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RE: Review on the Phytochemicals and Health Effects of Superfruits

Chang SK, Alasalvar C, Shahidi F. Superfruits: phytochemicals, antioxidant efficacies, and health effects – a comprehensive review. [published online January 23, 2018.] *Crit Rev Food Sci Nutr*. doi: 10.1080/10408398.2017.1422111.

The term "superfruit" is a marketing phrase intended to promote the popularity of certain fruits previously known only in their indigenous locations. "Exotic fruits," with shapes, colors, or flavors unfamiliar to North American and European consumers, are increasingly available with advances in processing, transportation, and storage. Blueberries (*Vaccinium* spp., Ericaceae), among the first to be hailed as a "superfruit," are exceptions as Northern hemisphere natives. While fruits from Europe and North America have been well-studied for their nutritional content, those from other areas, especially South America, are understudied. Tropical fruits growing wild in unique ecosystems or cultivated on a small scale may produce high levels of bioactive compounds, certainly the case with nine that are the focus of this review.

Without disclosing the basis of their choices, the authors selected fruits of açai (*Euterpe oleracea*, Arecaceae), acerola (*Malpighia emarginata*, Malpighiaceae), camu-camu (*Myrciaria dubia*, Myrtaceae), jaboticaba (*Myrciaria cauliflora*), goji berry (*Lycium barbarum*, Solanaceae), jambolan (jambolâo; *Syzygium cumini*, Myrtaceae), macqui (*Aristotelia chilensis*, Elaeocarpaceae), noni (morinda; *Morinda citrifolia*, Rubiaceae), and Brazil cherry (pitanga; *Eugenia uniflora*, Myrtaceae). Some botanical characteristics of each are described, as well as some traditional and modern uses. All but noni and Brazil cherry are berries, with noni fruit "grenade-shaped" and lumpy, and Brazil cherry shaped like a small pumpkin. Many of these fruits, when ripe, are dark red to deep purple, indicating the presence of anthocyanins.

While several are mostly eaten out-of-hand, others are used in juices, jellies, and preserves, or are concentrated to add to other beverages. Goji berry and jambolan are well-known medicinal foods, with the latter especially used to combat diabetes. Jambolan is also used as an anti-scorbutic, diuretic, and for gastrointestinal (GI) diseases. Noni fruit products, including juices and encapsulated powders, are popular functional foods in North America, Europe, and Asia.[‡] Most fruits reviewed are from South America. Besides Brazil, acerola is also grown in the Caribbean, parts of the United States, Japan, and the Republic of China (ROC). Goji berry grows in most parts of the People's Republic of China (PRC). Jambolan is of Asian origin, found especially in India and Southeast Asia. Noni, native to Southeast Asia and Australasia, is widely cultivated and naturalized throughout the tropics.

Phytochemicals in these fruits include phenolic acids, flavonoids, phytoestrogens, carotenoids, and others, but many constituents remain unidentified. The authors summarize reported phenolic content, including flavonoids, anthocyanins, proanthocyanins, and vitamin C, of the nine fruits reviewed. In data available, camu-camu and macqui have the highest total phenolic content; macqui and noni, the highest flavonoid levels; açai and noni, the most anthocyanins; camu-camu, the most proanthocyanidins and vitamin C. No vitamin C is found in macqui. No anthocyanins are reported in goji berry or noni. Only limited studies of the phenolic profiles of Brazil cherry, jambolan, and acerola have been conducted. Flavonols are reported in all nine fruits. Flavan-3-ols are found in most, but not açai; conversely, only açai is reported to have flavanonols or flavones. Both hydroxycinnamic and hydroxybenzoic acids are reported in most of these fruits but are not well characterized. Ellagic acid is found in all except noni and açai; gallic acid, in all but camu-camu and Brazil cherry. Ellagitannins are found in camu-camu and jaboticaba[‡‡]; procyanidins, in jaboticaba, açai, and acerola. Coumarins are reported in goji berry and noni. Iridoids have been found in noni. Terpenes, mostly monoterpenes, are reported in goji berry. A lengthy table sets outs phenolic compounds identified and amounts reported for the selected fruits; another, reported carotenoids and amounts for six (açai, acerola, camu-camu, goji berry, jambolan, and Brazil cherry). Carotenoids and their derivatives are not found in noni, jaboticaba, or macqui. Neoxanthin and zeaxanthin isomers are found in all six with carotenoids but Brazil cherry; lutein, all but camu-camu and goji berry; carotene, all six; lycopene, only Brazil cherry. Acerola, with over 20 carotenoids, has the most diverse carotenoid profile, and the most abundant.

Broader phytochemical profiles are also sketched for each fruit. Açai, for example, has over 22 phytochemicals, with perhaps the widest range of antioxidant compounds of the fruits discussed, with anthocyanins, flavanones, flavanonols, flavone-C-glycosides, flavones, dehydroflavones, flavanols, phenolic acids, and procyanidins. Açai also has lignans, lignoids, fatty acids, quinones, terpenes, norisoprenoids, and benzenoids. A 2017 study of phenolic acids in goji berry found coumaric, isoferulic, and caffeic acids and their derivatives predominant. Several novel compounds occur in goji berry. A new *N*-feruloyl tyramine dimer is its most abundant polyphenol, with better bioactivity than corresponding monomers. Goji berry is a rich source of polysaccharides (5-8% of dried fruit). Goji polysaccharides are highly branched glycopeptides with 18 amino acids.

Jambolan is the most phytochemically diverse after açai, with 74 phenolic compounds identified in its edible parts in one study, including gallotannins and hydrolysable tannins. Hydroxycinnamic acid derivatives were not found. All flavanonols in jambolan occur as dihexosides. Macqui's anthocyanins are diverse and abundant, with a large ratio of diglycosylated to mono-substituted compounds (84%:16%). Noni has anthraquinones and their glycosides, fatty acids and their derivatives, iridoids and their glycosides, saccharides, and volatile compounds, among others; proxeronine, enzymatically converted to xeronine, is of particular interest. It has been postulated that xeronine can modify proteins' molecular structures, restoring proper function. Four compounds reported in noni fruit and commercial juices from all different growing regions can be used to authenticate raw materials. A novel flavonoid, leucocyanidin-3-O-β-D glucoside, or aceronidin, has been found in acerola. In addition to high antioxidant activity, it inhibits α-glucosidase and α-amylase enzymes, potentially slowing carbohydrate digestion.

Several methods have been used to measure the antioxidizing efficacy of the selected fruits. Antioxidant activity varies depending on assay used, showing a need to conduct several measures to account for different mechanisms of action, units of measure, and assay limitations. Reported results are presented where data exist, but the authors do not rank selected fruits by antioxidant efficacy.

Potential health benefits for all selected fruits except acerola, an apparent omission, are presented in a table organized by effect; six are further discussed in the text. In a prospective study among 40 healthy young adult women, açai increased plasma antioxidant capacity, potentially protecting against atherosclerosis. In another study with 35 healthy young adult women, açai enhanced catalase activity and total antioxidant status while reducing radical oxygen species (ROS). It also altered plasma concentrations of compounds involved in endogenous antioxidant defense, enhancing protection. Cardioprotective, chemoprotective, lipid-lowering, and pain-relieving effects are reported for açai in human trials. Among tobacco (*Nicotiana tabacum*, Solanaceae) smokers, a double-blind, randomized, placebo-controlled trial (RCT) found that camu-camu had high potential to reduce oxidative stress and inflammatory biomarkers. An RCT of effects of goji berry consumption on exercise-induced adrenal stress found significant reductions in post-exercise tiredness in the active group. Anti-diabetic, immune-stimulating, eye health, and weight maintenance effects were reported for goji berry in human studies. Noni was reported to boost bone reconstruction, reduce formation of acute gastric lesions, and enhance memory in other human studies. In an RCT, noni improved pain and bleeding scores but had no effect on menstrual pain. Other effects of these fruits are suggested by in vivo studies. These include cancer preventing and anti-diabetic effects for noni, lipid lowering effects for camu-camu, ergogenic effects for goji berry, and more. For macqui, they include cardioprotective and anti-diabetic activities and restoring tear formation in dry eyes; for Brazil cherry, cardioprotection; for jaboticaba, an anti-diabetic effect. Neuroprotective and anti-aging effects have been reported for açai anthocyanins in a model organism, *Caenorhabditis elegans*. The authors say they considered only in vivo and human clinical studies, but for jambolan, only in vitro support is cited for its reported antibacterial, antifungal, antiviral, antidiarrheal, anti-allergic, antipyretic, antineoplastic, anti-inflammatory, chemopreventive, radioprotective, gastroprotective, hepatoprotective, free radical scavenging, cardioprotective, hypolipidemic, and hypoglycemic effects.

More clinical studies are needed of health benefits of the selected fruits, especially acerola, camu-camu, jaboticaba, jambolan, macqui, and pitanga. Epidemiological and clinical trials are needed in populations that habitually consume these fruits, and in those with high incidence of coronary heart disease, obesity, and type 2 diabetes. Additional safety and toxicology studies are also needed, especially for açai. Warning letters were sent by the US Food and Drug Administration (FDA) to online and manufacturing companies concerning açai products. Contamination with a disease-bearing parasite, *Trypanosoma cruzi,* is a concern. Mandatory food safety surveillance is required for açai products. Goji berry, while used and a functional food and traditional medicine for some 2500 years, has little toxicological information recorded and may interact with warfarin. More studies of goji berry polysaccharides should be conducted in vivo and in humans. Noni extract has been evaluated for toxicity in phase-I and phase-II clinical trials (CTs). Scopoletin, its main bioactive, caused no adverse events at a dose of 6-8 g/day in cancer patients. Scopoletin can be used as a biomarker in noni pharmacokinetic studies.

Polyphenols are extensively metabolized in the body. While many studies show that polyphenols themselves are not very bioavailable, various models show high availability for some, e.g., zeaxanthin from goji berry and total anthocyanins from açai pulp and juice. Not only were plasma levels of these polyphenols increased in CTs, but total antioxidant capacity was enhanced. In one goji berry CT, the latter benefit was seen in hypopigmentation and soft drusen accumulation in the macula region of the eye. While in vitro GI tract digestion models are helpful in investigating the effects of food matrices and digestion on polyphenols, they cannot accurately mimic conditions in the human gut. Insufficiency of existing data on factors that affect bioavailability of phytochemicals and their metabolites remains "a big challenge" in assessing the role of individual food compounds on health. The authors do not directly mention effects of the gut biota on metabolization, nor the great individual variability among humans in biota constituents.

Isotonic beverages made with açai, macqui, blackthorn (*Prunus spinosa*, Rosaceae), and lemon (*Citrus × limon*, Rutaceae) juice were more effective than commercial isotonic drinks in terms of antioxidant capacity, vitamin and mineral content, and biological activities. Future uses of "superfruits" will no doubt be based in part on the success of individual marketing strategies, such as has been implemented for pomegranates (*Punica granatum*, Lythraceae) in the United States, but other factors are also important. While consumers, given the choice, tend to select healthier fruit-based drinks and juices, consumer resistance, legislative barriers, ethical concerns related to sourcing, costs, and technological issues may affect or limit such choices. Esthetic qualities may also affect consumer acceptance. Noni fruit, for example, is described as having a "bitter and strong rancid odor." Many tropical fruits do not survive shipment well and must be processed immediately after harvest to limit spoilage. Processing facilities must be built and maintained for these fruits to reach distant markets. Fruit by-products, such as peels, are often rich in phytochemicals that may be beneficial. So far, of these nine fruits, only açai, acerola, and camu-camu byproducts have been assayed. Appropriate labeling of nutrition information and any health claims should be developed and approved by appropriate regulatory bodies such as the US Federal Drug Administration and European Food Safety Agency. While the term "superfruit" may itself be a catchall marketing concept, increased awareness and use of novel fruits and their unique phytochemicals can make important contributions to human health and to economic activity in producing regions.

It should be noted that the authors of this wide-ranging review do not describe their literature search strategy or selection criteria.

—Mariann Garner-Wizard

‡Although not mentioned by the authors, noni or morinda leaf infusions are used medicinally in the Caribbean and elsewhere for overall health. Also, acerola is used in some vitamin C products, especially chewables.

‡‡In different paragraphs, each of these fruits is said to be the only one containing ellagitannins.

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The American Botanical Council has chosen not to reprint the original article.