Journal of Functional Foods 48 (2018) 65–84

Contents lists available at ScienceDirect

Journal of Functional Foods

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

Encapsulation of natural active compounds, enzymes, and probiotics for fruit juice fortification, preservation, and processing: An overview

Elissa Ephrem[a,b], Amal Najjar[a], Catherine Charcosset[b], Hélène Greige-Gerges[a,*]

[a] Bioactive Molecules Research Laboratory, Faculty of Sciences, Lebanese University, B.P. 90656 Jdaidet El-Matn, Lebanon

[b] Laboratoire d'Automatique et de Génie des Procédés, Université Claude Bernard Lyon I, 43 Boulevard du 11 Novembre 1918, Bâtiment CPE 69 622, Villeurbanne Cedex, France

ARTICLE INFO

Keywords:
Bioactive molecules
Delivery systems
Enzymes
Fruit juice additives
Functional food
Probiotics

ABSTRACT

Fruit juices are low-fat, non-alcoholic, lactose-free, and nutritious beverages that are highly desired by consumers. However, fruit juices undergo microbial, enzymatic, and chemical deterioration, which shortens their shelf-life. The demand for healthy fresh fruit juice has encouraged the use of natural agents (such as antimicrobials, vitamins, anti-browning agents, and probiotics) for the protection and fortification of freshly squeezed juices. However, the use of these bioactive agents is limited by their low aqueous solubility, and/or physico-chemical instability, especially in acidic food products. Therefore, their incorporation into encapsulation systems to improve their stability and activity has been considered. This is a review of the literature on the characteristics and efficiency of delivery systems that can be used to load and deliver natural agents designed to be used in fruit juices.

1. Introduction

Fruit juices are widely consumed beverages worldwide. The global demand for high-quality, fresh fruit juices is continually increasing; especially as there is an increasing awareness of including healthy juices and fluids instead of soft drinks and sweetened beverages in the human diet. Fruit juices, which are naturally rich in bioactive compounds with health-promoting and disease-reducing properties, are important contributors to human nutrition. These natural health-promoting bioactive components provide consumers with a large variety of health benefits, such as maintaining normal blood pressure and protecting the skin (Cosgrove, Franco, Granger, Murray, & Mayes, 2007), bones (Mandadi et al., 2009; Trzeciakiewicz, Habauzit, & Horcajada, 2009; Trzeciakiewicz et al., 2010), cardiovascular system (Chong, Macdonald, & Lovegrove, 2010; Dalgård et al., 2009; Grassi et al., 2009), and nervous system (Dai, Borenstein, Wu, Jackson, & Larson, 2006; Macready et al., 2009; Vafeiadou et al., 2009). However, natural fruit juices are highly prone to deterioration, which makes the production of stable fresh beverages challenging.

Different techniques are used to prolong the shelf-life of fruit juices, including thermal (low-temperature/long-time and high-temperature/short-time) and non-thermal (membrane filtration, high-pressure technology, ultrasound, pulsed electric field) pasteurization methods. There are various drawbacks to the application of these techniques, including the loss of the organoleptic properties of the juice or a limited treatment efficacy (Chen, Yu, & Rupasinghe, 2013; Devlieghere, Vermeiren, & Debevere, 2004). Therefore, the use of natural additives for juice protection and fortification has been extensively investigated over the years. The list of natural juice additives extends from antimicrobials, such as essential oils and their components (Baskaran, Amalaradjou, Hoagland, & Venkitanarayanan, 2010; Smith-Palmer, Stewar, & Fyfe, 1998), to vitamins (de Lourdes Samaniego-Vaesken, Alonso-Aperte, & Varela-Moreiras, 2012), probiotics (Yoon, Woodams, & Hang, 2004), anti-browning agents (Ozoglu & Bayindirli, 2002), active peptides (Alessa et al., 2014), polyphenols (Shao, Zhang, Fang, & Sun, 2014), and carotenoids (Ribeiro, Ax, & Schubert, 2003). Enzymes such as

Abbreviations: AA, acrylic acid; ALG, alginate; Arto, artocarpanone; AsA, ascorbic acid; BHT, butylated hydroxytoluene; °Bx, Brix degree; $CaCl_2$, calcium chloride; CaS, calcium stearate; CD, cyclodextrin; CGA, chlorogenic acid; CIN, cinnamic acid; DHA, docosahexaenoic acid; DMSO, dimethyl sulfoxide; DPPC, dipalmitoylphosphatidylcholine; EE, encapsulation efficiency; EPA, eicosapentaenoic acid; FOS, fructooligosaccharide; FT-IR, Fourier transform infrared spectroscopy; GOS, galactooligosaccharide; ^{1}HNMR, proton nuclear magnetic resonance; HP, hydroxypropyl; MATH, microbial adhesion to hydrocarbon; MBC, minimal bactericidal concentration; ME, microemulsion; MD, maltodextrin; MIC, minimal inhibitory concentration; PBS, phosphate buffer saline; PdI, polydispersity index; PEG, polyethylene glycol; Prob, probiotic; PLGA, poly(lactide-co-glycolide); PNIPA, poly(N-isopropylacrylamide); PVA, polyvinyl alcohol; RS, resistant starch; S, steppogenin; SA, stearic acid; SEM, scanning electron microscopy; SME, steppogenin microemulsion; SPC, soy phosphatidylcholine; TW20, Tween 20; WPI, whey protein isolate; XRD, X-ray powder diffraction; ZP, zeta potential

* Corresponding author.
E-mail address: hgreige@ul.edu.lb (H. Greige-Gerges).

https://doi.org/10.1016/j.jff.2018.06.021
Received 31 January 2018; Received in revised form 15 May 2018; Accepted 25 June 2018

amylases, pectinases, and naringinase are widely used for fruit juice processing and may remain in the final products if they are not removed completely following the juice processing (Kumar, 2015).

The effectiveness of natural bioactive agents is limited by their physico-chemical characteristics, such as solubility and chemical stability. In fact, storage conditions, interaction with the food matrix, and the aqueous and acidic nature of fruit juices could decrease the stability of any added agents. The use of some bioactive agents is also limited by their undesired taste and aroma, especially at high concentrations (Ley, 2008). Moreover, the susceptibility of health-promoting agents to gastro-intestinal conditions limits their bioavailability (Bell, 2006).

Hence, the use of encapsulation systems has been considered useful for increasing stability and efficiency of these bioactive agents. The use of encapsulation systems is effective for the protection of natural molecules against environmental conditions (Azzi et al., 2017; Gharib, Auezova, Charcosset, & Greige-Gerges, 2017; Sebaaly, Jraij, Fessi, Charcosset, & Greige-Gerges, 2015). Additionally, the encapsulation of bioactive agents may enhance their solubility (Azzi et al., 2017) and bioavailability, positively control their release (Parris, Cooke, & Hicks, 2005), and mask their occasionally unpleasant flavor (Ley, 2008). Encapsulation systems have been used in various food products, including vegetables (Bhargava, Conti, da Rocha, & Zhang, 2015; Landry, Micheli, McClements, & McLandsborough, 2015), fruits (Kim et al., 2013), milk (da Silva Malheiros, Sant'Anna, Utpott, & Brandelli, 2012), and cheese (Benech, Kheadr, Lacroix, & Fliss, 2002).

The delivery systems addressed in literature data, include liposomes, emulsions, cyclodextrin (CD) inclusion complexes, alginate (ALG)-based systems, whey protein gel particles, κ-carrageenan-based systems, poly(N-isopropylacrylamide) (PNIPA) nanohydrogels, poly (lactide-co-glycolide) (PLGA) nanocapsules, caseinate-gum arabic nanoparticles, and polyvinyl alcohol (PVA) gel carriers. The immobilization of enzymes into a solid matrix and their subsequent use for fruit juice processing are also reviewed. The main components of fruit juice and the main pathways of deterioration are described in the early sections of this review. Bioactive agents that have been encapsulated for fruit juice application are described next. Finally, the physico-chemical characteristics of the encapsulation systems are described, followed by their applications to fruit juices.

2. Naturally occurring bioactive molecules in fruit juices

Fruit juices are mainly composed of water (70–93%) and contain hundreds of compounds, such as carbohydrates (glucose, fructose, starch, cellulose, and hemicellulose), amino acids, proteins, lipids, vitamins, fibers, acids, phenolic compounds, carotenoids, and minerals. The amounts of these compounds vary considerably according to the type, cultivar, and maturity of the fruit. These compounds contribute to the taste, aroma, color, and texture of the fruit juice. Hydrophobic carotenoids and water soluble anthocyanins are among the primary pigments that determine fruit color (Barrett, Beaulieu, & Shewfelt, 2010). A complex mixture of volatile compounds, including monoterpenes, sesquiterpenes, phenolic derivatives, and amino acid-derived and lipid-derived compounds determine the aroma of the fruit (Schwab, Davidovich-Rikanati, & Lewinsohn, 2008). Most of these volatile compounds are bound to sugars (Sarry & Gunata, 2004) and are released by the action of enzymes, acids, or heat (Reineccius, 2006). Soluble compounds such as organic acids and monosaccharides and disaccharides control the sourness and sweetness of the fruit, respectively (Gadže et al., 2011). Cellulose, hemicellulose, pectic substances, and proteins contribute to the texture of fruit juice (Barrett et al., 2010).

Moreover, some of these compounds greatly control the stability and nutritional value of the fruit, even if present in only small amounts. The importance of fruit juice consumption lies in their richness in phytochemicals which are known for their ability to prevent or delay the onset or continuation of chronic diseases in humans and animals (Guhr & Lachance, 1997).

The benefits of juice phytochemicals extend over a wide range of properties starting from the antioxidant activity of vitamins (such as vitamins C and E) to the antibacterial, antiviral, anti-mutagenic, anticarcinogenic, anti-angiogenic, and anti-inflammatory activities of polyphenols (Côté, Caillet, Doyon, Sylvain, & Lacroix, 2010; Del Rio et al., 2013; McKay & Blumberg, 2007).

The main bioactive constituents of a fruit juice, including polyphenols, carotenoids, vitamins, and organic acids, are introduced and discussed below.

2.1. Phenolic compounds

Fruit juice contains a complex mixture of phenols which contribute to the bitterness, astringency, color, flavor, odor, and oxidative stability of the fruit. The major classes of phenolic compounds include simple phenols, phenolic acids and aldehydes, quinones, flavonoids, tannins, coumarins, lignans, and stilbenes (Cheynier, Comte, Davies, Lattanzio, & Martens, 2013; Cowan, 1999; D'Archivio et al., 2007; Spencer, Abd El Mohsen, Minihane, & Mathers, 2008). They are present in plants in their free and polymeric forms or are bound to soluble and insoluble molecules, as with fatty acids and pectin or cellulose, respectively (Shahidi & Yeo, 2016). Most of phenolic compounds possess beneficial effects for human health (Vermerris & Nicholson, 2007). Phenolic acids and flavonoids inhibit lipid peroxidation (Lizcano et al., 2012), protect low-density lipoproteins against oxidation (Costa-Mugica et al., 2012), reduce blood platelet aggregation (Wang et al., 2002), and enhance vasodilation (Barona, Aristizabal, Blesso, Volek, & Fernandez 2012; Diebolt, Bucher, & Andriantsitohaina, 2001). The content of polyphenols in fruit juice is influenced by environmental growth factors to which the original plant was subjected, such as soil type, temperature, and the amount of sun exposure and rainfall. Moreover, phenol concentrations, with the exception of anthocyanin, decrease during fruit ripening (Lindsay & Astley, 2002; Williamson & Manach, 2005). Polyphenols are heat- and light-sensitive (Munin & Edwards-Levy, 2011) and are easily oxidized (Manach, Scalbert, Morand, Rémésy, & Jiménez, 2004), therefore, their concentrations in fruit juice are highly influenced by the storage conditions of the fruit juice. Polyphenol oxidation produces changes to the organoleptic properties of the fruit juice (Queiroz, Mendes Lopes, Fialho, & Valente-Mesquita, 2008; Martinez & Whitaker, 1995). In fact, juice browning can be a direct result of polyphenol oxidation caused by the formation of more or less polymerized substances (Queiroz et al., 2008; Martinez & Whitaker, 1995).

2.2. Carotenoids

Carotenoids are isoprenoid pigments synthetized by plants that color fruits and vegetables yellow, red, or orange (Bartley & Scolnik, 1995; Hornero-Mendez & Minguez-Mosquera, 2000; Rodriguez-Amaya & Kimura, 2004). The importance of most carotenoids lies mainly in their provitamin A activity (α-carotene, β-carotene, β-cryptoxanthin, and others) and their antioxidant capacity (Britton, 1995). Carotenoids have a role in the prevention of human health disorders such as cancer (Brennan et al., 2000; Maoka et al., 2001; Michaud et al., 2000), heart disease (Koh et al., 2011), and age-related macular degeneration (Wu, Cho, Willett, Sastry, & Schaumberg, 2015).

Carotenoids are hydrophobic molecules that undergo isomerization and/or degradation when oxidized (Mordi et al., 1993), or exposed to heat (Chen & Tang, 1998; Goula, Adamopoulos, Chatzitakis, & Nikas, 2006) and light (Chen & Tang 1998). For this reason, the protection of carotenoids such as lycopene, is essential when it is intended to be added to food products to impart health benefits to consumers (Ribeiro et al., 2003).

2.3. Organic acids

After sugars, organic acids are the most abundant soluble solids in