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Nutritional, Bioactive, and Health Potential of Pomelo (*Citrus Maxima*): An Exotic Underutilized Fruit

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Abstract

Pomelo scientifically known as *Citrus maxima* belongs to the family Rutaceae and is one of the largest fruits among citrus varieties. Mainly pomelo comes in different flesh colors such as red, pink, light pink, and white. The principal pomelo fruit polyphenols are phenolic acids, flavonoids, anthocyanins, and tannins. Pomelo fruit generates a large number of wastes including peel, pomace, and seeds which are comprised of bioactive compounds. The bioactive compounds carried in waste improve health functionalities. The hesperidin, narirutin, naringin, and their aglycone (naringenin), which have traditionally been acknowledged to constitute a characteristic component of pomelo, are the fruit's major constituents. Also, pomelo fruit juice is high in vitamins A and C, and the peel offers high protein, carbohydrate, and mineral content. Pomelo production and processing of different byproducts have become a perfect and long-lasting resource for agriculture and the food industry. The wastes loaded with immense essential components in pomelo have great importance in terms of human health. To have unique goods, to increase high consumer acceptability, and to have health advantages, this work gives a summary of recent advancements made to date with nutritional benefits, bioactive elements, and health benefits of pomelo fruit.

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Introduction

Citrus fruits are acclaimed as important constituents for human consumption as they are cholesterol-free and rich in folic acid, vitamin C, flavonoids, phenolics, pectin, and dietary fibers. Citrus fruits are the most significant fruit crops with a total production

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of 120 million tons per year.[1] Citrus includes fruit members such as bitter orange (*Citrus aurantium*), sweet orange (*Citrus sinensis*), mandarin (*Citrus reticulata*), grapefruit (*Citrus paradisi*), and pomelo (*Citrus maxima*). Pomelo (*Citrus maxima*) is one of the most common and the largest fruits among the citrus fruit varieties belonging to the *Rutaceae* family.[2,3] It is a natural, non-hybrid citrus fruit and is considered the principal ancestor of grapefruit. In Asia, Africa, and some parts of Australia citrus variety "pomelo" also regarded as "pummelo" or "shaddock" is widely grown and consumed in raw form or processed into juice. This fruit is referred to as chakotra in India. Due to different breeding and hybridization functioning with other species of citrus, there is development of different cultivars being available in many countries.[4] Mainly pomelo fruit has more popularity in Southeast Asia and other parts of the world and now is regarded as one of the most cultivated and consumed citrus fruits along with mandarin, orange, grapefruit, and lemon. It is the most consumed fruit and the global harvested area and yield of pomelo fruit (Including grapefruit) were 3.7 × 10^5 ha and 9.4 × 10^6 tons.[1] Pomelo fruit spreads up to 10-30 cm in width and weighs around 1-3 kg varying depending on the cultivars. Pomelo fruit contains high levels of vitamin C, just like other citrus fruits. The presence of a high amount of citric acid in juice gives pomelo a sharp taste and flavor.[5] The popularity of pomelo juice is due to its pleasant and refreshing flavor. The pulp is available in red, pink, and white colors with large spindle-shaped juice sacs. It contains a significant amount of naringin and a wide variety of polyphenolic substances, including hesperidin, caffeic acid, P-coumaric acid, ferulic acid, and vanillic acid. Furthermore, the chakotra fruit is exclusively accessible throughout the winter season, and its availability is limited worldwide.[4,6]

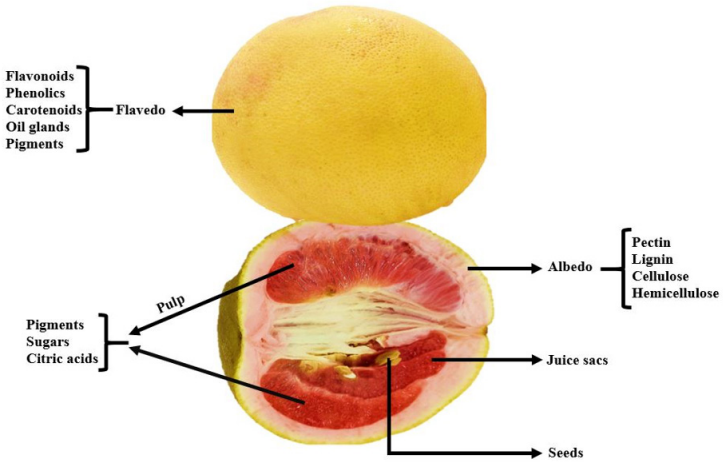

Fig. 1:Anatomy of pomelo fruit

Mainly the pomelo fruit is composed of different parts including flavedo, albedo, segment peel, pulp, juice, seeds, and pomace. The other portions are regarded as a waste part of pomelo fruit. Pomelo contains 3 key parts; exocarp (flavedo, green, peel), mesocarp (albedo, white spongy peel), and endocarp (fruit pulp). Fruit's peel is made up of a cuticle on the exterior, covered by a thin epidermal layer (flavedo), and oil sacs that contain pectin and essential oils. These oil sacs and pectin have commercial importance.[2,7] The albedo, or spongy layer, is made up of pectin and has parenchymatous cells. The center of the pomelo is made up of white, spongy tissue. Figure 1. represents the anatomy of the pomelo fruit. Pomelo fruits are consumed as raw fruit, or in juice form, and the peels are discarded as waste. Pomelo peel is considered to be the largest and thickest rind among all citrus fruits and comprises up to 40% of the fresh weight of the fruit. During juice processing and raw fruit consumption, a lot of waste is generated in the peel, albedo, seeds, and pomace form.[8] The main constituents of pomelo waste include cellulose, water, hemicellulose, lipids, sugars, and active constituents include phenolics, and flavonoids. The presence of bioactive compounds and health benefits from pomelo fruit cause popularity among consumers because of the development of emerging food products from the

waste of pomelo fruit.[9] The waste discarded during the production and processing processes contains a huge number of useful constituents and presents valuable prospects in the fields of technology and health promotion.[10] Food technologists, researchers, and industrialists are working on new extraction techniques and green tendencies to explore the field of fruit wastage for the production of new, innovative food and by-products.[6,11] As a result, the current review has been put together to highlight specific elements related to the utilization of *Citrus maxima* waste, with a focus on their nutritional profile and their function in the management of health, bioactive substances, food industrial approaches, and the proposed future prospectus.

Study Methodology

For this review, we used reputable search engines such as Google Scholar, Science Direct, PubMed, Web of Science, Scopus, and Research Gate. The time frame was 2014 to 2022, with a focus on recent literature. Types of publications included review articles, research papers, book chapters, and official reports collected from reputed journals, books, conference proceedings, and official websites.

Table 1. Nutritional profile of different parts of pomelo fruit

Nutritional aspects	Whole pomelo fruit	Peel	Pulp	Juice	References
Energy (Calorie)	231	188	164	159	2,8,25,29
Moisture (%/100g)	82-94	78.0	83.3	79.57	
Ash	3.14	2.49	1.15	0.73	
Protein	0.7-2.0	0.42	1.86	1.76	
Carbohydrate	3-12	71.57	21.34	16.79	
Fat	0.05-0.5	9.74	0.96	0.83	
Vitamins (mg/100g)					
Vitamin A	20-30	8.23-9.26	8.16	7.34-7.85	3,26,31
Vitamin B	0.2-4.0	0.2-3.23	NA	0.16	
Vitamin C	30-43	19.34	24.34-26.12	26.36	
Vitamin E	5.26	4.45	NA	2.11	
Thiamine (B1)	0.034	0.020	0.014	0.010	
Riboflavin (B2)	0.027	0.021	NA	NA	
Niacin (B3)	0.22	0.16	0.18	0.14	
Pyridoxine (B6)	0.036	0.030	0.028	0.026	
Minerals (mg/100g)					
Potassium	150-225	127	104	98.32	26,27,32,33,34
Sodium	0.38	0.68	0.10	0.12	
Calcium	21-30	28.8	14.5	13.26	
Phosphorus	20-27	21.9	18.9	18.96	
Magnesium	21.9	23.0	19.40	19.23	
Minerals (mg/100g)					
Iron	0.49	0.52	0.46	0.38	25,26,35
Zinc	0.11	0.12	0.10	0.09	
Copper	0.12	0.21	0.05	0.02	
Manganese	0.08	0.15	0.01	0.01-0.02	
Selenium (µg/100g)	1.61	2.00	1.30	1.26	

ND: Not Applicable

Results and Discussion of Study

Nutritional Profile of Pomelo Fruit

Pomelo is a complete fruit as it comprises essential nutrients such as proteins, carbohydrates, fats, vitamins, and minerals. Being covered with high nutritional value, pomelo fruits are mainly utilized for self-consumption.[12-15] With less utilization in rural areas, people used pomelo fruits during food scarcity

periods and these fruits have a significant role in food security in hills and mountains by enhancing dietary diversity and also income chances.[16-20] Pomelo fruit plays an encouraging role in food, nutrition as well as diverse food culture for poor people who have less access to major fruit crops. Pomelo fruit and its different fruit parts such as peel, segment peel, seeds, juice, and pomace are composed of an array of phytochemicals and nutritional components.[21-24] The nutritional profile of different parts of pomelo fruit has been tabulated in Table 1. Pomelo fruit provides many nutrients such as vitamins A and E, B vitamins (riboflavin, niacin, thiamine), and vitamin C. The peel waste product of pomelo is regarded as a potential source of nutraceuticals. The presence of macro and micro minerals in the pulp and peel of pomelo fruit improves the dietary and therapeutic value. As compared to pulp and juice, the peel portion of the fruit contains a higher dose of vitamins and minerals. Pomelo peel is 7-5 times rich in sodium than its pulp and has 20% more potassium in the peel portion than the pulp.[4, 25-26] The pulp, peel, and juice of pomelo fruit have promising sources of mineral elements that have health characteristics in food products. The albedo of pomelo mostly contains antioxidants and is also abundant in flavonoids. Seeds and pomace of pomelo fruit are rich in fibers and vitamins. The pomace of fruit is rich in fibers, sugars, and organic acids. Pomelo fruits have a delicious taste and distinct aroma with low-fat content.[8] Pomelo has the highest concentration of iron (0.1 mg) and copper (0.048 mg); thus, these fruits are taken into account when treating disorders of hemoglobin formation brought on by a deficiency in these nutrients. Pomelo fruits are a very valuable source of potassium, which is required to maintain the water and electrolyte balance. Besides, this pomelo contains a lot of vitamin C, exactly like citrus fruits.[10] Consuming pomelo fruit is a simple way to get fiber and vitamin C, both of which are crucial for the body's ability to absorb nutrients. In 100 g of flesh, pomelos contain 52.3 mg of ascorbic acid. An individual can reach a level of 100% vitamin C by consuming a moderate amount of pomelo fruit each day.[23-26] The folic acid present in pomelo fruit is composed of folate compounds namely 5-methyl tetrahydrofolate (monoglutamate) and polyglutamate. Pomelo is also composed of different levels of carotenoids such as lutein (2.95 µg/g), zeaxanthin (0.81 µg/g), β-cryptoxanthin (0.81 µg/g), and β-carotene (10.3 µg/g).[27-28] The trace elements present in fruit may be affected by the mineral makeup of the soil where the fruit is grown, the type of fertilizer used, climatic conditions, agricultural practices, and irrigation water composition. Pomelo can play a role in the creation of new, high-value food products that are also beneficial by controlling their nutritional significance and investigating their proximate and nutritional importance.[28]

Bioactive Constituents of Pomelo Fruit

The pomelo fruit is known for its different properties such as antioxidant, antidiabetic, anti-inflammatory, anticancer, antimicrobial, antiallergic, and lipid regulation metabolism. The different properties of pomelo fruit are due to the presence of different bioactive constituents including polyphenols, flavonoids, phenolic acids, carotenoids, triterpenoids, phytosterols, carbohydrates, coumarins, and some miscellaneous constituents. Table 2 provides details on different bioactive compounds present in different parts of pomelo fruit which are discussed below:

Polyphenols

Pomelo fruit contains different polyphenolic compounds including flavonoids and phenolic acids. Polyphenols are major phytochemical components with potential activities such as anti-inflammatory, antioxidant, antimicrobial, anti-nervous, and anti-metabolic. The different parts of pomelo fruit are rich in polyphenols at different ranges.[35] In comparison to other portions of the pomelo fruit, the peel contains a higher concentration of polyphenols. The structure-based grouped chemicals of pomelo polyphenols are the flavonoids and phenolic acids class.[19,36] A variety of extraction techniques, including maceration, ultra-high-pressure extraction, soxhlet extraction, microwave extraction, accelerated solvent extraction, supercritical fluid extraction, and heat reflux extraction are documented for the extraction of polyphenols. The polyphenolic profile of pomelo fruit can be affected by different factors such as extraction conditions, analysis methods, genotypes, environmental factors, and fruit color.[37,38] The data available in the literature define the different studies related to polyphenolic extraction of compounds, yield, and the effect of different biological activities on it. Tran *et al*. (2021) studied the effect of different extraction methods on the flavedo of pomelo fruit to obtain polyphenol yield.36 The different methods utilized for extraction were soxhlet, ultrasound, and microwave extraction to

obtain a high yield. For soxhlet extraction (35 min per cycle with 4 reflux cycles at 80 °C) was required. For ultrasound-assisted extraction (120 W, temperature 60 °C for 20 min) and microwave (150 W for 20 min) were utilized. Among the three methods, microwave-assisted extraction was efficient and yielded more polyphenols. In another study, Nguyen *et al*. (2020) examined the effect of microwave extraction of pomelo extract on polyphenols and defined the antioxidant activity of present polyphenols in pomelo fruit.[39] The microwave extraction was performed on the pomelo albedo portion with a power of 300 W for 2 min and had the highest polyphenol content (2.46 g GAE/L).

Flavonoid

Flavonoids are an important class of polyphenolic secondary metabolites with significant antioxidant components within the human diet found in fresh produce. Fruits have an abundance of flavonoids as compared to other polyphenolic compounds.[40] Flavonoids are composed of 10% dried pomelo fruit part. Pomelo fruit is composed of 75-90% of total flavonoids. Naringin makes up roughly 90% of the peel, pulp, and juice, whereas hesperidin makes up 0.015–0.025% of the juice. Subgroups of flavonoids include flavanones, flavones, flavonols, flavanonols, flavanols, isoflavones, and anthocyanins.[41] Flavanones are the most important class of flavonoids in pomelo fruit. Under flavanones, the peel, seed, pomace, and juice portion of pomelo fruit is composed of hesperetin, hesperidin, naringenin, narirutin, naringin, diosmin, eriocitrin, and hespeidin. The predominant flavanones are hesperedin and naringenin in pomelo fruit. Flavones are the second most important class under flavonoids. Apigenin, luteolin, and tangeretin are different flavones in the peel and juice portion of pomelo. The flavonols of pomelo fruit contain quercetin and kaempferol in the peel and the juice portion of pomelo.[40,41] Flavonoids are present in almost all the parts of pomelo fruit. The health benefits of flavonoids include antidiabetic, antiallergic, anticancer, anti-inflammatory, antimicrobial, antiproliferative, antioxidant, and anti-inflammatory activities. Flavonoids can be extracted using sonication, microwave assistance, supercritical fluid extraction, and soxhlet extraction. Centrifugation, vortexing, hydro distillation, and soxhlet extraction are the conventional techniques for extracting flavonoids.[40] Ultrasound extraction, microwave-assisted extraction, supercritical fluid extraction, and subcritical water extraction are some of the contemporary techniques used to extract flavonoids. These processes require less time, energy, and solvent. Furthermore, they enable a higher yield at a cheaper cost. The study conducted by Nguyen *et al*. (2020) on pomelo peel for flavonoid extraction was done using ultrasound and enzyme-assisted extraction.[39] The time for extraction of flavonoid using the enzyme technique was 65.23 min and for sonication, it was 69.26 min. The combination of ultrasonication and enzyme method favored more extraction of flavonoid (16.79 mg GAE/g) than the conventional method. Likewise, Phuong *et al*. (2021) identified the flavonoid content and biological activities of pomelo peel using water bath extraction.[42] The results defined that the maximum flavonoid content (6.0 mg/g) was extracted from the pomelo peel of the Tan Trieu variety.

Phenolic Acids

After flavonoids, the other main class is phenolic acids. The different phenolic acids reported from pomelo peel and segment peel are caffeic, chlorogenic, ferulic, sinapic, vanillic acid, and p-coumaric. Phenolic acids are secondary metabolites that serve as the building blocks for vinyl phenols.[32] For the extraction of phenolic acids, vortexing, centrifugation, soxhlet extraction, sonication, microwave irradiation, mechanical stirring, and pressurized liquid extraction techniques are utilized.[9,29] Mainly the optimum conditions for extraction of phenolic acids vary with extraction time, temperature, type, the composition of the solvent, solvent-to-solid ratio, the particle size of the sample, and extraction cycles.[9] Some studies revealed the effect of extraction conditions on the phenolic acids of pomelo fruit. Al-Juhaimi *et al*. (2021) studied the extraction of phenolic content and antioxidant activity in pomelo peel using different solvent mixtures.[32] The total phenolic content ranged between 12.43 (ethanol: water, 60:40 v/v) and 22.91 mg GAE/kg (methanol: water, 50:50 v/v). The combination of methanol and water at 1:1 ratio was effective for the extraction of phenolic content and for the determination of antioxidant activity. Similarly, Zhao *et al*. (2020) investigated the phenolic content in the flavedo, albedo, and pulp portion of pomelo fruit by using UHPLC-QqQ-MS/MS (Ultra high-performance liquid chromatography coupled with triple quadrupole mass spectrometry).[43]

Carotenoids

Carotenoids are present in the peel portion of pomelo fruit. Carotenoids not only have an eye appeal impact on the fruits but also have biological effects including immunomodulatory, antioxidant, anti-inflammatory, anticancer, antibacterial, and gastroprotective activities. There are estimated to be about 115 different carotenoids, ranging in color from yellow to red. The different carotenoids present in pomelo peel are α-carotene, β-carotene, lutein, zeaxanthin, β-cryptoxanthin, and roseoside.[9] The pigments, or color-preserving substances, that give pomelo its distinctive red, pink, and white color are located in the peel's cell walls. Carotenoids are responsible for golden yellow to pink or red colors to the fruit pulp and peel of the pomelo fruit. The red and pink-fleshed pomelos have higher amounts of carotenoids as compared to white-fleshed varieties.[34] Zhao *et al*. (2021) identified the carotenoids in pomelo fruit.[5] The different carotenoids extracted from the pomelo were lutein, α-carotene, and β-carotene and lutein was the maximum isolated compound. Likewise, Jiang *et al*. (2022) studied the different carotenoids in pomelo fruit using HPLC (High-performance liquid chromatography).[44] The different carotenoids isolated included lutein, α-carotene, and β-carotene.

Limonoids

Limonoids are a highly oxygenated and modified class of triterpenoids. Limonoids are present in the flavedo oil glands portion of the peel. Other portions of pomelo fruit reported with limonoids are seed, pomace, and albedo. Different limonoids present in the pomelo fruit are methyl nomilinate, limonin, nomilin, isoobacunoic acid, obacunoic acid, isolimonic acid, ichigan.[45] The pomelo fruit juice is bitter due to the presence limonin and nomilin compounds. The highest amount of limonin was found in the seed (9.50 mg/g), followed by the peel (4.69 mg/g) and the juice (0.218 mg/ml). The presence of limonoids in pomelo fruit provides anticancer, cytotoxic, antioxidant, anti-inflammatory, antibacterial, and anthelminthic activities.[32] The study accompanied by Xiang *et al*. (2014) defines the isolation and identification of limonoid compounds from the pomelo segment membrane by using HPLC (High-performance liquid chromatography).[46] The different compounds isolated from segment membranes were limonin, nomilin, and isoobacunoic acid. Another study conducted by Huang *et al*. (2021) examined the limonoids in the flavedo portion of pomelo fruit by using HPLC (High-performance liquid chromatography).[45] The different compounds isolated are limonin, nomilin, and limonin glucoside.

Phytosterols

Phytosterols are plant-based compounds with dietary cholesterol that is absorbed by the intestines and result in lower blood cholesterol levels. Citrus fruit is rich in phytosterols. Mainly citron, pomelo, grapefruit, tangerine, kinnow, and murcott have high phytosterols present in them.[47] Several phytosterols extracted from pomelo fruit are β-sitosterol, campesterol, daucosterol, and stigmasterol. These phytosterols are present in the peel and segment peel of pomelo contributing to antioxidant, anti-inflammatory, anti-cancer, and anti-inflammatory activities.[8]

Carbohydrates

The carbohydrates present in pomelo fruit's different portions include glucose, fructose, maltose, sucrose, trace amounts of mannose, maltose, heptulose, and galactose. These carbohydrates are present in peel, juice, and pomace parts. They are considered natural saccharides, non-toxic, biodegradable, and biocompatible with advantages for biomedical and pharmaceutical uses.[48] The biological activities directed by carbohydrates present in pomelo fruit are antibacterial, antifungal, antioxidant, antiallergic, anti-epileptic, and anti-inflammatory activities. Researchers are focusing on extraction yield and characterization of physical and chemical properties of the carbohydrates of pomelo fruit to have new fabrication of products.[8]

Coumarins

Coumarins are another group of secondary metabolites present in high amounts in pomelo fruit. The different coumarins reported from pomelo fruit are limettin, isopimpinellin, auraptene, 7-isopentenyloxycoumarin, and isoauraptene. The whole fruit and pericarp portion of pomelo fruit contains up to 17 coumarins.[9] Coumarins are mainly present in the peel and peel segment portion of pomelo fruit. In the peel portion of pomelo, they are present in the oil sacs. They are known for their anti-inflammatory, hepatoprotective and antitumor activities.[27]

Miscellaneous

Apart from flavonoids, phenolics, carotenoids, coumarins, carbohydrates, limonoids, other miscellaneous compounds are also reported. The compounds include α- tocopherol, ascorbic acid, chlorophylls, decyl acetate, malonic acid, fumaric acid, succinic acid, and citric acid.[15] The presence of these compounds in the peel, segment peel, juice, and pomace of pomelo fruit contribute to health benefits such as hypoglycemic, antimicrobial, antioxidant, anti-inflammatory, and anti-cancer activities.[49]

Table 2: Characterization of different bioactive compounds present in different parts of pomelo fruit

Classification	Bioactive compounds	Fruit part used	Biological activities	Action mechanism	References
Flavonoids • Flavanones	• Hesperetin • Hesperidin • Naringenin • Narirutin • Naringin • Diosmin • Eriocitrin • hespeidin	Peel, Seeds, Juice, Pomace	Antidiabetic, Antiallergic, Anticancer, Anti-inflamm -atory, Antimicrobial, Antiproliferative activities	• Improves the intes -tinal fate, bioavaila -bility, intestinal metabolism, and interaction with the gut microbiota • Treating cancer, diabetes mellitus, oxidative stress disorders, cardio vascular disease, and other diseases	1,24,27,29
• **Flavones**	• Apigenin • Luteolin • Tangeretin	Whole fruit, Juice	Antioxidant, Anti-inflam -matory, Antimicrobial, Anticancer activities	• Balance in bone metabolism on bone health • Reduction in hepatic and intestinal triglyceride accumulation	1,19,22
• **Flavonols**	• Quercetin • Kaempferol	Peel, Juice	Antiatherogenic, Neuroprotective effects	• Inhibition of metas -tasis • Inhibition of tumor progression • Inactivation of carcin -ogens and defense of DNA against oxidative damage	19,22,30
Phenolic acid	• Caffeic • Chlorogenic • Ferulic • Sinapic • vanillic acid • P-coumaric	Peel, Segment peel	Antioxidant, Anti-inflammatory, Anti-cancer, Antidiabetic, Antiallergic, Antimicrobial, Antiproli -ferative activities	• Prevents pancreatic, stomach, colon, breast, and skin cancers	24,27,31

Carotenoids	• α-carotene • β-carotene • Lutein • Zeaxanthin • β-cryptoxa nthin • Roseoside	Peel	Immunomodulatory, Antioxidant, Anti-inflammatory, Anticancer, Antibacterial, Antigenotoxic, Anthelminthic, Gastropr -otective, Anti-ulcerogenic activities	• Prevents skin tumori genesis and colon carcinogenesis	[1,8,9]
Triterpenoid					
Limonoids	• Methyl nomilinate • Limonin and nomilin • Isoobacunoic acid • Isolimonexic acid • Limonexic acid	Flavedo and albedo	Antioxidant, Anti-inflam matory, Anticancer, Antibacterial, Anthelminthic activities	• Preventative measures for colon cancer • Breast tumors caused by estrogen exhibit cytotoxic effects.	[8,24,32]
	• Obacunone • Nomilin • Obacunoic acid • Isolimonic acid • Deacetylnomilin • Ichigan • Isoobacunoic • Dictomnolide	Seeds, Pomace	Immunomodulatory, Antioxidant, Anti-inflammatory, Anticancer, Antibacterial, Antigenotoxic activities	• Balance in bone me tabolism on bone health • Prevent pancreatic, stomach, colon, breast, and skin cancers	[1,8,24,32]
Phytosterols	• β-sitosterol • Campesterol • Daucosterol • Stigmasterol	Peel, Seg-ment peel	Antioxidant, Anti-inflammatory, Anti-cancer, Anti-inflamm -atory activities	• Bone health depends on a balanced bone metabolism • Prevention of colon cancer and skin tumorigenesis	[9,19,29]
Carbohydrates	• Phytol • Synephrine • Methyl antra -linate • Fructose, Glucose, Sucrose, glucose, fructose, trace amounts of mannose, maltose,	Peel, Juice, Pomace	Antibacterial, Antif-ungal, Antioxidant, Anti-inflammatory, Anti-cancer, Antiallergic, Anti-epileptic, Anti-obesity, Anti-anxiety activities	• Promotes antioxidant free radical scavenger activity • Prevent the spread of pancreatic, stomach, colon, breast, and skin cancers	[30,31]

	heptuloses, galactose				
Coumarins	• 5-geranyloxy -7-methoxyco -umarin • Limettin • Isopimpinellin • Auraptene • 7-isopenteny -loxycoumarin • Isoauraptene • Meranzin	Peel, Segm -ent peel	Hypolipidemic, Hypog -lycemic, Antimicrobial, Antioxidant, Anti-infla mmatory, Anti-cancer, Anti-lipogenic	• Reduction in the growth of human colon cancer cell • Inhibits microglia activation	[29,33,35]
Miscellaneous	• α- tocopherol • Ascorbic acid • Chlorophylls • Decyl acetate • Malonic acid • Fumaric acid • Succinic acid • Citric acid	Peel, Juice, Segment peel, Pomace	Hypoglycemic, Antim -icrobial, Antioxidant, Anti-inflammatory, Anti-cancer activities	• Balance in bone metabolism on bone health • Prevent pancreatic, stomach, colon, breast, and skin cancers.	[9,29,31]

Health Benefits of Pomelo Fruit

The wide range of lifestyles across the world, consumers' attitudes toward herbal medications have changed. The demand for pomelo fruits has been increasing throughout the world because of their scientifically accepted health attributes and high antioxidant activity. The waste generated from pomelo fruit has a large number of value-added components and a defined variety of appreciated opportunities in the technological and health-improving provinces.[47] The whole fruit of pomelo provides nutritional properties and reduces the risk of several diseases such as metabolic syndrome, cardiovascular issues, neurodegenerative disease, type 2 diabetes, and cancer. Figure 2. indicates the health benefits associated with different parts of pomelo fruits. The peel portion of pomelo also known as flavedo combats diseases such as diabetes mellitus, pulmonary disease, cancer, nephropathy, cardiovascular disease, and neurodegenerative disease.[23,29] The flavedo portion of the pomelo fruit has anti-asthmatic activity, relaxing affection for the nervous system, and is used to treat headaches, diarrhea, vomiting, eye troubles, and problem of the abdomen.[7,47] The fiber present in the peel region of pomelo reduces the risk of heart attacks if consumed daily in the diet. The limonene found in the peel portion is attributed to health benefits such as relief of toothache, overcoming poor digestion, and relieving headaches, and pain in different parts of the body. The fruit portion of pomelo acts as a cardiotonic and is utilized against diseases such as asthma, cough, hiccough, leprosy, epilepsy, and mental aberration.[32] The fruit portion defined the anti-hyperlipidemic attributes, which causes a reduction in blood cholesterol and also triglyceride levels.[48] The peel segment of pomelo fruit is used against diseases such as cholera, epilepsy, cough, and also in hemorrhage treatment. The juice has been acting as an appetizer, stomach tonic, cardiac stimulant, and also as a remedy for insomnia, sore throat, and fever. Juice is good against wounds, acne, osteoarthritis, and minor skin disorders. The seeds of pomelo are utilized as a sedative for nervous problems.[9] The fruit skin has a high amount of active constituents and antioxidants. The active components present in pomelo fruit are directly or indirectly reliable for a wide range of health-enhancing effects. Despite pomelo being blessed with a diverse range of phytochemicals and other essential nutrients, this fruit is still considered an underutilized species in comparison to other species as it is composed of large-sized fruit, bitter juice, and thicker peels.[15,48]

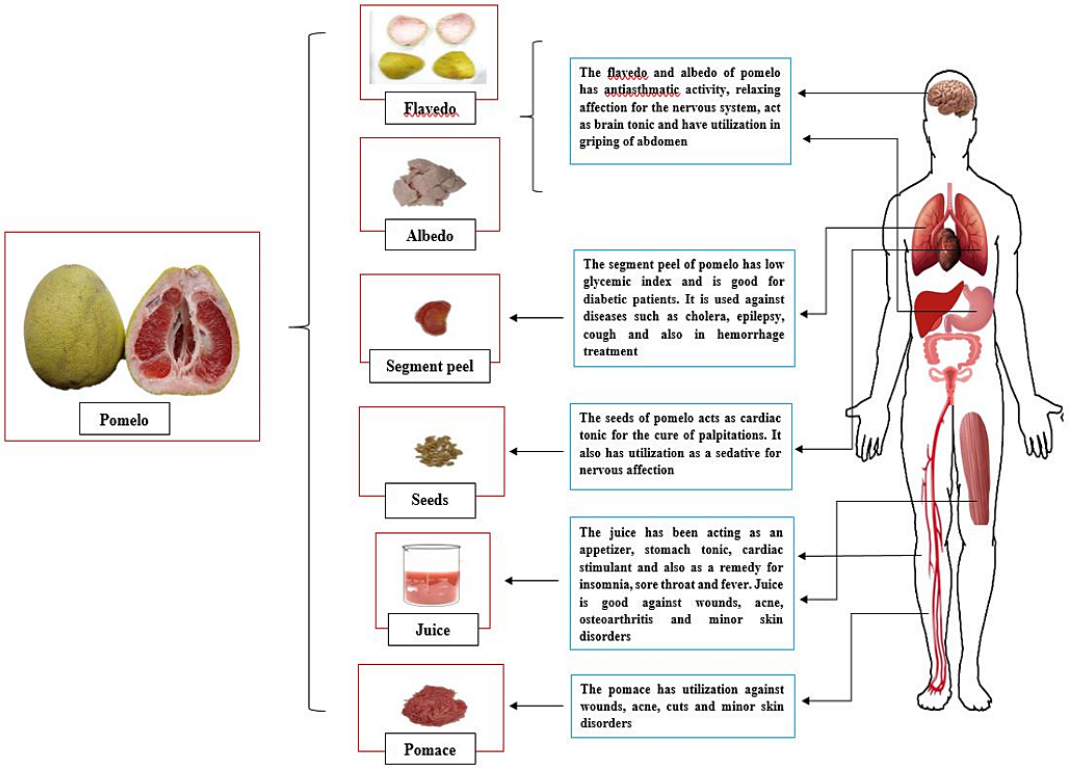

Fig. 2:Health benefits associated with pomelo fruit different parts

Applications of Pomelo Fruit in Food Industries

Pomelo processing in industries generates a lot of waste in the form of press cakes, including flavedo, albedo, juice vesicles, and seeds. Pomelo processing waste is being investigated for use in the creation of consumer products.[9] The different products developed from pomelo fruit are squash, noodles, jam, bread, beverages, breakfast cereals, wine, nectar, cake, and parathas. Figure 3. represents the outlook of food and by-products of pomelo fruit and their applications. The production of a massive amount of waste in the fruit juice industry, as well as the need for natural components in foods made from fruit by-products, is becoming a trend in the creation of health products.[29,49] The segment peel, and peel of pomelo are used to garnish the food. The pomelo juice is consumed in fresh form and as processed products, it is available in frozen, chilled, canned, blended, or concentrated form, cordials, syrups, and squash. The pomelo segment peel is added as a nutritional supplement to develop noodles. These noodles are for diabetic patients and have a good amount of fiber present.[50] The peel of pomelo is incorporated in custard, curries, and gravies to improve the flavor and aroma. The flavedo portion of pomelo is enriched in antioxidants and polyphenols. Due to its distinctively bitter taste, the naringin chemical isolated from pomelo fruit is used to flavor beverages, desserts, and baked goods. The dry-cured sausages contain albedo fibers in varying amounts, whether they are cooked or uncooked.[49] Pomelo seeds are generally regarded as useless and disposed of. Pomelo seeds are rich in protein and can be used for livestock feed. Seed can be used as flavoring agent, additive, and essence in different food products. Researchers evaluated that extruded snack products are generally high energy dense. The pomelo fruit peel was used by researchers to fabricate extruded snacks with high nutritional quality and health benefits.[30] There is an increasing trend in the market for value-added products with high nutraceutical value. Pomelo fruit is considered a high-value fruit as it consists of a large number of phytochemicals and multiple uses in the food industry. To enhance consumer, demand the production of value-added products with high nutraceutical value is much needed in the food industry.[29,49]

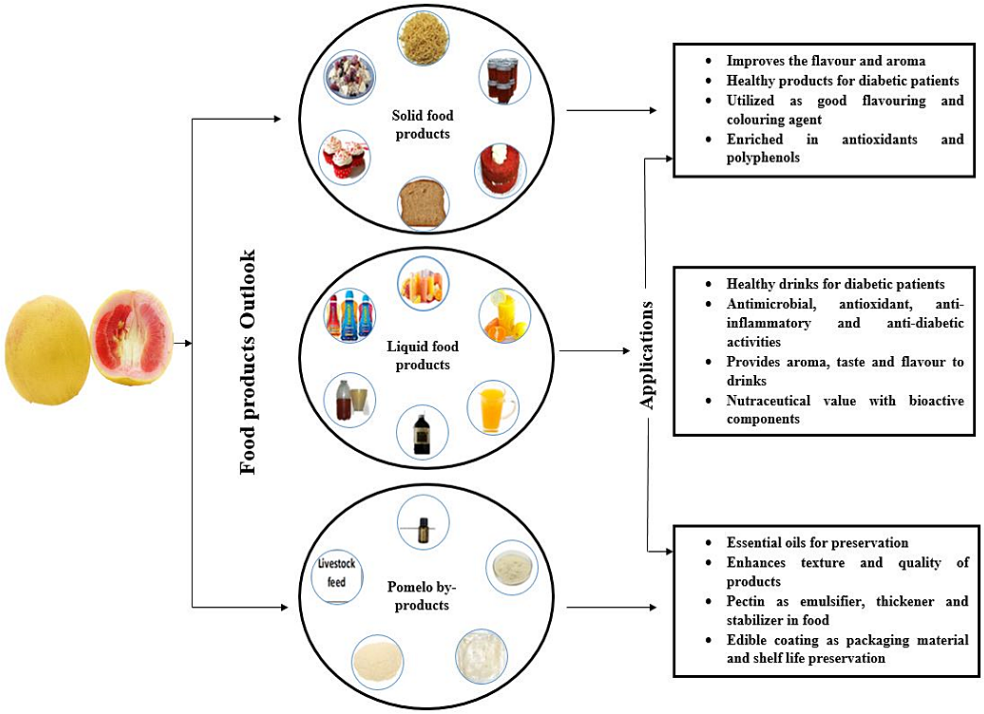

Fig. 3:An outlook of food and by-products of pomelo fruit and their applications

Table 3: Characterization of different food products from pomelo fruit and their processing approaches

Food products	Fruit part used for product development	Processing method	Health benefits of products prepared	Parameters tested after processing of product	Cited litera -ture
Pomelo bread	Fruit segments	Fresh (0, 10, 20, 30%) and dried (0, 2.5, 5, 7.5%) pomelo fruit segment was mixed with 2% yeast, 1% vegetable fat, 1% salt, 2.5% sugar and water. All the ingredients are combined and the dough was prepared. Fermentation was done at 30 °C, 75% RH (Relative humidity) for 90 min. after 90 min dough was molded, proofed, and baked for 25 min at 220 °C.	• Helping in preven -ting the risk of post -prandial hypergly-cemia by inhibiting the action of enzy-mes involved in starch breakdown.	Total phenolic content, Flavonoids, carotenoids, total starch, naringin content, resistant starch, glycemic index, total sugars, reducing sugars	52

Noodles	Fruit segments	Fresh pomelo fruit (10, 20, 30%) and dried (5, 10, 15%) were mixed with semolina flour (100 g). The blend was mixed with water and rested for 10-15 min. The dough was cut into noodle rods with a noodles cutter. The noodles were dried in a tray drier at 55°C for 2 hrs. and further packed for analysis.	• Lowered the glycemic index in the body	Total sugars, reducing sug -ar, total phenolic content, flavonoids, carotenoids, naringin content, total starch, resistant starch, glycemic index	[53]
Jam, Ready to serve beverage (RTS)	Pomelo pulp	The jam was prepared with pomelo alone and pomelo combined with 50% papaya pulp. RTS (ready-to-serve beverage) was prepared with pomelo alone and combined with orange (25, 50%)	• Improves metabolism • Less cholesterol and fat • Reduces risk of heart attack • Decreases blood pressure	Total soluble solids (TSS), titratable acidity, pH, Ascorbic acid	[54]
Extruded breakfast cereals	Pomelo rind	The peel was dried in the oven at 50 °C and mixed with brown rice (5, 10, 15%). The mixture was passed through a single screw extruder with a 30 cm length, 30 mm diameter, and 3 mm die. The screw speed was kept at 200 rpm with a feed rate of 9 kg/h while the die temperature was kept at 180 °C. To prepare the extruded goods for further testing, they were cooled and packaged in plastic bags	• Health-improved breakfast cereal product • Improves metabolism of the body	Moisture, expansion ratio, color, texture analysis, antioxidant properties, total phenolic content, oxygen radical absorbance capacity assay	[55]
Pomelo juice concen -trates	Juice	Fresh juice was extracted by homogenizer at 8000 rpm for 3 min and centrif- ugation was done for 10 min at 9000 rpm. The juice was formulated at different concentrations 20, 30.4, 40.4, 53.4, and 60.4 °Brix by utilization of small	• Healthy drink for consumption • Enhances body metabolism • Reduces heart disorders	Moisture content, rheo- logical characteristics, Antioxidant properties	[56]

		laboratory vacuum evapo -ration at 60 rpm at 50 °C.			
Pomelo wine	Juice	The wine was developed from fresh pomelo juice. The *S. cerevisiae* was used for fermentation of wine with the addition of yeast, and potassium metabisulfite. Further, after storage of wine antioxidant properties are studied.	• Good antioxidants and refreshing drink for the body	Total soluble solids, Titratable acidity, pH, Antioxidant properties	[57]
Nectar	Juice	The fresh juice was extracted from pomelo, mango, and kokum fruit. The blend was prepared from these juices in the ratio of (65:30:5). The sugar syrup was added and the final volume was adjusted with water. The prepared product was stored in bottles for further use.	• Refreshing, palatable, and nutritional product • Antioxidant-enriched drink	Total soluble solids, pH, Total sugars, Ascorbic acid, Titratable acidity	[58]
Blended beverage	Juice	The fresh juice was extracted from pomelo fruit and formulated with water in ratios (25:75) and (30:70). 1% citric acid and sodium benzoate was added to the blended beverage. The final product was pasteurized at 70 °C for 30 min. and stored for further analysis.	• Refreshing and nutritional drink for the body	Total soluble solids, Total sugars, Ascorbic acid, Titratable acidity	[59]
Pomelo enzyme beverage	Juice	The fresh raw juice was combined with the enzyme *Dictyophora indusiata* (1:2 v/v) with the addition of 0.1% yeast, lime, 30% white sugar, and salt.	• Natural nutrients rich drink • Improves body metabolism	Total soluble solids, Ascorbic acid, Total sugars,Titratable acidity, Reducing and Non-reducing sugars	[60]
Pomelo cake	Fruit segments	The fresh and dry fruit segments are used for the preparation of bioactive enriched pomelo	• Health-promoting and nutrients enriched cake -	Total phenolic content, Total flavonoid content, Carotenoids, Total fat, Protein, Ash	[61]

		cake. The 10, 20, 30% fresh, and 5, 10, 15% of dry fruit segments are used for pomelo cake production. The 30% fresh and 5% dry fruit segments enriched pomelo cake was considered acceptable for sensory.			
Pomelo Parathas	Fruit segments	The parathas were prepared by incorporating fresh (10, 20, 30%) and dry (2.5, 5, 7.5%) peel segments of pomelo fruit with wheat flour. Ingredients including whole wheat flour, fruit segments, salt, oil, and water were combined and the dough was prepared. After 10 min dough was utilized for the preparation of parathas on the hotplate for 2 min. at 180 °C. Parathas were cooled and packed in polypropylene bags for further evaluation.	• Improves the nutritional and functional properties of parathas • Provides hypoglycemic effect	Total sugars, Reducing sugars, Total phenolic content, Flavonoid, Carotenoids, Total starch, Resistant starch, glycemic index	[62]

The remaining residue after juice extraction of pomelo fruit is used as source material for the generation of valuable byproducts. Essential oils are a byproduct of pomelo fruit. Essential oils are aromatic compounds extracted from the flavedo portion of pomelo fruit and are well known due to their antimicrobial, antioxidant, and anti-inflammatory properties. Essential oil has a potential role in food industries when incorporated as ingredients in food additives and preservatives against spoilage.[27,48] Another byproduct extracted from pomelo fruit is dietary fiber is utilized as an ingredient in various food processing industries to have health benefits. The albedo of the pomelo fruit, which provides a significant source of fiber, is the most neglected part of the fruit. Pectin is a heterogeneous polysaccharide extracted from the flavedo of pomelo fruit. It is utilized as a texturizer, emulsifier, thickener, and stabilizer in food. It is also used as a component in fillings, confectionary, and dietary supplements.[47] The work on the edible coating, emulsion, packaging, and extension of shelf life of pomelo fruit is limited and needs to be explored to have better opportunities and utilization of pomelo fruit. The edible coating is used to maintain the postharvest fruit quality and shelf life by the incorporation of different plant extracts, essential oils, and other active constituents. The residue extracted from the pomelo fruit after extraction of high-value components such as peel and pomace which are rich in fiber content can be molded to have biodegradable packaging materials.[51] Table 3 indicates the different food products from pomelo fruit and their processing approaches. To improve its industrial demand, the development of more value-added products needs attention. There is a lot of scope in the near future for the preparation of value-added products.

Future Prospective and Conclusion

Pomelo is an excellent source of nutrients, vitamins, and minerals. Pomelo is mainly consumed as fresh fruit because of its refreshing appeal and flavor.

Pomelo fruit is utilized in food industries for the development of food products such as jam, jellies, beverages, bread, noodles, wine, and cake. Apart from food products pomelo has great potential for bioactive constituents available in different portions of fruit. The waste loaded in different portions including flavedo, albedo, segment peel, seeds, pomace, and juice of pomelo fruit has health functionalities and active constituents available. However, there is a wide gap and challenges related to the utilization of pomelo fruit for the fabrication of processed products with great nutraceutical potential. The edible coating production from pomelo fruit also needs concern from researchers and food industries to develop innovative coating by incorporating new additives with health-encouraging benefits. The therapeutic potential and nutritional value of pomelo fruit can be explored further for the production of healthy products which is a great benefit for pomelo growers for improving their income and also lowers postharvest losses.

Authors Contribution

Simple Sharma: Conceptualization, methodology, investigation, resources, and writing (original draft, review, and editing). Barinderjit Singh: Writing (original draft, review, and editing). Gurwinder Kaur: Supervision and writing (review and editing). Yashi Srivastava: Writing (review and editing). Rubrinder Singh Sandhu: Writing (review and editing). All authors approved the final version of the manuscript.

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Not applicable

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