Pomegranate Juice Processing by Membranes

Subjects: Food Science & Technology
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Pomegranate juice exhibits high antioxidant capacity because of its rich content of polyphenols, which represent the highest proportion of phytochemicals in pomegranate.
Conventional pressure-driven membrane operations and innovative membrane operations, such as osmotic distillation and pervaporation, are discussed in relation to their potential in juice clarification, fractionation, concentration and aroma recovery. Their implementation in integrated systems offer new opportunities to improve the healthiness and quality of the juice as well as to recover, purify and concentrate bioactive compounds for the formulation of functional ingredients.

Pomegranate juice Antioxidants Membrane operations Integrated membrane systems Functional ingredients

1. Introduction

Pomegranate (*Punica granatum* L.), also called “seeded apple” or “granular apple,” is an ancient fruit-bearing deciduous shrub that belongs to the *Punicaceae* family. Due to its good adaptation to a wide range of climate and soil conditions, pomegranate is grown in many different geographical regions including tropical and subtropical regions [1]. Currently, Mediterranean countries, India, Iran and California are the main producers. India, China, Iran and Turkey have the largest area of production [2].

The genetic diversity of pomegranate is demonstrated by an excess of 500 globally distributed varieties, approximately 50 of which are known to be commercially cultivated [3].

The global pomegranate market was valued at USD 8.2 billion in 2018 and is expected to reach USD 23.14 Billion by year 2026, at a Compound Annual Growth Rate (CAGR) of 14.0 percent [4]. Increasing demand for pomegranate and its derivatives (such as pomegranate powder, pomegranate juice, functional beverages) as well as other pomegranate-derived products is driven by its widespread popularity as a functional food and a source of nutraceuticals [5][6].

Pomegranate juice is the major food product obtained from arils, which constitute about 50% of the fruit weight and contain about 78% juice and 22% seeds [7].

Pomegranate-based “superfruits” have become mainstream within the juice and functional beverage category thanks to their properties to deliver nutritional benefit and antioxidants into the diet [8].

2. The Production Process of Pomegranate Juice

The production process of pomegranate juice, as reported in Figure 1, includes several steps such as washing, crushing, deshelling, pressing, clarification and pasteurization [9]. Traditional methods of clarification involve many steps, such as enzymatic treatment (depectinization), cooling, flocculation (gelatin, silica sol, bentonite and diatomaceous), decantation and filtration, which are labour and time consuming. In addition, these methods use large amounts of coadiuvants and additives with further drawbacks, such as the risk of dust inhalation caused by handling and disposal, environmental problems and significant disposal costs. Although the conventional thermal treatments do inactivate native enzymes and reduce the microbial load, they negatively impact the juice organoleptic properties. Flavour notes can be deteriorated, and juice darkening notes due to enzymatic browning and Millard reactions can occur. Off-flavour formation, colour change, reduction of nutritional values and high energy consumption are also typical drawbacks of thermal effects during evaporation processes for juice concentration [10]. Therefore, the use of mild technologies able to minimize the degradation of the functional molecules of the juice is strongly recommended to promote the development of high-quality products [11][12].

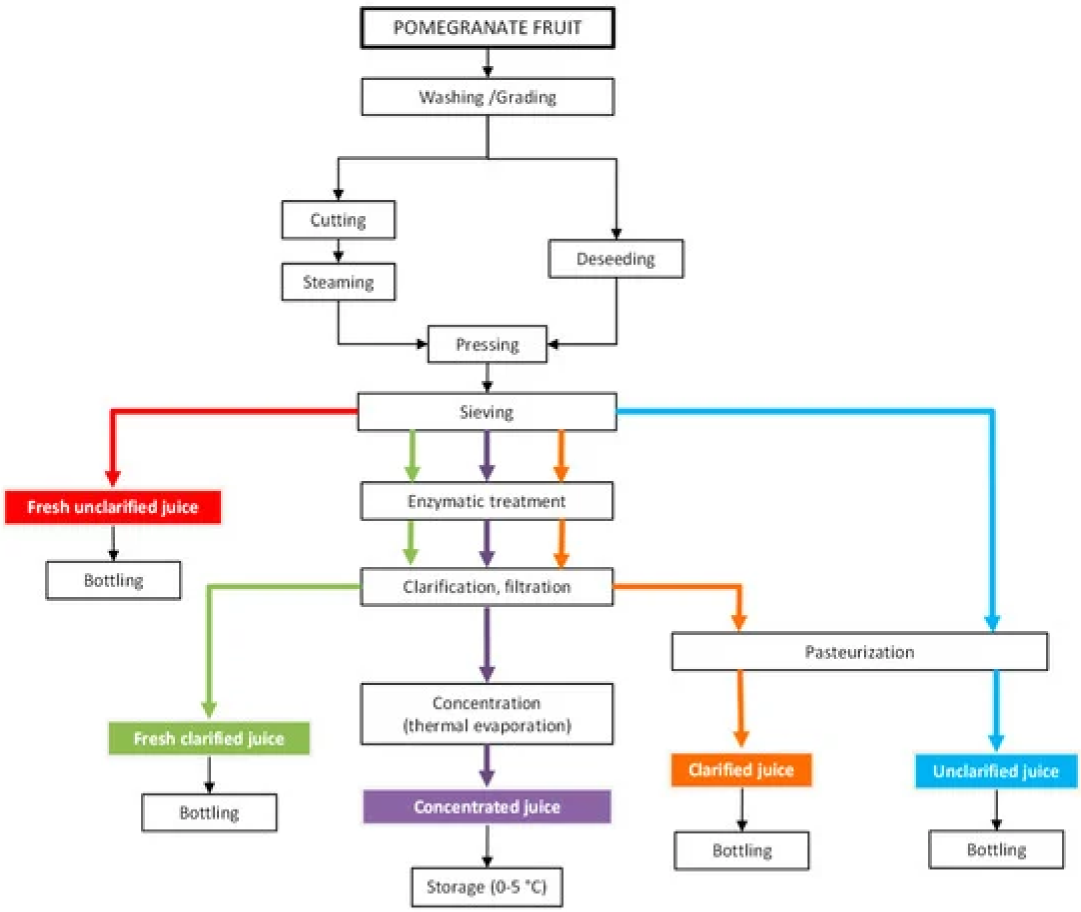

Figure 1. Flow diagram of processing operations for pomegranate juice production (adapted from [9]).

3. Juice Composition and Health Properties

Pomegranates produce a reddish-purple, moderately acidic juice containing in average 85.4% water and 15.6% dry substance, composed of sugars, organic acids, pectins, anthocyanins, polyphenols, vitamins and minerals. However, the juice composition, as well as organoleptic attributes, is strictly correlated to the pomegranate variety and juice production technology. Juices obtained from sarcotestas alone contain approximately 15% solids, lower than juices produced from whole fruits (16–17%). This is because sarcotestas are mainly sources of sugars, acids and minerals, while the rind is rich in polyphenolic compounds. On the other hand, juice pressed from whole fruits has a typical bitter taste due to the high content of phenolics [13].

Pomegranate juice exhibits high antioxidant capacity because of its rich content of polyphenols, which represent the highest proportion of phytochemicals in pomegranate. In particular, the antioxidant activity of the juice can be attributed mainly to ellagic acid and its derivatives, anthocyanins and hydrolysable tannins [14].

The soluble polyphenol content in pomegranate juice varies within the range of 0.2–1.0%, depending on variety, including mainly hydrolysable tannins, ellagic acid derivatives and flavonoids.

Punicalagin, a large polyphenol with a molecular weight greater than 1000 belonging in the family of ellagitannins is responsible for more than the half pomegranate juice's antioxidant effect [15].

Pomegranate juice is an important source of flavonoids including flavonols (catechin, epicatechin, gallocatechin) and anthocyanins. Anthocyanins are water-soluble plant pigments responsible of the red colour of both fruits and juice. They include 3-glucosides and 3,5-glucosides of delphinidin, cyanidin, and pelargonidin [16].

Phenolic acids include hydroxybenzoic acids (mainly gallic acid and ellagic acid) and hydroxycinnamic acids, principally caffeic acid, chlorogenic acid and p-coumaric acid [17][18]. Other chemical constituents in pomegranate juice include sugars (glucose, fructose, sucrose), organic acids (citric acid, malic acid, tartaric acid, fumaric acid, succinic acid, ascorbic acid, etc.), amino acids (proline, valine, methionine, glutamic acid, aspartic acid), indoleamines (tryptamine, serotonin, melatonin), tocopherols and minerals (Fe, Ca, Cl, Cu, K, Mg, Mn, Na, Sn and Zn) [19].

Pomegranate juice, being rich in bioactive compounds like polyphenols, has shown many health-related properties, such as antioxidant, anti-inflammatory, antihypertensive and antiatherogenic effects through in vivo and in vitro studies [20][21]. The healthiest constituents are ellagitannins, ellagic acid, punicic acid, anthocyanidins, anthocyanins, flavonols and flavones.

Ellagitannins have been associated to the prebiotic potential and antimicrobial activity of the juice [22]. In vitro studies have established the potential of pomegranate extracts as an antitumorigenic agent against various cancers including prostate cancer, renal cell carcinoma, papillary thyroid carcinoma cells and cervical cancer cell lines [23]. Mechanistic studies have revealed that Punica extracts and its components, individually or in combination, can modulate and target key proteins and genes involved in breast cancer [24]. A wide variety of molecules can be targeted by pomegranate to suppress tumour growth and metastasis, including those involved in cell-cell and cell-extracellular matrix adhesions, modulators of cytoskeleton dynamics and regulators of cancer cell anoikis and chemotaxis, pro-inflammatory and pro-angiogenic molecules [25].

Ellagic acid and punicalagin, have shown the ability to inhibit amine oxidases, α-glucosidase, dipeptidyl peptidase-4, lipase, triglyceride accumulation and adipogenesis-related genes, as well as to decrease lipogenesis and lipolysis in mouse and human adipose cells. These results support the development of functional foods for the prevention obesity, diabetes and dyslipidemias [26]. Studies with mice models have demonstrated that pomegranate juice exhibits a protective effect against oxidative damage in Parkinson's disease as well as antileishmanial activity [27][28].

Finally, human studies have shown the beneficial effects of the juice on blood pressure, serum triglycerides, high-density lipoprotein (HDL) cholesterol, oxidative stress and inflammation in haemodialysis patients [29]. The juice consumption allows also to reduce the serum erythropoietin level [30] as well as systolic and diastolic blood pressure in patients with type 2 diabetes [31].

All these studies confirm the interest for the implementation of innovative technologies, including membrane operations, that provide minimum influence of juice processing and preservation on functional properties. These technologies represent also a useful approach for recovering phytochemical compounds from second-quality and over-ripe pomegranate fruits not suitable for commercialization, which can be exploited for the formulation of functional ingredients. The processing of these fruits wasted as by-products generates more profits and minimizes production losses along with the subsequent environmental benefits.

4. Membrane operations in pomegranate juice processing

Microfiltration and ultrafiltration represent a valid alternative to the conventional clarification procedures of pomegranate juice resulting in savings in labour and capital costs, short processing time,
increased juice yield and avoidance of fining agents and filter aids. Juice freshness, aroma and nutritional value are well preserved in comparison to the use of fining agents allowing to obtain high-quality, natural fresh-tasting and additive-free clarified products[32]. Tight ultrafiltration and nanofiltration membranes offer new perspectives in juice fractionation aimed at recovering and purifying bioactive compounds of interest for the production of functional ingredients[33]. Reverse osmosis and osmotic distillation represent useful alternatives to thermal evaporation for juice concentration. High levels of total soluble solids can be reached through osmotic distillation operating at low pressure and temperatures so avoiding mechanical and thermal stress of the processed juice. The overall results indicate that the process is very effcient in preserving the original characteristics of the fresh juice including colour, total antioxidant activity, phenolic compounds and organic acids[34].

A flow diagram for the production of clarified and concentrated juice by integrated membrane process is schematically depicted in Figure 2.

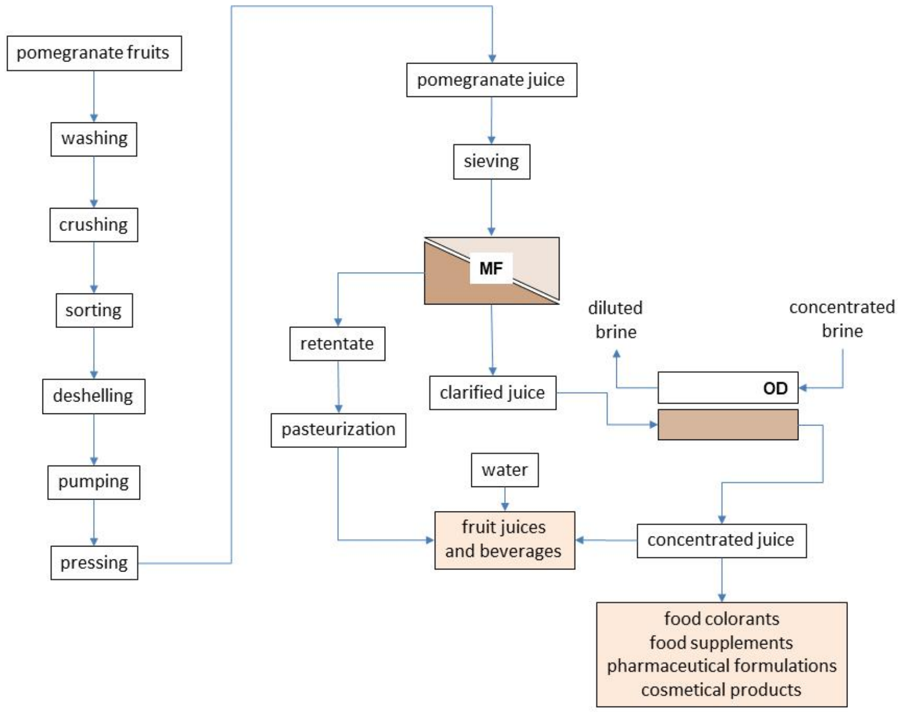

Figure 2. Flow diagram of processing operations for pomegranate juice production (adapted from [34]).

Pervaporation is a promising tool for the concentration of aroma compounds from pomegranate juice since it can be operated at moderate temperatures[35].

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