Can Tho University Journal of Science
website: ctujs.ctu.edu.vn

DOI: 10.22144/ctu.jen.2022.011

Bioactive compounds and strategy processing for acerola: A review

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Article info.

Received 06 Aug 2021
Revised 16 Nov 2021
Accepted 31 Dec 2021

Keywords

Acerola, bioactive compound, food processing, valorization

ABSTRACT

Various studies have evaluated that acerola fruit is one of the best natural sources of vitamin- C. Besides that, the fruits also contain a high level of phenolic and carotenoids. The result tested in vitro performed that acerola extract can be antioxidative, anti-inflammatory, antihyperglycemic, antitumor antigenotoxic and hepatoprotective activity. The techniques such as pasteurization, fermentation, extraction, drying, encapsulation can diversify acerola products.

1. INTRODUCTION

Acerola fruits are commonly grown in the provinces of the Mekong Delta, Viet Nam. In which, the yield of this fruit is noticeable high in Tien Giang province. Various studies showed that acerola is one of the richest sources of vitamin C, with a level higher at least 10 times than citrus fruits such as oranges, lemons and tangerines (Ruiz-Torralba et al., 2018). In addition, the researchers also found that acerola contains many phytochemical components such as anthocyanins, phenolic, and carotenoids (Ribeiro & de Freitas, 2020). These compounds were proved to be good for people's health with preventing effect on chronic diseases such as oxidation, hyperglycemic, inflammation, and obesity (Belwal et al., 2018). Moreover, acerola fruits have sweet and sour tastes and attractive yellow, orange, or red colors. However, the fast-ripening rate, thin skin, and succulent structure lead acerola fruits to the fact that they are easily damaged during transportation as well as rotten by microorganisms. Its shelf life performs a short period of 2 to 3 days after being harvested (Vendramini &Trugo, 2000).

Processing of several new valuable products from raw agricultural materials is one of the effective post-harvest preservations practices. However, in Viet Nam, the products made from acerola are still limited with a few traditional products like fresh fruit, juice, and jam. This report mentions the physicochemical properties of acerola fruit under the different maturity stages, as well as the postharvest techniques. Besides, the processing methods that diversify products from acerola are also mentioned.

2. MATURATION AND POSTHARVEST PRESERVATION

The quality of raw materials is one of the key factors that impact the quality of products. Raw material could be sorted based on nutrient content, organoleptic quality, shape, appearance, which are affected by environmental factors (temperature, light, fertilizer, water, cultivation conditions, harvest technique) and intrinsic factors (species) from cultivation to postharvest stages.

2.1. Maturation

Based on the skin's color, acerola fruits can be divided into 3 maturity indexes include unripe, half-

ripe, and ripe with skin's colors are green, yellow/ orange-red, and bright red, respectively (Figure 1) (Vendramini & Trugo, 2000). In acerola pulp, the total soluble solid increases following the increase of maturity index; in contrast, the total acidity content and pH are slightly different. Increasingly total soluble solid content within the advancing fruit maturity could be explained by a mechanism of the starch biosynthesis in the plant then starch hydrolyzed into sugar in the fruits (Kulkarni & Aradhya, 2005).

For bioactive compounds such as phenolic and vitamin C gradually decrease with advancing maturity, while anthocyanin and β-carotene increase from unripe to ripe fruit (Table 1). During the development of fruit, some enzymatic browning may be active which leads to reduced phenolic compounds as substrates. On the other hand, some phenolic materials contribute to the biosynthesis of anthocyanin structure (Kulkarni & Aradhya, 2005)

Depending on the demand of manufacturers the maturity index of acerola can be a choice suitable for processing. In a case, the extraction of bioactive compounds achieves high efficiency, the unripe fruits should be used; on the opposite, the ripe and half-ripe fruits are suitable for food processing due to high organoleptic quality.

Table 1. Physicochemical properties in acerola fruits under the different maturity stages

Attributes	Maturity index		
	Immature (Green)	**Intermediate (Yellow/Orange red)**	**Mature (Red)**
TSS%	7.8 [a]	7.7 [a]	9.2 [a]
	-	8.7 [b]	9.6 [b]
	6.9-7.6 [c]	7.1-7.8 [c]	7.7-8.6 [c]
pH	3.70 [a]	3.6 [a]	3.7 [a]
TA %	-	0.88 [b]	0.78 [b]
	1.86-2.11 [c]	1.67-2.05 [c]	1.67-2.05 [c]
L*	27.92 [a]	30.80 [a]	9.34 [a]
		75.51 [b]	55.36 [b]
	52.09 [f]	52.51 [f]	43.73 [f]
a*	-8.67 [a]	21.97 [a]	25.97 [a]
	-	-1.66 [b]	34.15 [b]
b*	11.37 [a]	12.13 [a]	-6.34 [a]
	-	39.09 [b]	27.39 [b]
	40.62 [f]	38.32 [f]	31.37 [f]
Vitamin C (mg AAE/100g fresh weight)	2164 [a]	1074 [a]	-
	-	1178.53 [b]	899.20 [b]
	3560 [c]	2590 [c]	2160 [c]
	-	894 [f]	470 [f]
TPC (mg GAE/g dry weight)	2623-2921 [e]	2060 [e]	1034-1048 [e]
	1131.7 [f]	1019.1 [f]	1028.3 [f]
Carotenoid (µg βcarotene/g fresh weight)	0.32-3.23 [d]	0.75-4.19 [d]	9.4-30.9 [d]
	28.38-30.79 [e]	30.06 [e]	28.15-46.23 [e]
CAN (mg/100g fresh weight)	0.92-1.74 [c]	1.92-4.30 [c]	6.79-7.28 [c]
$TEAC_{DPPH}$ (mM TE/kg)	251 [f]	142 [f]	101 [f]

TSS: total soluble solid, TA: total acidity, ACN: anthocyanin, AA: ascorbic acid, TPC: total phenolic content, GAE: gallic acid equivalent; TEAC: trolox equivalent antioxidant capacity, AAE: ascorbic acid equivalent, na: not avaiable, L: 0 indicates black, and 100 indicates white, a*: positive values indicate red and negative values indicate green, b*: positive values indicate yellow and negative values indicate blue.*

–: Data not informed in the reference

[a] Vendramini & Trugo (2000), [b] Le and Le (2018), [c] Ribeiro and de Freitas (2020), [d] Lima et al. (2005) [e] Vasavilbazo-Saucedo et al. (2018), [f] Delva & Schneider (2013).

The data had a format of "number – number" which means data were expressed under range value (i.e., from number to number).

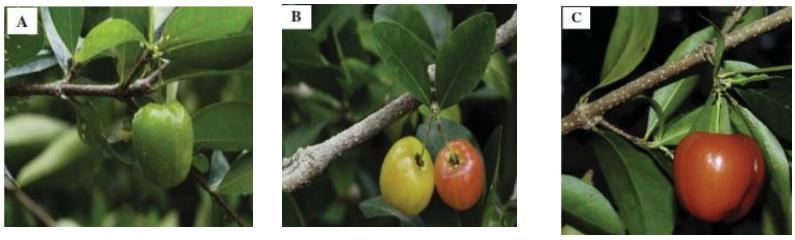

Figure 1. The skin color of acerola at the different maturity stages (A) unripe, (B) half-ripe, and (C) ripe

(Source: Delva & Schneider, 2013)

2.2. Postharvest preservation

After 3 or 4 weeks of flowering, acerola fruits achieve ripening (Vendramini & Trugo, 2000). Acerola fruit belongs to the climacteric group. These ripe fruits have a high rate of respiration and ethylene production so they have a short living after being harvested. In addition, acerola fruits have thin skin. If the skin layer is damaged, the pulp deteriorates rapidly. Therefore, fresh acerola fruits need to be treated quickly after harvest. The shelflife or quality of mature fruit is only 2–3 days at room temperature (Vendramini & Trugo, 2000). Its shelf life can be improved by storage at low temperature. According to a report by Ribeiro and de Freitas (2020), the temperature of 10-12℃, RH 90-95% limited the chilling injury during storage. Under these conditions, acerola fruits were maintained good quality after 14 days of storage.

Besides of controlling storage temperature, the modified atmosphere packaging can be also used to prolong the shelf life of acerola fruits. If these fruits were packed in polyvinyl chloride bags, which their shelf life could be improved to more than three days at room temperature, and 1 week at 8℃ (Alves et al., 1993). Moreover, solution of xanthan gum 1.4% was used as a coating material for acerola fruit to extend the living of fruit to 6 days at room temperature (29-31℃) (Quoc et al., 2015). Besides, the coated acerola fruits with 1% and 2% cassava biofilm could be stored up to 15 days at 10℃. Interestingly, acerola puree was used as an ingredient in biofilm formulation to preserve fresh acerola fruits. The biofilm contains alginate, acerola puree, cellulose whiskers, and montmorillonite which not only reduced weight loss, and ascorbic acid loss but also delayed the ripening process of the coated acerola (Azeredo et al., 2012).

3. COMPOSITION OF ACEROLA

3.1. Bioactive compounds

Phytochemicals are secondary metabolites that are present in plants. The major group of phytochemicals in acerola includes phenolic, ascorbic acid, carotenoid, anthocyanin. There are good benefits for human health such as anti-obesity, anti-inflammatory, antitumor, anti-cancer, improve collagen synthesis, and pro-vitamin A activity (Rasouli et al., 2017, Grosso et al., 2013). The phenolic content in acerola is higher than apple, mango, banana, grape, and orange. Especially, the vitamin C in acerola is higher approximately 10-20 times than citrus fruits (orange, pummelo, and lime) which are the traditional vitamin C sources. Moreover, the β- carotene content in acerola is higher than some vegetables (okra, cauliflower, cabbage) and fruit (mango, banana, pineapple), but lower than the vegetable and fruit have dark yellow, dark red, or dark green pigments such as pumpkin, capsicum, gac fruit (*Momordica cochinchinensis* Spreng). The anthocyanin content of acerola is lower than fruit berries such as blackberry, blueberry, grape and red currant (Table 2).

Table 2. The bioactive compounds and antioxidant activity of common fruit and vegetables

Sources	TPC (mg GAE/100g FW)	Vitamin C (mg AAE/100g FW)	β-carotene (µg/100g FW)	ACN (mg/100g FW)	$TEAC_{DPPH}$ (mg/100g FW)
Acerola	1028-1131 [a]	470-1238 [a]	-		101-251 [a*]
	805-1150 [b]	920.00 [b]	536.55 [b]	2.70–5.2 [b]	36.56-122.69 [b*]
Apple	197.00 ± 4.92 [c]	4.60 [d]	19.00 [g]	2.30 ± 0.80 [h]	52.90 ± 2.02 [i]
Banana	36.90 ± 1.94 [c]	8.70 [d]	40–130 [g]	-	52.90 ± 2.02 [i]
Blackberry	301.00 ± 16.2 [c]	21.00 [d]	-	245.00 ± 68.00 [h]	2210 ± 97.20 [i]
Blueberry	258.00 ± 2.15 [c]	9.70 [d]	-	386.60 ± 77.70 [h]	2210 ± 97.20 [i]
Cherry	70.20 ± 2.96 [c]	3.20 [d]	-	122.00 ± 21.30 [h]	242 ± 14.00 [i]
Grape red	124.00 ± 6.28 [c]	3.20 [d]	20.00 [g]	26.70 ± 10.90 [h]	713 ± 22.80 [i]
Grapefruit	71.20 ± 1.42 [c]	61.00 [d]	-	-	130 ± 1.19 [i]
Kiwi	71.70 ± 3.86 [c]	92.70 [d]	<20 [g]	-	130 ± 1.19 [i]
Lime	67.50 ± 2.23 [c]	29.10 [d]	-	-	130 ± 1.19 [i]
Mango	31.30 ± 0.71 [c]	36.40 [d]	-	-	130 ± 6.19 [i]
Nectarine	25.20 ± 0.12 [c]	5.40 [d]	-	-	80.4 ± 3.67 [i]
Strawberry	25.20 ± 0.12 [c]	58.50 [d]	-	21.20 ± 3.30 [h]	1053 ± 64.80 [i]
Passion fruit	292.00 ± 11.1 [c]	-	360–780 [g]	-	1125 ± 36.60 [i]
Peach	53.20 ± 2.92 [c]	-	-	-	46.5 ± 1.33 [i]
Pineapple	56.20 ± 1.51 [c]	47.80 [d]	140–350 [g]	-	202 ± 7.76 [i]
Pomegranate	133.00 ± 7.07 [c]	10.20 [d]	-	-	202 ± 7.76 [i]
Plum	134.00 ± 5.26 [c]	9.50 [d]	90-140 [g]	19.00 ± 4.40 [h]	621 ± 29.90 [i]
Strawberry	134.00 ± 5.26 [c]	58.50 [d]	-	21.20 ± 3.30 [h]	1053 ± 64.80 [i]
Watermelon	78.50 ± 2.76 [c]	-	310–780 [g]	-	1053 ± 64.80 [i]
Raspberry	266.00 ± 9.41 [c]	26.20 [d]	-	-	2150 ± 80.30 [i]
Redcurrant	269.00 ± 19.6 [c]	-	-	12.80 [h]	1929 ± 90.50 [i]
Blackurrant	-	181.00 [d]	-	476.00 ± 11.00 [h]	-
Lemon	-	53.00 [d]	-	-	-
Elderberries	-	36.00 [d]	-	1375.00 [h]	-
Gooseberries	-	27.70 [d]	-	10.40 ± 0.10 [h]	-
Nectarines	25.20 ± 0.12 [c]	5.40 [d]	-	6.80 ± 1.50 [h]	80.40 ± 3.67 [i]
Orange	75.70 ± 2.60 [c]	59.10 [d]	110-320 [g]	-	125 ± 3.65 [i]
Apricot	20.60 ± 0.99 [c]	10.00 [d]	590–3800 [g]	-	72.70 ± 3.72 [i]
Tangerine	85.10 ± 4.09 [c]	26.70 [d]	260.00 [g]	-	171 ± 3.40 [i]
Pumpkin	-	-	1135-1224 [e]	-	-
Capsicum	-	-	144-169 [e]	-	-
Cauliflower	-	48.20 [d]	1.00-2.50 [e]	-	-
Cabbage	-	36.60 [d]	20-32 [e]	-	-
Tomato	-	13.70 [d]	48-71 [e]	-	-
Green beans	-	12.20 [d]	220-257 [e]	-	-
Gac pulp	-	-	24000–43200 [f]	-	-
Gac aril	-	-	160000 [f]	-	-
Gac skin	-	-	38400–141600 [f]	-	-

Data of total phenolic content reported by [a] Delva & Schneider (2013), [b] Mezadri et al. (2008), [c] Ruiz-Torralba et al. (2018).

Data of vitamin C content reported by [a] Delva & Schneider (2013), [b] Mezadri et al. (2008), [d] Mieszczakowska-Frąc et al. (2021)

Data of β-carotene content reported by [b] Mezadri et al. (2018), [e] Kandlakunta et al. (2008), [f] Kha et al. (2013), [g] Elvira-Torales et al. (2019)

Data of anthocyanin content reported by [a] Delva & Schneide (2013), [b] Mezadri et al. (2008), [h] Wu et al. (2006).

*Data of antioxidant activity reported by [a] Delva & Schneider (2013), [I] Ruiz-Torralba et al. (2018), *: the unit of value was mmol trolox equivalent/kg.*

–: Data not informed in the reference

ACN: anthocyanin, AA: ascorbic acid, TPC: total phenolic content, GAE: gallic acid equivalent; TEAC: trolox equivalent antioxidant capacity, AAE: ascorbic acid equivalent, FW: fresh weight,

The data had a format of "number – number" which mean data were expressed under range value (i.e., from number to number).

By-products of fruits were picked up from peels, seeds, and unused flesh that were generated by different steps of the industrial process. They were organic residues, which should be treated properly, as their incorrect disposal may bring environmental problems, and loss of raw materials. In addition, to being used as a source of naturally occurring constituents, fruit by-products could be exploited in bioprocess to enhance their bioactive properties, being a possible added-value destination for these materials (Sagar et al., 2018). Acerola by-products had advantages characterized as rich sources of bioactive, such as phenolic compounds, carotenoids and vitamins C, besides to have important antioxidant activities (Table 3). According to Rezende et al., (2018), the performance of total anthocyanin, carotenoid, phenolic, and total flavonoid content in the extract of acerola residue (seed and peel) was higher than the pulp. Moreover, Marques et al. (2015) also found calcium, potassium, phosphorus, magnesium, dietary fiber in the acerola flour made from seed flour and bassage.

Table 3. The bioactive compounds and antioxidant activity of acerola-by product

Material	Total phenolic content (mg gallic acid/100g wb)	Anthocyanin content (mg/100g wb)	Ascorbic acid content (mg/100g wb)	Total antioxidant activity (µM Trolox/g wb)	References
Seed, peel, little pulp	545.98 ± 1.13	19.43 ± 1.1	175.76 ± 1.39	17.70 ± 1.56	(Carmo et al., 2018)
Bark and seed	-	-	30.13 ± 0.03	-	(de Oliveira et al., 2020)
Residue	12.59 ± 0.001	-	16.12 ± 0.003	-	(Duzzioni et al., 2013)
Skin, seed, residual pulp*	10286.1 ± 40.9	798.5 ± 21.3	1002.4 ± 13.8	113.7 ± 0.4	(Nóbrega et al., 2015)
Seed*	7265.29 ± 16.78	245.90 ± 24.38	-	-	(Da Silva et al., 2014)

*–: Data not reported in the reference * The value was calculated based on dry weight*

wb: wet base

3.2. Analytical methods

3.2.1. Total phenolic content

The Folin–Ciocalteu's reagent was used for total phenol content determination (Lim et al., 2007; Singleton & Rossi,1965). The aliquot of 0.3 mL of extract was added to 1.5 mL of Folin–Ciocalteu's reagent (diluted 10 times with distilled water) and 1.2 mL of 7.5% sodium carbonate. After vortexing, the samples were left for 30 min. The total phenol content was determined by using a spectrophotometer at a wavelength of 765 nm (Jasco, V730, Japan). The standard curve was prepared using solutions of gallic acid (GAE) and then total phenol content is expressed as mg GAE / 100 g dry matter (dm).

$$TPC\ (\text{mg/100g dry matter}) = \frac{A\ x\ V\ x\ df\ x\ 100\ x\ 100}{m \times 1000}$$

Where, A: phenolic content was picked up from the standard curve. V: volume of solution (mL). df: dilution factor, m: mass of sample based on dry matter (g). 100/1000: the coefficient converts from µg/g to mg/100g.

3.2.2. Ascorbic acid content

Ascorbic acid content was determined using the 2, 6- dichlorophenol-indophenol titration method (Dinesh et al., 2015). Dye reagent preparation: 84 mg of sodium bicarbonate, 104 mg of 2, 6-dichlorophenol indophenol was dissolved completely in 400 mL of distilled water. 5 mL of working standard (500 **µ**g/5mL) of L- ascorbic acid and 10 mL of 4% oxalic acid were poured into a 100 mL conical flask. This sample was titrated with the dye reagent until the appearance of pale pink color. The test sample was carried out similarly to the control sample.

$$Ascorbic\ acid\ content\ (mg/100g) = \frac{V_2\ x\ 25\ x\ 500\ x\ 100}{V_1\ x\ 5\ x\ 5}$$

Where: V_1: mL of dye reagent used to titrate the control sample, V_2: mL of dye reagent used to titrate the test sample.

3.2.3. Antioxidant activity

The DPPH reagent was used for antioxidant activity determinations (Thaipong et al., 2006) The aliquot of 0.2 mL of extract was added to 4 mL of 0.1 mM DPPH solution. After vortexing, the samples were left for 30 mins at room temperature. The antioxidant capacity was determined by using a spectrophotometer at a wavelength of 517 nm. The standard curve was prepared using solutions of Trolox (TE) and then antioxidant capacity is expressed as mg TE / 100 g dry matter (dm).

$$DPPH\ (\text{mg/100g dry matter}) = \frac{A\ x\ V\ x\ df\ x\ 100\ x\ 100}{m \times 1000}$$

Where, A: DPPH value was picked up from the standard curve. V: volume of solution (mL). df: dilution factor, m: mass of sample based on dry matter (g). 100/1000: the coefficient converts from µg/g to mg/100g.

3.2.4. Total anthocyanin content

Total monomeric anthocyanin content was determined by the pH differential method (Lee et al., 2005). The extract is simultaneously diluted with buffer pH 1.0 (potassium chloride 0.025 M) and buffer pH 4.5 (sodium acetate 0.4 M) to reach OD value at wavelenghth 520 nm stay in 0.2-1.4. Next, the sample is measured at wavelenghth 520 nm and 700 nm.

$$\text{A (mg/100g dry matter)} = \frac{\text{A xMWxDFxVx100}}{\varepsilon \text{xlxmx}(1-\%\,ẩm)}$$

Where, A = (A_{520nm}.pH = 1– A_{700nm}.pH = 1) - (A_{520nm}.pH = 4,5 – A_{700nm}.pH = 4,5) A_{520nm}, A_{700nm}: OD values at wavelength 520 and 700 nm, pH = 1 and pH = 4,5; MW: the molecular weight of anthocyanin was expressed in cyanidin 3-glucoside (449,2 g/mol); df: dilution factor, ε: molar extinction coefficient (26.900 $L.mol^{-1}.cm^{-1}$ at λ = 520 nm); l: cuvet pathlength (1cm).

4. PROCESSING OF ACEROLA

Normally, acerola fruit is used for fresh-cut, jam, and juice. Currently, in the domestic Vietnam market, there are a few commercial products such as acerola juice, acerola wine. Moreover, the other products such as acerola powder, smoothies and puree have appeared on the world market. Besides the application in food, acerola extract can also be utilized in the processing of cosmetics (Hanamura et al., 2006) and pharmaceutical products (Belwal et al., 2018; Hanamura et al., 2006). Fermentation, pasteurization, concentration and drying were applied conventionally in fruit and vegetable processing. Nowadays, emerging methods like membrane technology, extraction (assisted enzymes and sound waves), encapsulation, high-pressure processing have been also applied in fruit processing. (Rodrigues & Fernandes, 2012). Combining these processing methods (conventional and emerging technologies) promises to create valuable products from acerola fruit and its by-products. The summary diagram of potential development direction for acerola products is shown in Figure 2.

4.1. Thermal processing

Besides the inhibition growth of pathogenic microorganisms, thermal processing has a great influence on the degradation of heat-sensitive compounds such as vitamin C and phenolic (Jaeschke et al., 2016; Mercali et al., 2012). Currently, many emerging thermal treatments have also been developed such as ohmic heating (Jaeschke et al., 2016; Mercali et al., 2012), ultrasonication, and high-pressure processing (Feng et al., 2020). These techniques have many advantages including inhibiting effectively harmful microorganisms, limiting the loss of bioactive compounds, and reducing processing time. However, these methods require high investment costs, thus they are not suitable for application in companies that have a small and medium scale. Depending on the purpose of processing, the manufacturer can choose an appropriate method. Currently, the published papers related to acerola juice major used mild temperature long time method.

The beverage could be produced from pure or mixture of acerola juice, but most of the studies focus on developing mixed juice. Specifically, the mixed juice combined 50% acerola juice, 10% passion juice, and 40% pineapple juice. The product had a good sensory quality when its concentration was in a recipe of 70% and was pasteurized at 90°C for 34.39 minutes (Le et al., 2009). On the other hand, acerola juice could be mixed with cashew apple, mango; in which the high level of acerola and cashew apple pulps in formulation gave the product with high vitamin C and total phenolic contents; in contrast, the high mango pulp concentration increased to total carotenoids (Silva et al., 2016).

The beverage made from 25% acerola pulp, 75% green coconut water, sugar, and caffeine (125 mg/L) had a good organoleptic quality. The heated product

in transparent glass had a shell life at least 6 months at 27 ± 2 °C (Da et al., 2009). Other acerola products with 35% mixed fruit juice (cashew apple, papaya, guava, acerola, and passion fruit), 10% sugar, caffeine, and preservative agents were also found by De Sousa et al. (2010). This product performed a good sensory acceptance, which suggests a high commercial potential.

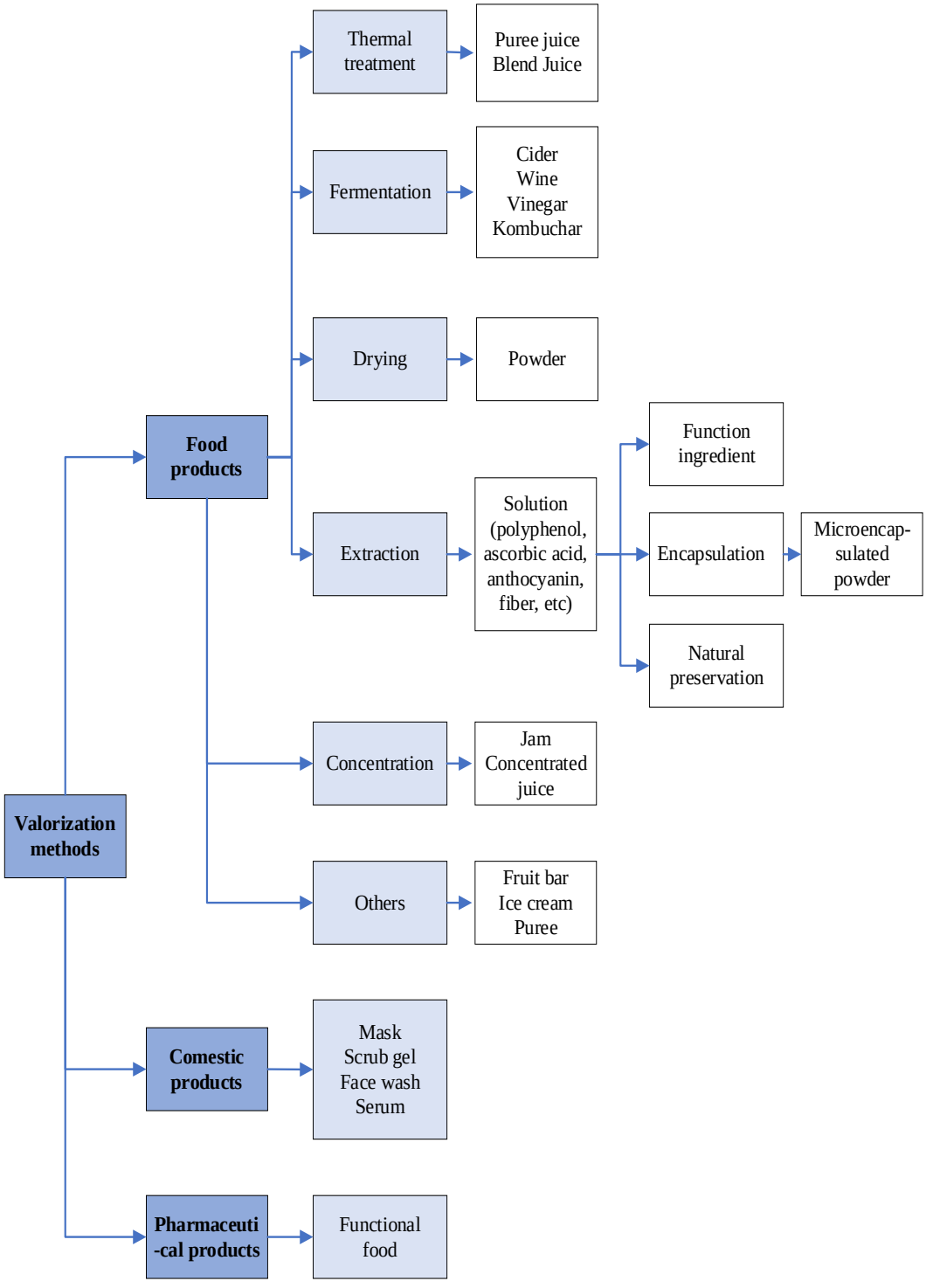

Figure 2. Flow diagram of valorization methods for acerola fruit and by-product

4.2. Extraction method

Extraction is the transportation of one or more components from biological sources (animals, plants, microorganisms) into the liquid phase (solvent). Most of the extraction procedures for biological compounds applied in the food industry were used with organic solvents. However, these solvents may remain in the extracted products, which are difficult for purification, as well as polluting the environment. Therefore, extraction techniques are required efficient and environmentally friendly (Lloyd & Van, 2012). Currently, acerola fruit and its by-products are rich sources for extracting bioactive compounds such as polyphenol, vitamin C (Le & Le, 2012), flavonoid and rutin (Silva et al., 2020; Reis et al., 2014), carotenoid and anthocyanin (Rezende et al., 2017).

The extraction condition of a bioactive compound of acerola residue (seed, peel) was optimized by Rezende et al., 2017. These authors found the collected extract under ultrasound-assisted method (frequency of 50kHz and power of 250 VA) had bioactive compounds and antioxidant activity higher than the conventional method. The optimal condition for extracting total anthocyanins, carotenoids, ascorbic acid, phenolic compounds, total flavonoids was built such as ethanol concentration of 46.49%, solvent: solid ratio of 8.66 mL/g, and extraction duration of 49.30 min. Optimization extraction of phenolic and flavonoid compounds of acerola waste also was carried out by Silva et al (2020). The optimal parameter of ethanol concentration, temperature and liquid/solid ratio, extraction time was 67.5%, 80.9℃, 59.8 mL/g, and 13.6 min, respectively. HPLC test showed acerola extract major had gallic acid, caffeic acid, p-coumaric acid, and rutin. In the research of Le & Le (2012), the extraction efficiency of vitamin C and phenolic compounds of enzyme-assisted (EAE) and ultrasound-assisted (UAE) extraction was compared. For EAE, acerola mash/distilled water ratio of 1/2 (w/w), Cellulast 1.5L concentration of 8.1 NCU/g, and temperature of 50°C for 120 min. Regarding UAE, acerola mash/distilled water ratio of 1/2 (w/w), ultrasonic power of 15 W/g, and temperature of 50°C for 6 min. The results obtained UAE more suitable than EAE for the extraction of bioactive compounds from acerola fruit, with higher vitamin C content, total phenolic compound, and antioxidant activities (DPPH, ABTS).

4.3. Fermentation method

Fermentation is one of the traditional methods used in food processing and preservation. During fermentation, useful microorganisms (yeast, mold, and lactic acid bacteria) grow and produce enzymes particularly amylase, proteases, and lipases. These enzymes hydrolyze macromolecular like protein, polysaccharide, and lipid (Steinkraus, 2002). The role of fermentation in food processing includes:

(1) The organoleptic quality as well as nutrition properties of food product be improved. For example, fermentation reduced trypsin inhibitory activity, amylase inhibitory activity, phytic acid, tannin in sorghum, and increased *in vitro* protein digestibility (Osman, 2004). According to Hashemi et al. (2017), ascorbic acid content, total phenolic content, antioxidant activity, and antibacterial activity of the fermented sweet lemon juice were higher than the non-fermented juice during the storage period.

(2) Extension food shelf life. For instance, some bio-compounds were produced by lactic acid bacteria such as bacteriocin, lactic acid, phenyllactic acid, cyclic dipeptides (Behera et al., 2018), and yeast such as alcohol in fermentation duration. These compounds inactivated pathogenic microorganisms responsible for food spoilage.

(3) Detoxification in food. In a review had been written by Adebijy et al. (2019), mycotoxin in products made from cereal could be reduced after fermentation by lactic acid bacteria and yeast activity.

Besides, traditional fermented fruit products such as alcoholic beverages and vinegar are fermented with yeasts and acetobacter bacteria, respectively. Nowadays, the development of fruit juice containing probiotic bacteria as a new probiotic product has been promising. The reason is that some consumers have galactosemia and lactose intolerance which make them cannot consume dairy products as a traditional source of probiotics. The fermented acerola products have been researched such as vinegar, wine, cider, and kombucha.

Regarding acetic acid fermentation, the *Acetobacter senegalensis* (10^5 cell/mL) and *Saccharomyces cerevisiae* (10^7 cell/mL) were used for fermentation of vinegar from acerola juice. The product had high acid content (6.99%) after 8 days of fermenting at room temperature of 28-32 °C (Trinh et al., 2016). The extract of acerola by-product has been proved to be a promising raw material to create a new

kombucha, as well as the medium for the production of cellulose from bacteria. The extract was prepared in an autoclave at 121℃ for 15 mins, where the concentration of acerola residue powder was 5%. After filtering, the extract was added with 7% sugar (fructose and glucose 1: 1) and 10% inoculum scoby. The vinegar achieved 16.3 g/L acetic acid after 6 days of fermentation (Leonarski et al., 2021).

Regarding alcoholic beverages, the cider made from sour acerola (*Malpiphia glabra* L.) had the sensory quality better than sweet acerola (*Malpiphia punicifolia* L.) and "Brazil" acerola (*Malpiphia emarginata* DC). The product maintained good organoleptic quality after 6 months of storage when pasteurized at 80 ℃ for 15 min (Le & Kha, 2018). The fermentation suitable for acerola wine was found such as initial total soluble solid of 28.6-29.0% and pulp mass of 1/7.5 - 1/6.0, initial pH of 4 - 5, and fermentation time of 336 hours. Under these parameters, wine had the best sensory acceptance for color, aroma, and flavor (Almeida et al., 2014).

Regarding probiotic drink, the mixed fruit contains acerola pulp, inulin, refined sugar, and citric acid was used as material for lactic acid fermentation. The mixed juice was heated and degassed at 50℃, 450-500 mmHg, followed by filling into glass bottle and heating in boiling water for 15 min. After reaching room temperature, the mixed juice was with *Bifidobacterium animali* (microencapsulation and free cell forms) and fermented at 5℃ for 35 days (Antunes et al., 2013). Enhancement ability of probiotic (i.e., *L. plantarum 53, L. paracasei 106, L. fermentum 56* and *L. casei L-26*) on bioactive compounds and antioxidant activity of acerola by-product extract was determined by de Oliveria et al. (2020). Its total phenolic content, total flavonoids, and antioxidant activity increased, and ascorbic acid content decreased after fermentation at 37 ℃ for 120 hours.

4.4. Drying method

Drying is a traditional method for dehydration to reduce the water activity of the material. This leads to the bacteria being inhibited and chemical reactions reduced (oxidation, non-enzyme browning) which extended the shelflife of products. Water in food has 2 types, free and bound, where the free water is easier to remove from food than the bound water. At the beginning of drying, the water in food receives heat energy from drying agent. Next, the free water is transferred gradually to the surface of the food, where the water is evaporated. After that, bound water is evaporated with a mechanism similar to free water (Calín-Sánchez et al., 2020). Besides preservation of raw material, drying methods also help to transport food products easier and improve the quality of product. Various studies show several drying methods can be applied in acerola processing such as spray drying, hot air drying, vacuum drying, and microwave drying.

In comparing different drying methods including hot air drying (temperature of 60-80℃), microwave drying (power of 280 - 560 W), and vacuum drying (temperature of 60-80℃, pressure of 3500 Pa), the result showed these methods suitable for drying acerola, but microwave drying had the shortest drying time, and the acerola powder dried by vacuum drying had the highest ascorbic acid content (Song et al., 2020).

Cryogenic freezing is the recommended technique for producing dried acerola when comparing with nitrogen vapor and by putting the samples in a freezer. For the cryogenic freezing method, the pulp and slice of acerola were dried at pressure of 1.3 x 10^{-1} mbar, temperature of -30 ℃ (the first stage), and 35℃ (the second stage), drying time of 12 hours. From the selected drying technique, the dried acerola had a low glass transition temperature (−32.1℃), a high rehydration capacity (10.1 kg/kg), and a vitamin C content of 153.4 mg/g dry solid (Marques et al., 2007).

In the research of Silva et al. (2016), the acerola extract was dried at air temperature of 59.3℃, air velocity of 2.25 (m/s), rotary speed of 2.7 rpm, and solids flow rate of 0.045 kg/min. The results showed that the roto-aerated dryer was a good method for drying acerola residue due to maintaining its bioactive compound after drying. Moreover, the study found that the material pretreated with ethanol increased the drying rate up to 80. The acerola residue was also dried by a convective dryer tray at temperature and air velocity of 80℃ and 6 m/s, respectively (Nóbrega et al., 2015).

4.5. Encapsulation method

The previous studies found that bioactive compounds (e.g phenolic, vitamin C, anthocyanin) were influenced by temperature, oxygen, light, which led these compounds to deterioration during the storage period (Ali et al., 2018; Touati et al., 2016). Several studies show that encapsulation plays an important role in maintaining the level and biological activity of bioactive compounds. Encapsulation is a technique by which core

materials are coated within a wall (Gibbs et al., 1999).

The spray-dried acerola powder can be processed from acerola pulp (Garcia et al., 2020) or mix with other fruit (Souza et al., 2020). In a study by Garcia et al. (2020), acerola pulp was mixed well with 5% maltodextrin (DE 12) and homogenized at 500 rpm for 30 minutes. The dispersion was dried by using an MSD 5.0 spray dryer with a 2.0 mm diameter injector nozzle, inlet temperature, outlet temperature, and flow rate were 120℃, 80℃, and 20 mL/min, respectively. In the other study, spray-dried acerola powder was prepared with acerola and seriguela juices (Souza et al., 2020). The feed solution contains the juice mix (60% acerola: 40% seriguela), water, and 20% maltodextrin (DE 10). This solution was dried by using a spray dryer at temperature of 140℃, a flow rate of 0.6 L/h, and an air pressure of 0.6 bar. The powder obtained from those parameters has a good organoleptic quality.

Spray drying and maltodextrin as the food aid are major techniques used for encapsulation of acerola extract. The extract of acerola residue was dried under the following operating conditions including peristaltic pump rate of 8.4 x 10-4 m^3/s, flow rate of 37.5 m^3/s, inlet temperature of 170℃, and the ratio between drying aid (maltodextrin DE10 with and without mixed cashew gum) to acerola of 5:1 (Moreira et al., 2010). Besides, maltodextrin and gum arabic can be used as a wall material for spray-dried extract of acerola residue. The drying procedure was followed by the encapsulation by spray drying at a feed rate of 0.36-0.6 L/h, an inlet temperature of 165-170℃ and outlet temperature of 70-82℃ (Rezende et al., 2018; Carneiro et al., 2020). Nowadays, encapsulated acerola powder contains lactic acid bacteria as a vehicle supply probiotic is explored by Souza et al. (2020). The powder is prepared from mixed juice of acerola, ciriguela, and *Lactobacillus* spp.

4.6. Using as the ingredient for producing the other foodstuff

The phytochemical microcapsules not only improve nutrition but also prolong the shelf life of foodstuff products (Nedovic et al., 2011). Actually, several studies proved the encapsulated extract of acerola by-product as a potential function ingredient (Carbonera et al., 2014, Bourekoua et al., 2021) and natural preservation agents (Choi and Jeong, 2020; Realini et al., 2015).

4.6.1. Functional ingredient

The extract made from acerola residue was applied in foodstuff products, which improved the nutrition of the product. For example, the ethanolic extract of acerola residue was added into the pelleted diet of tilapia fish, which improved the antioxidant activity of the fillets (Carbonera et al., 2014). Moreover, acerola pulp was added to the ketchup recipe, which increased the total ascorbic acid, total phenolics, total flavonoids, and total anthocyanins contents (Prakash et al., 2016). The best level of acerola fruit powder in bread's formulation was found to be 3% (w/w). The bread with acerola powder achieved total phenolic content (4 times) and antioxidant activity of bread (Bourekoua et al., 2021). Acerola pulp supplied noticeable antioxidant activity of goat cheeses, without impacting the survival of probiotic starter in goat cheeses. The product could be used as a functional food to provide bioactive compounds and probiotics (de Barcelos et al., 2020).

4.6.2. Natural preservative agent

Various studies found that the shelf file of foodstuff products can be extended by incorporating acerola extract. Specifically, the freezer dried powder made from the methanolic extract of the pulp and seed of acerola fruit could inhibit the growth of *Staphylococcus aureus* 29247, but not effective to *E. coli* 25922 and *Pseudomonas putida* ATCC 12633 (Delva & Schneider, 2013). The mixture of white kimchi and acerola powders could replace the food additives such as sodium nitrite and sodium ascorbate in the cured meat products (Choi and Jeong, 2020). Incorporation of mango pulp, acerola pulp, and cassava starch to produced bio-based film was carried out in Souza et al. (2011) report. During storage term, the total carotenoids loss and peroxide value of palm oil were packaged with biofilm lower than the oil-free package. Interestingly, the acerola pulp seemed to play as a pro-oxidation agent when used at a high concentration. Implemented acerola fruit extract in the formulation of salted beef patties could extend the shelf-life of the product by at least 3 days. Because of the addition of fruit extract, the patties were improved in color, lipid stability, and flavor (Realini et al., 2015). Chitosan film was mixed with the extract of acerola residue had a good performance in maintaining the quality of chicken meat stored at 4℃. This film not only reduced the lipid oxidation reaction, pathogenic microorganisms count but also kept the color and texture quality of meat (Portugal et al., 2018).

4.7. The other products

The seed and bagasse flours of acerola can be used material in cereal bar processing (Marques et al., 2015). The formulation was prepared from 50% the solid phase (acerola residue flours, rice flakes, and brown oats) and 50% liquid phase (brown sugar, glucose syrup, and salt). Favaro-Trindade et al. (2006) created the acerola ice cream. Firstly, the ingredients such as pasteurized milk, sucrose, emulsifier, and stabilizer were mixed well. Secondly, after pasteurization and stabilization, the mixture was cooled and incubated with probiotics (*S. thermophilus and L. delbrueckii spp. bulgaricus*, *Bifidobacterium longum*, *Bi. lactis*) at 40℃. Finally, the fermented ice cream mixture was stirred well with the acerola pulp and frozen at -18℃ by using an ice cream maker. Frozen acerola pulp and juice products have been available on the market; however, publications on these are still limited.

On a company, acerola fruits can be manufactured into many products under the processing diagram was presented in Figure 4.

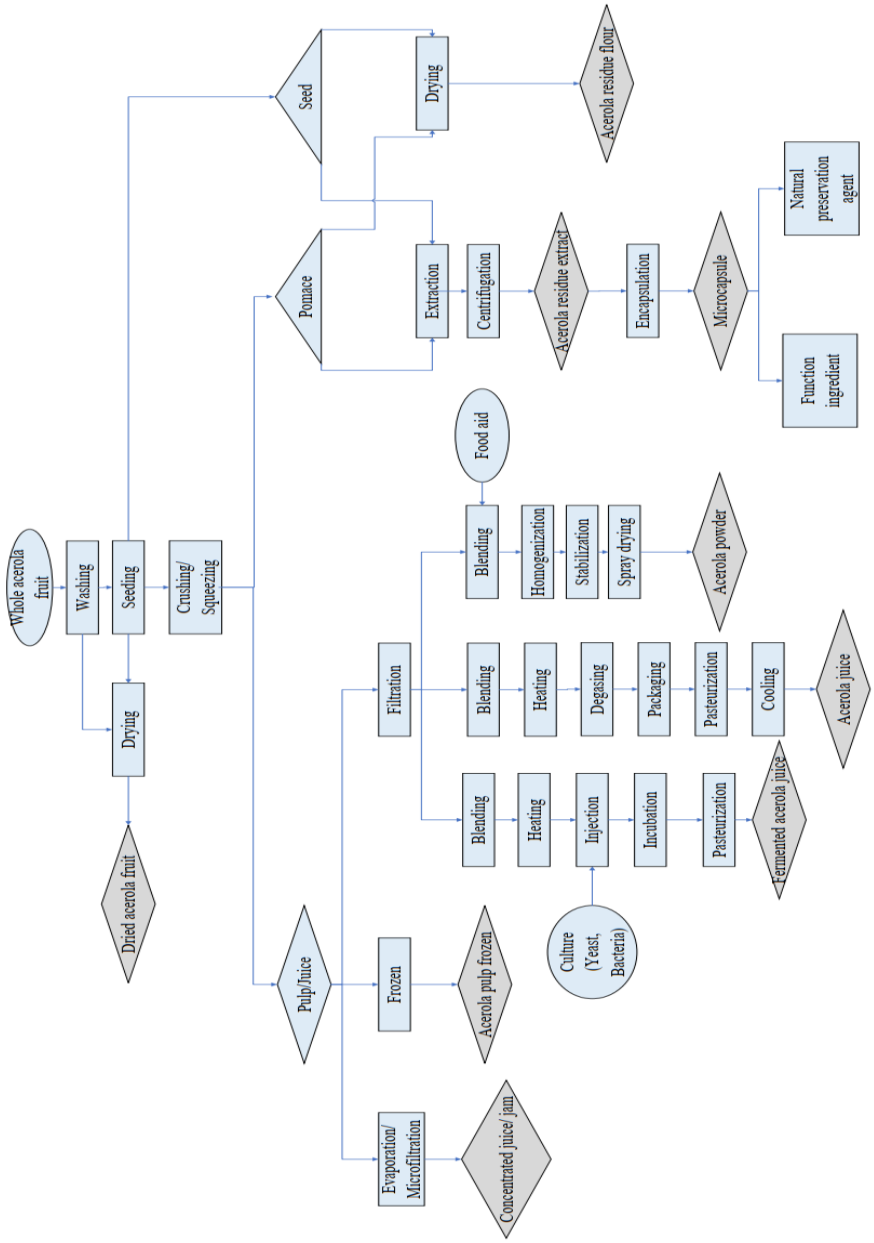

Figure 4. The diagram showing the summary processing of foodstuff products from acerola fruit

The pasteurized juice processing adapted from Lima et al. (2009), Silva et al. (2017); the fermentation processing adapted from Le and Le (2018), Antunes et al., (2013); the drying processing adapted from Ribeiro et al. (2018), Song et al. (2020); the extraction processing adapted from Silva et al. (2020), Le and Le (2012); the encapsulation processing (spray drying) adapted from Rezende et al. (2018), Carneiro et al. (2020)

5. CONCLUSIONS

Acerola fruit and its by-product contain numerous bioactive compounds such as vitamin C, phenolic, anthocyanins, carotenoids. These compounds depend on the maturity stages of fruit, in which unripe fruits are the richest of antioxidant compounds, and ripped fruits are good for foodstuff processing. Currently, a few studies have focused on postharvest preservation of acerola. Acerola fruits have a fast-ripening speed, and their shelf life is only 2-3 days at ambient temperature (29-31℃), approximately 15 days at 10-12℃.

Several techniques have been found to develop valuable products from acerola. The recommended processing scheme of all the parts of acerola fruit (e.g., pulp, seed, pomace) including pasteurization, encapsulation, drying, fermentation highlights how the utilization of the encapsulation of acerola powder into foodstuff. These techniques can be even applied to small and medium production scales, which are suitable for major food companies in Viet Nam. Acerola is used as a material in food processing, it is also used as a functional ingredient for improving the nutrition and shelf-life of food products. The products made from pulp and by-products of acerola are promising to be developed in the future, due to the gradually high demand of consumers in using products derives which are natural and healthy

ACKNOWLEDGEMENT

The authors would like to thank Nong Lam University was supported for this study through project CS-CB21-HHTP-08.

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