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REVIEW ARTICLE

A review about acerola *(Malpighia emarginata* DC.*)* by-products as a promising raw material for the generation of green products

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Abstract

The global consumption of acerola (*Malpighia emarginata* DC.) has been increasing over the years, both in the form of fresh fruits and in food products derived from its pulp. Consequently, this consumption has led to an increase in the number of by-products (peels, lumps, and seeds) generated. Therefore, this study emphasizes the results reported in the literature regarding the possibilities for using acerola by-products. Due to their high content and the different possibilities of extracting active compounds (mainly phenolic compounds), acerola by-products can serve as raw material for a range of products that can be used in the food industry for the production of flour, cookies, *nuggets,* and edible coatings, or in high-tech products, such as nano/microparticles and clean energy precursors. The use of acerola by-products is expected to grow exponentially with the consumption of fresh fruit and the derivatives of its pulp. Green alternatives for the reuse of fruit/vegetable by-products in general are environmentally interesting.

Keywords: Phytochemicals; Agroindustry; Waste; Biomass; Biomaterials; Sustainability.

Highlights

- Acerola by-products can have more phenolic compounds than fresh fruit
- Phenolic compounds are the main active compounds of acerola by-product
- *Green* alternatives are used to transform acerola by-products into new products

1 Introduction

Acerola *(Malpighia emarginata* DC.*)* is a fruit with economically relevant value, and its consumption has grown exponentially worldwide. It is easily cultivated and has an exotic flavor and many nutritional properties; moreover, the fruit can be consumed fresh or processed by the food industry (Abreu et al., 2020).

The consumption of fresh acerola is beneficial because its active contents have-different concentrations of vitamin C, phenolic compounds, and carotenoids, which are found in the fruit, depending on its stage of maturation. Much of the active compounds of the fruit are in the by-products (peel, lumps, and seeds) generated during its processing (Carrington & King, 2002; Moura et al., 2018).

Studies have shown that acerola by-products contain a higher content of phenolic compounds than pulp, which gives an added value to the raw material (Cruz et al., 2019). Several studies have focused on the generation of new products using acerola by-products, such as antioxidant or antimicrobial extracts (Silva et al., 2020a, 2021), micro/nanoparticles loaded with active compounds (Nascimento et al., 2019; Silva et al., 2021), foods (Abreu et al., 2020; Monteiro et al., 2020), adsorbents (Nogueira et al., 2019) or precursors of clean energy (Silva et al., 2020b).

In this regard, this article is a review that focuses on exploring the current scenario of acerola by-products as a raw material for industrial applications and their major active compounds of interest. First, acerola industrial processing is described, emphasizing the main active compounds present in their by-products and the extraction methods used. Then, the active potential and possible applications of acerola by-products are reviewed. Finally, a brief conclusion and future trends in this field are reported.

1.1 Acerola (*Malpighia emarginata* DC.) industrial processing

Acerola is the common name of *M. emarginata*, a native fruit throughout South and Central America. The acerola fruit can weigh from 2 to 15 g, and up to 80% of this mass corresponds to its mesocarp. The remaining fractions that correspond to acerola by-products are the peel (epicarp) and lumps, which may or may not contain two to three seeds (endocarp) (Silva et al., 2019; Delva & Goodrich-Schneider, 2013). This fraction is separated from the fruit during processing.

The processing of acerola pulp in the form of new foods is an alternative to consuming the fruit in the long term because about three days after harvesting the acerola reaches its maximum maturation and is no longer suitable for consumption (Chitarra & Chitarra, 2005; Abreu et al., 2020). Figure 1 illustrates the complete acerola processing scheme.

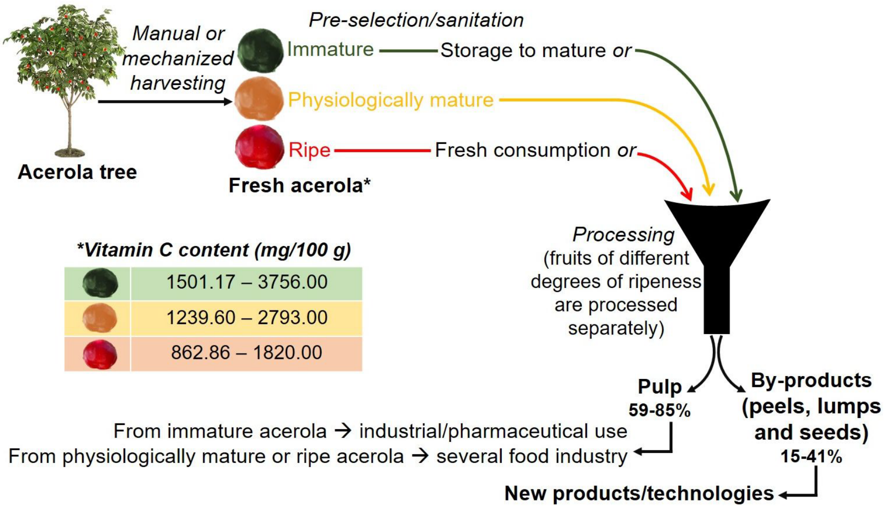

Figure 1. Acerola processing chain (results based on: Oliveira et al. (2012), Souza et al., (2014) and Moura et al. (2018)).

Processing begins with the harvest of the acerola in three maturation stages: immature (green), physiologically mature (orange), and mature (red). Different destinations are given to the fruit pulp, which is directly associated with the amount of vitamin C. Immature acerola fruits are stored under suitable cooling conditions while ripening occurs, or they are processed still green when destined for industrial or pharmaceutical use, as they contain higher amounts of vitamin C. Fruits harvested at physiological maturity are normally processed for different markets. Ripe acerola fruits are processed or marketed for consumption. The remaining by-products of the processing correspond to up to 41% of the total mass of the acerola (Souza et al., 2014; Moura et al., 2018). In the following topics, the main active compounds present in these by-products and their possible applications are discussed.

1.2 Active compounds from acerola by-products

The content of active compounds in acerola by-products highlights the importance of their use. Although different studies focused on valuing the active compounds of acerola by-products, it is not possible to predict the exact amount of these components in the different fractions obtained after processing: First, because the composition of acerola, and consequently of its by-products, is related to the region of cultivation, climatic conditions, cultural practices and application of pesticides (Silva et al., 2014); and second, because the recovery of active compounds is directly related to the by-product fraction studied and the extraction protocols used, which may be more or less effective depending on the type of equipment and solvent used. Sousa et al. (2011), for example, reported the direct interference of the solvent in obtaining active compounds. The authors extracted phenolic compounds from acerola by-products in different solvents using a magnetic stirrer for extraction. About 13% more (279.99 mg/100 g by-product) phenolic compounds were obtained in an ethanolic extract *versus* an aqueous extract (247.62 mg/100 g by-product). In another example, Silva et al. (2021) demonstrated how extraction methods affected the content of active compounds. The authors used ethanol as solvent and promoted the extraction by bath or tip ultrasound (sonication). Through the sonication process, it was possible to obtain 45% more phenolic compounds (1620.7 mg/100 g by-product) compared to extraction in the traditional ultrasound bath (1155.2 mg/100 g by-product).

To illustrate how wide the range of contents of compounds extracted from acerola by-products can be, Table 1 shows the amounts of these components found in the literature for various fractions of acerola by-products when different solvents and extraction methods were used.

Although it is difficult to predict the exact amount of each active compound in each part of the acerola, studies have already shown that vitamin C and carotenoids are predominantly present in the pulp (Moreira et al., 2010), while phenolic compounds are the main active compounds present in seeds and lumps (Lima et al., 2003; Cruz et al., 2019). In this context, High Performance Liquid Chromatography (HPLC) has been used to identify the main phenolic compounds of acerola by-products. Figure 2 shows the phenolic compounds recently quantified in the different fractions of by-products. In addition, qualitative studies have indicated the presence of other phenolic compounds, such as 3,4-dihydroxyhydrocinnamic acid, 4-hydroxybenzoic acid, trihydroxy(iso)flavone, 2-hydroxycinnamic acid, salicylic acid, coumaroylquinic acid, kaempferol-3-rhamnoside, trihydroxyflavanone (I and II), (iso)formononetin and quercetin 3-rhamnoside (Poletto et al., 2021; Silva et al., 2022).

The diversity of these phenolics present in acerola by-products confers a series of properties of interest to human health. The p-Coumaric acid (Figure 2, structure 1), for example, may have effects in preventing vascular disorders such as thrombosis. Caffeic and gallic acids can act as inhibitors in the lipid peroxidation process (Figure 2, structures 2 and 4, respectively). Rutin (Figure 2, structure 12) has anti-diabetic and anti-inflammatory properties, and quercetin (Figure 2, structure 14) is responsible for inhibiting oxidative stress (Alezandro et al., 2013; Silva et al., 2020a).

Table 1. Contents of ascorbic acid (AA), phenolic compounds (PC), anthocyanins and carotenoids (CA) obtained in acerola by-products.

By-product fraction	Active compound and amount extracted	Extraction method and/or solvent	Reference
Lumps, seeds and peels	**AA:** 1063.5 mg/100 g[d.b]	UAE; oxalic acid	Silva et al. (2021)
	PC: 1155.2 – 1620.7 mg GAE/100 g[d.b]	UAE; ethanol, water or chitosan suspension	
	PC: 247.6 – 280 mg GAE/100 g[d.b]	Magnetic stirring; water or ethanol	Sousa et al. (2011)
Peels and seeds	**PC:** 1835.4 mg/100 g[d.b]	Exhaustive extraction; methanol	Silva et al. (2022)
	Anthocyanins: 41.4 mg/100 g[d.b]		
	PC: 378.6 – 444 mg GAE/100 g[d.b]; and 2.3 mg PC/g[d.b]*	UAE or agitation; ethanol, methanol or acetone	Gualberto et al. (2021)
	CA: 584 mg β-carotene/100 g[d.b]	UAE; acetone	
	PC: 106.8 mg GAE/g extract	SFE; ethanol	Poletto et al. (2021)
	AA: 489 mg/100 g[d.b]	UAE; ethanol	Rezende et al. (2017)
	PC: 1068 mg GAE/100 g[d.b]; and 559 mg quercetin/100 g[d.b]		
	Anthocyanins: 16.6 mg/100 g[d.b]		
	CA: 559 mg β-carotene/100 g[d.b]		
	AA: 170.7 mg/100 g[d.b]	Soxhlet extraction; oxalic acid	Sancho et al. (2015)
	PC: 173.3 mg/100 g[d.b]	Soxhlet extraction; methanol/acetone	
	PC: 4856.5 – 20531.7 µMol catechin/L extract	Sequential extraction; ethanol, methanol or acetone	Caetano et al. (2011)
Non-pomace	**AA:** 2370 mg/100 g[d.b]	Hydrothermal extraction; water	Borges et al. (2021)
	PC: 3490 mg GAE/100 g[d.b]; and 334.4 µg PC/g[d.b]*		
Seeds, peels and pulp	**AA:** 525.2 mg/100 g[d.b]	Methanol/acetone	Carmo et al. (2018)
	PC: 647 mg GAE/100 g[d.b]		
	Anthocyanins: 20.54 mg/g[d.b]		
Seeds	**AA:** 509 mg/100 g[d.b]	-	Ramadan et al. (2019)
	PC: 225.6 mg GAE/100 g[d.b];		
	PC: 7265.3 mg GAE/100 g[d.b]	Sequential extraction; ethanol	Silva et al. (2014)
	Anthocyanins: 245.9 mg/100 g[d.b]	Homogenization; ethanol	
	CA: 272.8 µg β-carotene/100 g[d.b]	Homogenization; acetone/hexane	
Not specified	**PC:** 931.2 mg GAE/100 g[d.b]; and 4.8 mg RE/100 g[d.b]	UAE; ethanol	Silva et al. (2020a)
	AA: 10355 mg/100 g[d.b]	Manual agitation; oxalic acid	Nascimento et al. (2019)
	AA: 134.6 mg/100 g[d.b]	Oxalic acid	Silva et al. (2019)
	PC: 1266.8 mg GAE/100 g[d.b]; and 4.7 mg RE/100 g[d.b]	Methanol	
	PC: 3.3 mg GAE/L extract; and 152.2 mg PC/L extract*	Reflux; methanol	Marques et al. (2016)
	AA: 126.2 mg/100 g[d.b]	-	Duzzioni et al. (2013)
	PC: 46.2 mg GAE/100 g[d.b]		

[d.b]: dry basis of by-product. *: sum of various quantified PC. GAE: Gallic Acid Equivalent. RE: Rutin Equivalent. UAE: Ultrasound-Assisted Extraction. SFE: Supercritical Fluid Extraction. -: no method or solvent was mentioned. Non-pomace = suspended solids separated by decantation from the acerola juice clarification step. Not specified = the characterized fraction was named as “acerola wastes”, “acerola by-products”, “acerola residues” or “acerola bagasse”.

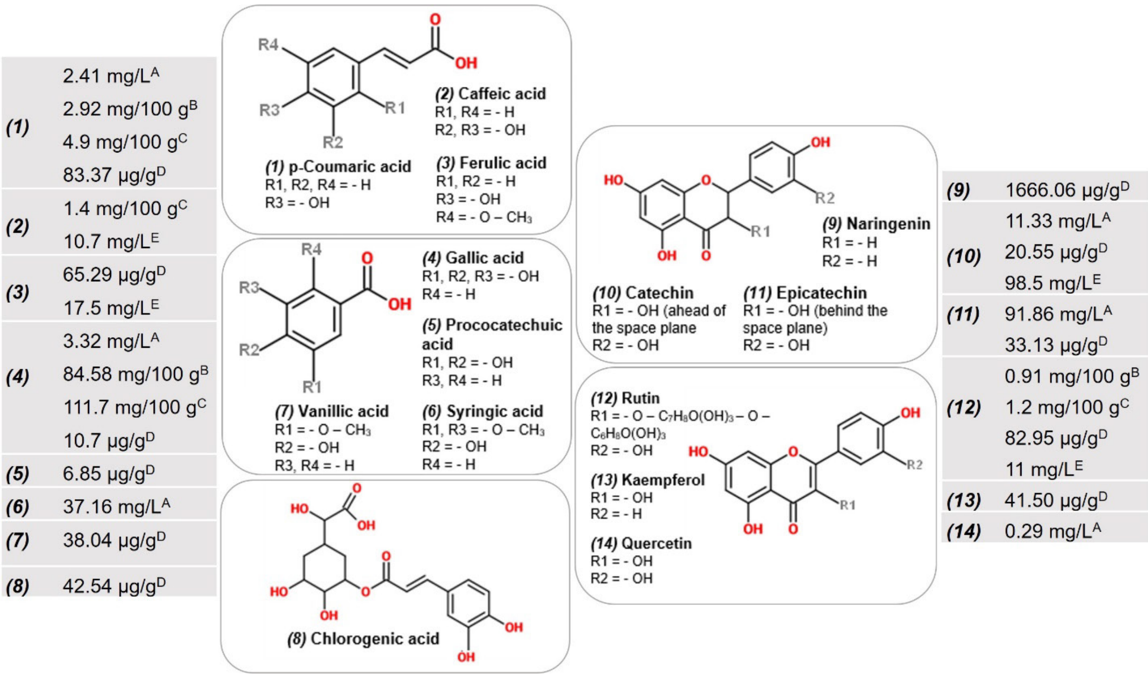

Figure 2. Types and contents of phenolic compounds found in acerola by-products, expressed in mass of active component/mass of dried acerola by-product, or mass of active component/volume of acerola by-product extract, based on: (A) Marques et al. (2016); (B) Nogueira et al. (2019); (C) Silva et al. (2020b); (D) Gualberto et al. (2021); and (E) Borges et al. (2021).

2 Active characteristics of extracts based on acerola by-product

2.1 Antioxidant properties

The antioxidant capacity of different vegetal species is directly related to their content of active compounds. These molecules can eliminate or stabilize free radicals (responsible for oxidation) through the donation of hydrogen from one of their hydroxyl groups (-OH). As seen in Figure 2, the phenolic compounds mostly present in acerola by-products are rich in -OH groups. In addition, anti-inflammatory or oxidative stress inhibitory properties, such as those mentioned above, are directly associated with the antioxidant potential (Alezandro et al., 2013; Silva et al., 2020b). For this reason, a series of studies has focused on the antioxidant analysis of acerola by-products to use them as a source to produce active extracts (Miskinis et al., 2023).

The antioxidant capacity is commonly measured through analytical methods based on the ability to remove organic radicals (ABTS, 2,20-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)), on the reducing capacity of the metal (FRAP, Ferric Reducing Antioxidant Power), or in the peroxidation of a radical (DPPH, 1,1-diphenyl-2-picrylhydrazyl). An aqueous and/or organic-based extract must first be produced for these analyses. In this case, different extraction bases have already been studied for acerola by-products, and there is still no standard protocol focused on optimizing their antioxidant capacity. The solvents used in the extraction range from those tested in the last decade, such as ethanol, methanol, and acetone (Caetano et al., 2011; Sousa et al., 2011), to recently tested pure water or chitosan polymeric medium dissolved in acetic acid (Silva et al., 2021). This variation of solvents results in different levels of antioxidant activity found in the literature, and some examples are shown in Table 2. The notable point is that the different possibilities of solvents for extraction allow different applications for the final extracts. For example, when chitosan suspension was used to produce an antioxidant extract, the final extract was used immediately after the process as an edible polymeric coating.

Table 2. Antioxidant activity levels by different analytical methods.

Base of extraction* / Analytical method	ABTS	FRAP	DPPH
	µMol TE/g (d.b)	µMol TE/g (d.b)	EC_{50}
Ethanol	1445.10[1]	282.89[3]	308.07[2]
	743[2]		
	155.63[3]	93[4]	0.22[1]
	46.7[4]		
Acetone	291.71[1]		0.33[1]
Methanol	1145.50[1]		0.23[1]
Water	518[2]	273.8[4]	386.46[2]
	48.5[4]		
Chitosan suspension	81.4[4]	279[4]	

*: Extraction bases may or may not be mixed with water. µMol TE/g (d.b) = µMol Trolox Equivalent/g of acerola by-product for results expressed on a dry basis. EC_{50} = expressed in µMol/µMol DPPH for [1], and in µg DPPH/mL extract for [2]. [1]: Caetano et al. (2011); [2]: Sousa et al. (2011); [3]: Rezende et al. (2017); [4]: Silva et al. (2021).

Despite being easily produced, the limitation of antioxidant extracts is in the high degradation of the active compounds in solution. Phenolic compounds, e.g., are unstable at a pH greater than 5 (Santos et al., 2017) and at temperatures greater than 100 ºC (Liazid et al., 2007). In view of these limitations, some authors choose to encapsulate their extracts in micro/nanoparticles in order to preserve their active properties. This new technology will be further discussed in Topic 5.

2.2 Antimicrobial properties

Previous works have shown that active extracts can have effects against Gram-positive or Gram-negative microorganisms, depending on the phenolic structures that constitute them, as well as at different intensities, depending on the amount of compounds present. Although acerola by-products have the potential to be used as a source of antimicrobial extracts, only two recent studies were found about their use. In this context, Lima et al. (2021) studied the effect of acerola by-product extracts against *Escherichia coli* strains and confirmed their antimicrobial potential, and they reported that the strain count was 99.9% lower than the sample without acerola by-product extract. Carneiro et al. (2020) also obtained good results with nanoparticles loaded with active extract based on acerola by-products, and these authors showed that the nanoparticles associated with the extract had a better effect than those without the extract against *Escherichia coli* and *Listeria monocytogenes*.

3 Technologies/materials based on acerola by-products

There are a large number of studies that offer a new destination for acerola by-products. Table 3 shows the form of production and the major characteristics of these products.

Among the products highlighted in Table 3, micro/nanoparticles are the technologies most recently used in the use of acerola by-products. The encapsulation of active compounds is a way to preserve their antioxidant/antimicrobial properties and minimize their degradation in variable conditions, such as pH, temperatures, and light. Particularly, the encapsulation methods of active compounds extracted from acerola by-products mentioned in the literature were ionic gelation and *spray drying*. The recent studies shown in Table 3 showed that it is possible to encapsulate different active compounds, such as phenolics, anthocyanins, vitamin C, and carotenoids (Rezende et al., 2018; Nascimento et al., 2019; Silva et al., 2022). The different encapsulation efficiency values are directly related to the method and the interaction of the active compound with the encapsulated agent. One of the problems involved in encapsulation methods is that many of them can be economically unfeasible. The encapsulation of synthetic compounds, such as quercetin (Jardim et al.,

2021) or gallic acid (Wu et al., 2019), makes the final product even more expensive. Thus, using the compounds extracted from a natural source, such as from acerola by-product, is a more sustainable alternative for the production of nanoparticles.

Table 3. Products based on acerola by-product.

Products	Formulation	Major Findings	Reference
Micro/ nanoparticles	• Dried and triturated by-product;	Encapsulation efficiency of phenolics: 35-50%;	Silva et al. (2022)
	• Extraction of phenolics in chitosan/acetic acid solvent, sonication and filtration;	Particles (optimum condition) with 127 nm and zeta potential +25.6 mV;	
	• Sodium tripolyphosphate dripping for particle formation by ionic gelation.	Particles stable under conditions of accelerated centrifugation and controlled release at different pH during 10 hours.	
	• Wet and triturated by-product;	Encapsulation efficiency of phenolics: 52%;	Silva et al. (2021); Silva & Martelli-Tosi (2021)
	• Extraction of phenolics in chitosan/acetic acid solvent, sonication and filtration;	Particles with 295 nm and zeta potential +28.0 mV;	
	• Sodium tripolyphosphate dripping for particle formation by ionic gelation;	Application as active guava coating: conservation for 15 days.	
	• Application in guavas.		
	• Lyophilized by-product;	Protection of active compounds for 44 days at 50 °C (5% degradation);	Carneiro et al. (2020)
	• Encapsulation by *spray drying* using gum arabic and maltodextrin.	Addition in acerola nectar for *in vitro* simulation: bioaccessibility and stability in gastrointestinal conditions.	
	• Non-detailed by-product processing;	Encapsulation efficiency of vitamin C: 64%;	Nascimento et al. (2019)
	• Extraction of vitamin C in chitosan/cloridric acid solvent, manual stirring and centrifugation;	Particles with 231 nm and zeta potential +19.2 mV;	
	• TPP dripping for particle formation by ionic gelation.	Application in nanocomposites film based on galactomannan matrix: activation and increase in elongation.	
	• Triturated by-product;	Encapsulation efficiency of: anthocyanins = 25.04%, carotenoids = 51.87%, and phenolics: 69.34%;	Rezende et al. (2018)
	• Extraction of active compounds in ethanol;	Particles with 99.26 μm.	
	• Encapsulation by *spray drying* using gum arabic and maltodextrin.		
Flour	• Dried and triturated by-product.	Presence of macronutrients such as proteins (7.32%) and carbohydrates (83.01%);	Monteiro et al. (2020)
		Identification of active compounds such as carotenoids and anthocyanins;	
		High levels of dietary fibers (77%): potential for incorporation in food formulations.	
	• Dried and triturated by-product.	Presence of macronutrients, such as proteins (8.51-11.55%);	Marques et al. (2013)
		Identification of micronutrients (such as iron, potassium and calcium);	
		Stability in water/oil emulsion: potential to be applied as a supplement to meat and bakery products.	
	• Dried and triturated by-product.	Presence of macronutrients, such as proteins (16.94%), fibers (26.54%), and carbohydrates (57.24%);	Aguiar et al. (2010)
		Identification of micronutrients (such as iron, potassium and calcium);	
		Presence of vitamin C (0.066%).	

Table 3. Continued…

Products	Formulation	Major Findings	Reference
Cookies	• Dried and triturated by-product;	Higher fiber content (45.7%) compared to cookies without acerola by-product (17.4%);	Lima et al. (2014)
	• Mixing the by-product with commercial flour/other ingredients and baking in oven.	Major sensory acceptance in relation to flavor (>98%).	
	• Dried and triturated by-product;	Nutritional enrichment (vitamin C: 0.021%);	Aquino et al. (2010)
	• Mixing the by-product with commercial flour/other ingredients and baking in oven.	Potential for partial replacement of commercial flour	
Nuggets	• Triturated by-product; • Mixture of the by-product with macerated cowpea/other ingredients and baking in oven.	Majority (51%) sensorially accepted compared to the traditional formulation (without by-product/with commercial flour).	Abreu et al. (2020)
Antioxidant dietary fiber	• Triturated by-product; • Enzymatic treatment for fiber isolation.	High levels of dietary fibers (77.81%): potential for incorporation in food formulations.	Carmo et al. (2018)
Adsorbent	• Dried and triturated by-product; • Hydrothermal carbonization.	Modification of functional groups and adsorption of dyes (environmental contaminants) in aqueous medium.	Nogueira et al. (2019)
Thermochemical industry	• Dried at different temperatures and triturated by-product.	High amounts of carbon (17.61-21.98%) and volatile material (75.36-79.74%);	Silva et al. (2020b)
		Possibility of use in the pyrolysis process.	
	• Dried (>100 °C) by-product.	High amounts of carbon (47.48%) and volatile material (75.33%);	Barbosa et al. (2017)
		Good hydrothermal carbonization or pyrolysis source.	

Furthermore, it is important to note that simultaneous extraction and encapsulation are possible depending on the encapsulating polymer, which can be an economically viable alternative. Silva et al. (2021, 2022) and Silva & Martelli-Tosi (2021) promoted the extraction of phenolic compounds directly in chitosan suspension. First, a chitosan extract with active compounds was produced (Table 2). Then, a cross-linking agent (sodium tripolyphosphate) was added to promote particle formation and entrapment of the compounds. After producing the material, the authors demonstrated the effectiveness of encapsulation by applying the extract and nanoparticles as an edible coating on guavas. Guavas coated with extract had a shelf life of 13 days; while guavas coated with encapsulated active compounds had a shelf life of 15 days. Along the same lines, a study conducted by Nascimento et al. (2019) focused on the extraction of vitamin C from acerola by-products directly in a chitosan suspension dissolved in hydrochloric acid. Particle formation also occurred by direct dripping of sodium tripolyphosphate into the suspension. The procedure made it possible to optimize the production of particles loaded with vitamin C from a natural source for application in polymeric matrices.

Another alternative to using acerola by-products is as additives or bases for food products. Flour based on an agro-industrial by-product is more economically viable compared to the traditional product. Moreover, studies have shown that the flour from the acerola by-product has many macronutrients, such as fibers, proteins, and carbohydrates, and micronutrients, such as calcium, potassium, iron, and zinc (Monteiro et al., 2020; Marques et al., 2013; Aguiar et al., 2010). The active composition of the by-product flour is also a differentiator. Vitamin C, for example, is commonly added to foods to preserve, nutritionally enrich, or stabilize color and aroma parameters. In the case of acerola by-product flour, up to 66 mg/100 g of this nutrient was obtained (Aguiar et al., 2010). Acerola flour has already been used in the formulation of various foods and its use is a way of fortifying the nutritional content of foods and reducing production costs.

Finally, acerola by-products are still being used in the areas of thermal and environmental treatment. Due to the important contents of organic matter, acerola by-products have levels of carbon and volatile material that facilitate combustion or hydrothermal carbonization in consequent conversion to generate clean energy (Barbosa et al., 2017 and Silva et al., 2020b). As the reactivity of its biomass is high, its burning results in greater production of liquid fuels. Still, within the combustion process the by-product can be used as an adsorbent material, since after burning its functional groups are oxygenated. A study carried out by Nogueira et al. (2019), for example, showed that it was possible to adsorb a cationic dye, proving that it is possible to use waste as a source of adsorbent for environmental contaminants.

In general, studies have shown that producing materials or technologies based on a by-product is not only a way to take advantage of this biomass, but also to impart particular properties of the by-product to the final product. Furthermore, with the same extract from the by-product, more than one application is possible, unlike what occurs with synthetic compounds. For example, the same extract of active compounds may contain more than one class of phenolic compounds in its composition and present simultaneous properties of antioxidant and antimicrobial action. In the same way, from a food point of view, flour based on a by-product is not only more economically viable but also has a higher nutritional content.

4 Conclusion and future trends

Phenolic compounds make the by-products of acerola an interesting material for the extraction of active compounds. Extracts can be obtained by using organic solvents and then encapsulated and used for the formulation of medicines, food fortification, or application in edible packaging. The presence of macronutrients, such as fibers, proteins, and carbohydrates, allows the use of the residue to produce highly nutritious and low-calorie flour, which can be used in the manufacture of food. The presence of volatile materials in the acerola by-product also places it as an important precursor in the generation of clean energy. In general, the products generated from acerola by-products not only have a sustainable origin but also prove to be competitive with the traditional ones available on the market. The studies conducted so far have shown that new work involving the feasibility of producing these materials on a large scale would enable the use of the acerola by-product as an industrial raw material.

References

Abreu, B. B., Moreira, L. R. L. F., Cavalcante, R. B. M., Campos, C., Gonçalves, M. F. B., Oliveira, É. L. C., Brandão, A. C. A. S., & Moreira-Araújo, R. S. R. (2020). Desenvolvimento de um “nugget” à base do resíduo da acerola (Malpighia emarginata D.C) e feijão-caupi (Vigna unguiculata L.). *Brazilian Journal of Development*, *6*(2), 9446-9453. http://dx.doi.org/10.34117/bjdv6n2-307

Aguiar, T. M., Rodrigues, S., Santos, R., & Sabaa-srur, A. U. O. (2010). Chemical characterization and evaluation of the nutritional value of Malpighia punicifolia seeds. *Food Science and Technology (Campinas)*, *33*(3), 91-102.

Alezandro, M. R., Granato, D., & Genovese, M. I. (2013). Jaboticaba (Myrciaria jaboticaba (Vell.) Berg), a Brazilian grape-like fruit, improves plasma lipid profile in streptozotocin-mediated oxidative stress in diabetic rats. *Food Research International*, *54*(1), 650-659. http://dx.doi.org/10.1016/j.foodres.2013.07.041

Aquino, A. C. M. S., Móes, R. S., Leão, K. M. M., Figueiredo, A. V. D., & Castro, A. A. (2010). Avaliação físico-química e aceitação sensorial de biscoitos tipo cookies elaborados com farinha de resíduos de acerola. *Revista do Instituto Adolfo Lutz*, *69*(3), 379-386.

Barbosa, G. A. N., Sehnem, G. S., Nogueira, G. D. R., Duarte, C. R., & Barrozo, M. A. S. (2017). Caracterização do resíduo de acerola visando a conversão termoquímica. *Congresso Brasileiro de Engenharia Química em Iniciação Científica*, *1*(4), 881-886. http://dx.doi.org/10.5151/chemeng-cobeqic2017-152

Borges, O. M. A., Cesca, K., Arend, G. D., Alvarez-Rivera, G., Cifuentes, A., Zielinski, A. A. F., & Poletto, P. (2021). Integrated green-based methods to recover bioactive compounds from by-product of acerola processing. *LWT*, *151*, 1-9. http://dx.doi.org/10.1016/j.lwt.2021.112104

Caetano, A. C. S., Araújo, C. R., Lima, V. L. A. G., Maciel, M. I. S., & Melo, E. A. (2011). Evaluation of antioxidant activity of agro-industrial waste of acerola (Malpighia emarginata D.C.) fruit extracts. *Food Science and Technology (Campinas)*, *31*(3), 769-775. http://dx.doi.org/10.1590/S0101-20612011000300034

Carmo, J. S., Nazareno, L. S. Q., & Rufino, M. S. M. (2018). Characterization of the acerola industrial residues and prospection of their potential application as antioxidant dietary fiber source. *Food Science and Technology (Campinas)*, *38*(Suppl.1), 236-241. http://dx.doi.org/10.1590/fst.18117

Carneiro, A. P. G., Aguiar, A. L. L., Lima, A. C. S., Sousa, P. H. M., & Figueiredo, R. W. (2020). Bioactive potencial of acerola by-product (Malphigia sp. L): bioacessibility in néctar. *Research*. *Social Development*, *9*(9), 1-22.

Carrington, C. M. S., & King, R. A. G. (2002). Fruit development and ripening in Barbados cherry, Malpighia emarginata DC. *Scientia Horticulturae*, *92*(1), 1-7. http://dx.doi.org/10.1016/S0304-4238(01)00268-0

Chitarra, M. I. F., & Chitarra, A. B. (2005). *Pós-colheita de frutas e hortaliças: Fisiologia e manuseio* (2. ed.). Lavras: UFLA.

Cruz, R. G., Beney, L., Gervais, P., Lira, S. P., Vieira, T. M. F. S., & Dupont, F. (2019). Comparison of the antioxidant property of acerola extracts with synthetic antioxidants using an in vivo method with yeasts. *Food Chemistry*, *277*, 698-705. PMid:30502205. http://dx.doi.org/10.1016/j.foodchem.2018.10.099

Delva, L., & Goodrich Schneider, R. (2013). Acerola (Malpighia emarginata DC): Production, postharvest handling, nutrition, and biological activity. *Food Reviews International*, *29*(2), 107-126. http://dx.doi.org/10.1080/87559129.2012.714433

Duzzioni, A. G., Lenton, V. M., Silva, D. I. S., & Barrozo, M. A. S. (2013). Effect of drying kinetics on main bioactive compounds and antioxidant activity of acerola (Malpighia emarginata D.C.) residue. *International Journal of Food Science & Technology*, *48*(5), 1041-1047. http://dx.doi.org/10.1111/ijfs.12060

Gualberto, N. C., Oliveira, C. S., Nogueira, J. P., Jesus, M. S., Araujo, H. C. S., Rajan, M., Neta, M. T. S. L., & Narain, N. (2021). Bioactive compounds and antioxidant activities in the agro-industrial residues of acerola (Malpighia emarginata L.), guava (Psidium guajava L.), genipap (Genipa americana L.) and umbu (Spondias tuberosa L.) fruits assisted by ultrasonic or shaker extraction. *Food Research International*, *147*, 110538. PMid:34399515.

Jardim, K. V., Siqueira, J. L. N., Bao, S. N., & Parize, A. L. (2021). *In vitro* cytotoxic and antioxidant evaluation of quercetin loaded in ionic cross-linked chitosan nanoparticles. *Journal of Drug Delivery Science and Technology*, *74*, 103561. http://dx.doi.org/10.1016/j.jddst.2022.103561

Liazid, A., Palma, M., Brigui, J., & Barroso, C. G. (2007). Investigation on phenolic compounds stability during microwave-assisted extraction. *Journal of Chromatography. A*, *1140*(2), 29-34. PMid:17141250. http://dx.doi.org/10.1016/j.chroma.2006.11.040

Lima, M. C., Magnani, M., Lima, M. S., Sousa, C. P., Dubreuil, J. D., & Souza, E. L. (2021). Phenolic-rich extracts from acerola, cashew apple and mango by-products cause diverse inhibitory effects and cell damages on enterotoxigenic Escherichia coli. *Letters in Applied Microbiology*, *74*(2), 1-13. PMid:34687563.

Lima, P. C. C., Avila, R. G., Silva, D. V., Cardoso, P. F., & Oliveira, M. D. (2014). Utilização de resíduo do processamento de acerola (Malpighia Emarginata D.C.) na confecção de biscoito tipo língua de gato. *Revista Brasileira de Tecnologia Agroindustrial*, *8*(2), 1488-1500. http://dx.doi.org/10.3895/S1981-36862014000200004S1

Lima, V. L. A. G., Melo, E. A., Maciel, M. I., & Lima, D. E. S. (2003). Avaliação do teor de antocianinas em polpa de acerola congelada proveniente de frutos de 12 diferentes aceroleiras (*Malpighia emarginata D.C.*). *Food Science and Technology (Campinas)*, *23*(1), 101-103. http://dx.doi.org/10.1590/S0101-20612003000100021

Marques, T. R., Caetano, A. A., Simão, A. A., Castro, F. C. O., Ramos, V. O., & Corrêa, A. D. (2016). Metanolic extract of Malpighia emarginata bagasse: phenolic compounds and inhibitory potential on digestive enzymes. *Brazilian Journal of Pharmacognosy*, *26*(2), 191-196. http://dx.doi.org/10.1016/j.bjp.2015.08.015

Marques, T. R., Corrêa, A. D., Lino, J. B. R., Abreu, C. M. P., & Simão, A. A. (2013). Chemical constituents and technological functional properties of acerola (Malpighia emarginata DC.) waste flour. *Food Science and Technology (Campinas)*, *33*(3), 526-531. http://dx.doi.org/10.1590/S0101-20612013005000085

Miskinis, R. A. S., Nascimento, L. A., & Colussi, R. (2023). Bioactive compounds from acerola pomace: A review. *Food Chemistry*, *404*(Pt A), 134613. PMid:36444022. http://dx.doi.org/10.1016/j.foodchem.2022.134613

Monteiro, S. A., Barbosa, M. M., Maia da Silva, F. F., Bezerra, R. F., & Silva Maia, K. (2020). Preparation, phytochemical and bromatological evaluation of flour obtained from the acerola (Malpighia punicifolia) agroindustrial residue with potential use as fiber source. *Food Science and Technology (Campinas)*, *134*, 1-7.

Moreira, G. E. G., Azeredo, H. M. C., Medeiros, M. D. D., Brito, E. S., & Souza, A. C. R. (2010). Ascorbic acid and anthocyanin retention during spray drying of acerola pomace extract. *Journal of Food Processing and Preservation*, *34*(5), 915-925. http://dx.doi.org/10.1111/j.1745-4549.2009.00409.x

Moura, C. F. H., Oliveira, L. S., Souza, K. O., Franca, L. G., Ribeiro, L. B., Souza, P. A., & Miranda, M. R. A. (2018). Acerola–*Malpighia-emarginata* (pp. 7-14). In S. Rodrigues, E. O. Silva & E. S. Brito (Eds.), *Exotic Fruits.* London: Academic Press. http://dx.doi.org/10.1016/B978-0-12-803138-4.00003-4.

Nascimento, J. A. A., Gomes, L. K. S., Duarte, D. S., Lima, M. A. C., & Britto, D. (2019). Stability of nanocomposite edible films based on polysaccharides and vitamin C from agroindustrial residue. *Materials Research*, *22*(3), 10. http://dx.doi.org/10.1590/1980-5373-mr-2019-0057

Nogueira, G. D. R., Duarte, C. R., & Barrozo, M. A. S. (2019). Hydrothermal carbonization of acerola (Malphigia emarginata D.C.) wastes and its application as an adsorbent. *Waste Management (New York, N.Y.)*, *95*, 466-475. PMid:31351633. http://dx.doi.org/10.1016/j.wasman.2019.06.039

Oliveira, L. S., Moura, C. F. H., Brito, E. S., & Mamede, R. V. S. (2012). Antioxidant metabolism during fruit development of different acerola (Malpighia emarginata DC) clones. *Journal of Agricultural and Food Chemistry*, *60*(32), 7957-7964. PMid:22834960. http://dx.doi.org/10.1021/jf3005614

Poletto, P., Álvarez-Rivera, G., López, G. D., Borges, O. M. A., Mendiola, J. A., Ibáñez, E., & Cifuentes, A. (2021). Recovery of ascorbic acid, phenolic compounds and carotenoids from acerola by-products: an opportunity for their valorization. *LWT*, *146*, 1-8. http://dx.doi.org/10.1016/j.lwt.2021.111654

Ramadan, L., Duarte, C. R., & Barrozo, M. A. S. (2019). A new hybrid system for reuse of agro-industrial wastes of acerola: Dehydration and fluid dynamic analysis. *Waste and Biomass Valorization*, *10*(8), 2273-2283. http://dx.doi.org/10.1007/s12649-018-0247-4

Rezende, Y. R. R. S., Nogueira, J. P., & Narain, N. (2017). Comparison and optimization of conventional and ultrasound assisted extraction for bioactive compounds and antioxidant activity from agro-industrial acerola (Malpighia emarginata DC) residue. *Food Science and Technology (Campinas)*, *85*, 158-169.

Rezende, Y. R. R. S., Nogueira, J. P., & Narain, N. (2018). Microencapsulation of extracts of bioactive compounds obtained from acerola (Malpighia emarginata DC) pulp and residue by spray and freeze drying: Chemical, morphological and chemometric characterization. *Food Chemistry*, *254*, 281-291. PMid:29548455. http://dx.doi.org/10.1016/j.foodchem.2018.02.026

Sancho, S. O., Silva, A. R. A., Dantas, A. N. S., Magalhaes, T. A., Lopes, G. S., Rodrigues, S., Costa, J. M. C., Fernandes, F. A. N., & Silva, M. G. V. (2015). Characterization of the industrial residues of seven fruits and prospection of their potential application as food supplements. *Journal of Chemistry*, *2015*(8), 1-8. http://dx.doi.org/10.1155/2015/264284

Santos, S. S., Rodrigues, L. M., Costa, S. C., & Madrona, G. S. (2017). Antioxidant compounds from blackberry (Rubus fruticosus) pomace: Microencapsulation by spray-dryer and pH stability evaluation. *Food Packaging and Shelf Life*, *20*, 5.

Silva, J. D. O., Santos, D. E. L., Abud, A. K. S., & Oliveira Júnior, A. M. (2020a). Characterization of acerola (Malpighia emarginata) industrial waste as raw material for thermochemical processes. *Waste Management (New York, N.Y.)*, *107*, 143-149. PMid:32283488. http://dx.doi.org/10.1016/j.wasman.2020.03.037

Silva, L. M. R., Figueiredo, E. A. T., Ricardo, N. M. P. S., Vieira, I. G. P., Figueiredo, R. W., Brasil, I. M., & Gomes, C. L. (2014). Quantification of bioactive compounds in pulps and by-products of tropical fruits from Brazil. *Food Chemistry*, *143*, 398-404. PMid:24054258. http://dx.doi.org/10.1016/j.foodchem.2013.08.001

Silva, N. C., Assis, O. B., Sartori, A. G. O., Alencar, S. M., & Martelli-Tosi, M. (2022). Chitosan suspension as extractor and encapsulating agent of phenolics from acerola by-product. *Food Research International*, *161*, 111855. PMid:36192901. http://dx.doi.org/10.1016/j.foodres.2022.111855

Silva, N. C., Barros-Alexandrino, T. T., Assis, O. B. G., & Martelli-Tosi, M. (2021). Extraction of phenolic compounds from acerola by-products using chitosan solution, encapsulation and application in extending the shelf-life of guava. *Food Chemistry*, *354*(30), 129553. PMid:33756316. http://dx.doi.org/10.1016/j.foodchem.2021.129553

Silva, N. C.; Martelli-Tosi, M. (2021). BR 10 2021 011708 7. Extração de compostos fenólicos de resíduos da polpa de acerola: encapsulação em micro/nanopartículas e quitosana. São Paulo: Universidade de São Paulo.

Silva, P. B., Duarte, C. R., & Barrozo, M. A. S. (2019). A novel system for drying of agro-industrial acerola (Malpighia emarginata D. C.) waste for use as bioactive compound source. *Innovative Food Science & Emerging Technologies*, *52*, 350-357. http://dx.doi.org/10.1016/j.ifset.2019.01.018

Silva, P. B., Mendes, L. G., Rehder, A. P. B., Duarte, C. R., & Barrozo, M. A. S. (2020b). Optimization of ultrasound-assisted extraction of bioactive compounds from acerola waste. *Journal of Food Science and Technology*, *57*(12), 4627-4636. PMid:33087974. http://dx.doi.org/10.1007/s13197-020-04500-8

Sousa, M. S. B., Vieira, L. M., & Lima, A. (2011). Fenólicos totais e capacidade antioxidante in vitro de resíduos de polpas de frutas tropicais. *Brazilian Journal of Food Technology*, *14*(3), 202-210. http://dx.doi.org/10.4260/BJFT2011140300024

Souza, K. O., Moura, C. F. H., Brito, E. S., & Miranda, M. R. A. (2014). Antioxidant compounds and total antioxidant activity in fruits of acerola from Cv. Flor Branca, Florida Sweet and Brs 366. *Revista Brasileira de Fruticultura*, *36*(2), 294-304. http://dx.doi.org/10.1590/0100-2945-410/13

Wu, C., Li, Y., Du, Y., Wang, L., Tong, C., Hu, Y., Pang, J., & Yan, Z. (2019). Preparation and characterization of konjac glucomannan-based bionanocomposite film for active food packaging. *Food Hydrocolloids*, *89*, 682-690. http://dx.doi.org/10.1016/j.foodhyd.2018.11.001

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