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Value-addition of pummelo (*Citrus grandis*) Peel: A Review

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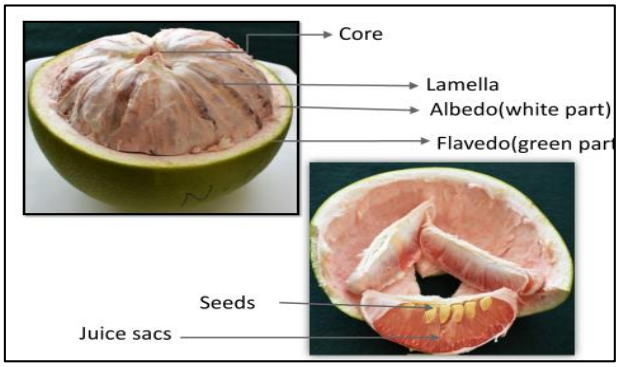
Abstract
The peel of pummelo accounts for approximately 30% of fruit weight. Pummelo peel which has been considered as a by-product is rich in various nutrients and functional compounds, while most of the by-product is disposed as wastes. The utilization of pummelo peels could not only result in valued-added products/ingredients, but also reduce the environmental threats. Essential oil, polyphenols and pectin were recovered from pummelo peel by many ways. By mainly reviewing the recent articles, pummelo peels could be directly used to make marmalade. It can be candied or dipped in chocolate and served. It can eaten raw in salads and drinks as well as candied pummelo peel, tea, jams, etc. Including, the functional components (essential oils, pectin, polyphenols, etc.) could be extracted from pummelo peels and applied in food, pharmaceutical fields. The methods like extraction exerted significant influences on the composition, physicochemical properties, bioactivities and structures of the resultant fractions. The essential oils are also An eco-friendly option for insect pest management. The *Citrus maxima* peel essential oil (CMEO), A waste product, characterized it, and evaluated its potential for insect pest management. Furthermore, pomelo peel was exploited to make bioethanol, adsorbents, packaging etc.

Keywords: Pomelo peel, utilization, bioactive components, essential oil, pectin and polyphenol

1. Introduction
Citrus maxima (Burm.) Merri or *Citrus grandis* (L.) Osbeck is widely distributed. Pummelo is one of the largest of the citrus fruit having diameter of 15-25 cm, and shape is round to oblong. It is also called Chinese grapefruit, shaddock, and pummelo. In Indian languages It has several names that is batabilebu (Bengali), papnus (Gujarati and Marathi), chakotra (Hindi), chakkota in Kannada, bombilimas (Malayalam and Tamil) and pamparapanasa in Telugu. Fruit is seeded to seedless with a very thick rind. The green to yellow colour outer layer is known as flavedo. The flesh color varies from white, red to pink-coloured. The taste of the fruit is sweet and is slightly acidic with a hint of bitterness. The nutritional value (Energy 159 kJ Carbohydrates 9.62 g Dietary fiber 1 g Fat 0.04 g Protein 0.76 etc (Wikipedia Shivananda *et al*., 2014) [18] is seen as follows. Pummelo is a species of monoembryonic and cross-pollinated. It was introduced into the Caribbean during the discovery period of the New World, where it is named shaddock and it is a commercially important cultivar of the citrus genus, belongs to the family Rutaceae which is widely cultivated around the world. Vegetables and fruits are rich in numerous bioactive compounds which have shown many applications in human well-being. The peels of citrus are a rich source of essential oil, nutrients and phenolic compounds. As they are produced in large amounts during fruit processing, these residues can be used as a nutraceutical resource instead of disposal as the wastes in the environment. In plants the most represented compound was limonene. Other predominant compounds detected are Linalool (9.4%), myrcene (3.5%), -pinene (1.2%), n-octanal (1.1%), and -terpineol (1.2%) were the volatile oils found in *C. sinensis* peel. According to data released from FAO (2019 -Food and Agriculture Organization of United Nations), the worldwide production of pummelo is about 9.3 million metric tons. China and the United States are the leading pummelo producers around the world, with approximately of 5 and half million metric tons, respectively. According to the FAO Statistical bulletin, in 2020 the entire production of Citrus fruits over the world exceeded 70,000 tons, whereas, the transformed products utilized for jam preparation, as a food supplement ingredient or its utilization for liquors obtained by cold extraction. The Phytochemicals including polyphenols found in plant materials have gained interest due to their scavenging activity and antioxidant properties responsible for anti-inflammatory, anticarcinogenic, and vasodilatory effects, which are just a few of their many health beneficial effects. The pollution and environmental issues created by agriculture and food wastes are an important and emerging concern. The creation of bioactive by-products and secondary metabolites, on the other hand, is a new area of agri-food waste management.

Among these, the essential oils isolated from food wastes can have significant economic value. Essential oils are vital plant-derived chemicals with powerful biological properties that can be used in agriculture, medicine, and biotechnology. The Citrus peel used in cattle feed, pectin's, softdrinks etc. Recently, the utilization of citrus waste for the development of nanoparticles of iron as well as silver having cytotoxicity (mainly effective).



2. Materials and Methods

Table 1: Applications of citrus peel waste in food and non-food sector

Food applications of citrus peels

S. No.	Applications	Specific Role	Findings	Reference
1	Additive in food products	Development of dietary fiber-rich muffins Preparation of nutrient-rich biscuits Fat replacer in preparation of brioches-a bakery product	Muffins prepared by incorporating 15% dietary fiber from *Citrus sinensis* (orange) bagasse resulted in declined predicted glycemic index. 6% incorporation of *Citrus reticulata* peel powder showed improved nutritional and antioxidant potential. 50% incorporation of debittered *Citrus sinensis* fiber exhibited good fat replacer properties in preparation of brioches- a bakery product	(Romero-Lopez *et al*., 2011) [22] (Ojha & Thapa, 2017) [23]
2	Storehouse of bioactive compounds Polyphenols	Polyphenols Carotenoids Pectin	Phenols extracted from *Citrus inshiu* peels through microwave-assisted extraction exhibited high hesperidin (5860 mg/100 g extract) and narirutin (1310 mg/100 g extract) content. Sequential microwave-assisted solvent extraction of bioactives from Kinnow (*Citrus reticulata*) peels showed higher extract yield (30.743%), total phenolics (88.404 mg GAE/g), total flavonoids, DPPH radical inhibition ABTS radical inhibition (86.173%), total carotenoids (49.533 mg BET/g) and ascorbic acid (119.712 mg AA/g) content. *Citrus* × *clementina* peels exhibited high hesperidin content. Carotenoids extracted from citrus peel by high voltage electric discharge showed improved bio-accessibility with an increase in the energy. Pectin extracted from *Citrus sinensis* peels through surfactant-based microwave-assisted extraction showed a high yield (28%) at 400 W power, 7minand 1.2 pH.	(Inoue, Tsubaki, Ogawa, Onishi & Azuma, 2010) [24] (Yousuf, 2019) [25] (Gomez-Mejia *et al*., 2019) [26] (Buniowska, Carbonell-Capella, Zulueta, Frigola & Esteve, 2015) [27] (Su *et al*., 2019) [28]
3	Prebiotic	Prebiotic activity of citrus pectic oligosaccharides	The developed product showed greater prebiotic effects because of the improved antimicrobial and modulating-microbiota properties.	
4	Encapsulating agent	Resveratrol loaded citrus pectin/zein nanoparticle as an oral delivery agent	Nanoparticles enriched with resveratrol obtained from citrus peel pectin and zein showed good heat (80 °C for an hour) and pH (2–7) stability.	(Huang *et al*., 2019) [29]

Non-Food applications of citrus peel

1	Bio-adsorbent	*Citrus limetta* peels based FeCl3-impregnated activated carbon adsorbent	Removal of heavy metals such as fluoride ions from wastewater	
2	Source of biofuels	Bio-ethanol Production	Mandarin peel waste led to the production of ethanol through pre-treatment with steam explosion, enzymatic hydrolysis and fermentation with Saccharomyces cerevisiae.	(Boluda-Aguilar *et al*., 2010) [30]
3	Packaging material	As an edible packaging material	Development of edible coating for fresh strawberries from *Citrus limon* and *Citrus aurantifolia* peels.	(Munoz-Labrador *et al*., 2018) [10]

2.1 Pummelo Marmalade

By using a sharp vegetable peeler or paring knife, cut the thin outer layer of pomelo (*Citrus grandis* (L.) Osbeck) peel (without any white pith) into 1- to 2-inch wide strips. take the strips and cut them crosswise into very thin slices; it should have about quadruple of the cup. Mix the peel and enough cold water to cover by inch in a heavy saucepan and bring to a full boil over medium-high heat. Take out the peel from heat and pour off all of the water. By Using a sharp knife cut off the top and the bottom of the fruit so it will sit flat on the cutting board. Starting where you see the pummelo separate from the white pith, cut away one section of pith, following the line of the fruit. It will expose the underlying fruit. Just Continue cutting away sections of the pith until only fruit remains. When it's done, go back over the fruit, removing any traces of pith. Take over a bowl, separate each segment; it should have about one and half cups pulp. Strain the pummelos, reserving the juice. Peel the pith and separate the pulp from the membrane; then discard the pith and membrane. Later Strain the pulp, preserve the juice. Add enough additional pummelo, orange or grapefruit juice to the strained juice to measure 1 cup. The juice should be add, along with the pulp and cardamom pods to the peel. Bring the mixture to a simmer heat. Then Continue cooking, stirring frequently, until the pulp separates into mini pieces and the mixture is reduced to one quadruple of the cup for, about 20 minutes. Mix in the sugar and continue cooking, stirring frequently until the marmalade thickens slightly and is reduced to 2 1/4 cups, 10 to 15 minutes. Shift the marmalade into jars and cool completely. Tightly Seal the jars and refrigerate up to 2 months or can following canning instructions.

2.2 Pummelo Tea

Remove the pummelo skin from the flesh of the fruit. The great way to have the skin would be something similar to this. Keep aside 3/4 segments of the fruit to use later, while the rest you can eat at your pleasure. Then prepare a pot of water with about two tablespoons of salt and add boiling water. Later add a little cool water to lower the temperature of the water. Once water has cooled down to about 70 degrees Celsius, drop the pummelo skin to soak in the water making sure that the skin is covered. Soak for few hours or overnight. Mainly this is to remove the waxy layer of the skin and lower the bitterness. Bring some ordinary salt and scrub the skin of the pomelo, then remove from the salt water. Wash the skin as thoroughly as possible. The more you scrub the skin, the less bitter the final tea will taste. Dry the skin and carefully with a knife, remove as much of the thick white part of the skin away from the outer yellow/green layer. The width should be of five mm thick. Chop the skin into thin strips of about 3mm thick and however long you can get them to be. Place the sliced strips into a cooking pot. Water should be add so it covers the content of the pot over 3 cm. Boil the mixture a few times whilst stirring. Drain away the hot water and rinse the skin with cool water. Break the flesh and mix into the pot. Squeeze the juice of a lemon or lime into the mixture just to add more flavour. Later, add as much or little honey and brown sugar as you would like. It is better to add somehow less now and more later if required. The mixture should be covered with 5 cm of water. Heat the mixture and bring to a boil about five times. During intervals continue to stir the mixture. Add required amount of water to cover mixture. Let simmer the mixture for about ½ hour on a medium heat with a half cover. Carefully taste the mixture to see with less water. Mainly, the mixture should become a little thicker and syrupy like this continue to watch over the mixture and mix on a low heat, occasionally adding small amounts of water. In required hours the "tea" mixture should be complete. Later cool it down and then transfer it to a container. To make the tea, add a tablespoon of the mixture to a cup/mug/teapot, fill with boiling water, mix, and enjoy. The tea mixture can be kept in the fridge for about one- two weeks, but make sure you check it to see/smell if it is ok to consume. A perfect summer or winter drink that has tremendous health benefits and costs very little to make.

2.3 Wholemeal of pummelo peels

The wholemeal of pummelo peels was made from dry debitterized pummelo peels by various micronization techniques. The dietary fiber was the major component of pummelo peel wholemeal accounting for approximate 70% (w/w, db.). Thus, it was commonly used as an ingredient to make high-dietary-fiber foods. The pummelo peel wholemeal was characterized with excellent water- and oil-holding capacities and swelling capacity (Wang *et al.*). When pomelo peel wholemeal was incorporated below 10%, the rice noodles presented significantly higher cooking weight (136% ~ 166%) in contrast to the control sample (125%). Regardless of its level of integration, the pomelo peel wholemeal reduced the elongation of the noodles (Wandee *et al*., 2014) [1]. More interestingly, a health beneficial rice noodles with a total dietary fiber content of 14.4% (w/w) was successfully developed by adding the mixture of cassava pulp and pummelo peel wholemeal (80%:20%, w/w). In contrast to the control noodles, the obtained rice noodles displayed a higher cooking weight and comparable tensile stress and elongation. Similar trends were observed on fresh wheat noodles. When pummelo peel wholemeal was enriched into bread, the product hardness, chewiness, elasticity and adhesiveness increased with the wholemeal addition and the optimal addition was concluded as 12% (w/w) in terms of the consumer acceptability.

2.4 Wine

Li-Ming and Jin-duo developed a pummelo wine to evaluate the effect of its fermentation process and antioxidant effect. Anjana *et al*. also prepared pummelo wine using *S. cerevisiae* and spontaneous fermentation which had high antioxidant activity.

2.5 Fortified Bread

Reshmi *et al*. developed pummelo enhanced bread using pummelo segments. They reported that supplemented bread with 20% fresh and 5% dry pummelo segment was acceptable to customers. The supplemented brown bread had more bioactive components. They also reported that the naringin of pummelo fruit inhibited digestive enzymes and contributed to a lower glycemic index.

3. Food Applications and Fractionization of functional ingredients from pummelo peels

3.1 Essential oils

Essential oils are the volatile compounds, generally found in oil sacs of cuticle and citrus peels. It is extracted from citrus peels is used as fragrances and flavors. Nevertheless, it is worth noting that the citrus peel essential oil yield and

chemical composition vary. Solvent-free microwave extraction technique for extraction of essential oils from *Citrus limon* peel resulted in the recovery of limonene (1.26%) (The supercritical fluid method for oil extraction from *Citrus limon* peels resulted in a higher D-limonene yield (4.5%). In a similar study, super critical CO2 extraction of limonene from mandarin (*Citrus unshiu* Kuno) peel revealed a high limonene yield of 33% at 300 bar pressure while limonene yield of 13.14% was found at 100 bar pressure. So that, the super critical method was observed to be effective for oil extraction, however, the major issue was identified as high equipment cost and maintenance.

3.2 Source of bioactive compounds

Mostly researchers have been working on how to utilize processed fruit waste for green and clean production. The procedures that are taken for sample preparation plus processing are of certain interest to the scientific use. Isolation, and characterization and extraction of bioactive components from the fruit waste are fundamental steps towards the regain of bioactive compounds. Action should be followed to ensure that the bioactive constituents are not destroyed, or distorted during the extraction process. Moreover, the selection of solvent should be based on the nature of bioactive compound being focused. Polar solvents like methanol, ethanol, or ethyl acetate are utilised for the extraction of water-soluble chemicals, whereas dichloromethane or a combination of dichloromethane/ methanol in an equal ratio is used for fat-soluble compounds. Furthermore, the extraction technique used for the recovery of certain bioactive chemicals must be evaluated. To the improved performance, zero usage of organic solvents, lower expenditure of time, energy etc.

A lot of studies have recently been conducted on the comprehensive valorization of citrus peel for the recovery of bioactive components using green extraction methods. Green techniques such as microwave-assisted extraction, ultrasound-assisted extraction, supercritical water/CO_2 extraction, pulsed electric field extraction, pressurised liquid extraction, and high voltage electric discharge are some of the potentially used methods for extracting bioactive compounds from citrus peel waste such as polyphenols, pectin, essential oils, dietary fibres, carotenoids, and so on.

3.3 Polyphenol

In different varieties of citrus fruits polyphenols are found. The principal phenolic components found in citrus peels are flavonoids, which include flavonols, flavonones, flavones, isoflavones, and anthocyanidins. Carry out the extraction of phenols from citrus peel, where ultrasound-assisted extraction exhibited a maximum yield of 26.52% which was found to be 1.77 times higher as compared to microwave-assisted extraction. Polyphenols were extracted from kinnow mandarin (*Citrus reticulata*) and mousambi (*Citrus limetta*) peels using maceration and ultrasound-assisted extraction, with the ultrasound-assisted extraction approach outperforming the maceration method. Extraction yield obtained through ultrasound-assisted extraction of kinnow mandarin and mousambi was 5.85% and 12.95%, respectively while 5.20% and 12.20% yield of the same was achieved through maceration technique. In another study, utilized a combination of solid-liquid extraction involving ethanol aqueous solution, CLC-DAD, and chemometrics for extraction as well as quantification of polyphenols from *Citrus sinensis* L. Osbeck, *Citrus lemon* L. and *Citrus* × *clementina* peels, where high quantities of hesperidin (ranging from 280 to 673 mg/g) was observed in citrus peel extract.

Additionally, super critical CO_2 extraction was employed for the extraction of polyphenols from citrus peel, where hesperidin (0.16 to 15.07 mg/g) was abundantly found in citrus peel waste. However, 5-hydroxymethylfurfural (5-HMF) and chlorogenic acid were also detected at high temperature Extraction of polyphenols from three hybrid cultivars of mandarin (Clemenvilla, Ortanique, and Nadorcott) by using ultrasound-assisted extraction technique at power (400 W), temperature (40 °C), and duty cycle (80%) was examined. Ultrasound extraction for shorter times (between 5 and 15 minutes) improved the physicochemical profile, bioactive component content, and antioxidant activity of mandarin peel extracts. This demonstrates that ultrasonic technology is an effective and long-lasting extraction method.

3.4 Pectin

Citrus peel pectin is a gelling agent used in the food industry to produce jellies and jams. Mostly, the world's commercial pectin is made from citrus peel waste. The pectin can be fresh peels of citrus fruits *viz*, lemon, grapefruit, and orange or washed plus dried peels. Fresh citrus peels contain 1-3% pectin, and dried peels contain 9%-19% pectin. Scientists passionately worked on extracting pectin from citrus peel by non-traditional techniques. Extraction of pectin from microwave peels of *Citrullus lanatus* at varying microwave power, liquid-solid ratio, and irradiation time (60–180 s) was conducted, where the pectin yield of 25.79% was realized at power (477 W), time (128 s), and the solid-liquid ratio (1:20) has been utilized in the past. Moreover, pectin extracted from *Citrus sinensis* peels through surfactant microwave-assisted extraction showed a pectin yield of 28% at power, time, and pH. The pectin yield from sequential microwave-assisted solvent extraction of mandarin (Kinnow) peel was (27.58%). Furthermore, the pectin derived from citrus peel can be used to manufacture jams.

4. Conversion of pummelo peels into adsorbents, biofuels and others

4.1 Pharma drug

Apart from serving as a culinary additive, colourant, bioactive ingredient, or encapsulating agent, citrus peels also serve a use in the pharmaceutical business. The presence of bioactive components makes it a suitable ingredient for the formulation of medicine. Several researchers described the health-promoting effect of citrus peels, for example, anti-microbial, anti-aging, hepato-protective, immunosuppressive, and cardio-protective effects.

Essential oil obtained from Citrus Changshan-huyou Y.B. Chang demonstrated inhibitory activity against planktonic Listeria monocytogenes cells with a minimum inhibitory concentration of 4%, zone of inhibition of 25.8 ± 1.4 mm, and minimum bactericidal concentration of 8%. The anti-biofilm property is exhibited by citrus peel essential oil. The possible use of citrus peel essential oil as an anti-microbial agent in the medical sector. Further research focused on the impact of polymethoxy flavonoid compounds derived from *Citrus sinensis* peel extract in the treatment and management of gastric ulcer in male albino rats. It was discovered that after administering peel extract, the gastrointestinal pH increased

dramatically while the number of lesions, gastric volume, and gastric acid output reduced.

Citrus peel exhibits anti-obesity effects. For example, a study done by examined the anti-obesity activity of aged citrus peels (chenpi) by intervening it in mice for 11 weeks. Intervention led to significant weight loss, inhibition of fat cell enlargement, and accumulation of lipids in adipose tissue probiotic growth, and regulating the configuration of the gut microbiota highlight Citrus peel extract has a strong prebiotic effect.

4.2 Bio-Adsorbents

In recent years, agro-waste has primarily been used as a low-cost bio-adsorbent for heavy metal removal from solutions. Many scientists worked on citrus peel as a green bio-adsorbent for removing heavy metals or harmful chemicals. A low-cost, environmentally friendly activated carbon was prepared from *Citrus limetta* peels through carbonization and alkali chemical activation to remove ranitidine in pharmaceutical wastewater. The study reported major removal of ranitidine at 39 °C temperature, 140 rpm agitation speed at 6 pH, adsorbent dose (200 mg), and adsorbent concentration of 10 ppm. In addition, a FeCl3-impregnated activated carbon adsorbent was developed using *Citrus limetta* peels. The bio-sorbent potential of alkali modified lemon peel on the removal of heavy metals. The study reported 90% sorption of nickel and cadmium in the initial five minutes. Another study looked at the effect of an orange peel-based bio-absorbent and silicon sand on soil filtration by seawater irrigation. As a result, orange peel-based bio-absorbents may be considered the new age low-cost natural bio-absorbent.

4.3 Source of biofuels

Citrus peel waste is also used to produce biofuels such as bioethanol, biodiesel, and biogas. For the bio-conversion of citrus peels into biofuel, various natural processes, such as fermentation and anaerobic digestion, are utilised. For instance, Bioethanol was prepared from mandarin peel utilizing pre-treatment with steam explosion and microbial fermentation. The study stated the ethanol yield of 0.495 g/g and productivity of 4.85 g/Lh. Recently, *Citrus limetta* peels were used as a raw material for bioethanol production by following the acid-catalyzed steam pre-treatment, accompanying enzymatic hydrolysis and fermentation. The study reported an ethanol yield of 64% obtained at pH 4 after 48-hour treatment.

Likewise, Bio diesel can be acquired from citrus peel waste through trans-esterification of essential oil with alcohol. Thus; citrus peel waste can also be utilized as a renewable source of energy.

4.4 Packaging material

Pummelo (*Citrus grandis*) peel flour and tea polyphenols were exploited for developing bioactive edible packaging film by casting method. The study reported that pummelo peel and tea polyphenol-based composite packaging material having a 10% concentration of tea polyphenol proved to be a good moisture barrier, and have effective anti-microbial, antioxidant and mechanical effects. It could also be a green alternative for the packaging. Lately, a blend of blood orange peel pectin and was used for the preparation of the edible film. An edible film comprising of 50% of orange peel pectin and 50% of fish gelatin exhibited high tensile strength, antioxidant and antimicrobial activities. The edible film that is prepared was also used for wrapping method and the study showed improved physicochemical, textural, and microbial stability of the cheese (ricotta) wrapped in blended edible film.

5. Pummelo as a Nutraceutical

Many biologically active phytochemicals have been extracted from pummelo and tested for their nutraceutical effects.

5.1 Anticancer Property

The outer peel of pummelo is rich in flavonoids. Flavonoid plays an important role in preventing breast cancer by eliminating extra estrogen. Recently, evidence for antitumor effects of pummelo peel was reported in an *in vivo* study. In this study, female Kunming mice were subcutaneously injected with S180 tumour cells and given pummelo peel-derived polysaccharides orally. Oral administration of polysaccharides to tumor cell– transplanted mice suppressed tumor cell growth.

5.2 Antidepressant Property

The ethanolic leaf extract of pummelo was reported to have anti-depressant activity. The Forced Swim Test and Tail Suspension Test were used in the investigation on numerous animal depression models. The findings revealed that pummelo extract's antidepressant action was mediated by inhibition of norepinephrine uptake, which resulted in an increase in norepinephrine levels in synapses.

5.3 Prevent Cancer

The rind of pummelo is rich in bioflavonoid. Pummelo rind is commonly used in Chinese cooking to add flavor to dishes. Plant extracts' anticancer properties were also investigated using the HeLa cell line. The results of *C. maxima* leaf and fruit peel extracts may be useful in developing Nutraceutical products for cancer prevention.

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