Trends in Food Science & Technology 74 (2018) 99–106

Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: www.elsevier.com/locate/tifs

Review

Phytopharmacology of Acerola (*Malpighia* spp.) and its potential as functional food

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ARTICLE INFO

Keywords:
Acerola
Malpighia glabra
M. emarginata
Vitamin C
Health beneficial effects
Functional foods

ABSTRACT

Background: The fruits of *Malpighia glabra* and *M. emarginata* (Family: Malpighiaceae) are commonly known as 'Acerola cherry' or 'Barbados cherry'. Acerola fruits are well known for their high content of vitamin C, phenolic compounds, including benzoic acid derivatives, phenylpropanoids, flavonoids, anthocyanins, and carotenoids. In recent years, there is a growing interest in the role of Acerola as a nutraceutical or functional food with increasing market value. Extracts and bioactive compounds isolated from Acerola are studied for their various health promoting activities and biological activities such as antioxidant, antitumor, antihyperglycemic and skin protecting/skin whitening.

Scope and approach: This article reviewed the scientific studies regarding the bioactive chemical constituents and the health beneficial effects of Acerola extracts and isolated compounds. These findings may help in future research concerning Acerola and Acerola based nutritional products.

Key findings and conclusions: Acerola fruits can be considered as good candidates for the development of novel functional foods. However, detailed *in vitro*, *in vivo* and clinical studies, particularly mechanism-based studies are needed for the development of evidence-based functional food products in future.

1. Introduction

The genus *Malpighia* belonging to the family Malpighiaceae contains about 45 species of shrubs or small trees, which are mainly cultivated for the sweet taste of their juicy fruits rich in vitamin C (Mezadri, Villaño, Fernández-Pachón, García-Parrilla, & Troncoso, 2008; Righetto, Netto, & Carraro, 2005). Among them, *M. glabra* and *M. emarginata* have been commonly used for commercial cultivation and consumption. These plants are native to Central America and Northern South America and are now being cultivated mainly in Brazil, Mexico and some parts of South East Asia and India (Duke, 1993; Rezende, Nogueira, & Narain, 2017). The cherry of *Malpighia* is commonly known as 'Acerola cherry' or 'Barbados cherry' (Fig. 1). Besides a high content of vitamin C, the fruit also contains amino acids, phenolic compounds including anthocyanins and flavonoids, and carotenoids, which makes it a suitable candidate for being classified as a nutraceutical (Marques et al., 2016; Hanamura, Uchida, & Aoki, 2008a; Hanamura, Uchida, & Aoki, 2008b). Various commercial products containing Acerola are being used as dietary supplements for boosting immune response, antioxidant potential and for nutritional requirements. Acerola extracts also showed potent antioxidative, anti-inflammatory, antihyperglycemic, antitumor, antigenotoxic and hepatoprotective activity (Dias et al., 2014; Hanamura, Hagiwara, & Kawagishi, 2005; Hanamura, Mayama, Aoki, Hirayama, & Shimizu, 2006; Motohashi et al., 2004). However, Acerola is not much studied for its pharmacological/therapeutic activities and scientific data concerning dose consideration, interactions and toxicity are not so many. To the best of our knowledge, till date phytopharmacology of Acerola was not reviewed.

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https://doi.org/10.1016/j.tifs.2018.01.014
Received 18 October 2017; Received in revised form 3 January 2018; Accepted 26 January 2018
Available online 01 February 2018
0924-2244/

Fig. 1. Flower and fruit of Acerola (*Malpighia glabra*) (Photo by Dr. H.P. Devkota).

Thus, the present review will discuss the aspects of phytopharmacology and highlight Acerola's potential as a functional food and its market trend. Moreover, the review will help to find current challenges and opportunities for making wider use of Acerola as nutraceutical or functional food.

2. Economic value and relevance of Acerola for the functional food area

With increasing health awareness across the world, functional foods are becoming more and more popular, especially in treating chronic disease (Khan, Grigor, Winger, & Win, 2013). Moreover, a considerable demand is seen for Acerola products in the United States of America, Japan, and Europe due to its high content of vitamin C. The fruit, because of a short shelf life is converted immediately after harvest into pulp and clarified juice and some of them exported as frozen fruits for processing into a variety of products. The juice is a bit tart and is best used in combination with other juices or other formulations. Brazil is the major worldwide producer and exporter of Acerola fruit (De Rosso & Mercadante, 2005). The global Acerola extract market is estimated to reach US$17.5 billion by 2026 with 8.5 percent of compound annual growth rate (CAGR). In 2016, North America accounted for 24 percent of the global Acerola market, and it is estimated to grow at CAGR of 9.7 percent. Similarly, an 8.7 percent CAGR growth is forecasted for Western Europe. [Acerola Extract Market (http://www.futuremarketinsights.com/reports/Acerola-extract-market)]. This growth is likely due to an increased production of Acerola-based beverages, bakery and confectionery products, meat preservation and so on. Among the total Acerola extract market share in 2016, food supplements and beverages were estimated to be 27% and 22%, respectively. Some major Acerola based product manufacturers have been listed in the Future Markets Insight Survey. Some of the popular brands are Green Labs LLC, Nutrilite (Amway), Naturex, Nature's Power Nutraceuticals Corp., Florida Food, Inc., Diana Naturals and Vita Forte, that are operating in the global Acerola extract market [Acerola Extract Market (http://www.futuremarketinsights.com/reports/Acerola-extract-market)].

Berries similar to Acerola such as strawberries, cranberries, blueberries and raspberries have been extensively studied. These berries have been found to be rich in phenolic acids, flavonoids and anthocyanins, and have emerged as popular functional foods across the world (Lasekan, 2014). However, long term impact of berries intake on specific populations and their individual claims have not been fully investigated. Some well-documented nutritional properties of Acerola have made it to be an important functional food. For instance, reports suggested that fresh Acerola juice contains 50 to 100 times more vitamin C than an equal portion of orange juice (Freire, Abreu, Rocha, Corrêa, & Marques, 2013; Vendramini & Trugo, 2000) and it is also rich in carotenoid content (371–1881 μg/100 g) (De Rosso & Mercadante, 2005). High antioxidant activity and anthocyanins levels, which are of great value to manufacturers of functional food products, are specific for Acerola fruit extracts (Hanamura et al., 2008b). Also, the low-carbohydrate content makes it an ideal low-calorie high-nutrient density food supplement. For example, the seeds and bagasse generated during production of Acerola juice were found to be of great value in the production of cereal bars (Marques et al., 2015). These products are having low caloric value besides higher nutritional value, dietary fiber and antioxidant activity.

3. Bioactive constituents

Acerola fruits are well-known for their high vitamin C content (Mezadri et al., 2008; Righetto, Netto, & Carraro, 2005; Vendramini & Trugo, 2000). Besides this, various other phytochemicals have been detected in Acerola. Mallic acid is also found in high amount in Acerola fruits, with trace amounts of citric and tartaric acids as well. Fructose and glucose are the main monosaccharides found in Acerola fruits (Righetto et al., 2005). Acerola fruits also contain phenolics, carotenoids, anthocyanins, and amino acids, mainly, asparagine, alanine, proline, aspartic acid, serine and γ-aminobutyric acid (GABA) (Hanamura et al., 2008b).

Vitamin C content in Acerola fruits may vary upon ripening stages, cultivars, cultivation place and environmental factors (Hanamura et al., 2008a; Righetto et al., 2005; Vendramini & Trugo, 2000). The vitamin C content is high in immature fruits (1.9 g/100 g of juice) and decreases during ripening (0.97 g/100 g of juice in mature fruits) (Righetto et al., 2005). Vendramini and Trugo (2000) also studied the vitamin C content at three different ripening stages: immature (green), intermediate (yellow) and mature (red). Higher vitamin C content was found in immature stage (2.16 g/100 g) as compared to intermediate (1.06 g/100 g) and mature stages (1.07 g/100 g). One of the main reasons for the decrease of vitamin C content during maturation is suggested to be biochemical oxidation (Vendramini & Trugo, 2000). Hanamura et al. (2008a) analyzed the compounds in three cultivars of Acerola from Brazil ('BOK', 'Flor Branca', and 'NRA309'), and one cultivar each from Vietnam ('Vietnam') and Japan ('Okinawa') for their chemical composition. Among them, 'BOK' showed the highest vitamin C and mallic acid content as compared to other cultivars from Brazil, Vietnam and Japan. In addition, the level of fructose was higher in mature fruits juice as compared to immature fruits juice. The sugar contents were also influenced by cultivars and growing regions, where higher fructose and glucose contents were observed in cultivars 'NRA309' from Brazil and 'Vietnam'. Mariano-Nasser et al. (2017) also studied the variation of content for vitamin C, total phenolics and flavonoids, and antioxidant

Table 1
Major phenolic compounds reported from Acerola.

Compound name	Source	References
Benzoic acid derivatives		
Gallic acid (**1**)	Acerola bagasse, Acerola juice	Marques et al., 2016; Righetto et al., 2005
Syringic acid (**2**)	Acerola bagasse, Acerola juice	Marques et al., 2016; Righetto et al., 2005
Phenylpropanoid derivatives		
p-Coumaric acid (**3**)	Acerola bagasse, Acerola puree, Acerola juice, Acerola pulp	Marques et al., 2016; Bataglion, da Silva, Eberlin, & Koolen, 2015; Hanamura et al., 2008a; Righetto et al., 2005
Ferulic acid (**4**)	Acerola puree, Acerola juice, Acerola pulp	Bataglion et al., 2015; Hanamura et al., 2008a; Righetto et al., 2005
Caffeic acid (**5**)	Acerola puree, Acerola juice, Acerola pulp	Bataglion et al., 2015; Hanamura et al., 2008a; Righetto et al., 2005;
Chlorogenic acid (**6**)	Acerola bagasse, Acerola puree, Acerola juice	Marques et al., 2016; Hanamura et al., 2008a; Mezadri et al., 2008
Flavonoids		
Catechin (**7**)	Acerola bagasse, Acerola juice	Marques et al., 2016; Righetto et al., 2005
Epicatechin (**8**)	Acerola bagasse,	Marques et al., 2016; Mezadri et al., 2008
Epigallocatechin 3-*O*-gallate (**9**)	Acerola bagasse, Acerola juice	Marques et al., 2016; Mezadri et al., 2008
Quercetin (**10**)	Acerola bagasse	Marques et al., 2016; Bataglion et al., 2015
Quercetin 3- *O*-*α*-rhamnoside (quercitrin) (**11**)	Acerola puree	Hanamura, & Aoki, 2008; Hanamura et al., 2005, 2008b
Quercetin 3- *O*-*β*-galactoside (hyperoside) (**12**)	Acerola puree	Hanamura, & Aoki, 2008; Hanamura et al., 2008b
Rutin (**13**)	Acerola juice	Mezadri et al., 2008
Kaempferol (**14**)	Acerola pulp	Bataglion et al., 2015
Kaempferol 3-*O*-*α*-rhamnoside (**15**)	Acerola puree	Hanamura et al., 2008b
Luteolin (**16**)	Acerola pulp	Bataglion et al., 2015
Dihydroquercetin 3- *O*-*α*-rhamnoside (**17**)	Acerola puree	Hanamura et al., 2008b
Dihydrokaempferol 3-*O*-*α*-rhamnoside (**18**)	Acerola puree	Hanamura, & Aoki, 2008; Hanamura et al., 2008b
Procyanidin B1 (**19**)	Acerola juice	Mezadri et al., 2008
Aceronidin (**20**)	Acerola puree	Kawaguchi, Tanabe, & Nagamine, 2007
Anthocyanins		
Cyanidin (**21**)	Acerola puree	De Rosso et al., 2008; Hanamura et al., 2008b
Cyanidin 3-*O*-*α*-rhamnoside (**22**)	Acerola puree	De Rosso et al., 2008; Hanamura, & Aoki, 2008; Hanamura et al., 2005, 2008b
Pelargonidin (**23**)	Acerola puree	De Rosso et al., 2008; Hanamura et al., 2008b
Pelargonidin 3-*O*-*α*-rhamanoside (**24**)	Acerola puree	Hanamura, & Aoki, 2008; Hanamura et al.,2005, 2008b
Delphinidin (**25**)	Acerola puree	Hanamura et al., 2008b
Peonidin (**26**)	Acerola puree	Hanamura et al., 2008b

activity in eight different varieties of Acerola collected from Brazil. Among different varieties, namely BRS 236-Ceraja, had the highest antioxidant activity and ascorbic acid and phenolic content, but the lowest content of flavonoids.

Another class of main constituents of Acerola fruits are phenolic compounds, including benzoic acid derivatives (gallic acid and syringic acid), phenylpropanoids (caffeic acid, ferulic acid, etc), flavonoids and anthocyanins (Table 1, Fig. 2). Hanamura et al. (2005) isolated and identified two anthocyanins, cyanidin 3-*O*-*α*-rhamnoside and pelargonidin 3-*O*-*α*-rhamnoside and a flavonoid, quercitrin, from the fruits of Acerola. Hanamura et al. (2006) also prepared a crude Acerola polyphenol fraction (C-AP) by passing ethanol extract through C-18 cartridge column and eluting with ethanol containing 10% acetic acid. The polyphenol content of C-AP was reported to be 40%. Cyanidin 3-*O*-α-rhamnoside and pelargonidin 3-*O*-α-rhamnoside were the main constituents of C-AP. Ribeiro da Silva et al. (2014) also reported a high level of total phenolics in Acerola pulp, suggesting it as an excellent source of phenolic compounds. Marques et al. (2016) also reported catechin, epicatechin, epigallocatechin gallate, quercetin, gallic acid, syringic acid and *p*-coumaric acid (Table 1, Fig. 2) as main phenolic compounds of Acerola bagasse. These compounds were reported as active enzyme inhibitors of α-amylase, α -glucosidase, lipase and trypsin. Silva, Crispim, Erik, and Vieira (2017) studied the effect of processing temperature on the anthocyanin content of Acerola fruits and suggested an optimal condition of heating to obtain a minimal loss. Alvarez-Suarez et al. (2017) also analyzed the phenolic compounds in Acerola fruits by HPLC-DAD/ESI-MS and identified two anthocyanin derivatives, cyanidin 3-*O*-α-rhamnoside and pelargonidin 3-*O*-α-rhamnoside; three phenylpropanoid derivatives, dihydrocaffeoylquinic acid, caffeoyl hexoside and coumaroyl hexoside; and flavonoid derivatives including the glycosides of quercetin, dihydroquercetin, methylquercetin and kaempferol.

The quantity and the composition of phenolic compounds also depends upon the ripening stage as the total phenolic content of juice was decreased from 3.8 mg catechin/g in immature fruits to 1.35 mg in mature fruit juice (Righetto et al., 2005). Hanamura et al. (2008a) reported that proanthocyanidins were the major phenolic compounds in immature fruits but during ripening, the amount of these compounds decreased and anthocyanins were the main polyphenolic compounds in mature fruits. The content of phenolics was also dependent upon the cultivar types, as the cultivar 'NRA309' showed the highest phenolics content as compared to other cultivars. There were also significant differences in the content of individual phenolic compounds among these cultivars. The phenolic content of Acerola was also influenced by harvesting season at different stages of maturity. As such, the phenolic content was higher in the mature fruits collected in dry season as compared to rainy season (Lima et al., 2005).

Carotenoids are another important bioactive compound class present in Acerola. De Rosso and Mercadante (2005) studied the presence of carotenoids in different Acerola genotypes by an HPLC-PDA method. They found that neochrome, neoxanthin, violaxanthin, luteoxanthin, lutein, zeaxanthin, 5,6,5′,6′-diepoxy-β-cryptoxanthin, 5,6-epoxy-β-cryptoxanthin, 5,8-epoxy-β-cryptoxanthin, zeinoxanthin, β-cryptoxanthin, 5,6,5′,6′-diepoxy-β-carotene, 5,8-epoxy-β-carotene and β-carotene were the main carotenoid constituents. Carotenoid content was also influenced by the genotypes, sunlight exposure (De Rosso & Mercadante, 2005), harvesting season and different stages of maturity (Lima et al., 2005). Mature fruits showed higher carotenoid content as compared to immature and half-mature fruits. Carotenoid content was also higher in mature fruits collected in rainy season as compared to those collected in dry season.

The constituents of the waste products such as seed and bagasse obtained during preparation of Acerola juice are also studied, and results suggested that these waste products are also rich in phenolic

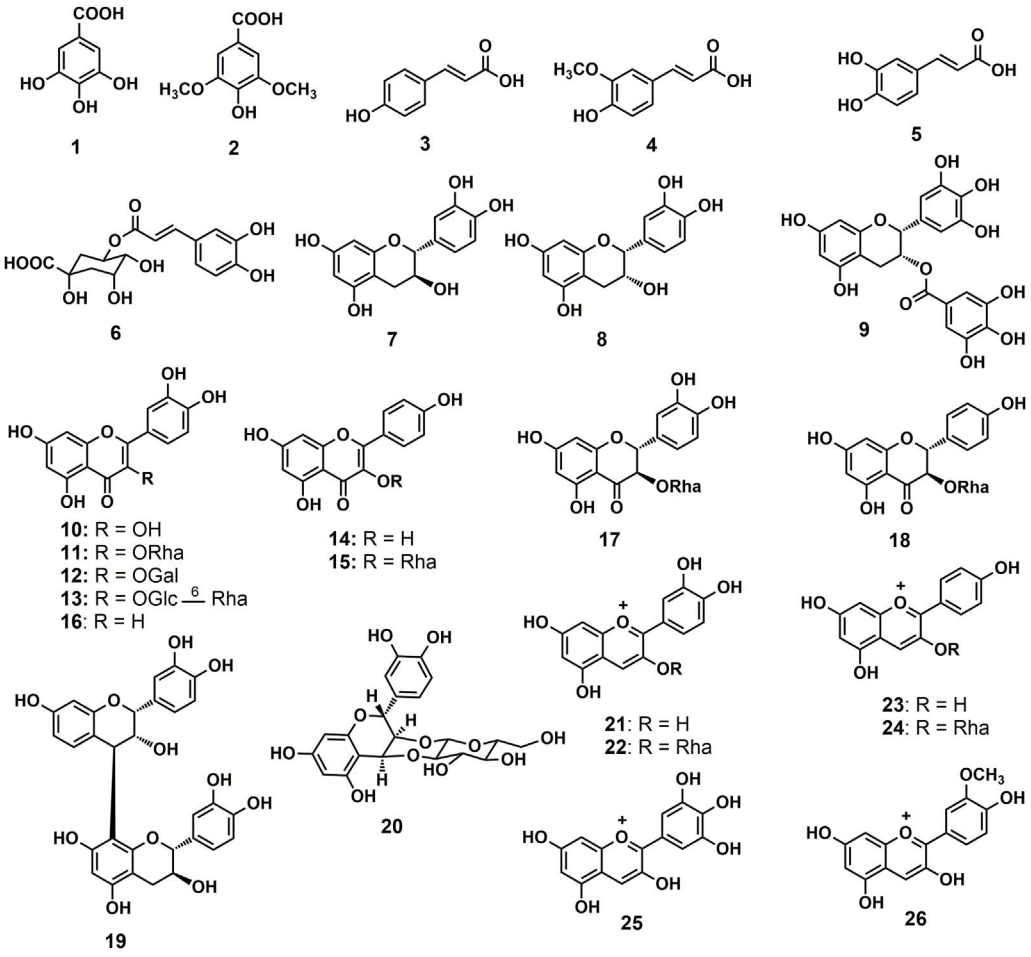

Fig. 2. Chemical structure of phenolic compounds identified in Acerola.

compounds, anthocyanins and carotenoids (Marques, Corrêa, Lino, Abreu, & Simão, 2013). The residues left behind after separating pulp and juice have also been evaluated under optimum extraction conditions and found to contain a higher concentration of bioactive compounds which also showed higher *in vitro* antioxidant activity. The main bioactive compounds were identified as carotenoids, anthocyanins, phenolic acids, flavonoids and ascorbic acid (Rezende et al., 2017).

Pino and Marbot (2001) extracted the volatile flavor constituents of Acerola fruits by steam distillation and analyzed the constituents by GC-MS. Among 170 separated constituents, 150 were identified, which comprised of mainly aliphatic esters (31%), terpenoids (24%), aldehydes and ketones (15%), followed by small amounts of alcohols, acids and amino compounds. Among individual compounds, furfural, hexadecanoic acid, 3-methyl-3-butenol and limonene were main constituents. Nevertheless, Klosterhoff et al. (2018) analyzed the polysaccharide constituents in Acerola fruits, and isolated and identified an arabinan-rich pectic polysaccharide as main constituent.

4. Health-promoting properties of Acerola

Acerola has been investigated for its various biological activities using *in vitro* and *in vivo* models, and possible mechanisms underlying some of them have been determined (Table 2, Fig. 3). Extracts from different fruit parts of Acerola showed potent antioxidant, antitumor, antimutagenic, antidiabetic, hepatoprotective and skin protecting activity. Some of these activities are discussed below.

4.1. Antioxidant activities

Antioxidants present in the diet may have a significant effect on the prophylaxis and progression of various diseases associated with oxidative stress. Along with vitamin C, anthocyanins present in Acerola represent a potent source of natural antioxidants, which have health promoting and disease preventing activities (Lima et al., 2005). *In vitro* studies reported the beneficial antioxidant traits of Acerola juice (Nunes et al., 2011, 2013). Acerola extracts showed scavenging activities against DPPH and ABTS free radicals (Mezadri et al., 2008). Linoleic acid peroxidation (Caetano, Araújo, Lima, Maciel, & Melo, 2011) and oxidation of LDL (Hwang, Hodis, & Sevanian, 2001) were inhibited as well by Acerola extract. Paz et al. (2015) investigated the antioxidant activity of eight tropical fruit pulps from Brazil and Acerola showed the highest activity. Moreover, the antioxidant activity of Acerola juice was also found to be higher as compared to polyphenols-rich extracts of strawberry, grape and apple juice (Mezadri et al., 2008).

In vivo antioxidant studies of Acerola extract have also been performed. Leffa et al. (2015b) evaluated the effect of a Acerola juice as supplemental food on the levels of minerals in the liver and kidney of mice fed with cafeteria diet. They found that the intake of Acerola juice with fat and calorie rich diet leads to a change in mineral composition in these organs and thus helps in providing antioxidant defense against oxidative stress. In another study, unripe Acerola juice showed preventive activity by decreasing diet-induced lipid and protein oxidative damage in the hippocampus, liver, kidney and heart of rats. Moreover, the unripe, ripe and industrial Acerola juices were examined in mice fed

Table 2
Pharmacological activity of Acerola extract, pulp and juice tested in different *in vitro/in vivo* models.

S.No.	Activity	Model used	References
1	Antihyperglycemic and antihyperlipidemic	Male mice and CaCo-2 cells	Hanamura et al., 2006
		Inhibition of α-glucosidase and maltase activities	Hanamura et al., 2005
		Diabetic Wister rats	Barbalho et al., 2011
		Enzyme inhibition test (α-amylase, α-glucosidase, lipase and trypsin)	Marques et al., 2016
2	Anti-photoaging/Skin lightening effect	Human study (50 women)	Costa et al., 2012
		Brownish guinea pigs subjected to controlled UVB irradiation	Hanamura et al., 2008b
		Ultraviolet B (UVB)-induced skin pigmentation in senescence marker protein 30 (SMP30)/gluconolactonase (GNL) knockout (KO) hairless mice	Sato et al., 2017
3	Antioxidant	Male rabbit aortic endothelial cells	Hwang et al., 2001
		ABTS, DPPH, ORAC and FRAP activity	Mezadri et al., 2008; Paz et al., 2015; Rufino et al., 2010
		β-Carotene bleaching method	Lima, Melo, Pinheiro, & Guerra, 2011
		in vitro human dermal fibroblast (HDFa) model	Alvarez-Suarez et al., 2017
		H_2O_2-induced intracellular reactive oxygen species production in HEK-293 cells.	Anantachoke et al., 2016
4	Anti-inflammatory	Obese mice enzyme-linked immunosorbent assays	Dias et al., 2014
5	Hepatoprotective	Male Wistar rats with induced hepatic damage by acetoaminophen	Luveena et al., 2012
6	Antigenotoxic and antimutagenic	Obese mice-effects on bone marrow, peripheral blood, liver, kidney, and brain	Leffa et al., 2014; Horta et al., 2016
		Chromosomal aberration test in the bone marrow cells of Wistar rats	Düsman et al., 2016
		Mice blood cells	Nunes et al., 2013
		Male mice	Nunes et al., 2011
		Bone marrow cells of Wistar rats (*Rattus norvegicus*) that were treated *in vivo* with radioisotope iodine-131	Düsman et al., 2014
7	Antimicrobial	Disk diffusion test against *S. aureus, P. putida, P. fluorescens, P. fragi* and *Brochothrix thermosphacta*	Delva & Goodrich-Schneider, 2013; Tremonte et al., 2016
		Gram positive and gram negative bacteria	Motohashi et al., 2004; Paz et al., 2015
8	Antitumor	Tumor cell lines: human oral squemous cell carcinoma (HSC-2) and human submendibular gland carcinoma (HSG)	Motohashi et al., 2004
9	Anti-obesity	Obese mice-on the concentrations of minerals in the liver and kidney of mice	Leffa et al., 2015a
		Obese mice-oxidative damage in the cortex, hippocampus, liver, kidney, and heart	Leffa et al., 2015b

with palatable cafeteria diet to examine their effects on enzymes of the energy metabolism in the brain (Leffa et al., 2017). Results revealed that the unripe Acerola juice was superior in preventing inhibition of citrate synthase in the brain tissue, and thus helping in the prevention of brain damage by oxidative stress. This is because of the fact that the citrate synthase enzyme plays an important role in the prevention of

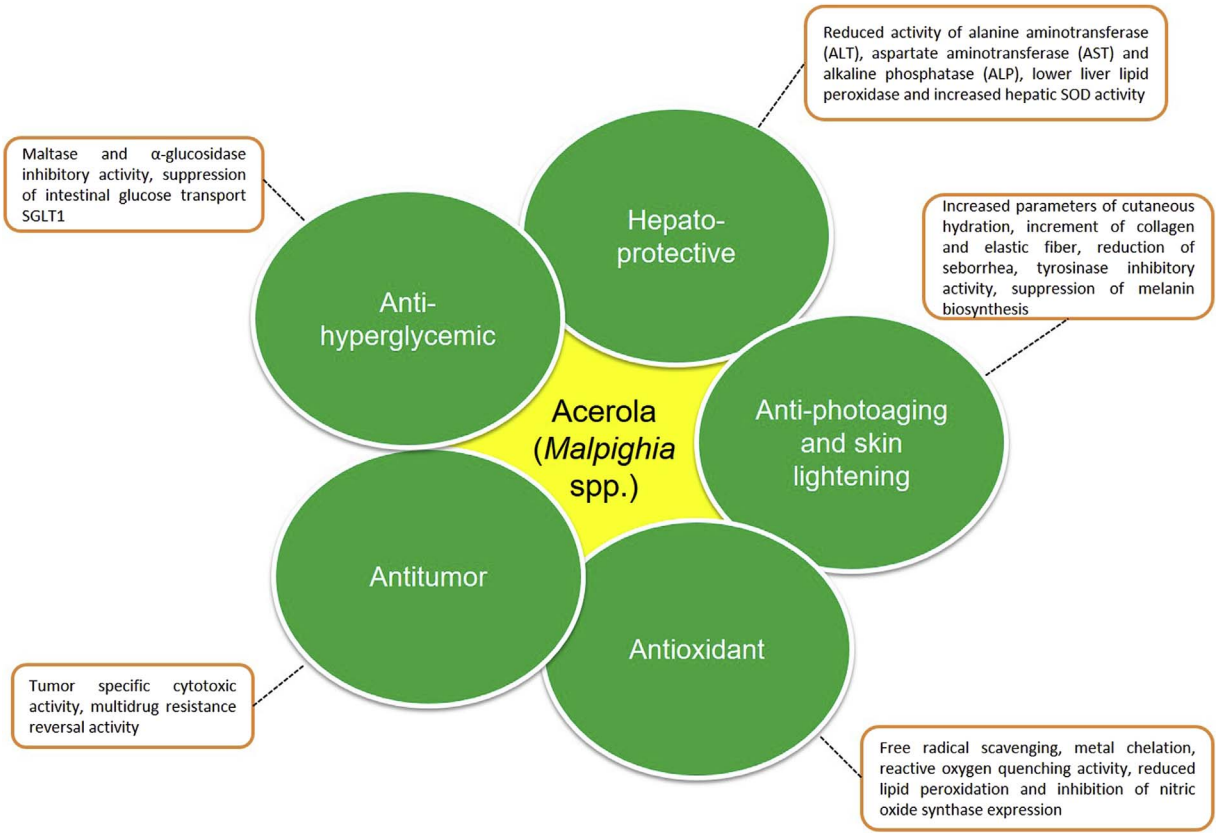

Fig. 3. Reported biological activities and proposed mechanisms of action of Acerola.

sepsis, which is associated with increased reactive oxygen species level, oxidative stress and marked decrease in endogenous antioxidant concentrations (Scaini et al., 2010).

Acerola fruit extract has been also tested against oxidative damage in the *in vitro* model of human dermal fibroblast (HDFa). The HDFs were incubated with Acerola fruit extract before exposing to oxidative stress. The HDFs treated with fruit extract had lower apoptosis and ROS level, and decreased lipid and protein oxidation. The levels of antioxidant enzymes, such as the catalase and superoxide dismutase were increased due to the Acerola fruit extract treatment along with improvement in mitochondrial functionality (Alvarez-Suarez et al., 2017). In another experiment, eleven different fruits from Thailand were examined for their phenolic content and antioxidant potential. Among all tested fruits, total phenolic content and *in vitro* DPPH antioxidant activity were found to be highest in Acerola (*M. glabra*) fruit extract. Moreover, Acerola extract was found to reduce intracellular ROS production induced by H_2O_2 treatment in HEK-293 cells. The antioxidant enzymes (SOD, GPx and catalase) expression was also increased after the fruit extract treatment (Anantachoke, Lomarat, Praserttirachai, Khammanit, & Mangmool, 2016). Nonetheless, arabinan-rich pectic polysaccharide fraction from Acerola fruit significantly decreased the H_2O_2-induced cytotoxic effects and the levels of reactive oxygen species in a murine fibroblast cell line (3T3) (Klosterhoff et al., 2018).

4.2. Antitumor, antigenotoxic, and antimutagenic activities

Antitumor activity of Acerola fruit extract was tested in tumor cell lines such as human oral squamous cell carcinoma (HSC-2) and human submandibular gland carcinoma (HSG), and found to be effective (Motohashi et al., 2004). Acerola juice was also found to be effective in preventing genotoxicity/DNA damage induced by hydrogen peroxide due to rich antioxidant and nutrient composition (Düsman, Almeida, Tonin, & Vicentini, 2016; Leffa et al., 2014). Also, it has been reported that the supplementation of Acerola juice leads to a partial reversal of fat diet-induced DNA damage in the blood, kidney, liver and bone marrow in obese mice (Tremonte et al., 2016). These beneficial impacts were observed through its main bioactive components (vitamin C and rutin) that have a marked effect in reducing oxidative stress, resulting in a decrease of genotoxicity under obesogenic conditions (Leffa et al., 2014). Antigenotoxic effect and cytotoxicity of Acerola fruit extract were evaluated using the comet test (DNA damage) and the MTT assay. The extract showed DNA damage preventive activity against oxidative stress (Nunes et al., 2011). Recently, radioprotective activity of Acerola extract was tested using a chromosomal aberration test in bone marrow cells of Wister rats. Treatments showed that the extract significantly reduces the chromosomal alteration percentage induced by cyclophosphamide. (Düsman et al., 2016). Acerola (*M. glabra*) fruit extract at a dose of 5 mg/100 g of body weight was tested against the mutagenic activity of the radiopharmaceutical iodine-131 (25 μCi) in the bone marrow cells of Wistar rats (Düsman et al., 2014). The fruit extract was found to protect the cells against radioiodine mutagenic effects and to decrease the chromosomal alterations. However, post-treatment exposure of Acerola extract showed no protective effect (Düsman et al., 2014).

4.3. Antihyperglycemic activity

Acerola phenolic fraction suppressed intestinal glucose transport and induced inhibition of glucosidase, thus acting towards prevention of diabetes mellitus and related complications (Barbalho et al., 2011; Delva & Goodrich-Schneider, 2013). Hanamura et al. (2006) studied the antihyperglycemic effects of crude Acerola polyphenolic fraction (C-AP) on Caco-2 cells and male ICR strain mice. C-AP showed *in vivo* antihyperglycemic activity by inhibiting the glucose uptake in Caco-2 cells, and by α-glucosidase inhibition. Also, the polyphenolic fraction from Acerola fruit extract inhibited α-glucosidase and maltase activity, which is of relevance for the intestinal absorption of glucose (Hanamura et al., 2006). In another study, Acerola extract has been tested against hyperglycemic and hyperlipidemic conditions in diabetic Wistar rats (Barbalho et al., 2011). In comparison to the untreated diabetic rats, Acerola extract-treated rats showed reduction in the level of glucose, cholesterol, triglycerides while increased the level of HDL (Barbalho et al., 2011).

4.4. Skin protectant, and anti-photoaging activity

Melanogenesis is the overproduction of melanin pigment due to increased exposure to UV radiation. One of the possible reasons is the upregulation of tyrosinase enzyme due to UV exposure, which plays an important role in melanin formation. C-AP, when tested against hypermelanogenesis under UV irradiation in guinea pigs, effectively reduced melanin pigment formation and showed skin lightening effect (Hanamura et al., 2008b). This was due to the inhibition of tyrosinase activity upon C-AP treatment. In another study, a nutraceutical product containing lycopene, Acerola extract, grape seed extract and Biomarine complex T was tested in photoaged human skin of 50 women for 120 days of treatment and further biopsy of the tissues was performed (Costa et al., 2012). Results revealed an improvement of general status of the skin in all cases with increased parameters of cutaneous hydration, reduction of pH, and increasing ultrasound density and histological increment of collagen and elastic fibers, overall indicating a positive effect against skin photoaging. In another experiment, Acerola juice was examined for its protective effect against ultraviolet B induced skin pigmentation in a gene knockout mice model (Sato et al., 2017). Acerola juice was found to prevent skin pigmentation by increasing ascorbic acid level in skin and stratum corneum water content, and also by decreasing the expression level of an enzyme (*i.e.* dopachrome tautomerase) involved in melanogenesis and its related genes. In another similar experiment, the effect of Acerola fruit extract was tested for its anti-melanogenesis effect in B16 mouse melanoma cells (Wang, Li, He, Dong, & Wang, 2015). The extract was found to decrease melanin and tyrosinase level and to exert anti-melanogenesis effect. Also, the extract showed DPPH antioxidant protective activity. Moreover, skin patch test was also conducted and no adverse reaction of the Acerola extract was found. Thus, the fruit extract was recommended for its use as an antiaging functional food, and in the composition of whitening cosmetic products.

4.5. Other effects

Obesity is a fast growing health problem and affects a high number of people throughout the world. It is mainly due to stressful life style, uncontrolled diet and excessive intake of high calorie content foods. In some cases, genetic/heredity factors could be responsible for obesity as well. Diverse enzymes play a crucial role in the metabolism of basic building blocks such as carbohydrates, proteins and lipids, etc., to be assembled into useful products. As such, α-amylase and α-glycosidase are responsible for the breakdown of carbohydrates into monosaccharides and thus help in carbohydrates absorption. Similarly, lipase is an enzyme involved in fat metabolism and it helps in triglyceride absorption. Under the presence of Acerola bagasse flour extract, inhibition of these enzyme activities was recorded (Marques et al., 2016). The extract showed presence of polyphenolic compounds which played effective role in the inhibition of these enzymes' activities and thus could be a possible adjuvant in treating obesity and dyslipidemic conditions (Marques et al., 2016). Moreover, Acerola extract also showed antimicrobial activity against *Staphylococcus aureus*, *Pseudomonas putida, P. fluorescens, P. fragi* and *Brochothrix thermosphacta*, with the use of *in vitro* and *in situ* tests which showed a strong inhibition of both intentionally induced bacteria and naturally occurring microorganisms (Delva & Goodrich-Schneider, 2013; Tremonte et al., 2016). These data suggested the possible application of Acerola extracts in meat preservation. Moreover, Acerola extract was tested against acetaminophen-induced

hepatic injury in rats (Luveena, Karthiayini, & Sreekumar, 2012). The results showed a positive effect of the extract, which was confirmed by liver histopathology and reduction in the activity of alkaline phosphatase (ALP), alanine aminotransferase (ALT) and aspartate aminotransferase (AST). Also the glutathione level was reduced in treated rats (Luveena et al., 2012). Garcia et al. (2016) identified fifty strains of lactic acid bacteria in by-products of Acerola fruit pulp processing and reported the inhibitory effect of selected *Lactobacillus* strains against *Staphylococcus aureus, Salmonella typhimurium, S. enteritidis, Listeria monocytogenes* and *Escherichia coli.*

Innovative food products containing Acerola, or other vegetables and fruits have been infused with probiotic bacteria. For example, commercial preparations with probiotic infused beverages including Acerola, cranberry, blueberry, pomegranate, apple, blackcurrant, acai, guarana, mango, grapes, cherries, kiwi fruits, strawberries, peach and plums have already been formulated (Sun-Waterhouse, 2011). Most probiotic-based beverages currently in market are dairy-based products which are not suitable to be consumed by people with lactose intolerance. Thus mixing these probiotics with Acerola juice will be particularly beneficial for such people.

5. Conclusion and future prospects

Healthy foods are becoming popular worldwide with the increasing rate of obese population. The major multinational companies and fast food manufacturers who previously were focused on comfort foods are now experimenting and introducing natural ingredient-based products, which are of low calorie but high nutritional value. Various companies have already diversified fruit juices and have created products fortified with vitamins and other supplements. In this regard Acerola was found to be rich in bioactive compounds especially ascorbic acid and polyphenolics and showed varied health beneficial effects. Hence, Acerola is anticipated to be a good candidate for dietary supplements and functional food manufacturers looking to the development of new products.

Expansion of the functional food market, including Acerola extract-based products, is highly influenced by the regulatory environment, consumer demand, and farm to fork supply chain linkages. This market has flourished in regions where the business environment is conducive for their growth. Emerging markets aspiring to cultivate and leverage this functional food will have to work towards creating the right regulatory environment and permit industry to build a farm to fork supply chain for such products to flourish.

Not much work has been done on Acerola pharmacological activity and underlying mechanisms with potential benefit in diverse disease conditions. To categorize Acerola fruit under the frame of functional food products, more clinical and molecular mechanism-based studies should be performed (in both *in vitro* and *in vivo* conditions), which will open new areas for formulating effective Acerola-based phytopharmaceuticals or functional foods. As Acerola fruit gets deteriorated quickly after harvest due to its short shelf life, efforts should also be made on increasing its self-life and further process optimization for its maximum utilization. Moreover, development of varieties, cultivars and harvesting practices, as well as storage and handling methods, can improve the nutritional content, bioactive compounds, and health beneficial effects.

Conflicts of interest

No conflict of interest is declared.

Acknowledgements

Atanas G. Atanasov acknowledges the support by the Polish KNOW (Leading National Research Centre) Scientific Consortium “Healthy Animal—Safe Food,” decision of Ministry of Science and Higher Education No. 05-1/KNOW2/2015.

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