2.31 ± 0.27 g/g total sugars). The highest glycerol production was obtained with a non-supplemented balanced (50:50) mixture of AP and CP (61.51 ± 0.44 g/kg of substrate), with a yield of 2.19 ± 0.49 g/g total sugars. In a study of CA and glycerol production by *A. niger* using Amberlite as substrate, Gutiérrez-Rojas et al. (1995) reported a maximum glycerol production of 12.5 g/L when using 400 g/L of glucose. Also, Semkiv et al. (2020) and Wang et al. (2001) mentioned that *Saccharomyces cerevisiae* was able to produce 55 g/kg of glycerol from molasses in batch sulfite mode with a yield of 0.25 g/g total sugars, 35 g/kg of glycerol from glucose in batch mode with a yield of 0.23 g/g total sugars, and 80 g/kg of glycerol from molasses in fed-batch sulfite/vacuum mode with a yield of 0.25 g/g total sugars. In our unpublished data, glycerol production is promising with not only high amounts being produced per kg of substrate but also high yields being obtained per sugar units consumed. Furthermore, it can be concluded that the use of CP as a solo substrate, with no use of supplements, seems to be more promising in glycerol production than in CA production while bringing economic benefits resulting from the unnecessary addition of supplements.

Regarding organic acids, as expected, malic acid was detected, and oxalic acid was quantified to a lesser extent (cf. Table 1). Sette et al. (2020) considered similar results on AP characterization, namely the presence of natural

carbohydrates and organic acids, for the preparation of natural syrups with antioxidant potentials such as medicinal and nutraceutical tablets or capsules, as well as obtaining powder products to be incorporated in compound foods such as cereal, fruit bars or candies. Our analyses did not detect any fatty acid, which is not surprising since this parameter is usually analyzed on apple seed oil obtained from AP, corroborating the idea that our pressing process was not efficient to the point of breaking the apple seeds. Tocopherol, also known as vitamin E, occurs naturally in plants, being the main fat-soluble antioxidant in plasma and tissue membranes. It is composed of eight isomers such as alpha (α), beta (β), gamma (γ), and delta (δ). In the characterization conducted by Rodríguez Madrera and Suárez Valles (2018), the oils also revealed considerable antioxidant activity alongside remarkable values of tocopherols (total tocopherols 1280 ± 104.8 mg/kg oil). In all cases, the highlight was the abundance of β-tocopherol (794.5 ± 62.2 mg/kg oil) followed by α-tocopherol (439.2 ± 34.5 mg/kg oil). These results contrast with ours, in that we only detect the α-tocopherol in the crude pomace (cf. Table 1). However, considering that we are comparing different matrices (apple seeds and their oils vs. crude pomace), again this difference may be related to the fact that in our case there was no breaking of the apple seeds. Nevertheless, our findings are in accordance with the literature, where the α-tocopherol is identified as the most common of these naturally occurring forms of vitamin E (Guinazi et al., 2009). Vitamin E has been extensively studied in several areas of knowledge since it plays especially important roles in normal reproduction and antioxidant mechanisms of animal and plant tissues (Azzi & Stocker, 2000), so their presence increases and diversifies the potential for recovery of cider waste, making them a raw material of food, pharmacological or cosmetic interest.

3.3 | Phenolic profile determination

Polyphenols (including flavonoids) are the most abundant phytochemicals in plant kingdom that serve as a supply source of health-beneficial properties such as antimicrobial and antioxidant activities in the human diet (Kiani et al., 2021; Soleimani et al., 2022). There are substantial bodies of literature focusing on dietary polyphenols of edible plant parts because these non-enzymatic antioxidants act by directly scavenging free radicals (Luca et al., 2020; Pandey & Rizvi, 2009). The detailed phenolic composition identification and quantification of CP are presented in Table 2. The evaluated extracts showed the presence of nine compounds, of which three phenolic acids (caffeic acid derivatives) and six flavonoids (*O*-glycosylated quercetin derivatives). Peak **3** ($[M-H]^-$ at *m/z* 179) was identified as caffeic acid comparing their chromatographic responses with the available standard compound. Peaks **1** and **2** ($[M-H]^-$ at *m/z* 341) were tentatively identified as caffeic acid hexoside as previously described by Majdi et al. (2020). These three compounds were only found in trace amounts in the studied samples.

Regarding the flavonoid compounds peaks **4** ($[M-H]^-$ at *m/z* 609), **5/6** ($[M-H]^-$ at *m/z* 463), **7/8** ($[M-H]^-$ at *m/z* 433), and **9** ($[M-H]^-$ at *m/z* 447), presented a unique MS^2 fragment at *m/z* 301 (quercetin aglycone), corresponding to the loss of a 308, 162, 132, and 146 u, respectively, being tentatively identified as quercetin-*O*-

TABLE 2 Chromatographic analysis for phenolic compounds identification and quantification (mg/g of extract) in the hydroethanolic extracts of craft cider pomace (mean ± SD).

Peak	Rt (min)	λ_{max} (nm)	$[M-H]^-$ (*m/z*)	MS^2 (*m/z*)	Tentative identification	Quantification (mg/g extract)
1[A]	4.84	330	341	179 (100), 161 (12), 135 (5)	Caffeic acid hexoside	tr
2[A]	5.64	330	341	179 (100), 161 (23), 135 (7)	Caffeic acid hexoside	tr
3[A]	10.05	329	179	161 (100), 135 (8)	Caffeic acid	tr
4[B]	16.61	356	609	301 (100)	Quercetin-*O*-deoxyhexosyl-hexoside	0.463 ± 0.004
5[B]	17.33	356	463	301 (100)	Quercetin-*O*-hexoside	0.496 ± 0.001
6[B]	17.58	359	463	301 (100)	Quercetin-*O*-hexoside	0.472 ± 0.001
7[B]	19.18	345	433	301 (100)	Quercetin-*O*-pentoside	0.467 ± 0.002
8[B]	20.17	346	433	301 (100)	Quercetin-*O*-pentoside	0.468 ± 0.002
9[B]	21.05	348	447	301 (100)	Quercetin-*O*-deoxyhexoside	0.479 ± 0.001
					TPA	tr
					TF	2.834 ± 0.001

Note: Standard calibration curves: A—Caffeic acid ($y = 388{,}345x + 406{,}369$, $R^2 = 0.9939$, LOD = 0.78 μg/mL and LOQ = 1.97 μg/mL); and B—Quercetin-3-*O*-glucoside ($y = 34.843x - 160.173$, $R^2 = 0.9998$, LOD = 0.21 μg/mL; LOQ = 0.71 μg/mL).

Abbreviations: TF, total flavonoids; TPA, total phenolic acids; tr, trace amounts.

deoxyhexosyl-hexoside, quercetin-*O*-hexoside, quercetin-*O*-pentoside, and quercetin-*O*-deoxyhexoside, respectively. This family of compounds makes a total amount (cf. Table 2) that is more than double the amount obtained by Cerda-Tapia et al. (2015) (1.0615 mg/g) for AP. In the same study, phloridzin, with content values of about 24%, was the main phenolic compound quantified, and quercetin *O*-glycosides as the main flavonoid compound identified. Quercetin is a major constituent of many fruits and vegetables. Among the biological activities, they are associated with anti-inflammatory, antidiabetic, hepatoprotective, neuroprotective, antiplatelet, and antibacterial potential, as well as combat free radicals (Khursheed et al., 2020). In general, the results obtained differ from the phenolic profile of AP extensively studied by other authors, in that in addition to the quercetin glycosides, the samples were also abundant in chlorogenic acid, caffeic acid, (+)-catechin, (−)-epicatechin, and quercetin-3-*O*-rutinoside (Barreira et al., 2019). The number of individual phenolics is low in CP, however, it should be noted that although AP and CP come from the same raw material (apple), the second is subjected to a whole fermentation process that possibly promotes the degradation of pomace. In this way, several factors may be involved in the degradation of molecules, that is, during cider making process the CP can experiment with different degrees of oxidation, photodegradation, enzymatic browning, microbial attacks, and so forth, thus influencing the phenolic composition and antioxidant action. Besides, these differences can be also strongly related to the technological processing factors (pressing system, aeration) (Diñeiro García et al., 2009), as well as the apple cultivars herein studied. For example, "Golden Delicious" apple cultivars showed a greater phenolic content than those from conventional cultivars. Such within species variation is particularly important for the content and type of polyphenols in apples (Stracke et al., 2009) and other plant species (Kiani et al., 2021; Soleimani et al., 2022). In any event, the interest of phenolic compounds, recovered from AP, have become increasingly popular for several applications, including the cider industry to increase bioactivity and improve the sensorial quality of cider (Benvenutti et al., 2019), as well as its antioxidant activity (Bortolini et al., 2020). Other applications addressed include potential use in dermal formulations (Barreira et al., 2019) and for active packaging (Urbina et al., 2019).

3.4 | Mineral profile

The mineral profile detected through AAS of CP from craft cider is presented in Table 1. The mineral analysis showed high K content comparatively with the amounts of Na, Ca, and Mg (cf. Table 1). Our results are in line with those obtained for the APs in the juice industries since clearly, K is the major constituent of the mineral analysis performed (Dhillon, Kaur, & Brar, 2013). For biotechnological applications, it is well known the brutal influence that the mineral profile of the substrate as well as the interdependence of the fermentation medium constituents have on bioproducts production yield (Banik, 1976; Vandenberghe et al., 1999).

4 | CONCLUSIONS

The determination of the nutritional, chemical, phenolic, and mineral profile of CP from craft cider showed that, in general, the constitution of the CP is similar to the AP. However, some interesting results were obtained. CP was found to contain a residual amount of ashes which aided in the stability of novel food ingredients. On the other hand, a significant amount of sugars combined with the presence of ethanol and minerals such as K and Mg make CP an ideal substrate for biotechnological purposes. Finally, the presence of flavonoids is also a benefit that extends the range of applications to other areas related to the bioactive and antioxidant potentialities. The findings of this work, alongside our preliminary results from unpublished data, indicate that CP could favor the production of glycerol by fermentation with *A. niger* when compared with AP. Hence, future work includes to study glycerol production since it is a very used compound in multiple industries such as cosmetics, paint, automotive, food, and textile industries (Wang et al., 2001).

It is also important to mention that the process of craft cider production that results in the CP analyzed in this study is in itself a way of adding value to apples that would otherwise be wasted, as those that do not meet the visual standards for sale in the fresh market are harnessed for this purpose. Thus, in harmony with the emerging concept of a circular bioeconomy, the economic and environmental impact of this approach is not only positive but also translates into cleaner production.

AUTHOR CONTRIBUTIONS

Ana Sofia Brandão: Conceptualization; investigation; writing—original draft. **Cristina Caleja**: Investigation; writing—original draft. **Maria Inês Dias**: Investigation; writing—original draft. **Asma Ben Salha**: Investigation. **Feriel Rezouga**: Supervision. **Paula Rodrigues**: Supervision; writing—review and editing. **Isabel C. F. R. Ferreira**: Supervision. Lillian Barros: Resources; supervision; writing—review and editing. **José M. R. C. A. Santos**: Conceptualization, funding acquisition, supervision, writing—review and editing.

ACKNOWLEDGMENTS

The authors are grateful to the Foundation for Science and Technology (FCT, Portugal) for financial support through national funds FCT/MCTES (PIDDAC) to

CIMO (UIDB/00690/2020 and UIDP/00690/2020) and SusTEC (LA/P/0007/2020). Ana Sofia Brandão and José M. R. C. A. Santos would like to thank the FEDER under Programme PT2020 for financial support to INTERREG POCTEP project "INBEC—Circular bio-economy. Promotion and development of a sustainable economy through innovation and business cooperation" (ref. 0627_INBEC_6_E). Maria Inês Dias and Lillian Barros would like to thank the national funding by FCT, Paula Rodrigues, through the institutional scientific employment program-contract for their contracts; to the project Healthy—PETFOOD for the contract of Cristina Caleja (POCI-01-0247-FEDER-047073). This work is funded by the European Regional Development Fund (ERDF) through the Regional Operational Program North 2020, within the scope of Project GreenHealth—Digital strategies in biological assets to improve well-being and promote green health, Norte-01-0145-FEDER-000042.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Ethics approval was not required for this research.

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How to cite this article: Brandão, A. S., Caleja, C., Dias, M. I., ben Salha, A., Rezouga, F., Rodrigues, P., Ferreira, I. C. F. R., Barros, L., & Santos, J. M. R. C. A. (2023). Valorization of pomace from craft cider: Nutritional value, chemical composition, and phenolic and mineral profiles. *eFood*, *4*(3), e85. https://doi.org/10.1002/efd2.85