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Review Article

From Pomegranate Processing By-Products to Innovative value added Functional Ingredients and Bio-Based Products with Several Applications in Food Sector

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Abstract

The vast majority of by-product streams generated throughout industrial processes arises immense environmental, societal and economic related issues. The development of strategies for the valorization of these industrial residues will not only address these problems but also promote bioeconomy, satisfying sustainable development principles. Pomegranate juice production process generates high quantities of different by-product streams, plant derived non-edible leftovers, comprised mainly of biodegradable compounds and solids. Pomegranate peel (PP) and pomegranate seed (PS) are valuable sources of bioactive phytochemicals, the vast majority of which hold a great potential through appropriate processes to be converted into value added products. So, pomegranate by-products could be used as substrate for the production of nutritionally valuable and biologically active components that could find several applications as functional food ingredients, food additives, nutraceuticals and supplements and in phenolic-rich diets. To date, there has been limited assessment about the potential of converting non-edible pomegranate production process residues, through the development of novel efficient systems, to value added products such as antioxidants, dietary fibers, industrial enzymes and single cell protein. The scope of this study is to review and identify pomegranate by-product streams nutritional and nutraceuticals potential and to exploit possible processes for the production of medicinal and bioactive compounds through fractionation, as well the production of other value added products through bioprocesses. Furthermore, the study aimed to investigate actual and possible applications of produced valuables, as food preservatives, quality enhancers and prebiotics in food products. The biorefinery approach leading to sequential production of several valuables seems to be a promising alternative for the valorization of pomegranate juice solid by-product steams.

Key Words: Pomegranate Peel; Pomegranate Seed; Agrowaste; Value Added Products; Biorefinery; Bioactive Compounds; Cardiovascular Disease; Antioxidant; Prebiotics; Single Cell Protein; Microbial Enzymes; Functional Ingredients; Food Supplements

Introduction

Recent years, pomegranate fruit (*Punica granatum L*) is gaining more and more attention especially due to its possible health benefits. The edible part of the fruit can be consumed fresh, although a large proportion of worldwide fruit production is processed for pomegranate juice items.

The most well-known processing technology for juice extraction involves cut opening of the outer membrane of the fruit, separation of the seeds within the fruit and pressing using a screw press or a basket press. In literature cited publications, many processes have been proposed regarding the extraction methodology followed, yielding variant concentrations of the extracted juice. Vardin et al. [1] succeeded in obtaining 30 to 40 percent pomegranate juice by pressing the whole fruit, in batches of 10 kg for 5 minutes by using a manually operated packaged type press. They also mentioned that pomegranates can be pressed either as whole fruit or as divided parts or as granulated sac. They concluded that the best results, regarding the pressing cost and time, were attained when the whole fruits were pressed. The final derived juice was more astringent and bitter, owning to the fact that higher pressures led to higher extraction yields of phenolic compounds in the juice. After the extraction of juice, clarification is a vital step in fruit juice processing, in order to remove haze precursors and more specifically phenolic compounds (especially tannins), which through polymerization and/or condensation form polymeric complexes, collected at the bottom of juice storage bottles. Bentonite, clays, protein-based substances (albumin, gelatin, casein) and polysaccharide-based polymers (chitosan, xanthan gum) have been applied as clarifying agents to remove phenolic compounds [2]. It seems that conventional heating might be applied for deactivating physically present enzymes and specific microorganisms into pomegranate juice. It has been also stated that pasteurization may be applied after clarification and filtering. Then, pasteurized pomegranate juice is bottled and is ready to be

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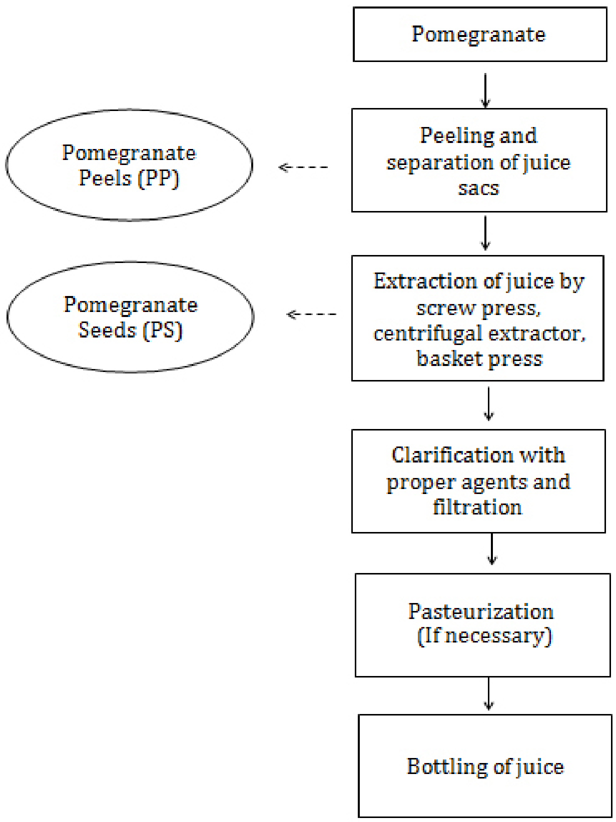
consumed [3]. Throughout the juice production process two main solid by-product streams are generated after extraction of juice from fruit and separation of seeds from juice: pomegranate peel (PP) and pomegranate seed (PS).



PP, accounting about 50% of the whole fruit, is the non-edible fraction comprised mainly of several bioactive compounds such as hydrolysable tannins at variant concentrations ranging from 27 to 172 g/Kg [4] (pedunculagin, punicalin, punicalagin and ellagic and gallic acids), flavonoids (catechins, anthocyanins, and other complex flavonoids), complex polysaccharides and minerals (phosphorus, magnesium, calcium, potassium and nitrogen) [5]. The primary polyphenols in PP are gallic acid (14.147 %), proto catechuic acid (14.512 %), chlorogenic acid (2.355 %), vanillic acid (3,851 %), coumarin (3.534 %), caffeic acid (2.748 %), oleuropein (0.590 %), ferulic acid (1.857 %) and quercetin (0.949 %), while PP also contains caffeine (6.420 %) [6].

PS, accounts about 10 % of the edible part of pomegranate; the edible part is known as aril comprising the 50% of the fruit. Pomegranate seeds ranging from 40 to 100 g/Kg of fruit, are rich sources of total lipids (12-20% w/w of total seed), containing high concentrations of polyunsaturated (n-3) fatty acids. More specifically, the oil consists up to 80% of conjugated octadecatrienoic fatty acids with a high percentage of cis, trans, cis-Δ-9, 11,13 acid (for instance punicic acid) [7]. Fatty acid content reaches up to 95% of the seed oil, of which almost 99% is considered triacylglycerols. Also, in minor quantities pomegranate seed oil contains sterols, steroids, tocopherols and cerebroside [8]. The seed envelop is consisted of lignin and probably some antioxidant lignin' derivatives, as well as hydroxybenzoic/cinnamic acids and iso flavones. Recently, it has been revealed that PP powder contains much higher content of lysine, leucine, aromatic fatty acids (phenylalanine and tyrosine), threonine and valine, while having less concentration of sulfur-containing amino acids (methionine and cysteine), than the reference protein pattern of FAO/WHO (FAO/WHO, 1973). Also, pomegranate's seed powder sulfur containing amino acids (metheionine and cysteine), aromatic fatty acids (phenylalanine and tyrosine), leucine and isoleucine were much higher than the corresponding mentioned in reference protein pattern of FAO/WHO [9].

Table 1: Average chemical composition of pomegranate peel and seed powder.

Component	Pomegranate peel powder (%)	Pomegranate seed powder (%)
Moisture	13.7	5.82
Protein	3.10	13.66
Fat	1.73	29.60
Ash	3.30	1.49
Fiber	11.20	39.36
Carbohydrate	80.50	13.12
Total phenolic	27.92	0.25

[1] *All data expressed as %, mean of triplicate determinations result*
[2] *Adapted from Rowayshed et al., 2013 [9]*

It has to be noted that the concentration of bioactive compounds in original pomegranate fruit and as logical in the derived juice, as well as the residues generated through industrial juice processing procedure, depends strongly on the cultivar, the growing area, the maturity of the collected fruit, the cultural practices and of course of the specific industrial process followed each time. The recent interest in pomegranate juice and other pomegranate-based products might be attributed to the pomegranate's fruit possible positive effect in the prevention of several diseases such as prostate cancer and cardiovascular disease; due to potential attenuation of atherosclerosis, low density lipoprotein oxidation and platelet aggregation [10,11]. Several scientific studies have confirmed pomegranate biological activities and medicinal effects of the edible part of the fruit, but very few data exist about the bioactivity of pomegranate peel, seed, powder and extracts. Therefore, more research has to be done in that field.

Valorization of pomegranate juice by-products stream rich in valuable bioactive compounds (Table-2) could led to the production of several products such as: 1) additives used in industrial food sector to increase self-life of products 2) functional ingredients to enhance food quality and promote human health, 3) single cell protein and industrial enzymes by using a proper pomegranate by-product streams based on fermentation media. In that way would not only reform the existing structure in pomegranate's juice production sector, but also give rise to the development of new products with diversified market outlets, handling simultaneously waste management related issues.

Table 2: Major phytochemical compounds present in pomegranate juice

and its industrial process by-product streams.

Pomegranate Juice	Anthocyanins; glucose; ascorbic acid; phenolics such as ellagic acid, caffeic acid; catechin; epigallocatechin galate; quercetin; rutin; aminoacids and minerals
Pomegranate Seed oil	Punicic acid; ellagic acid; fatty acids; sterols(daucosterol, campesterol, stigmasterol and b-sito sterols; phenyl aliphatic glycosides; isoflavones and coumesterol;
Pomegranate Peel	Phenolic compounds like punicalagins, gallic acid, catechin, epigallocatechin galate, quercetin, rutin, anthocyanidins and other flavonoids; dietary fibers; neutral sugars (xylose, aravinose)

[1] *Adapted from]; Farag et al., 2014 [6]; Rowayshed et al., 2013 [10]; Liu et al., 2009 [11]*

Valorization of Pomegranate Peels and Seeds into Marketable value added Products with Nutritional Interest

Biorefinery is a facility, process or even a cluster of facilities that integrates in a sustainable manner biomass into a spectrum of marketable products, such as biochemicals, power and fuels. Industrial biorefinery is a novel strategy for converting waste to value added products. The development of novel biorefineries for the valorization of pomegranate peels and seeds will address several waste management issues, while simultaneously "give birth to" novel end products such as antioxidant compounds, dietary ingredients, prebiotics and several functional ingredients as well as industrial enzymes and single cell proteins. Since the production of the previous mentioned products have high economic value and many applications in food sector, satisfying also the social demand for the production of health promoting products, the valorization of pomegranate peels and seeds via chemical modifications or by employing microbes is a field of high interest.

Phenolic compounds: Extraction, Potential Beneficial Effects in Health And Usage as Food Lipid Stabilizers

Pomegranate peel and seed are rich in bioactive compounds such as phenolics [12]. Thinking that both are costless residues of pomegranate juice production, the extraction of them either by chemical or green processes seem to be economically beneficial.

The commercial food grade solvents used for the extraction of antioxidants are water, ethanol and methanol as well mixtures of them. Optimization of the extraction process is of high priority regarding each parameter, such as the type of the solvent used, the particle size of the material, and the extraction temperature and time, aiming to extract the maximum possible concentration of food grade antioxidants.

Zaki et al (2015) [13] screening phenolic compounds and antioxidant activities in methanol and aqueous extracts of pomegranate peels of two varieties (Wardey and Manfalouty), concluded that methanol was the best extracting solvent for phenolic compounds. El falleh et al. (2012) [14] reported that pomegranate peel contains higher antioxidant activity when compared with seed, as it can be seen in Table-3.

Malviya et al. (2014) [15] investigating antioxidant potential of pomegranate peels of Ganesh variety using either water or ethanol or methanol or mixtures of them, found out that the highest DPPH and ABTS inhibition activity was observed when methanol or a mixture with water (70% ethanol: 30% water) used as extracting solvents. Also, the researchers found out that the highest total phenolic content measured into the water extract (438.3 ± 14.15 mg tannic acid equivalents/g pomegranate peel extract, PP). Higher pomegranate peel phenolic content of 8673.87 mg gallic acid equivalent/100 g of dw achieved employing ultrasonic assisted extraction of PP phenolics under optimal conditions (70% ethanol-30% water as a mixture, temperature 60 °C, 30 min extraction time) [15]. Pulsed ultrasound assisted extraction seems to become one of the most promising extraction techniques, better than the conventional ones, providing higher extraction yields, less energy, solvents and chemicals. However, very few studies have been done in ultrasound assisted extraction of phenolic compounds from pomegranate peels [15]. Enzyme assisted supercritical fluid extraction process proved of being better compared to enzyme assisted solvent extraction. In fact, supercritical fluid extraction of enzyme preparations doubled the recovery of crude extracts with increased level of phenolic constituents, improved radical scavenging capacity, trolox equivalent antioxidant capacity and inhibition of linoleic acid per oxidation. Optimization of the process regarding enzyme concentration, temperature, incubation time and pH maximized the extractable phenolics and other

Table 3: Antioxidants content: total polyphenols, flavonoids, anthocyanins and hydrolysable tannins of pomegranate peels and seeds.

By-products	Total polyphenol (mg/g GAE, db*1)		Total flavonoids (mg/g RE, db*2)		Total anthocyanins (mg/g CGE, db*3)		Hydrolysable tannins (mg/g TAE, db*4)	
	Water	*Methanol*	*Water*	*Methanol*	*Water*	*Methanol*	*Water*	*Methanol*
Peel	53.65	85.60	21.03	51.52	51.02	102.2	62.71	139.63
Seed	7.94	11.84	3.30	6.79	19.62	40.84	32.86	29.57

[1] *mg gallic acid equivalents per g dry weight*

[2] *mg rutin equivalents per g dry weight*

[3] *mg cyanidin-3-glucoside equivalents per g dry weight*

[4] *mg tannic acid equivalent per g of dry weight*

[5] *Adapted from Zaki et al., 2015 [13]; Elfalleh et al., 2012 [14]*

antioxidants [16]. High performance liquid chromatography coupled with diode array detector and electro spray ionization mass spectrometer (HPLC-DAD-ESI–MS) used to characterize phenolic compounds in the PP extracts, demonstrated the presence of vanillic acid as the main phenolic compound followed in order by syringic, caffeic acid and p-coumeric and ferulic acids as it can be seen in Table-4 [17].

ml combined with 1μMtamoxifen evaluated for their ability to increase the action of tamoxifen and in turn inhibit MCF-7 cell proliferation [24]. Despite the fact that in vitro cultured cell and animal-estrogenic studies on pomegranate extracts have been carried out with success, the effects of pomegranates extracts from fruit and peels on serum hormone levels and its activity in humans should be further investigated. Recently, it has been suggested that

Table 4: Phenolic acids composition in pomegranate peel extracts produced by enzyme assisted ethanol extraction and pulsed ultrasound assisted extraction, by High performance liquid chromatography coupled with diode array detector and electro spray ionization mass spectrometer (HPLC-DAD-ESI–MS).

Sample number	Phenolic - Bioactive compounds	Retention time (min)	Molecular Mass	Peak area (μ AV)	Concentration (μg/g)
1	p-Coumaric acid	26.23	164	173292780	0.12-14.87
2	Vanillic acid	20.28	169	52538123	65.87-108.36
3	Gallic acid	6.54	171	567982	0.041-0.37
4	Caffeic acid	21.47	181	220897401	3.88-75.19
5	Ferulic acid	28.34	195	381444951	0.15-8.84
6	Syringic acid	22.04	199	83240425	15.17-88.24
7	Sinapic acid	28.78	225	366915314	2.13–3.58

[1] *Adapted from Muhammad et al., 2015 [17]*

Epidemiological studies have revealed a possible inverse relationship between chronic diseases and phenolic compounds nutrition intake. In fact, phenolic groups are able of accepting an electron, forming phenoxyl radicals, interrupting chain oxidative reactions in cellular components. It has been stated that polyphenols possibly offer a significant protection against cancer, diabetes, cardiovascular diseases, asthma, hypertension, neurological disorders (such as Alzheimer's disease), psychiatric and in general cognitive diseases. It should be noted that the potential cardio-protective action of polyphenols is likely to be considered as the synergistic outcome of several biological activities including endothelial functionality improvement, LDL uptake decrease, LDL oxidation diminution and aggregation, blood pressure reduction and platelet aggregation inhibition [18,19].

Pomegranate peels owning to its high antioxidant activity have the potential of inhibiting LDL oxidation and as a consequence may decelerate atherosclerosis progression, reducing arterial foam cell levels [20]. It has been stated that pomegranates punicalagin, gallic acid and ellagic acid may increase the expression and secretion, in a dose-dependent manner, of hepatocyte paraoxonase-1, thereof lessen the risk of atherosclerosis development [21]. Potential inhibition of nitrous oxide synthase expression, down regulation of redox sensitive ELK-1 and p-JUN genes and expression of endothelial nitrous oxide induced by wall shear endothelial stress have been attributed to pomegranates polyphenols [22]. Treatment of Los Angeles prostate cancer cells (LAPC4) with pomegranate extract of 10μg/L contained 37 % (w/w) punicalagin, is attributed to the inhibition of cell proliferation accompanied with the induction of apoptosis [23]. Past studies have verified that pomegranate's phenolic may induce apoptosis in human breast cells (MCF-7). Recently, pomegranate extracts of 300 μg/

pomegranates are capable of inhibiting melanocyte proliferation and melanogenesis by inhibiting tyrosinase activity [25]. Also, it has been reported that pomegranates ellagic tannins at a concentration range of 500-10,000 mg/L, may protect skin from UVA and UVB induced free radicals generation and as logical DNA fragmentation and de pigmentation [26]. The anti-inflammatory and anti-allergic properties of pomegranate extracts have also been reported. In a recent study, the inhibitive effect against stimulators of inflammation has been verified in mice throughout induced-carrageenan paw edema after oral administration of 2.5 and 10 mg/kg granatin B. Very strong inhibitory effects developed after a 6 h peel-active component administration in comparison with indomethacin [27].

Due to oxidation of lipids, food systems undergo deterioration highly linked with the formation of off-flavors and increased concentration of toxic by-products. Plant-rich extracts hold a great potential to be used as natural antioxidants replacing synthetic counterparts such as BHT and PHA. Devatcal et al. 2012 reported that supplementation of 1% of pomegranate peel extract reduced 40% the concentration of thiobarbituric acid reactive substances (TBARS) (TBARS are indicators of oxidative deterioration in meat and their products) in goat meat, compared with vacuum packaging technology, which reduced TBARS to a lower percentage equal to 27% [28]. Another clue that make pomegranate peel extracts a very promising material to be used as food additives is that they are resistant to processing and storage conditions such as thermal processing and refrigeration, opening new roads in that field. A very recent research revealed that pomegranate peel extracts stored at refrigeration temperatures retains 67% of the initial concentration of the soluble phenolic content and the 58 % of the scavenging activity after 4.5 months approximately, making our previous suggestion more reliable [29].

Despite all the above advantageous effects of pomegranate's phenolic compounds in health and their possible functional application in food systems as additives and promoting agents, more research should be done not only in the optimization of the extraction process (emphasizing in green methods), but also in the field of specific health effects of pomegranate residues and its extracts as well as their application in food industry.

Pomegranates as Inhibitors of Food-Borne Pathogen Stains

It has been reported that polyphenols, flavonoids and hydrolysable tannins, being abundant in vegetables, herbs and spices extracts, may prevent and sometimes even treat a broad range of infections. Pomegranate peel extract's phenols, tannins, and flavonoids have shown antibacterial and antifungal activity against several species such as *Bacillus cereus, Bacillus coagulans, Bacillus subtilis, Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa, Staphylococcus aureus, Salmonella typhimurium, Aspergillus niger, Mucor indicus, Penicillium citrinum, Rhizopus oryzae,* and *Trichoderma reesei* [30,31]. Malviya et al (2014) studying antibacterial activity using different pomegranate peel extracts found out that the maximum activity against the tested strains was in order against the tested species as follows: *S. aureus > S. typhi > E. aerogenes > K. pneumoniae*. *P. granat* [15].

Table 5: Inhibition zones exhibited by pomegranate peel extract against foodborne pothegens.

Bacterial Species	Zone of inhibition (mm)		
	Methanol	Water	70% ethanol: 30 % water
Staphylococcus aureus	24.5 ± 0.5	22.6 ± 0.3	22.9 ± 0.4
Enterobactera erogenes	18.2 ± 0.4	18.4 ± 0.5	19.3 ± 0.7
Salmonella typhi	18.3 ± 0.3	28.0 ± 0.4	24.3 ± 0.3
Klebsiella pneumoniae	11.3 ± 0.3	11.2 ± 0.2	14.3 ± 0.5

[1] *Adapted from Malviya et al., 2013[15]*

It seems that the antimicrobial mechanism of phenolic compounds is based on the reaction of phenolics with proteins and/or protein sulfhydryl components existing in microbial cell membrane, forcing the precipitation of membrane protein and inhibition of enzymes (for instance glycosyltransferases), thereof leading to microbial death [31,32].

Pomegranate Residues as Dietary Supplements

Dietary fibers derived from fruits and vegetables has the potential to be used as functional ingredients, owning to their numerous health related beneficial effects, including their ability to decrease cholesterol levels, improving glucose tolerance and insulin response, decreasing hyperlipidemia and hypertension, contributing to gastrointestinal health and possibly preventing the development of certain cancers such as colon cancer. Dietary fiber, owning to its capacity of holding water, plays a pivotal role in the digestion process [19].

A recent study verified pomegranate's bagasse potential to be used as source of total, soluble and insoluble fiber. In that study it was noted that the pomegranate bagasse powder co-product exhibited a water holding capacity (WHC) 4.86 times its own weight. It should be mentioned that this WHC value is similar to other fibrous residues such as sugar cane (4.98 g water/g product) and pear (5 g water/g product) indicating the potential to be used as functional dietary ingredient. Oil holding capacity of 5.9 g oil/g fiber was also measured in that study for pomegranate bagasse samples, indicating that even if pomegranate bagasse is added in products or used for frying processes would not retain much oil [33]. On the other hand, Hasnaoui et al. (2014) measuring oil holding capacity (OHC) of 12 varieties of pomegranate peels found out that its values ranked from 2.8 g/g to 4.05 g/g among different cultivars, stressing the potential usage of pomegranate peels as fat replacers in food preparations [34]. Orange peels having OHC of 3.63 g/g, meaning comparable values compared to pomegranate peel, have been used as fat replacers in ice-cream [35]. A very important index regarding dietary fibers and its usage as functional ingredients in food is the ratio of IDF (insoluble dietary fibers) to SDF (soluble dietary fiber). It is well known that a ratio of IDF to SDF ranking from 1 to 2.3 is beneficial regarding health aspects. Regarding pomegranate bagasse that ratio was measured of being approximately 1.6 to 1.7, values that indicate a balance ratio of dietary fibers in pomegranate by-products [33]. On the other hand, pomegranate peel extracts have quite less values (equal to 1), since bagasses contain also the seeds which logically increase IDF portion [34].

From all the above is obvious that pomegranate peel could be used for the production of fiber enriched products or even hygiene low fat products using dietary fibers as fat replacers.

Microbial production of industrial enzymes and single cell protein from pomegranates peel lignocellulose as well as lovostatin from pomegranate seeds

Enzymes have got a wide range of applications in food industry. Invertases or β-fructofuranosidases are generally produced by controlled aerobic fermentation of a non-pathogenic strain of *Saccharomyces cerevisiae* and is mostly extracted via washing and autolysis [36]. In food sector this enzyme is a very significant agent for the production of artificial sweeteners. Moreover, due to its fructosyltransferase activity it is used for the production of short-chain fructo-oligosaccharide compounds. More specifically, invertase is extensively used for the production of confectionaries with soft or liquid centers and other confections such as chocolates, milk powders for infants and for assimilation of wines with alcohol. Invertases are also used for the biotransformation of sugar cane molasses into ethanol [36,37]. Uma et al. 2012 produced invertase with specific activity of 197. 5 U/mL using a fungal strain (*Cladosporium cladosporioides)* in submerged fermentations at 30^{o}C, pH values of 4 and after 96h of incubation, using pomegranate peel as carbon and yeast extract as nitrogen source [38]. Invertase production has also been evaluated using pomegranate peel waste as fermentation feedstock by *Aspergillus flavus* bioconversions [36].

Proteins are the leaving blocks for all organisms and essentials for development and growth. Nowadays, world widely the deficiency of protein is becoming a major problem and especially in countries such as Algeria and Nigeria. Single cell proteins (SCP) meaning dried cells of bacteria, algae, yeast, and fungi, rich in proteins could be alternatively instead of common sources of proteins (for instance cereals, nuts, meat), used as dietary supplements to address protein-related food scarcity and nutrition deficiency issues. Single cell protein can be produced by a number of vegetables, cereals and fruits. There is limited research in that field and till now very few researchers have reported the potential production of single cell protein. Khan et al. 2010 evaluated the potential production of SCP through *Saccharomyces cerevisiae* fermentations using pomegranate rind as substrate. The researchers achieved in yielding 54. 28 % crude protein from 100 g pomegranate rind [39].

Lovostatin is a fungal secondary metabolite which is a potent inhibitor of 3-hydroxy-3-methyl glutaryl coenzyme A (HMG-CoA), used in the treatment of hypercholesterolemia and other diseases such as atherosclerosis, peripheral vascular disease, ischaemic disease and bone fracture [40]. Naik et al. 2012 evaluated lovastatin production using different agro-industrial residues as substrate via solid state fermentation. It was reported that pomegranate seeds proved of being the best substrate enriched with 0.1% w/v potassium dihydrogen phosphate (KH_2PO_4), 5% w/v glucose, 60% w/w moisture, at pH 5 after 15 days of optimized solid state fermentation for the production of 4.2 ± 0.03 mg lovastatin/gm dfm. Maximum lovastatin yield of 6.5 ± 0.07 mg/gm dfm achieved by mutation studies using ethyl methyl suplphonate (EMS), using pomegranate seed as fermentation substrate [41].

Conclusion

In the present study, the potential of developing value added products from pomegranate juice by-product streams was evaluated. Pomegranate peel and seed may form, even being undervalued, excellent sources for the development of a novel biorefinery leading to the production of several bioactive compounds such as phenolic compounds, tannins, flavonoids, sterols, fatty acids, dietary fibers, minerals and vitamins. Pomegranate by-products could be also used via bioprocessing for the production of single cell protein, industrial enzymes, and lovastatin with diversified market outlets and several economic as well as waste management benefits. Pomegranate peel extracts, seed oil and pomegranate bagasses might be used for the fortification of food commodities generating the formation of functional novel products with diverse health benefits, increased quality and longer self-life.

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