The Pharma Innovation Journal 2022; 11(7): 3489-3497

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(7): 3489-3497

www.thepharmajournal.com
Received: 12-05-2022
Accepted: 13-06-2022

Monika
Department of food science and nutrition Lovely Professional University, Phagwara, Punjab, India

Lagna Choudhury
Department of food science and nutrition Lovely Professional University, Phagwara, Punjab, India

Corresponding Author:
Lagna Choudhury
Department of food science and nutrition Lovely Professional University, Phagwara, Punjab, India

Current applications of citrus and its underutilized parts: A review

Monika and Lagna choudhury

Abstract
Citrus fruits have a history of having medicinal and therapeutic value because they contain a wealth of bioactive components. Fruit processing produces significant volumes of waste that are either given to animals or dumped, adding to the environmental burden. The waste poses a major threat to the environment in terms of land and water pollution, aesthetic nuisance, and the spread of illness because of its high content of fermentable carbohydrates. However, waste is created, primarily in the form of peel, seeds, wastewater, and pomace. This leftover waste from processing causes environmental contamination and health risks. Citrus wastes contain starch, cellulose and hemicellulose fibres, ash, pectin, fat, and protein, as well as various bioactive chemicals that have potential uses as food additives, encapsulants, nanoparticles, prebiotics, pectin sources, essential oils, health beverages, packaging material, cosmetics, and pharmaceuticals. Citrus waste can be used in both food and non-food sector. In light of the significance and health advantages of bioactive chemicals discovered in citrus waste, the current review discusses recent work on citrus fruit waste valorization for recovery of value- added compounds, leading to zero wastage.

Keywords: Citrus, flavonoids, phytochemicals, nutraceutical, dietary fibre

Introduction

Citrus fruits, which are members of the Rutaceae family, are among the most widely grown fruits in the entire globe. Citrus is thought to have originated in the warm southern Himalayan slopes of north-eastern India and northern Myanmar. Some scholars believe that the Yunnan province of China is where some citrus species first appeared (Gmitter *et al*.,1990; Liu *et al*.,2012) [10, 11]. These fruits grown for commercial purposes include the orange (Citrus sinensis), mandarin (Citrus reticulate), lemon (Citrus limon), lime (Citrus aurantiifolia), and grapefruit (Citrus paradisi) (Rashid *et al*., 2013) [1]. One of the most significant and nutritious fruits that are produced and eaten globally is citrus fruit. These fruits are popular because of their delicious flavour, pleasant aroma, and nutritional benefits. The main producers of citrus are Brazil, China, the United States, Mexico, India, and Spain (Karoui and Marzouk 2013; Marti *et al*. 2009) [6]. Around the world, tropical and subtropical regions produce more than 120 million tonnes of citrus fruit each year (Mahato *et al*.,2021) [17].

In 2020, the world produced approximately 158.49 million MT of citrus fruit, with Asia producing the greatest proportion (43.7%), followed by Africa (43.7%), America (8.1%), Europe (0.4%), and Oceania (0.1%). Mandarin production is at its highest level in China, while grapefruit production is at its highest level in the United States. Additionally, the European Union is a significant producer of sweet oranges, lemons, and mandarins whereas, Mexico is the fifth-largest producer of oranges (Kimball *et al*.,2012). Future increases in output of all four varieties of citrus (lemons, oranges, tangerines/mandarins, and grapefruits) are anticipated as a result of scientifically enhanced cultivation, management practises, improved phytosanitary conditions, and favourable weather.

Citrus fruits were once solely traded and eaten as fresh fruits, However, citrus fruit industrialisation has become inescapable because of the ongoing expansion of plantation area and crop size. These fruits are used in the production of essential oil extraction facilities as well as industries that make jams, jellies, and marmalades. In the canning industry, citrus fruits are further processed to make marmalade, mandarin segments, and to recover bioactive essential oils and flavonoid compounds (Izquierdo *et al*.,2003) [8]. Citrus fruit consumption and interest are growing, and trash generation is also increasing, adding to the environmental load.

Between 40 and 60% of the fruit is inedible and is discarded. The amount of residue collected from the fruit's accounts for about 50% of the original whole fruit mass, and the amount of industrial citrus waste is projected to be over 40 million tonnes worldwide (Marín *et al*.,2007) [12]. This waste biomass consists of seeds, peels, pulp, and pith residues. Citrus processing wastes are high in moisture (between 75 and 85 percent), making them difficult to dry. Citrus peels that are about 80% water decay quickly, attracting bugs, bacteria, mildew, and other poisons. Peels, leftover pulp, and seeds are all included in this waste biomass. Citrus peel waste has a low pH and large quantities of organic compounds. The existence of essential oils, which have antibacterial capabilities, is the main challenge for biological management alternatives (Zema *et al*.,20) [70]. Large amounts of fermentable sugars are present in the pulp and pith waste, which prevents appropriate fermentation processes.

Citrus pulp is extremely perishable because it includes high amounts of water and soluble carbohydrates. Citrus wastes have a high rate of fermentability as a result, which creates numerous issues for the economy and the environment (Laufenberg *et al*.,2003; Montgomery *et al*.,2004) [13, 14]. These fruits have a high-water content, making it difficult to dry them using standard methods or commercial drying equipment. Fruit processing produces a variety of wastes, including solid, liquid, and distillery effluents. In fact, typical citrus waste disposal methods (such as landfilling) are currently inadequate and troublesome in terms of their effects on the environment and energy efficiency (Satari and Karimi, 2018; Mao *et al*., 2019) [65]. Citrus waste disposal may contaminate the soil and water sources. The waste also contains large amounts of simple carbohydrates which include glucose, fructose, complex carbohydrates such as dietary fibre, starch, pectin), protein, organic acids (citrus, malic, oxalic acids), lipids (linolenic, oleic, palmitic, stearic acids), peel oil (D-limonene), carotenoids (carotene, Xanthophyll, and lutein), water-soluble vitamins (Vitamin C and B-complex vitamins), minerals (calcium and potassium), and (Boukroufa *et al*., 2015) [15].

Several uses of the residues from the citrus processing industry have been studied in recent decades to reduce management costs and prevent environmental harm. The practicality of each approach for handling citrus waste or valorising it depends on a number of different criteria. On the other hand, citrus fruit waste, such as peels (flavedo and albedo), seeds, and pomace, is seen as a possible bio-resource material for a variety of uses. Citrus processing wastes have many health advantages and can be used to create designer foods due to the bioactive substances they contain. Fruit waste, including the peels, seeds, and pomace, is rich in valuable chemicals and is considered a powerful bio-resource material for use in both food and non-food industries (Suri *et al*.,2022) [18]. Waste contains naturally occurring bioactive substances that can be employed as food additives, encapsulants, nanoparticles, prebiotics, pectin sources, essential oils, polyphenols, carotenes, or dietary fibre. Additionally, waste derived from citrus processing industry can be employed as a natural ingredient in packaging, pharmaceuticals, cosmetics, and synthetic fuels. Using citrus trash for bio-absorbents, biofertilizers, biodiesel, biogas, and bioethanol are some further non-food uses. There are numerous artificial additives that have been discovered to cause allergies and cancer, including colourants, preservatives and perfumes. These synthetic compounds, especially when employed as food and cosmetic additives, are now recognised for promoting itchiness, carcinogenicity, mutagenicity, and various other adverse reactions in both foods and cosmetics (Joshi and Pawal, 2015; Suzuki, 2010) [16, 17].

The pharmacological potentials of fixed oils extracted from various herbs, plants, and seeds have received more attention recently, especially from academia and industry, in an effort to determine their multifunctional applicability, including their traditional roles as food and cosmetic substrates or additives. Citrus trash has a variety of uses and can be put to use in a number of different ways.

Peels, pulp, pomace, and seeds from citrus fruit are considered citrus waste. These materials contain a variety of bioactive phytochemicals, including pectin, essential oils, polyphenolic-flavonoids, carotenoids, dietary fibre, limonoids, organic acids, and vitamins (Di Donna *et al*., 2020) [19]. These bioactive components derived from the citrus waste could be isolated and used to make nutraceuticals and functional foods (Zhu *et al*., 2020). [20] Citrus trash is also used to make some biofuels like bioethanol, animal feed, and compost (Bernal-Vicente *et al*.,2008; Casquete *et al*., 2015) [21, 22]. Citrus peel is used in the food, beverage, fragrance, medicine, and cosmetic industries as a strong source of phytochemicals.

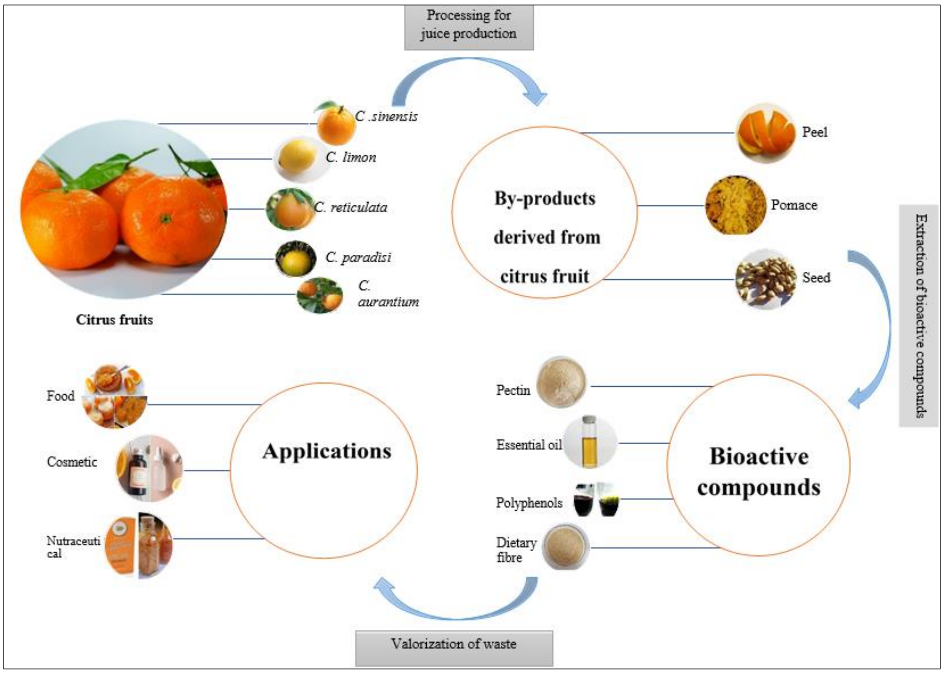

Fig 1: Application of Underutilized parts of citrus in various industries

Nutrition composition of whole citrus fruit

Citrus is a fruit that promotes good health because it contains polyphenols, vitamins, minerals, dietary fibres, essential oils, and carotenoids, all of which have been identified in a number of studies. It was also believed that citrus fruits were a good source of numerous natural chemicals, auraptene, bergamottin, imperatorin, oxypeucedanin, and numerous additional prenyloxycoumarins that have been identified from citrus juice and peel extracts (Epifano *et al*.,2013; Genovese *et al*.,2014) [28, 29]. Citrus species from various origins have been assessed for their contribution to health promotion and their phytochemical composition (Proteggente *et al*., 2003; Gorinstein *et al*., 2004; Anagnostopoulou *et al*., 2006) [30, 31]

The main waste is citrus peel, which is a valuable source of molasses, pectin, and limonene. In tangerine peel, hesperidin was shown to be the most prevalent flavonoid, followed by tangeretin and nobiletin. Citrus peel, which is made up of white, spongy, and cellulosic tissue, could be thought of as a potential source of pectin (Terpstra *et al*., 2002) [37].

Citrus (Citrus L. from Rutaceae), one of the most widely grown fruit crops in the world, has a variety of active phytochemicals that can promote health. Additionally, it supplies a good amount of potassium, folic acid, pectin, and vitamin C. The primary examples of terpenoids are carotenoids and limonoids, whereas the primary examples of phenolic chemicals found in citrus fruits are flavonoids (naringenin, naringin, hesperidin, quercetin, and rutin), phenolic acids, and coumarins.

Ascorbic acid content

Ascorbic acid, often known as vitamin C, is one of the most crucial vitamins and is necessary for both human and animal existence, and it is in abundance in citrus fruits as mentioned in table (1). This water- soluble vitamin aids in the healing of wounds, helps prevent cancer and scurvy, relieves the symptoms of the common cold, and stimulates the production of collagen (Iqbal *et al*., 2004). Pomelo typically has 61.29 mg/100 ml of ascorbic acid, while citron typically contains 17.4 mg/100 ml. Ascorbic acid is reported to have an average concentration of about 34.8 mg per 100 ml in lemon, 29.89 mg per 100 ml in bitter orange, 39.80 mg per 100 ml in grapefruit, and 25.11 mg per 100 ml in sweet orange, respectively.

Table 1: Ascorbic acid content of citrus peel

	Najwa *et al*.,2015 [39]	**Shrestha *et al*.,2015 [40]**	**Reda *et al*.,2016 [41]**	**Czech *et al*.,2021 [42]**
Ascorbic acid	58.30±0.53	25.88±1.46	68±0.012	42.50±3.66

Mineral content in citrus fruit

Citrus peels were regarded as sources of minerals because of the fruit's high quantities of potassium, calcium, and magnesium as mentioned in table 2 Fruits like citrus are a great source of potassium. One glass of orange juice is considered to provide 10% of the daily recommended intake (DRI), compared to one orange, which is thought to provide 6% of the DRI (Baghurst *et al*.,2003) [47]. Citrus fruit peels exhibited a higher concentration of this element than the pulp, similar to calcium, but only lemon and red grapefruit showed statistical significance (the difference between the peel and the pulp was about 32 percent). The magnesium concentration of the various fruit components. The peel of some fruits, such as oranges, pomelo, lemons, and red and white grapefruit, contained significantly more of this macronutrient than the pulp. Iron predominates as a micronutrient in both the citrus fruits' pulp and peel. Zinc level was much higher in the peel of orange, lemon, and all grapefruit varieties than in the pulp (Gorinstein *et al*.,2001) [48]. Citrus fruits have substantially less manganese present. Except for lemon, zinc is substantially less common in the flesh of citrus fruits than it was in the peel.

Table 2: Mineral composition of citrus peel

	Minerals	**Barros *et al*.,2012 [43]**	**Ani *et al*.,2018 [44]**	**Rehman *et al*.,2019 [44]**	**Tiencheu *et al*.,2021 [46]**
Macro-minerals	K	140±2.2	1.30±0.06	141±3.2	0.23±0.08
	Na	2.0±0.1	46.12±1.46	2.55±0.09	0.08±0.03
	Ca	1.87±0.1	132.7±2.38	-	0.21±0.05
	Mg	10.3±0.1	1.88±0.05	10.3±0.1	0.07±0.01
	P	-	38.96±3.44	-	0.12±0.02
Micro-minerals	Fe	171.0±6.6	2.12±0.17	0.25±0.005	0.06±0.01
	Zn	91.3±2.9	-	0.066±0.003	0.01±0.00
	Mn	45.4±0.6	-	0.055±0.002	-

Organic acid

The flavour and customer acceptance of citrus fruit beverages are significantly influenced by the citrus organic acid as well as sugars. Citric, malic, oxalic, and ascorbic acids are the principal organic acids (as shown in table 3) present in citrus fruits, which plays and important role in various ways.

Table 3: Organic acid content of citrus peel

Organic acid	**Nile *et al*., 2017 [50]**	**Randhawa *et al*.,2014 [51]**	**Violeta *et al*.,2010 [52]**
Citric acid	15.2±0.65	925.9±37.03	13.918
Malic acid	2.2±0.24	519.62±20.78	0.336
Ascorbic acid	0.80±0.12	51.43±2.06	0.636
Oxalic acid	17.7±1.11	-	0.109

Table 4: Sugar content of citrus peel

Sugar	Nile *et al.*,2017 [50]	Czech *et al.*,2021 [42]	J. Zhang *et al.*,2022
Sucrose	62.50±1.6	1.52±0.060	53.39±1.88
Glucose	35.65±1.2	0.264±0.031	26.29±0.81
Fructose	30.46±1.1	5.52±0.801	23.14±0.41

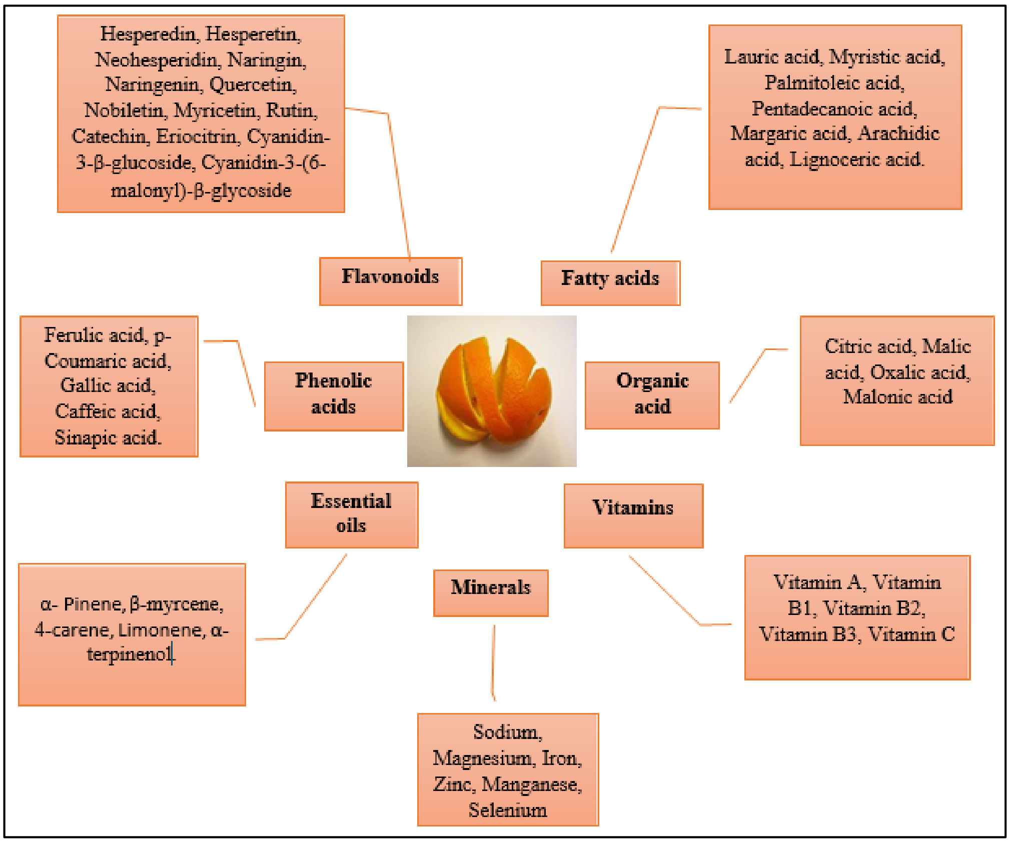

Fig 2: Bioactive compounds present in citrus peel

Strategies for valorization of unutilized parts of citrus fruits: Citrus waste has rich functional components, so researchers are using it in a variety of useful ways to reduce environmental harm from incorrect waste disposal and growing concern about waste valorization. Waste from citrus is also used to produce some biofuels like bioethanol, animal feed, and compost (Bernal-Vicente, Ros, Tittarelli, In-trigliolo & Pascual, 2008; Casquete *et al.*, 2015) [21, 22]. Different citrus waste applications in the food and non-food sectors have been proposed. Citrus waste is a natural resource which can be used to produce a variety of vital goods, including biofuel, bioethanol, biogas, biooil, natural acids, enzymes, etc. Currently, citrus peels can be found on many people's dinner tables (Ademosun *et al*., 2018) [86]. Research is still being done to identify further therapeutic applications for citrus peels as well as how the peels affect food products and consumer acceptance. Below is a list of many non-food products that citrus waste bioprocessing can produce.

Non- food sector Pharma/drug

Citrus peels are used in the pharmaceutical industry. It is a suitable ingredient for the creation of medicines due to the presence of bioactive components. Citrus peel contains flavonoids in addition to the essential oils. In particular, polymethoxylated flavonoids like nobiletin and tangeretin have been shown to have a variety of pharmacological actions against cancer, oxidative stress, and inflammation (Manthey *et al*., 2001; Tripoli *et al*.,2007) [33, 56]. It was shown that when peel extract was administered, the number of lesions, gastrointestinal volume, and gastric acid output all decreased while the gastric pH increased noticeably (Aboul Naser *et al*.,2020) [57]. The study recommended using citrus peel essential oil as a potential anti-microbial agent or preservative in the pharmaceutical industry (Liu *et al*., 2021) [58].

Packaging material

A new field of study is using leftover citrus peel to create biodegradable packaging materials. An edible film with good tensile strength, antioxidant, and antibacterial properties was made up of 50% orange peel pectin and 50% fish gelatin. The study demonstrated the increased physicochemical, textural, and microbiological stability of the cheese (ricotta) wrapped in blended edible film. The created edible film was also employed for covering cheese by the method of wrapping (Jridi *et al*.,2020) [59]. Peels from citrus limon and citrus aurantifolia were used to create an edible coating for fresh strawberries (Muñoz-Labrador *et al*.,2018) [60].

Skin care products

Agroindustrial waste is now used as an active ingredient in skincare products since it is a rich source of bioactive chemicals, antioxidants, vitamins (vitamin C, vitamin E), and polyphenolic compounds (Pinto *et al*.,2021) [61]. One such agricultural waste that is widely used in the beauty sector is citrus peel waste. The antioxidants found in citrus peel assist in delay aging of skin and reduce oxidative damage as well as skin-related problems like acne, wrinkles, dark spots, and other skin-related concerns. Nevertheless, citrus wastes are similarly being investigated for the creation of beauty care products that brighten the skin (Sharma *et al*., 2017) [3].

Utilizing citrus seed oil, which is a naturally occurring resource, can reduce exposure to synthetic chemicals while also improving seed waste utilisation. Citrus seeds are economically used in the cosmetic sector as a rich source of natural oil for the preparation of soaps, body lotions, and other cosmetic goods (Rosa *et al*., 2019) [63].

Bio-fuel

Biofuels are both gaseous and liquid fuels made from agricultural waste or biomass. Studies have shown the value of anaerobic digestion combined with fermentation for the production of biofuels using orange peel waste. For instance, bioethanol was produced from mandarin peel by microbial fermentation and pretreatment of the peel with steam explosion (Brethauer *et al*.,2010) [65]. Citrus peel waste is a good biofuel substrate because of the availability of carbohydrates and the low lignin content (Satari *et al*.,2018) [65]. Citrus seed oil is another potential source of biofuel. Additionally, the trans-esterification method was used to create biodiesel from the seeds of Citrus sinensis, with a yield of 76.93 percent noted (Ezekoye *et al*.,2019) [66]. The use of seed oil as a component in the production of biofuels has recently gained attention, and several researchers are working on it.

Bioethanol

A renewable source of biofuel is bioethanol. When ignited, bioethanol generates a high level of thermal efficiency and power. Liquid ethanol is frequently used as a fuel for vehicles (Demirbas *et al*.,2008) [67]. With the world's crude oil reserves declining, numerous governments are shifting their attention to renewable energy sources. Peels from citrus fruits like lemons, mandarins, oranges, and grapefruits have been used to produce bioethanol (Boluda-Aguilar *et al*.,2013; Wilkins *et al*.,2007) [68, 69].

Bio gas

Methane and carbon dioxide from the anaerobic decomposition of organic molecules make up the majority of biogas (Zema *et al*.,2018) [70]. Additionally, it also has lower amounts of hydrogen, oxygen, nitrogen, and hydrogen sulfite. Citrus waste, which has a high mineral content and is useful for increasing methane yield, can be used to make biogas. Utilizing agro-waste, such as citrus waste, which has a high mineral content and is favourable for increasing methane output, could produce biogas (Bożym *et al*., 2015) [84]. Citrus waste is also enhanced with minerals including zinc, magnesium, iron, cobalt, and nickel that are good for the health of methanogenic microorganisms (Martín *et al*.,2010) [71].

Bio-diesel

Bio-diesel is a class of non-toxic, biodegradable fuel that can be obtained from unrenewable sources and is a good alternative to petrol and diesel. Citrus seeds and peel waste can also be converted into biodiesel by trans esterifying essential oils with alcohol l (Taghizadeh-Alisaraei *et al*., 2017) [82]. Citrus reticulate (mandarin) seeds were used by Rashid *et al*. (2013) [1] in a methanol-based, alkali-catalyzed trans-esterification process to produce biodiesel.

Bio-Adsorbents

Compounds called bio-adsorbents are used to speed up the elimination of heavy metals. Numerous studies focused on using orange peel as a green source of bio-adsorbent for removing hazardous or heavy metals (Akkaya *et al*.,2020; Bhattacharyya *et al*.,2019) [72]. The bio- sorbent capacity of alkali-modified lemon peel was investigated by Villen-Guzman *et al*., 2021 [74] to remove the heavy metals nickel and cadmium from industrial effluents, according to the study, nickel and cadmium sorption reached 90% in the first five minutes. Citrus peel- based bio-absorbents may therefore be considered a modern low-cost natural bio-absorbent. Additionally, citrus pomace pectin is used to make porous carbon adsorbents for the removal of metals and organic dyes from industrial waste.

Bio-Fertilizer

Utilizing citrus waste as a bio-fertilizer to increase the soil's fertility is another use for the waste. Citrus waste-based biofertilizer has powerful antibacterial characteristics and removes harmful heavy metals from soil because of its high pH and lignocellulose content (Zema *et al*.,2018) [70].

Material for 3D printing

Similar to other organic celluloses, the cellulose, hemicelluloses, pectin, and proteins found in citrus peels have great tensile strength because of the high molecular weight chain length of cellulose as well as strong heat resistance because of its crystalline form (Mahato *et al*.,2020) [85].

Food sector- Food additive

Food additives are compounds that give a food product its flavour, colour, texture, and nutritional properties. Citrus rind and peel are frequently used as food additives in the creation of candied items for the confectionary and bakery sectors due to their distinctive flavour, colour, and nutritional value. In order to make bread, wheat flour was combined with fibre (2.50%) and citrus peel pectin (0.23%). Citrus peel fibre was said to improve water absorption by 6.5 % in the farinograph, 6.4 % in the mixolab, 7 % in the mixograph, and 10% in baking, according to dough rheology (Miller *et al*., 2011) [75]. In addition, 3, 6, and 9 percent of the wheat flour in biscuits was replaced by mandarin peel powder. Compared to the control biscuits with no substitution, the ones containing 6% peel powder had higher levels of fibre (0.85 %), ash %), ascorbic acid (1.5 mg/100 g), carotenoids (69 g gallic acid equivalents/g), polyphenol (2150 g gallic acid equivalents/g), and antioxidant activity (24.5%) (Ojha *et al*.,2017) [76]. The employment of peel pectin as a thickening, stabilising, emulsifier, and gelling agent in the creation of fruit jams, jellies, as well as low-fat or sugar goods, is another prominent usage of citrus peel in food applications (Sharma *et al*., 2017) [3].

Citrus seed waste can also be used to make value-added products and food applications due to its high protein, mineral, and fibre content. Citrus seed flour is used as a food additive in the creation of pancakes, doughnuts, and muffins due to its outstanding oil holding capacity.

Prebiotic

Citrus peel pectin has powerful prebiotic benefits. The potential use of orange peel waste in the creation of functional prebiotic foods with enhanced bio-functionality has been revealed by a number of recent studies. Citrus peels include naringin and hesperidine, which have been demonstrated in *in vitro* experiments and clinical trials to show prebiotic properties by favourably influencing the growth of beneficial microbes and hindering the growth of pathogenic ones (Lima *et al*.,2019; Fidélix *et al*.,2020) [92, 93]. Oligosaccharides made of citrus pectin seem to be a dynamic prebiotic component (Foti *et al*., 2021) [77]. Another study by Foti *et al*. (2021) [77] recommended using orange peel fibre to create oligosaccharides with a high value- added. In comparison to pectin from the commercial market, pectin produced by the enzymatic hydrolysis of orange peel-based fibre was found to have higher prebiotic activity.

Biscuits and cakes

According to Mahmoud *et al*. (2017), adding orange peel to biscuits had antioxidant effects and reduced the lipid peroxidation of the biscuit samples. Biscuits with respectable sensory qualities by adding 10% orange peel powder to wheat flour. The biscuits had significant amounts of crude fibre, flavonoids, and antioxidants. In their 2019 study, (Khormaeepour *et al*.,2019) [87] supplemented sponge cake with lemon peel and substituted stevia for sugar. The cake's rigidity was raised, and peroxides were reduced by the use of lemon peel powder. The sensory characteristics of the sample with 5% lemon peel inclusion were comparable to those of the control sample.

Ice creams

All around the world, ice cream is a favourite treat. However, as awareness of the connection between nutrition and health and wellbeing has grown, several creameries are working to enhance the therapeutic qualities of their products without sacrificing public acceptance. Additionally, Tomar *et al*., 2019 [88] produced ice creams with essential oils obtained from orange, lemon, and mandarin peels at concentrations of 0.1%, 0.3%, and 0.5% inclusion and found that the essential oils had antibacterial and antifungal properties and did not affect the ice creams' sensory qualities. The sensory and physico-chemical characteristics of chocolate ice cream prepared with orange peel fibre as a fat replacement were assessed by (Comas *et al*. 2013) [89].

Noodles

The phenolic compounds in orange peels inhibited the enzymes α-amylase and α-glucosidase, reducing the quantity of glucose absorbed in the blood, which resulted in a reduction in the glycemic indices after the peels were added. (Ji *et al*. 2017) revealed that gum peach polysaccharide and dietary fibre from pomelo peel enhanced the quality of noodles.

Mushroom production.

In order to grow mushrooms, agricultural industrial waste is used, which helps solve the world's waste management issues. Citrus processing waste is an excellent source of soluble and insoluble carbohydrates, making it an ideal starting point for bioconversion (Inácio, *et al*.,2015) [78]. Wheat straw was employed as a control substrate while dried fruit peels from orange, pineapple, avacado, mango, banana, and watermelon were used for mushroom cultivation, which revealed that the mushroom made from fruit waste has a high antioxidant content (total phenol, total flavonoids, and total tannins).

Encapsulating agent

Citrus peel pectin has been employed as an encapsulant for the past few years due to increased study in the field of nanotechnology. According to a study, a citrus peel waste-based oil emulsion was made using a pectin-based hydro-soluble citrus waste component, citric acid, calcium, and ascorbic acid. The emulsion was stable and had smaller droplets (Ren *et al*., 2020). So, it stands to reason that citrus by-product might be used as an encapsulant.

Livestock feed

Various studies have demonstrated that citrus processing waste can be used as a source of food for cattle. According to Pourhossein *et al*. (2015), feeding orange peel to broiler chicks increased their content of white blood cells, lymphocytes, immunoglobulin G, and immunoglobulin M. According to Seidavi *et al*.,2020 [79], orange peel waste can be used as a nutritious, affordable, and hygienic feed for poultry diets.

Vermicelli

Citrus waste-infused food products high in fibre are also becoming increasingly popular. Citrus pomace could be used as a source of pectin in the food industry. Additionally, citrus pomace is used in a variety of foods as a source of fibre. Wheat flour that had been enhanced with debittered Citrus reticulata (kinnow) pomace and pulp was used to create fiber-rich vermicelli. Vermicelli's desired quality attributes were achieved by adding 15% debittered pomace and pulp.

Conclusion

This review highlights the most recent research on citrus fruit waste valorization, which aims to recover components with added value and prevent waste. Citrus waste is the best source for value-added compounds since it contains large amounts of chemical components. These compounds can be produced using various techniques and used in the food, pharmaceutical, and cosmetic sectors. Citrus fruit waste may be utilised to produce commodities other than food, in an effort to ascertain if it is feasible to recover energy from citrus processing waste, researchers have examined biomethane and bioethanol production under varied environmental conditions and organic loading. However, with the right procedures, the citrus waste's bioenergy conversion systems should be further enhanced while minimising the detrimental effects of EO on the microbial mass. Numerous studies have emphasised the nutraceutical and functional properties of numerous substances extracted from citrus waste. Nevertheless, more research is required to determine whether citrus waste can be used to make edible packaging. Waste utilisation may be viewed as very promising due to the high additional market values of these substances (pectins, dietary fibres, flavonoids, flavouring agents, citric acid, etc.). However, despite recent advances in research aimed at effectively valorizing citrus waste, these methods have not yet been applied on an industrial scale. In order to properly assess resources for environmental sustainability and economic progress, research with an industrial focus must be conducted.

References

1. Rashid U, Ibrahim M, Yasin S, Yunus R, Taufiq-Yap YH, Knothe G. Biodiesel from Citrus reticulata (mandarin orange) seed oil, a potential non-food feedstock. Industrial Crops and Products. 2013;45:355-359.
2. Mahato N, Sharma K, Sinha M, Dhyani A, Pathak B, Jang H. Biotransformation of citrus waste-I: Production of biofuel and valuable compounds by fermentation. Processes. 2021;9(2):220.
3. Sharma K, Mahato N, Cho MH, Lee YR. Converting citrus

wastes into value-added products: Economic and environmently friendly approaches. Nutrition. 2017;34:29-46.
4. Mahato N, Sharma K, Sinha M, Cho MH. Citrus waste derived nutra-/pharmaceuticals for health benefits: Current trends and future perspectives. Journal of Functional Foods. 2018;40:307-316.
5. Mahato N, Sharma K, Koteswararao R, Sinha M, Baral E, Cho MH. Citrus essential oils: Extraction, authentication and application in food preservation. Critical reviews in food science and nutrition, 2019;59(4):611-625.
6. Marzouk B. Characterization of bioactive compounds in Tunisian bitter orange (Citrus aurantium L.) peel and juice and determination of their antioxidant activities. BioMed research international, 2013.
7. Martí N, Mena P, Cánovas JA, Micol V, Saura D. Vitamin C and the role of citrus juices as functional food. Natural product communications. 2009;4(5):1934578X0900400506.
8. Izquierdo L, Sendra JM. Citrus fruits| composition and characterization. 2003.
9. Ziegler LW, Wolfe HS. *Citrus growing in Florida* (No. 2. ed.). University of Florida Press. 1975.
10. Gmitter FG, Hu X. The possible role of Yunnan, China, in the origin of contemporary Citrus species (Rutaceae). Economic Botany, 1990;44(2):267-277.
11. Liu Y, Heying E, Tanumihardjo SA. History, global distribution, and nutritional importance of citrus fruits. Comprehensive reviews in Food Science and Food safety. 2012;11(6):530-545.
12. Marín FR, Soler-Rivas C, Benavente-García O, Castillo J, Pérez-Alvarez J. By-products from different citrus processes as a source of customized functional fibres. Food chemistry. 2007;100(2):736-741.
13. Laufenberg G, Kunz B, Nystroem M. Transformation of vegetable waste into value added products::(A) the upgrading concept;(B) practical implementations. Bioresource technology. 2003;87(2):167-198.
14. Montgomery R. Development of biobased products. Bioresource Technology. 2004;91(1):1-29.
15. Boukroufa M, Boutekedjiret C, Petigny L, Rakotomanomana N, Chemat F. Bio-refinery of orange peels waste: A new concept based on integrated green and solvent free extraction processes using ultrasound and microwave techniques to obtain essential oil, polyphenols and pectin. Ultrasonics Sonochemistry. 2015;24:72-79.
16. Joshi LS, Pawar HA. Herbal cosmetics and cosmeceuticals: An overview. Nat Prod Chem Res. 2015;3(2):170.
17. Suzuki D. The "Dirty Dozen" ingredients investigated in the David Suzuki Foundation Survey of chemicals in cosmetics. Backgrounder, 2010, 1-15.
18. Suri S, Singh A, Nema PK. Current applications of citrus fruit processing waste: A scientific outlook. Applied Food Research, 2022, 100050.
19. Di Donna L, Bartella L, De Vero L, Gullo M, Giuffrè AM, Zappia C. Vinegar production from Citrus bergamia by-products and preservation of bioactive compounds. European Food Research and Technology. 2020;246(10):1981-1990.
20. Zhu Z, Gavahian M, Barba FJ, Roselló-Soto E, Kovačević DB, Putnik P. Valorization of waste and by-products from food industries through the use of innovative technologies. In Agri-food industry strategies for healthy diets and sustainability. Academic Press. 2020, 249-266.
21. Bernal-Vicente A, Ros M, Tittarelli F, Intrigliolo F, Pascual JA. Citrus compost and its water extract for cultivation of melon plants in greenhouse nurseries. Evaluation of nutriactive and biocontrol effects. Bioresource technology, 2008;99(18):8722-8728.
22. Casquete R, Castro SM, Martín A, Ruiz-Moyano S, Saraiva JA, Córdoba MG. Evaluation of the effect of high pressure on total phenolic content, antioxidant and antimicrobial activity of citrus peels. Innovative Food Science & Emerging Technologies. 2015;31:37-44.
23. Magiorkinis E, Beloukas A, Diamantis A. Scurvy: Past, present and future. European journal of internal medicine. 2011;22(2):147-152.
24. Pak CY. Medical management of urinary stone disease. Nephron Clinical Practice. 200;98(2):c49-c53.
25. Sica DA. Interaction of grapefruit juice and calcium channel blockers. American journal of hypertension. 2006;19(7):768-773.
26. Coelho RCLA, Hermsdorff HHM, Bressan J. Anti-inflammatory properties of orange juice: possible favorable molecular and metabolic effects. Plant foods for human nutrition. 2013;68(1):1-10.
27. Álvarez-González I, Madrigal-Bujaidar E, Sánchez-García, VY. Inhibitory effect of grapefruit juice on the genotoxic damage induced by ifosfamide in mouse. Plant foods for human nutrition. 2010;65(4):369-373.
28. Epifano F, Genovese S. Recent acquisitions on naturally occurring oxyprenylated secondary plant metabolites. Chemistry and Pharmacology of Naturally Occurring Bioactive Compounds, first ed. CRC Press, Boca Raton, 2013, 239-257.
29. Genovese S, Fiorito S, Locatelli M, Carlucci G, Epifano F. Analysis of biologically active oxyprenylated ferulic acid derivatives in Citrus fruits. Plant Foods for Human Nutrition. 2014;69(3):255-260.
30. Proteggente AR, Saija A, De Pasquale A, Rice-Evans CA. The compositional characterisation and antioxidant activity of fresh juices from sicilian sweet orange (Citrus sinensis L. Osbeck) varieties. Free Radical Research. 2003;37(6):681- 687.
31. Gorinstein S, Cvikrová M, Machackova I, Haruenkit R, Park YS, Jung ST. Characterization of antioxidant compounds in Jaffa sweeties and white grapefruits. Food chemistry. 2004;84(4):503-510.
32. Anagnostopoulou MA, Kefalas P, Papageorgiou VP, Assimopoulou AN, Boskou D. Radical scavenging activity of various extracts and fractions of sweet orange peel (Citrus sinensis). Food chemistry. 2006;94(1):19-25.
33. Manthey JA, Grohmann K. Phenols in citrus peel byproducts. Concentrations of hydroxycinnamates and polymethoxylated flavones in citrus peel molasses. Journal of Agricultural and Food Chemistry. 2001;49(7):3268-3273.
34. Wang L, Wang J, Fang L, Zheng Z, Zhi D, Wang S.
35. Anticancer activities of citrus peel polymethoxyflavones related to angiogenesis and others. BioMed research international, 2014.
36. Tomás-Barberán, F. A., & Clifford, M. N. (2000). Flavanones, chalcones and dihydrochalcones–nature, occurrence and dietary burden. *Journal of the Science of*

Food and Agriculture, *80*(7), 1073-1080.

37. Terpstra AHM, Lapre JA, De Vries HT, Beynen AC. The hypocholesterolemic effect of lemon peels, lemon pectin, and the waste stream material of lemon peels in hybrid F1B hamsters. European journal of nutrition. 2002;41(1):19-26.
38. Zou Z, Xi W, Hu Y, Nie C, Zhou Z. Antioxidant activity of Citrus fruits. Food chemistry. 2016;196:885-896.
39. Najwa FR, Azrina A. Comparison of vitamin C content in citrus fruits by titration and high performance liquid chromatography (HPLC) methods. International Food Research Journal. 2017;24(2):726.
40. Shrestha N, Shrestha S, Bhattarai A. Determination of ascorbic acid in different citrus fruits of Kathmandu Valley. Journal of Medical and Biological Science Research. 2016;2(1):9-14.
41. Reda AH, Gebremeskel FG. Determination of ascorbic acid in citrus sinensis and ananas comosus using poly (3, 4-ethylenedioxythiophene) modified glassy carbon electrode. Am. J. Appl. Chem. 2016;4:1-7.
42. Czech A, Malik A, Sosnowska B, Domaradzki P. Bioactive substances, heavy metals, and antioxidant activity in whole fruit, peel, and pulp of citrus fruits. International Journal of Food Science, 2021.
43. de Moraes Barros HR, de Castro Ferreira TAP, Genovese MI. Antioxidant capacity and mineral content of pulp and peel from commercial cultivars of citrus from Brazil. Food chemistry. 2012;134(4):1892-1898.
44. Ani PN, Abel HC. Nutrient, phytochemical, and antinutrient composition of Citrus maxima fruit juice and peel extract. Food Science & Nutrition. 2018;6(3):653-658.
45. Rehman SU, Abbasi KS, Qayyum A, Jahangir M, Sohail A, Nisa S. Comparative analysis of citrus fruits for nutraceutical properties. Food Science and Technology, 2019;40:153-157.
46. Tiencheu B, Nji DN, Achidi AU, Egbe AC, Tenyang N, Ngongang EF. Nutritional, sensory, physico-chemical, phytochemical, microbiological and shelf-life studies of natural fruit juice formulated from orange (Citrus sinensis), lemon (Citrus limon), Honey and Ginger (Zingiber officinale). Heliyon. 2021;7(6):e07177.
47. Baghurst KI. Dietary guidelines: the development process in Australia and New Zealand. Journal of the American Dietetic Association. 2003;103(12):17-21.
48. Gorinstein S, Martıń-Belloso O, Park YS, Haruenkit R, Lojek A, Ĉıž M. Comparison of some biochemical characteristics of different citrus fruits. Food chemistry. 2001;74(3):309-315.
49. Reazai M, Mohammadpourfard I, Nazmara S, Jahanbakhsh M, Shiri L. Physicochemical characteristics of citrus seed oils from Kerman, Iran. Journal of Lipids, 2014.
50. Nile SH, Baskar V, Keum YS. Characterization of organic acids, sugars, antioxidant and anti-inflammatory activities of Citrus reticulate Blanco cv. Nagpur. 2017.
51. Randhawa MA, Rashid A, Saeed M, Javed MS, Khan AA, Sajid MW. Characterization of organic acids in juices of some Pakistani citrus species and their retention during refrigerated storage. The Journal of Animal and Plant Sciences. 2014;24(1):211-215.
52. Violeta NOUR, Trandafir I, Ionica ME. HPLC organic acid analysis in different citrus juices under reversed phase conditions. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 2010;38(1):44-48.
53. Czech A, Malik A, Sosnowska B, Domaradzki P. Bioactive substances, heavy metals, and antioxidant activity in whole fruit, peel, and pulp of citrus fruits. International Journal of Food Science, 2021.
54. Zhang J, Zhang J, Kaliaperumal K, Zhong B. Variations of the chemical composition of Citrus sinensis Osbeck cv. Newhall fruit in relation to the symptom severity of Huanglongbing. Journal of Food Composition and Analysis, 2022;105:104269.
55. Manthey JA, Guthrie N, Grohmann K. Biological properties of citrus flavonoids pertaining to cancer and inflammation. Current medicinal chemistry. 2001;8(2):135-153.
56. Tripoli EGM, Giammanco S, Majo DD, Giammanco M. Citrus flavonoids: Molecular structure, biological activity and nutritional properties: A review Food Chem. 2007;104:466-479.
57. Aboul Naser A, Younis E, El-Feky A, Elbatanony M, Hamed M. Management of Citrus sinensis peels for protection and treatment against gastric ulcer induced by ethanol in rats. Biomarkers. 2020;25(4):349-359.
58. Liu N, Li X, Zhao P, Zhang X, Qiao O, Huang L. A review of chemical constituents and health-promoting effects of citrus peels. Food Chemistry. 2021;365:130585.
59. Jridi M, Abdelhedi O, Salem A, Kechaou H, Nasri M, Menchari Y. Physicochemical, antioxidant and antibacterial properties of fish gelatin-based edible films enriched with orange peel pectin: Wrapping application. Food Hydrocolloids. 2020;103:105688.
60. Muñoz-Labrador A, Moreno R, Villamiel M, Montilla A. Preparation of citrus pectin gels by power ultrasound and its application as an edible coating in strawberries. Journal of the Science of Food and Agriculture. 2018;98(13):4866-4875.
61. Pinto D, de la Luz Cádiz-Gurrea M, Silva AM, Delerue-Matos C, Rodrigues F. Cosmetics—Food waste recovery. In Food Waste Recovery. Academic Press. 2021, 503-528.
62. Sharma K, Mahato N, Cho MH, Lee YR. Converting citrus wastes into value-added products: Economic and environmently friendly approaches. Nutrition. 2017;34:29-46.
63. Rosa A, Era B, Masala C, Nieddu M, Scano P, Fais A. Supercritical CO2 extraction of waste citrus seeds: Chemical composition, nutritional and biological properties of edible fixed oils. European Journal of Lipid Science and Technology. 2019;121(
64. 7):1800502.
65. Brethauer S, Wymaz CE. Continuous hydrolysis and fermentation for cellulosic ethanol production. Bioresource technology. 2010;101(13):4862-4874.
66. Satari B, Karimi K. Resources, Conservation & Recycling Citrus processing wastes: Environmental impacts, recent advances, and future perspectives in total valorization. Resour. Conserv. Recycl. 2018;129:153-167.
67. Ezekoye V, Adinde R, Ezekoye D, Ofomatah A. Syntheses and characterization of biodiesel from citrus sinensis seed oil. Scientific African. 2019;6:e00217.
68. Demirbas A. Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. Energy conversion and management. 2008;49(8):2106-2116.
69. Boluda-Aguilar M, López-Gómez A. Production of

bioethanol by fermentation of lemon (Citrus limon L.) peel wastes pretreated with steam explosion. Industrial crops and products. 2013;41:188-197.
70. Wilkins MR, Widmer WW, Grohmann K. Simultaneous saccharification and fermentation of citrus peel waste by Saccharomyces cerevisiae to produce ethanol. Process Biochemistry. 2007;42(12):1614-1619.
71. Zema DA, Calabrò PS, Folino A, Tamburino VINCEZO, Zappia G, Zimbone SM. Valorisation of citrus processing waste: A review. Waste management. 2018;80:252-273.
72. Martín MA, Siles JA, Chica AF, Martín A. Biomethanization of orange peel waste. Bioresource technology. 2010;101(23):8993-8999.
73. Akkaya Sayğılı G, Sayğılı H, Yılmaz C, Güzel F. Lead recovery from aqueous environment by using porous carbon of citrus fruits waste: Equilibrium, kinetics and thermodynamic studies. Separation Science and Technology, 2020;55(15):2699-2712.
74. Bhattacharyya S, Das P, Datta S. Removal of ranitidine from pharmaceutical waste water using activated carbon (AC) prepared from waste lemon peel. In *Waste water recycling and management*. Springer, Singapore. 2019, 123-141.
75. Villen-Guzman M, Cerrillo-Gonzalez MDM, Paz-Garcia JM, Rodriguez- Maroto JM, Arhoun B. Valorization of lemon peel waste as biosorbent for the simultaneous removal of nickel and cadmium from industrial effluents. Environmental Technology & Innovation. 2021;21:101380.
76. Miller RA. Increased yield of bread containing citrus peel fiber. Cereal chemistry. 2011;88(2):174-178.
77. Ojha P, Thapa S. Quality evaluation of biscuit incorporated with mandarin peel powder. Scientific Study & Research. Chemistry & Chemical Engineering, Biotechnology, Food Industry. 2017;18(1):19.
78. Foti P, Ballistreri G, Timpanaro N, Rapisarda P, Romeo FV. Prebiotic effects of citrus pectic oligosaccharides. Natural Product Research, 2021, 1-4.
79. Inácio FD, Ferreira RO, De Araujo CAV, Peralta RM, De Souza CGM. Production of Enzymes and Biotransformation of Orange Waste by Oyster Mushroom, Pleurotus pulmonarius (Fr.) Quél. Advances in Microbiology. 2015;5(01):1.
80. Seidavi A, Zaker-Esteghamati H, Salem AZ. A review on practical applications of Citrus sinensis by-products and waste in poultry feeding. Agroforestry Systems. 2020;94(4):1581-1589.
81. Singla G, Krishania M, Sandhu PP, Sangwan RS, Panesar PS. Value additon of kinnow industry byproducts for the preparation of fiber enriched extruded products. Journal of food science and technology. 2019;56(3):1575-1582.
82. Taghizadeh-Alisaraei A, Hosseini SH, Ghobadian B, Motevali A. Biofuel production from citrus wastes: A feasibility study in Iran. Renewable and Sustainable Energy Reviews. 2017;69:1100-1112.
83. Rashid U, Ibrahim M, Yasin S, Yunus R, Taufiq-Yap YH, Knothe G. Biodiesel from Citrus reticulata (mandarin orange) seed oil, a potential non-food feedstock. Industrial Crops and Products. 2013;45:355-359.
84. Bożym M, Florczak I, Zdanowska P, Wojdalski J, Klimkiewicz M. An analysis of metal concentrations in food wastes for biogas production. Renewable energy. 2015;77:467-472.
85. Mahato N, Sharma K, Sinha M, Baral ER, Koteswararao R, Dhyani A. Bio-sorbents, industrially important chemicals and novel materials from citrus processing waste as a sustainable and renewable bioresource: A review. Journal of Advanced Research. 2020;23:61-82.
86. Ademosun AO, Oboh G, Olasehinde TA, Adeoyo OO. From folk medicine to functional food: a review on the bioactive components and pharmacological properties of citrus peels. Oriental Pharmacy and Experimental Medicine. 2018;18(1):9-20.
87. Ademosun AO. Citrus Peels Odyssey: From the Waste Bin to the Lab Bench to the Dining Table. Applied Food Research, 2022, 100083.
88. Khormaeepour M, Vazirizadeh A. Fortification of sponge cake by lemon peel and using of Stevia as a replacement of sugar. Journal of food science and technology (Iran). 2019;16(88):135-145.
89. Tomar O, Akarca G. Effects of ice cream produced with Lemon, mandarin, and orange peel essential oils on some physicochemical, microbiological and sensorial properties. Kocatepe Veterinary Journal. 2019;12(1):62-70.
90. Comas C, de Moraes Crizel T, de Araujo RR, de Oliveira Rios A, Flôres SH. Development of chocolate ice cream using orange peel fiber as fat replacer/Desenvolvimento de sorvete de chocolate utilizando fibra de casca de laranja como substituto de gordura. Ciência Rural. 2013;43(10):1892-1898.
91. Ji P, Ji X, Fu S, Zhang L. Study on nutrition fresh noodles formulated with pomelo peel and peach gum. Food and Fermentation Industries. 2017;43(1):156-162.
92. Lima ACD, Cecatti C, Fidélix MP, Adorno MAT, Sakamoto IK, Cesar TB. Effect of daily consumption of orange juice on the levels of blood glucose, lipids, and gut microbiota metabolites: controlled clinical trials. Journal of medicinal food. 2019;22(2):202-210.
93. Fidélix M, Milenkovic D, Sivieri K, Cesar T. Microbiota modulation and effects on metabolic biomarkers by orange juice: A controlled clinical trial. Food & function. 2020;11(2):1599-1610.
94. Kimball DA. Citrus processing: A complete guide. Springer Science & Business Media. 2012.
95. Mao G, Wu D, Wei C, Tao W, Ye X, Linhardt RJ. Reconsidering conventional and innovative methods for pectin extraction from fruit and vegetable waste: Targeting rhamnogalacturonan I. Trends in Food Science & Technology. 2019;94:65-78.
96. Iqbal K, Khan A, Khattak MMAK. Biological significance of ascorbic acid (vitamin C) in human health-a review. Pakistan Journal of Nutrition. 2004;3(1):5-13.
97. Mahmoud GA, Abdel-Aal SE, Badway NA, Elbayaa AA, Ahmed D. A novel hydrogel based on agricultural waste for removal of hazardous dyes from aqueous solution and reuse process in a secondary adsorption. Polymer Bulletin. 2017;74(2):337-358.
98. Pourhossein Z, Qotbi AAA, Seidavi A, Laudadio V, Centoducati G, Tufarelli V. Effect of different levels of dietary sweet orange (C itrus sinensis) peel extract on humoral immune system responses in broiler chickens. Animal Science Journal. 2015;86(1):105-110.