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REVIEW ARTICLE

Acerola, an untapped functional superfruit: a review on latest frontiers

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Abstract Acerola (*Malpighia emarginata* DC.) is one of the richest natural sources of ascorbic acid and contains a plethora of phytonutrients like carotenoids phenolics, anthocyanins, and flavonoids. There is an upsurge of interest in this fruit among the scientific community and pharmaceutical companies over the last few years. The fruit contains an exorbitant amount of ascorbic acid in the range of 1500–4500 mg/100 g, which is around 50–100 times than that of orange or lemon. Having a reservoir of phytonutrients, the fruit exhibits high antioxidant capacity and several interesting biofunctional properties like skin whitening effect, anti-aging and multidrug resistant reversal activity. Countries like Brazil, realizing the potential of the fruit have started to exploit it commercially and have established a structured agro-industrial based market. In spite of possessing an enriched nutrient profile with potent "functional food" appeal, acerola is underutilized in large part of the globe and demands greater attention. A comprehensive literature analysis was carried out with reference to the latest frontiers on the compositional characteristics of the fruit. Emphasis has been given on newer dimensions of functional aspects of ascorbic acid and allied work and pectin and pectin methylesterase. The range of nutraceutical phytonutrients present in acerola and their biofunctional properties has been discussed. Recent advances in the value addition of the fruit highlighting the use of techniques like filtration, encapsulation, ultrasound, sonication, etc. are also elaborated. Furthermore, the potential use of acerola pulp in edible films and waste utilization for development of valuable byproducts has been highlighted.

Keywords Acerola · Ascorbic acid · Phytonutrients · Value addition · Biofunctional properties

Introduction

Acerola (*Malpighia emarginata* DC.) also known as Barbados cherry or West Indian cherry, belongs to Malpighiaceae family. The fruit is known to be one of the richest natural sources of ascorbic acid in the world, whose vitamin C content is comparable to only camu camu (*Mirciaria dubia*) (Delva and Schneider 2013a). The plant has synonyms like *Malpighia glabra* L., and *Malpighia punicifolia* L., but *Malpighia emarginata* DC. has been accepted as the present scientific name by the taxonomists (Assis et al. 2008).

The evergreen shrub of acerola which flourishes in warm and tropical climates bears a small trilobite cherry-like fruit (Mezadri et al. 2008; Delva and Schneider 2013b). It grows from the South Texas, through Mexico and Central America to northern South America and throughout the Caribbean and has of late been introduced in the sub-tropical areas throughout the world including India (Assis et al. 2008). The tree flowers from April to November and the fruit matures in 3–4 weeks after flowering. Fruits are small (1–4 cm diameter) weighing 2–15 g, whose skin color is green at the immature stage of ripening

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which changes to orange-red and to a final bright red color on maturation (Supplementary Figure 1). Although the sweetness of the fruit varies according to the variety but barring a few varieties that are sweet, most of them are quite tart and acidic.

Apart from containing an exorbitant amount of ascorbic acid the fruit also contains several phytonutrients like carotenoids, phenolics, flavonoids, and anthocyanins (Mezadri et al. 2008) and possess numerous biofunctional properties. Therefore, value addition to this super fruit can be of great functional importance. This review discusses the current status of acerola in the world and in India and summarizes the latest research publications and patents, along with their implications on the wholesome compositional characteristics, biofunctional properties and value addition to the fruit.

Status in world

Asenjo and de Guzman of Puerto Rico were the first ones to point out the unusually high content of ascorbic acid in acerola, in the year 1946. Since then, over the years, the popularity of the fruit has increased and has at present been well established as a fruit of functional importance. Over the last few decades, Brazil has started to exploit acerola commercially and now is the largest producer of acerola, with 11,000 hectares of acerola plantation, producing 3000 kg/ha and a total of 32,990 tons/year (Pommer and Barbosa 2009). Brazil has also dominated in marketing and export of processed products from acerola like frozen fruit, juice, marmalade, frozen concentrate, jam, and liquor (Delva and Schneider 2013a). To preserve the genetic variability and provide evaluation and indication of promising genotypes of acerola, an Acerola Active Germplasm Bank (AGB) was established in June 1998, by Federal Rural University of Pernambuco, Brazil (Lima et al. 2005). The fruit is also cultivated in a small scale in American continent. In France, Germany and Hungary, the fruit is used largely in juice form, whereas in the United States it is utilized by the supplement and pharmaceutical industries as a rich source of ascorbic acid (Delva and Schneider 2013b). In Chinese market too, acerola supplements are available.

In India, the cultivation of the fruit goes back before the year 1962, wherein it was cultivated in the gardens of Chennai and Mysore cities (The Wealth of India 1962). As of now, the fruit is grown as a backyard tree in the states of Tamil Nadu, Kerala, Maharashtra and Karnataka. During 1995–1996, a few selections of plants were introduced in Andaman and Nicobar islands that performed well due to tropical and humid climate (Singh 2006). Acerola is an exotic fruit that has an exceptional agro-industrial potential and represents an alluring economic prospect. Due to the lack of awareness of its nutritional value and cultivation, the crop has not yet gained popularity among Indian farmers and still remains a lesser-known and underutilized fruit. India being a tropical country, well suited for the growth of acerola crop holds immense potential for the commercial cultivation and exploitation of the fruit.

Fruit development and changes during fruit ripening

Acerola fruits show a biphasic pattern of growth, with an increase in most of its size in the first phase of growth and an equal weight gain in each growth phase of about 2 weeks duration. The development of full maturity of fruit with deep red color is reached after 24–26 days of anthesis. It is a climacteric fruit with a very high respiratory rate (900 ml CO_2 kg^{-1} h^{-1}) and a low rate of peak ethylene production (3 µl C_2H_4 kg^{-1} h^{-1}). Fully mature acerola fruits are highly delicate with the shelf life of only 2–3 days at ambient temperature. The fruits have in fact a high metabolic activity after harvest and are too perishable for the fresh market (Delva and Schneider 2013a).

The ripening of acerola involves a sequence of complex biochemical reactions. There is hydrolysis of starch, conversion of chloroplast into chromoplast, production of carotenoids, anthocyanins, and other phenolic compounds, and the formation of volatile compounds (Vendramini and Trugo 2000). All these are important for the peculiar flavor and the final characteristics of the mature fruit.

Vendramini and Trugo (2000) analyzed the chemical composition of acerola fruit at three stages of maturity. They found that titrable acidity, sugars, and soluble solids increased and Vitamin C and protein decreased with ripening. Further, Lima et al. (2005) evaluated the total phenolic and carotenoid contents in 12 acerola genotypes at three stages of ripening and observed that the phenolics degrade and carotenoids are biosynthesized during fruit maturation. A lower total antioxidant activity was found on fruit ripening by Oliveira et al. (2012) due to the decrease in total vitamin C and total soluble phenols content. They further reported that on ripening there was a reduction in activities of oxygen scavenging enzymes and increase in membrane lipid peroxidation, indicating that acerola ripening is characterized by a progressive oxidative stress.

Composition of acerola

Acerola is a source of several macro and micronutrients, which are summarized in Table 1. Glucose, fructose and a small amount of sucrose are the major sugars present in the

Table 1 The composition of acerola (100 g fresh weight) (*Source*: adapted from USDA, National Nutrient Database for Standard Reference)

Water	91.41 g	Zinc	0.10 mg
Energy	32 kcal	Total ascorbic acid	1677.6 mg
Protein	0.40 g	Thiamine	0.020 mg
Total lipid (fat)	0.30 g	Riboflavin	0.060 mg
Carbohydrate, by difference	7.69 g	Niacin	0.400 mg
Fiber, total dietary	1.1 g	Vitamin B-6	0.009 mg
Calcium	12 mg	Folate	14 µg DFE
Iron	0.20 mg	Vitamin A	38 µg RAE
Magnesium	18 mg	Fatty acids, total saturated	0.068 g
Phosphorus	11 mg	Fatty acids, total monounsaturated	0.082 g
Potassium	146 mg	Fatty acids, total polyunsaturated	0.090 g
Sodium	7 mg		

mature acerola fruit. Among the organic acids, malic acid represents 32% of the total acids present in the mature fruit whereas citric acid and tartaric acid are present in minor amounts (Righetto et al. 2005). The physicochemical properties of acerola fruit and its nutritional value depend on several factors, including growing locations, environmental conditions, cultural practices, stage of maturation, processing and storage (Delva and Schneider 2013a). The detailed composition of the fruit is discussed herein.

Ascorbic acid

Ascorbic acid is one of the most important water-soluble vitamins, essential for collagen, carnitine and neurotransmitters biosynthesis. Most animals and plants can synthesize ascorbic acid, but humans are unable to synthesize it due to non-functional enzyme L-gulono-1,4,-lactone oxidase, which catalyzes the final step in the ascorbic acid biosynthesis in animals (Naidu 2003). Therefore, humans require it as an essential supplement in their diet. Acerola is a natural source of vitamin C, whose content of ranges from 1000 to 4500 mg/100 g, which is around 50–100 times that of orange or lemon (Moreira et al. 2009; Almeida et al. 2014). The Recommended dietary allowances (RDA) of ascorbic acid for adults (> 19 yr) are 75 mg/day for women and 90 mg/day for men (Naidu 2003). Therefore, consumption of three acerola fruits per day could satisfy the vitamin C RDA for an adult (Matta et al. 2004). However, one should abstain from eating large amounts of the fruit as extreme intake of vitamins can act as pro-oxidant and generate changes in DNA. To substantiate the hypothesis, Dusman et al. (2012), investigated the cytotoxic and mutagenic effects of acerola fruit pulp and vitamin C in animal and plant systems. Their study showed that fresh acerola pulp diluted in water at a concentration of 0.4 mg ml^{-1} and commercial frozen acerola pulp diluted at concentration of 0.2 mg ml^{-1} inhibited cell division in *Allium cepa* L. In the Wistar rats, all treatments of acerola, either in acute and subchronic, were found to be neither cytotoxic nor mutagenic.

It has been reported that the vitamin C of acerola is better absorbed by human beings than the synthetic ascorbic acid (Assis et al. 2008). Uchida et al. (2011) studied the comparison between absorption and excretion of ascorbic acid alone and acerola juice in healthy Japanese subjects. Their results indicated that some component of acerola juice favorably affected the absorption and excretion of ascorbic acid. Vitamin C is readily absorbed when the intake is up to 100 mg/day; and at elevated levels of intake (500 mg/day), the efficiency of absorption of ascorbic acid swiftly declines (Naidu 2003). A much detailed study on the absorption, bioavailability and toxicological effect of ascorbic acid present in food matrix of acerola is needed to ascertain the possible holistic health benefit of the fruit.

However, as ascorbic acid is highly unstable, its loss incurred in value added products during processing should also be considered. Our group showed a ~ 18–29% retention of ascorbic acid in various ketchup formulations developed from acerola and tomato (Prakash et al. 2016). In another study, Moreira et al. (2009) reported a 6–15% loss of ascorbic during spray drying of acerola pomace extract.

Understanding the molecular mechanism of the genes responsible for the abundance of vitamin C in acerola can open up new avenues for the propagation of commonly cultivated crops with enriched vitamin C content in it. Several detailed study on the expression patterns of genes of enzymes that are involved in various steps of the ascorbic acid synthesis in acerola through Smirnoff–Wheeler (SW) pathway have been studied by Badejo and his Japanese group. However, more detailed studies are required to elucidate the precise molecular mechanism for elevated biosynthesis of ascorbic acid in the fruit (Badejo et al. 2008).

Phytonutrients

Phytochemicals are non-nutrients present in plants, which are known to have diverse biological activities and reduce the risk of many chronic diseases. The major group of phytochemicals includes carotenoids, phenolics, alkaloids, nitrogen-containing compounds, and organosulfur compounds. Acerola is one of the few fruits, which apart from having an exorbitant content of ascorbic acid, also contains a plethora of other phytonutrients like phenolics, flavonoids, anthocyanins and carotenoids in a fair amount. The fruit also contains pro-vitamin A, vitamins B1 and B2, niacin, albumin, iron, phosphorus and calcium (Assis et al. 2000; Delva and Schneider 2013a). Aptly, acerola is considered a "super fruit".

Phenolic compounds are one of the key secondary metabolites having diverse structures that are present ubiquitously in plants. The major phenolics present in acerola are in the form of phenolic acids, flavonoids, and anthocyanins. The phytonutrients content vary depending on the variety, genotype, stage of maturity, and growing and processing conditions. Mezadri et al. (2008) evaluated the total phenolics in different commercial frozen pulps and crushed and squeezed juices and reported values of 452–751, 805–1050, and 973–1060 mg gallic acid equivalent per 100 g (GAE/100 g). The anthocyanins content in commercial pulps were around 2.7 mg/100 g cyanidin-3-glucoside while the content in crushed and squeezed juices ranged around 46.9–52.3 mg/L cyanidin-3-glucoside. The phenolic content in acerola pulp and juices is higher than the fruits like caqui, pineapple, mango, guayaba, etc., but the anthocyanins content are lower than other fruit juices rich in anthocyanins like strawberries or blood oranges (Mezadri et al. 2008) Prakash et al. (2016) developed ketchup from different blended proportions of acerola and tomato and found varied retention of color after blending and blending.

Carotenoids are organic pigments present in many fruits and vegetables, which are known to possess several physiological functions. The carotenoid content in 12 different acerola genotypes harvested in the dry and rainy season was found in the range of 9.4–40.6 $\mu g\ g^{-1}$ β carotene equivalents by Lima et al. 2005. Four major carotenoids β-carotene, lutein, β-cryptoxanthin and α-carotene were identified in acerola by Rosso and Mercadante 2005.

Pectin

Pectin, a methylated ester of polygalacturonic acid that constitutes about one-third of the cell wall dry substance in higher plants, has been successfully used for years in the food and beverage industry as a gelling agent, a thickening agent, and a colloidal stabilizer. In acerola, Assis et al. (2001) reported a yield of 4.51% pectin in the immature green stage of the fruit, which was found to decrease to 2.99% on fruit ripening. The yield is comparatively lesser than the other pectin rich source like apple pomace (10–15%) and citrus peel (20–30%) (Srivastava and Malviya 2011).

Pectin methylesterase

The enzyme pectin methylesterase (PME), present in most plant tissues, removes methyl groups from cell wall pectic constituents during ripening, which can then be depolymerized by polygalacturonase, decreasing the intercellular adhesivity and tissue rigidity (Assis et al. 2001). PME activity was found to be highest (2.08 units g^{-1}/g) in the immature stage of acerola (Assis et al. 2001). In a different study, they reported that the acerola PME were very stable at 50 °C and needed 110 min for inactivation at 98 °C. In fact, these values were found to be much higher than those of citrus PME inactivation, which requires only 1 min at 90 °C for inactivation. The heat inactivation of acerola PME was found to be nonlinear, which suggested the presence of fractions of PME with different heat stabilities (Assis et al. 2000). Further, in a separate study, the same group partially purified and characterized the acerola PME and reported that, the total and partially purified PME specific activity increased with temperature. The total acerola PME retained 13.5% of its specific activity after 90 min of incubation at 98 °C. The Km values of 0.081 and 0.12 mg/ml were reported for the total and partially purified PME isoforms respectively (Assis et al. 2002).

Since immobilized pectic enzymes can be used for clarification of various fruit juices (Demir et al. 2001), the same group of researchers further went on to try acerola PME immobilization on different supports. They immobilized total and partially purified PME from acerola on porous silica particles and reported the efficiency value of 114 and 351% respectively (Assis et al. 2003). Later, they screened various supports viz. glass, Celite, chrysolite, agarose, concanavalin A Sepharose 4B, egg shell, polyacrylamide and gelatin for the immobilization. Among them, the highest immobilization yields were obtained with concanavalin A Sepharose 4B (81.7%) and in gelatin-water (78.0%) (Assis et al. 2004b).

In another study, they optimized the conditions for the production of low methoxyl pectin using PME from acerola immobilized in gelatin using factorial and response methodology. The optimum conditions of activity in immobilized enzyme were found to be at the NaCl concentration of 0.15 M and a pH of 9.0 (Assis et al. 2004a).

Novel compounds

Few novel compounds have been reported from acerola fruit and different parts of the tree. Leucocyanidin-3-O-β-D-glucoside, a novel flavonoid possessing a 4,2″—glycosidic linkage was isolated from green mature acerola puree and named "aceronidin" by Kawaguchi et al. (2007). From the branches and roots of acerola tree, Liu et al. (2013) isolated three novel norfriedelanes, A–C. Among them, Norfriedelin A (possessing a α-oxo-β-lactone group) and norfriedelin B (with a keto-lactone group) was shown to have significant acetylcholinesterase inhibitory effects. Later, the group identified three new tetranorditerpenes acerolanins from the aerial parts of the plants with a rare 2H-benz[*e*]inden-2-one substructure possessing cytotoxic activity (Liu et al. 2014).

Biological activities

Acerola being a rich source of potent antioxidants like ascorbic acid and other phytonutrients like phenolics, and carotenoids appear to be a promising candidate in combating various diseases associated with the oxidative stress. In fact, a range of biological activities has been demonstrated using different extracts of acerola and its phyto constituents.

The in vitro antioxidant activity of the acerola fruit, it's various extracts and purified phytonutrients have been carried out using different assays like DPPH, ORAC, TEAC, etc. by various researches in the past few years. However, it is difficult to compare the results reported by different laboratories as many of them have not mentioned the variety used in the experimentation, and there are substantial differences in the methodology of sample preparation, extraction of antioxidants, selection of end-points and expression of results even for the same method. However, having a complex matrix of a range of antioxidants, the total antioxidant capacity of acerola is thought to be due to the synergistic action of its range of phytonutrients. Mezadri et al. (2008) reported that the contribution of ascorbic acid to the hydrophilic antioxidant activity in acerola fruits, commercial pulps, and juices ranged between 40 and 83%, while the remaining activity were due to polyphenols, mainly the phenolic acids. They reported that the antioxidant activity values obtained from acerola juice were more than those reported for other fruit juices particularly rich in polyphenols such as strawberry, grape, and apple juices. In a different study by Righetto et al. (2005), it was reported that the antioxidant activity of the acerola juices depended on the synergistic action of the constituents of different fractions, with most significant components being phenolic compounds and vitamin C. Delva and Schneider (2013b) evaluated the contribution of phenolic fractions in acerola towards antioxidant capacity and reported the following order: anthocyanins $<$ phenolic acids $<$ flavonoids.

In an extensive study by Motohashi et al. (2004), acerola fruit was fractionated using column chromatography with various organic solvents and a range of biofunctional properties were investigated viz. radical generation, superoxide anion scavenging activity, tumor-specific cytotoxic activity, anti-HIV activity, antibacterial activity, antifungal activity, anti-*Helicobacter pylori* activity and MDR reversal activity. They reported that few acetone and hexane fractions showed higher cytotoxic activity against tumor cell lines as against the normal cells. Their most important finding was the MDR reversal activity of few hexane fractions, which inhibited the Pgp function in the MDR cancer cells, more effectively than the positive control, verapamil. Thus, authors interestingly stated that the tumor-specific cytotoxic activity and MDR reversal activity of Barbados cherry suggest its possible application in cancer chemotherapy and prevention.

Using acerola fruit juice as an active ingredient, a bacteriostatic agent against thermo-resistant and acid-resistant bacteria was patented by Tanada et al. (2007). Apart from these, several other biological activities like hepatoprotective, anticarcinogenic activity, antihyperglycemic effect, anti-genotoxicity activity, etc. have also been studied in acerola, which are summarized in Table 2.

Value addition and techniques for value addition

Acerola, possessing high nutritional attributes, has a short shelf life with a low sensorial appeal (Sousa et al. 2010). Being highly perishable and acidic, the fruit is by and large consumed after being processed, in the form of pulps and juices. The fruit is commercially processed into puree, juice or juice concentrates and is perfect for the preparation of jams, jellies, fruit juices and supplements. The fruit can also be used to prepare a range of other products like ice cream, gelatin, juice, soft drinks, nectar, gum, fruit conserve, nutraceutics, yogurts and sodas. It is also used in the fortification of infant foods and for the production of nutritional and pharmacological products (Badejo et al. 2008). Of late, many new and diversified products have appeared in the Brazilian market like blends of acerola and cashew, acerola and orange, and blends with guarana, powdered refreshments and concentrated juices (Matta et al. 2004).

Influence of various techniques like filtration, drying, heating, sonication, encapsulation, etc. and its associated processing parameters and methodologies can have a significant effect on the end products. Application of such

Table 2 Different biofunctional properties of acerola

Biological activities	Extract used	Model system	References
Antihyperglycemic effect	Crude polyphenolic extract	Glucose uptake in Caco-2 cell and glucose and maltose uptake in ICR mice	Hanamura et al. (2006)
Antigenotoxicity activity	Lyophilized acerola pulp diluted in water	Comet assay	Nunes et al. (2011)
Antimicrobial activity	Phenolic extract of acerola	*Staphylococcus aureus*	Delva and Goodrich-Schneider (2013)
Anticarcinogenic activity	Acerola cherry extract (dry powder of acerola suspended in saline)	Lung tumorigenesis in mice	Nagamine et al. (2002)
Hepatoprotective effect	Acerola juice	Female swiss mice	Rochette et al. (2013)
Skin lightening effect	Crude polyphenol concentrated extract	UVB-irradiated skin pigmentation Melanin content in B 16 melanoma cells	Hanamura et al. (2008)
Radioprotective effect	Fruit juice	Bone marrow cells of Wistar rats	Dusman et al. (2014)
Multidrug reversal activity	Purified solvent extracts of acerola	Mouse lymphomas-5178 cells	Motohashi et al. (2004)
Inhibition of sugar catabolic enzyme	Aceronidin	Alpha–glucosidase and alpha amylase inhibition assay	Kawaguchi et al. (2007)
Prevention of hyperglycemia and dyslipidemia in diabetic dams	Acerola juice	Diabetic and nondiabeticWistar rats	Barbalho et al. (2011)

techniques in preparation of acerola juice and powder are summarized in Table 3. Comprehensive inputs from the application of these approaches can pave a roadmap for the development of novel, convenient and efficient nutritional value added products from acerola.

Powder

Several researchers have attempted to prepare ascorbic acid rich powder from acerola. In 1961, Morse and Habra in a patent claimed to prepare a vitamin C concentrate in the form of powder from acerola with enhanced stability, excellent color and reduced ascorbic acid oxidase content which can be directly administered in small doses into the human body. The steps involved in the invention included fermentation and solvent precipitation of the insoluble solids. Later, in an another invention, they produced a substantially non-hygroscopic powder containing high ascorbic acid content, with an excellent shelf life (a year or more without refrigeration) and pleasant flavor. For the production of the said powder, the inventors prepared a single strength juice, brought its pH around 7 or 7.5 using suitable base and allowed it to precipitate. The juice was then filtered, concentrated and dried in a powder form (Morse and Habra 1963). Still later, a method for preparing acerola fruit powder comprising 51–60 mass percent of acerola cherry-juice solids and 40–49 mass percent of oxidized starch was described by Chai et al. in a patent published in 2014. Their method comprised preparing a concentrate of acerola cherry-juice, adding oxidized starch to the concentrate and spray-drying it.

Blends

Blending different fruit juices offers advantages over conventional juices in terms of nutritional and sensorial quality by combining different aromas and flavors (Lima et al. 2009; Matsuura et al. 2004). Since, acerola can easily be blended with more flavorful juices (Lima et al. 2009); few studies have focused on the formulation of blended products from acerola and study of its physicochemical, microbial and sensorial attributes. Some examples includes—preparation of nectar from cashew apple, papaya, guava, acerola fruit and passion fruit with added caffeine (Sousa et al. 2010), nectar from acerola pulp, papaya pulp and passion fruit juice (Matsuura et al. 2004) and preparation of beverage from whey butter cheese and acerola juice (Cruz et al. 2009).

Fermented products

Fermentation is a gradual decomposition process, wherein microorganisms or enzymes basically change organic substance like carbohydrates to alcohols or organic acids. Fermentation of fruit and vegetables can offer several advantages, as it helps in preservation and production of wholesome, nutritious foods in a wide variety of flavors, aromas, and textures and remove the antinutritional factors to make the food harmless to eat (Swain et al. 2014). Few studies on the fermentation of acerola fruit have also been done.

Favaro-Trindade et al. (2006) prepared six fermented acerola ice creams through the combination of different

Table 3 Influence of application of various techniques on acerola

Value added product	Technique	Objective	Methodology	Findings	Reference
Juice	Filtration	Clarification and concentration of acerola juice by microfiltration and reverse osmosis	Fruit pulp + enzymatic hydrolysis + clarification by microfiltration + concentration by reverse osmosis	Final product had high nutritional and sensorial qulaity, with 4.2 fold increase in Vitamin C content in concentrated juice. Microfiltration reduced microbial count	Matta et al. (2004)
	Sonication	Evaluation and comparison of efficiency of pectolytic treatment of non-sonicated and sonicated barbados cherry mash in juice processing	Barbados cherry mash sonicated and subsequently treated by pectinase preparation. Response surface methodology used to optimize enzyme concentration and pectolytic time	Combination of ultrasound and pectinase increased extraction yield by 9.2%, decreased enzyme concentration by 27.2% and pectolytic time by 24.1% in comparision with the conventional enzymatic treatment Juice obtained from combined treatment of ultrasound and pectinase had higher level of total phenolics, sugars and free amino nitrogen in comparison with juice from the pectolytic treatment	Dang and Le (2012)
	Ultrasound	Application of combined treatment of ultrasound and pectinase in the juice processing of acerola mash	Acerola mash + pectinase and ultrasound treatment + optimization of pectinase concentration and pectolytic time by response surface methodology	Maximum extraction yield (87.4%) obtained with combined application of ultrasonication and pectinase treatment (at 0.12% v/w of pectinase concentration and 26.3 min of pectolytic time)	Dang et al. (2012)
	Concentration	Production of high quality concentrated acerola juice by an integrated membrane process, alternative to thermal evaporation	Clarification of acerola juice by microfiltration + pre-concentration of clarified juice by reverse osmosis up to 28° Brix + osmotic evaporation of concentrated juice to 55° Brix	The vitamin C, anthocyanins content and antioxidant increased by 2.21, 1.41 and 2.28 folds respectively as against pre-concentrated juice A decrease in anthocyanins content was observed after processing	Pagani et al. (2011)
		Preparation and evaluation of acerola juice using separation processes with membranes	Acerola juice + treated with citrozym ultra L enzyme at 45 °C for one hour + ultrafilteration + concentrated by reverse osmosis using a spiral membrane of a compound film	Physicochemical characteristics of the juice preserved and had 75% of the consumers liked the juice	Gomes et al. (2005)

starter cultures and probiotics i.e. *Bifidobacterium longum*, *Bi. Lactis*, *Streptococcus thermophilus* and *Lactobacillus delbrueckii* spp. *Bulgaricus* having a final pH of either 4.5 or 5. During 15 weeks storage, the viable counts for probiotic cultures remained above the recommended minimum limit of 10^6 cfu/g even in products with pH of 4.5. Thus, authors concluded that fermented acerola ice cream could be used as a suitable food for the delivery of vitamin C and *Bifidobacterium* strains.

Wine is a commonly consumed alcoholic beverage prepared from fermented fruits. Studies have been done on optimization of conditions for production of wine from

Table 3 continued

Value added product	Technique	Objective	Methodology	Findings	Reference
Powder	Drying	Impact of processing parameters on degrees of retention of ascorbic acid and anthocyanins during spray drying of acerola pomace extract	Acerola pomace extract obtained by grinding pomace in water (5:1) + filtered through sieve + added maltodextrin (MD) or cashew tree gum (CTG) + spray drying by variation in inlet temperature, drying aid to acerola and replacement of MD by CTG	Degree of ascorbic acid and anthocyanins were impaired by increasing the inlet temperature, and favored by increasing drying aid to acerola ratio	Moreira et al. (2010)
		Assess the impact of temperature and drying aids on physical properties of spray dried acerola pomace extract	Acerola pomace diluted with water (5:1) + filtered through sieve + added maltodextrin (MD) or cashew tree gum (CTG) according to central composite design with three variables i.e. inlet temperature, drying aid/acerola solid ratio and percent replacement of MD by CD + spray drying	Higher inlet temperature favored the desired physical properties of powder Drying aids decreased the powder hygroscopity	Moreira et al. (2009)
		To investigate the drying kinetics of acerola residue, in a fixed-bed dryer and analyze the effect of process variables on the antioxidant properties of the residue	Acerola residue from industry dried in a fixed bed dryer based on complete factorial design 3^2 using different air velocities and air-drying temperature as independent variables	The highest content of ascorbic acid and phenolic acid were at temperature and air velocity of 60 °C and 1 ms^{-1} and 50 °C and 1.5 ms^{-1} respectively.	Duzzioni et al. (2013)
		Quality parameter evaluation of freeze-dried acerola fruits	Applied three freezing techniques i.e. Cryogenic freezing with liquid N_2 and vapor nitrogen and by freezing in the freezer and evaluated different parameters	Variation of water activity along the drying and sorption isotherms obtained for different freezing techniques Cryogenic freezing using liquid N_2 was the most recommended technique for freezing	Marques et al. (2007)
	Encapsulation	Evaluate the survival of a probiotic microorganism microencapsulated in cellulose acetate phthalate, added in acerola nectar	3 processing runs carried out on a semi-industrial scale, each containing a 15-liter batch of acerola nectar with added prebiotics and a microencapsulated probiotic culture	After 30 days storage the acerola nectar containing microencapsulated probiotic microorganisms and free *Bifidobacterium animalis* exhibited counts above 8 log CFU per 200 ml and and 5.9 log CFU per 200 ml respectively	Antunes et al. (2013)

acerola. Almeida et al. (2010) standardized the processing conditions for wine production from acerola using RSM optimization and reported that the wines produced with high °Brix and low fruit mass were the best products. The group later prepared seven wine samples with varying amount of pulp and sugar content using a simulated annealing technique to obtain optimal sensory qualities and cost of the wine. Their experiments showed that the best conditions were found at the mass ratio between 1/7.5 and 1/6 and total soluble solids between 28.6 and 29.0 °Brix. Under such conditions, the sensory acceptance values were 6.9, 6.8 and 8.8 for color, aroma and flavor, respectively; and the production cost were 43–45% lower than the traditional wines commercialized in Brazil (Almeida et al. 2014).

A process for producing vitamin C enriched health vinegar using acerola was described in a patent by Nakashima (1989). His invention was performed by adding acerola during a stage of manufacturing, cooking or directly added to the produced vinegar. Apart from these, fermentate from acerola can also be used for enhancing the skin quality. A composition for topical use containing acerola cherry fermentate and organic acid was patented by Zimmerman and Belo (2000) whose use could help in enhancing the rate of skin desquamation. Likewise, a skin whitener composition for external use containing acerola cherry fermentate incorporated with known whitening agents was patented by Dornoff et al. (1998).

Edible films and coatings

Few studies have been done on preparation, feasibility and application of edible films and coatings from acerola. An edible film was prepared and characterized by Azeredo et al. (2012a) using acerola and alginate, plasticized with corn syrup. The incorporation of cellulose whiskers in the film was found to improve its water vapor barrier, tensile strength, and modulus. The authors concluded that such films could be used as edible coatings in several fruits and vegetables for extension of shelf life. Furthermore, alginate-acerola films without whiskers could be consumed as snacks, as this purpose does not require great mechanical or barrier properties. The group also prepared nanocomposite edible films (casted on glass plates) and edible coatings (applied on acerola fruit surfaces) through acerola and alginate reinforced with cellulose whiskers or montmorillonite. The coatings applied to fresh acerola fruit decreased it's weight loss, decay incidence, and ripening rate. The montmorillonite reinforced alginate-acerola puree was found out be the most effective in reducing weight loss and maintaining the visual acceptance in acerola (Azeredo et al. 2012b).

In a separate study, the feasibility of blending mango and acerola pulps into a biodegradable matrix as a source of polyphenols, carotenoids, and other antioxidants was evaluated (Souza et al. 2011). Authors prepared bio-based films using cassava starch with a varied incorporation of mango and acerola pulp based on response surface methodology and used it for packing palm oil. Results indicated that although the film-forming procedure affected the antioxidant compounds, the antioxidant additives added in the films protected the packaged product. However, the investigators suggested that the use of vitamin C pulps should be avoided as additives in films since they found that the high content of ascorbic acid in acerola acted as prooxidant agents.

Supplements

Since acerola has very high content of vitamin C, it has been used in producing ascorbic acid concentrates, supplements, and in the enrichment of other processed products. Moreover, given the fact that the vitamin C of acerola is better absorbed by human beings than the synthetic ascorbic acid (as discussed earlier), the supplements and concentrates from acerola presents an attractive alternative for individuals with vitamin c deficiency. The available products in the market are either vitamin C that have been derived from the acerola fruit or are in the form of acerola supplements that are the condensed form of the fruit itself. The supplements available in the global market under diverse brands are generally in the form of chewables, tablets, powders and capsules. Many such products have additional ingredients added to it like the inclusion of other fruits and its extracts, sugars, and flavors. It is to be underlined that, although sellers claim several beneficial effects of their supplements from acerola still no scientific data on long-term epidemiological studies on human subjects are available to support their say. In fact, the whole fruit concentrate having additional ingredients manufactured under varied processing conditions may have a different bio-efficacy than presumed.

Waste utilization

The industrial processing of acerola fruit into pulps and juices yields a dark red residue, which is thrown away as waste, which constituents around 40% of the fruit volume (Marques et al. 2013). In a study to characterize the physicochemical parameters and functional compounds in the industrial residues of acerola, it was found that residues can be a valuable source of anthocyanins, phenolics, and vitamin C and can be used as food supplements (Sancho et al. 2015). Interestingly, on quantification of level of bioactives in pulps and by-products of 12 tropical fruits from Brazil including acerola, it was found that the anthocyanins and yellow flavonoid content in the byproduct of acerola residue were more than that of its pulp (Silva et al. 2014).

Caetano et al. (2011) evaluated the antioxidant capacity of the agro-industrial waste from acerola. They reported that the hydro ethanolic and hydro methanolic extracts obtained using sequential extraction was found to exhibit good DPPH and ABTS scavenging activity with high percentage inhibition of peroxidation of linoleic acid and the ability to retard the formation of peroxides and conjugated dienes.

Seed is one of the main components of the industrial waste from acerola. The dried and processed flour from acerola seeds have low water (9.4%) and high-calorie content (332 kcal). 100 grams flour contain 3.2 ± 0.02 g lipids, 16.94 ± 0.81 g protein and 57.24 ± 2.44 g carbohydrates. The flour also has high content of crude fiber (26.54%), ash (0.44%), ascorbic acid (66 mg g^{-1}) and minerals such as iron (37.23 mg 100 g^{-1}), calcium (41.76 mg 100 g^{-1}), potassium (41.39 mg 100 g^{-1}), magnesium (22.24 mg 100 g^{-1}), zinc (0.09 mg 100 g^{-1}), manganese (0.74 mg 100 g^{-1}) phosphorus (0.08 mg 100 g^{-1}) and copper (0.15 µg 100 g^{-1}). Fatty acids profile obtained in lipid fraction includes: oleic (31.9%), linoleic (29.2%), palmitic (21.8%), stearic (13.9%) and linolenic (1.3%). Owing to the absence of toxic and allergenic compounds in the acerola seed flour, it can be of potential use in diet (Aguiar et al. 2010). Marques et al. (2013), prepared flour from the waste generated during processing i.e. seeds and bagasee. They found high levels of soluble and insoluble fiber and phenolic compounds in it that could be used for enriching foods. The flour also showed high absorption of water, oil and emulsion stability, which illustrates it's potential for inclusion in meat and bakery products.

Since the residue generated during acerola processing are of low cost but have potent nutritional and functional significance, it can be used for the preparation of inexpensive dietary supplements meant for the low-income communities.

Conclusion and future scope

Acerola, considered a "super fruit", has received much attention in the recent past as it contains an exorbitant content of ascorbic acid along with other phytonutrients like phenolic acids, flavonoids, anthocyanins, and carotenoids. Recent studies have profiled the individual bioactive compounds and the biological activities of the fruit and its extracts. Being one of the richest natural sources of ascorbic acid, several value added products and vitamin C supplements from acerola are available in the global market. Several processing tools and techniques have also been studied to develop suitable value added products from acerola.

Quite a few studies have focused on the molecular aspect of the ascorbic acid synthesis in acerola. However, much detailed studies are warranted to fully understand the basis of the high ascorbic synthesis in the fruit. The gained knowledge can help in developing commonly grown plants with elevated ascorbic acid synthesis. As acerola is rich in pigments like anthocyanins and carotenoids, the use of fruit as food colorants would be another interesting area of work. Studies on the efficacy and stability of acerola pigments as colorants can bring in new dimension as a substitute to the commonly used synthetic dyes.

Possessing a wealthy nutrient profile with numerous bioactivities and being untapped in large part of the world, acerola essentially requires greater focus and holds promising agro-industrial and pharmaceutical applications. However, the full-proof health benefits of the fruit can only be established with long term epidemiological study and comprehensive work on the bioavailability of the various phytonutrients entrapped in the complex food matrix. Future work on the said lines can help in establishing a bold claim linked to the fruit and also bring in new insights regarding the mechanistic changes of the fruit matrix occurring in the human system.

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