Pomegranate by-Products

Subjects: Food Science & Technology
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In recent years, considerable importance is given to the use of agrifood wastes as they contain several groups of substances that are useful for development of functional foods. As muscle foods are prone to lipid and protein oxidation and perishable in nature, the industry is in constant search of synthetic free additives that help in retarding the oxidation process, leading to the development of healthier and shelf stable products.

Keywords: pomegranate ; bioactive compounds ; lipid and protein oxidation ; meat ; fish ; shelf life

1. Introduction

Muscle foods, in particular meat and fish, are considered excellent sources of high-quality proteins containing balanced amino acids, vitamins (B group), minerals, and a number of other nutrients [1][2][3][4]. Even though having high nutrient contents, muscle foods also contain metal catalysts, haem pigment, various oxidizing agents, and abundant unsaturated fatty acids, which are unstable, especially when exposed to extreme environmental conditions such as constant high temperature, air, and light [5]. These food products with high water content and moderate pH are perishable in nature, hence cannot be stored for longer periods without any preservatives [6]. The susceptibility of these products to spoilage results from microbial activities and undesirable chemical changes, such as oxidation of muscle proteins and lipids during storage [7][8][9]. Lipid oxidation of muscle foods results in an extensive color loss, structural damage to protein, and production of rancid or unpleasant flavors [4][10][11]. These changes negatively affect the sensory quality, nutritional value, and consumer acceptability, and consequently shorten the shelf life of muscle foods [12][13][14][15][16][17]. As far as protein oxidation in muscle foods is concerned, it changes the amino acid structures, leading to the formation of carbonyl and reduction of sulfhydryl content [18]. Oxidative changes ultimately affect the tenderness and water holding capacity of muscle food during storage [19][20].

There are different ways to prevent the microbial activities and oxidative deterioration of muscle foods. Synthetic chemicals are mostly used to inhibit such types of changes and minimize the formation of toxic compounds such as cholesterol oxidation products [21][22]. However, in recent times, natural preservatives extracted from various agrifood wastes are being explored by food processors that not only contain antimicrobials and antioxidants but also are abundant, cheap, and environment friendly. In addition, many plant parts (fruits, roots, bark, leaves) and their coproducts are also reported to provide a rich source of natural bioactive compounds (polyphenolic, dietary fibre, and flavonoids) that not only play a vital role in inhibiting oxidative changes (antioxidants) but also help in suppressing microbial growth (antimicrobial), thereby preventing several diseases [23][24]. Again, consumers worldwide also prefer these natural preservatives, which are considered safe and exert positive health effects over synthetic chemicals that have toxicity and health risks [5][25][26].

Pomegranate (*Punica granatum* L.), a member of the family Punicaceae, is a deciduous shrub or small tree widely cultivated in the Middle East, European, and Southeast Asian countries [5]. Each and every part of the pomegranate plant (leaves, stem, fruits, bark and roots) possess numerous bioactive compounds like phenolic compounds, including hydrolyzable tannins (pedunculagin, punicalin, punicalagin, and ellagic and gallic acids), flavonoids (catechins, anthocyanins, and other complex flavonoids) and complex polysaccharides [27][28]. It is a fruit, commonly known as “seeded apple” or “granular apple”, highly valued and consumed worldwide for its pleasant taste, nutritional values, and medicinal properties [29]. Pomegranate fruit is used in the fruit processing and beverage industry for the preparation of juice and soft drinks, and during the production process, a large quantity of fruit-derived low-cost nonedible waste (mostly peel and seed) is generated. These wastes are valuable sources of bioactive compounds and could either be used as functional food ingredients or as food additives, nutraceuticals, and supplements to enrich phenolic content in diets [29][30]. These bioactive compounds, apart from being natural, exert antioxidant and antimicrobial activity and are reported to improve the quality, safety, and extend the shelf life of different types of food products such as oils [5], meat [23][31][32][33], fish [34][35][36], and dairy products like cheese, curd, fermented milk [37], cereal-based cookies [38].

2. Pomegranate Fruit and Its By-products

Pomegranate fruit, regarded as superfruit of the next generation, is quite popular throughout the globe due to its sweetness, acidic juices, and extensive medicinal properties, including antimicrobial, antioxidant, antimutagenic, antihypertensive, and hepatoprotective properties [37][39][40]. The outer hard covering of the fruit is red-purple in colour and called the pericarp, whereas the inner spongy wall is called mesocarp (white "albedo"), where seeds are attached. A mature pomegranate fruit measures about 6–10 cm in diameter, weighs 200 g on an average and usually contains 50% peel, 40% arils and 10% seeds. Further, the pomegranate fruit processing establishments also generate a large quantity of by-products/wastes after the extraction of juice from the fruits. The wastes are called pomace or bagasse, which is nothing but a mixture of peel, seed, and mesocarp, which remains underutilized in the food industry. These wastes could be fortified in various food systems for the design and development of healthy functional foods with improved quality and shelf life, offering health benefits [41][42][43]. The fruit is a good source of dietary fibre (both soluble and insoluble), but contains no cholesterol or saturated fats and is low in sugar. In addition, it also contains about 80–85 calories per 100 g, vital minerals (potassium, copper, manganese, and zinc), and vitamin C and B complex groups, such as pantothenic acid (vitamin B-5), folates, pyridoxine, and vitamin K [44]. The proximate composition, major micronutrients, vitamins, and polyphenolic contents of pomegranate peel and seed powder are represented in Table 1.

Table 1. Proximate composition, major micronutrients, vitamins, and polyphenolic content of pomegranate peel and seed powder.

Parameters	Pomegranate Peel	Pomegranate Seed Powder
Moisture (%)	13.7	5.8
Protein (%)	3.1	13.7
Fat (%)	1.8	29.6
Ash (%)	3.3	1.5
Fibre (%)	11.2	39.4
Carbohydrates (%)	80.5	13.5
Calcium (mg/100g)	338.50	229.20
Potassium (mg/100g)	146.40	434.40
Sodium (mg/100g)	66.43	33.03
Phosphorus (mg/100g)	117.90	481.10
Iron (mg/100g)	5.93	10.88
Vitamin C (mg/100g)	12.90	3.02
Vitamin E (mg/100g)	3.99	1.35
Total polyphenol (mg/g GAE)	53.65 (WE) 85.60 (ME)	7.94 (WE) 11.84 (ME)

Total flavonoids (mg/g TE)	21.03 (WE) 51.52 (ME)	3.30 (WE) 6.79 (ME)
Total anthocyanins (mg/g CGE)	51.02 (WE) 102.02 (ME)	19.62 (WE) 40.84 (ME)
Hydrolyzable tannins (mg/g TAE)	62.71 (WE) 139.63 (ME)	32.86 (WE) 29.57 (ME)

GAE: gallic acid equivalents, TAE: tannic acid equivalents, CGE: cyanidin-3-glucoside equivalents, WE: water extract, ME: methanol extract. Source: [29][45][46].

3. Polyphenolic and Flavonoid Compounds in Pomegranate Fruit By-Products

Polyphenols are a structural class of organic chemicals containing large multiples of phenolic structural units. The chemical structure of major phenolic compounds from pomegranate fruit and its by-products are presented in Figure 1, including ellagitannins (ellagic acid, punicalagin, gallic acid, punicalin), anthocyanins (cyanidin and pelargonidin), phenolic acids like caffeic acid, chlorogenic acid, and flavonoids (quercetin).

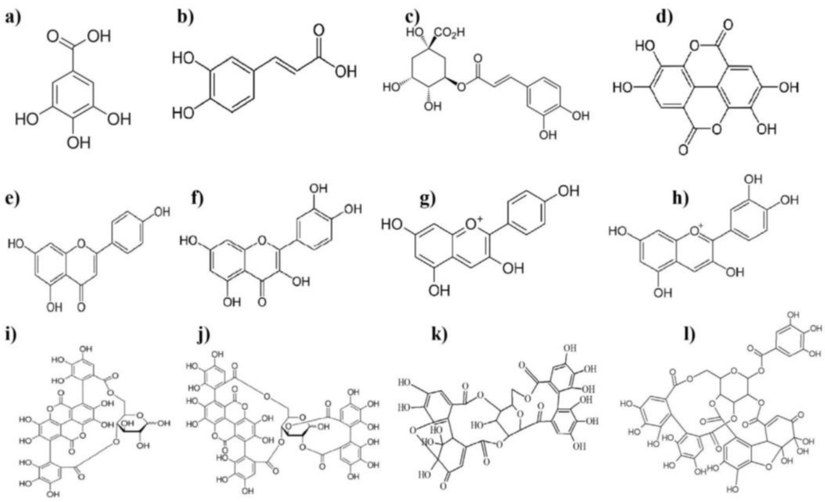

Figure 1. Chemical structure of major phenolic compounds from pomegranate fruit: (**a**) gallic acid, (**b**) caffeic acid, (**c**) chlorogenic acid, (**d**) ellagic acid, (**e**) apigenin, (**f**) quercetin, (**g**) pelargonidin, (**h**) cyanidin, (**i**) punicalin, (**j**) punicalagin, (**k**) granatin A, and (**l**) granatin B.

The phenolics and polyphenolic compounds in pomegranate fruit and its by-products (seed, juice, pomace, and peel) have been studied in detail by several workers. Not only the succulent testa of pomegranate fruit, but the peels are also sources of phenolics, pectin, and complex polysaccharides, whereas the arils are rich in water, sugars, organic acids, and polyphenolic compounds, especially flavonoids. In addition, the major phenolic compound in the pomegranate juice is anthocyanin, the pericarp, and mesocarp are sources of hydrolyzable tannins [37][47]. The by-products also contain important compounds and chemicals that are valuable sources of antioxidants, tannins, dynes, and alkaloids [29][48]. The major chemical constituents, phenolics, and organic compounds reported in different pomegranate plant parts are presented in Table 2.

Table 2. Pomegranate plant parts and their chemical constituents.

Pomegranate Plant Parts	Chemical Constituents

Pomegranate juice from the succulent testa	Glucose, ascorbate, ellagic acid, anthocyanins, caffeic acid, catechin, quercetin, amino acids and minerals.
Seed oil	Punicic acid, ellagic acid, sterols, phytoestrogens
Peel (pericarp)	Phenolic punicalagins, gallic acid, catechin, flavones, etc.; Flavonoids (catechin, flavan-3-ol, epicatechin, quercetin, kaempferol, rutin, kaempferol 3-O-glycoside, kaempferol 3-O-rhamnoglycoside, naringin epigallocatechin 3-gallate, luteolin, and luteolin 7-O-glycoside); Ellagitannins (punicalagin, punicalin, corilagin, gallagyldilacton, tellimagrandin, casuarinin, pedunculagin, granatin A, and granatin B); Pelletierine alkaloids (pelletierine); caffeic acid; p-coumaric acid; chlorogenic acid; quinic acid; polyphenols (saponins, ellagic tannins, ellagic acid, and gallic acid); anthocyanidins; additionally, triterpenoids, steroids, glycosides, carbohydrate, vitamin C, ascorbic acid, and tannins
Leaves	Tannins, flavone glycosides, luteolin, apigenin
Flowers	Gallic acid, urosolic acid, triterpenoid compounds, including maslinic and asiatic acid
Bark and roots	Punicalin, punicalagin, piperidine alkaloids, ellagitannins

Source: [29][45][46].

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