Environment, Development and Sustainability
https://doi.org/10.1007/s10668-024-04998-4

REVIEW

Pharmacological and insecticidal attributes of common fruit peels: a review

Shweta Gupta[1] · **Shivani Sharma**[1] · **Neha Loach**[1] · **Arun Pratap Sikarwar**[2] · **Lalit Mohan**[1]

Received: 1 September 2023 / Accepted: 29 April 2024

Abstract

India has the biggest market for fruits, vegetables, and flowers in Asia and generates enormous amounts of garbage every day. Numerous food sectors throughout the globe generate a substantial amount of waste in the form of peels or by-products. The environmental system is severely harmed by these wastes. Today, numerous methods are employed to come up with other applications for these wastes since the by-products are a great source of diverse bioactive compounds beneficial to human health, such as creatine, carotenoids, flavonoids, polyphenols, and polysaccharides. The current review offers several unique perspectives on using fruit peels to minimise waste generation and its detrimental effects. An innovative bio-refinery strategy would try to turn fruit peel waste into a greater variety of useful compounds. The leftovers from most extraction procedures may also be utilised as sustainable resources to make biofuels. This paper also discusses the use of various techniques employed while analysing substances in plant-based goods, including the latest advanced technology. Moreover, to make certain effective waste management solutions, a careful assessment of the economic and environmental advantages relative to current choices is required.

Keywords Fruit peel · Extract · Antioxidant · Extraction · Risk assessment · Antimicrobial

✉ Lalit Mohan
lalitmohan@dei.ac.in

Shweta Gupta
shwetagupta163334@dei.ac.in

Shivani Sharma
shivani.sharmaa93@gmail.com

Neha Loach
neha.loach5@gmail.com

Arun Pratap Sikarwar
arunsikarwar@dei.ac.in

1 Applied Entomology and Vector Control Laboratory, Department of Zoology, Faculty of Science, Dayalbagh Educational Institute (Deemed to be University), Agra 282005, India

2 Neurobiology Laboratory, Department of Zoology, Faculty of Science, Dayalbagh Educational Institute (Deemed to be University), Agra 282005, India

Published online: 19 May 2024

1 Introduction

In developing countries, plants were used traditionally to prepare herbal medicines as they exhibit several pharmacological properties (Ahmad et al., 1998). India is home to around 15% of the 20,000 medicinal plants found worldwide, or 300–5000 plants (Lydia et al., 2016a). Because of their ease of availability and little to no toxicity, previous studies have focused on the development and use of therapeutic plants. The growing trend of using plants as medicine has resulted in about 80% of the world's population relying on alternative medicine sources. One substitute source for this is fruit peels, which are discarded into the environment instead of being employed for their various pharmacological characteristics and are regarded as agricultural waste (Abdollahzadeh et al., 2011; Saleem & Saeed, 2020). The consumption of the fruits, (like production of jams and jellies) produced wastes on exceptionally large scale by fruit processing industries and cause environmental pollution due to improper utilization and disposal. Therefore, using fruits peels to prepare herbal drugs are beneficial to our environment in all aspects, as they can reduce the environmental pollution, can be used to make products from them and, also, hundreds of diseases can be cured by the products prepared from these wastes. The peels of such fruits are a great source of nutrients and function as a rich source of valuable compounds, supplements, food additives and some value-added products can be produced by them (Pathak et al., 2019). It's been noted that fruit peels include phenolics, tannins, flavonoids, triterpenoids, glycosides, carotenoids, ellagitannins, anthocyanins, vitamin C, and essential oils. The amount of total phenolics and flavonoids in the same fruit peels might vary depending on the solvent used, as shown in Table 1. Sugar components can also be extracted from peels of different fruits such as almond fruit, banana, calabash, custard apple, muskmelon, orange, papaya, pineapple, pomegranate (Kumar et al., 2012). Some fruit peels namely *Carica papaya* (papaya), *Ananas comosus* (Pineapple) and *Actinidia deliciosa* (Kiwi) have proteolytic enzyme activity, hence, they can be a suitable alternative to produce enzymes at low cost as they utilize the fruit waste and reduce the pollution (Vel & Stanley, 2015). Due to their potential for diversified bioactivities, such as anti-carcinogenic, digestive, analgesic, antioxidative, antiviral, and antibacterial effects, moreover, these volatile substances are exploited in the pharmaceutical business (Liang et al., 2022). According to Parashar et al., 2014, fruit peels have enormous the ability to function as a source of newer, better, healthier, and more efficient for various purposes. The fruits have specific and identifiable scent, since there is a diverse variety of volatile chemicals. Aroma is a key sensory quality that has a considerable impact on how customers perceive and accept fruit and its products. The applications of common fruit peels are depicted in Fig. 1. Marina and Noriham (2014) studied the mango peel extract possesses more phenolic content compared to guava and papaya peel extract i.e., mango peel extract has more antioxidant effects than guava and papaya peel extract. Antioxidants are frequently employed to increase the shelf life and stabilization of lipids and foods containing lipids additionally to preserve and safeguard foods against microbial spoilage, dis-colouration, or degeneration brought on by auto-oxidation (Sultana et al., 2012). Radical initiated reaction can be prevented by antioxidants. Antioxidant and antibacterial property are reported in different kind of fruit peels such as *Maclura pomifera* (Osage orange), *Punica granatum* (Pomegranate or Anar), *Musa balbisiana* (Banana), *Citrus limetta* (Sweet lime or Mousambi), *Malus domestica* (Apple), *Carica papaya* (Papaya), and *Mangifera indica* (Mango) (Prakash et al., 2013). Table 2 demonstrates the antioxidant capability of various fruit peels as determined by various workers through different tests (Fig. 2).

Table 1 Total Phenolic and Flavonoid contents present in different fruit peels

Name of fruit peels	Extraction solvent	Total phenolic content	Total flavonoid content	References
Pomegranate peel	Aqueous	161.25 mg/g	–	Kanatt et al., (2010)
Citrus reticulata	Aqueous	40.8 mg GAE/g	7.62 mg CE/g	Ho & Lin, (2008)
Citrus sunki	Ethanol	14.52 mg/g	–	Shin et al., (2011)
Orange peel	Methanol	165.38 mg/g	28.36 µg/g	Hegazy & Ibrahium, (2012)
	Ethanol	169.56 mg/g	29.75 µg/g	
	Dichloromethane	98.64 mg/g	17.39 µg/g	
	Acetone	145.79 mg/g	21.87 µg/g	
	Hexane	63.20 mg/g	13.89 µg/g	
	Ethyl acetate	85.27 mg/g	18.36 µg/g	
Citrus paradassi	Acetone	13.1 mg/g	0.93 mg/g	Oboh & Ademosun, (2012)
Citrus hystrix	Ethanol	0.318 mg GAE/ mg	0.206 mg RE/ mg	Wijaya et al., (2017)
Citrus maxima	Ethanol	17.99 mg/g	15.11µg/g	Ani & Abel, (2018)
Citrus sinensis	Ethanol	21.38 mg GAE/g	2.59 mg CE/g	Liew et al., (2018)
	Methanol	36.09 mg GAE/g	4.61 mg CE/g	
C. Limonia Osbeck	Ethanol	17.37 mg/g	–	Saleem & Saeed, (2020)
	Methanol	18.7 mg/g	–	
	Ethyl acetate	16.2 mg/g	–	
	Aqueous	29.72 mg/g	–	
Orange peel	Ethanol	12.42 mg/g	–	Saleem & Saeed, (2020)
	Methanol	15.2 mg/g	–	
	Ethyl acetate	12.4 mg/g	–	
	Aqueous	25.21 mg/g	–	
Banana peel	Aqueous	30.0 mg/g	196.1 mg/g	Pathak et al., (2017)

Table 1 (continued)

Name of fruit peels	Extraction solvent	Total phenolic content	Total flavonoid content	References
Banana peel	Ethanol	11.48 mg/g	–	Saleem & Saeed, (2020)
	Methanol	8.6 mg/g	–	
	Ethyl acetate	11.48 mg/g	–	
	Aqueous	15.6 mg/g	–	
Mangifera indica peel (Raw)	Acetone	109.70 mg/g	–	Ajila et al., (2007)
Mangifera indica peel (Ripe)	Acetone	100.00 mg/g	–	
Mangifera indica peel (Unripe)	Ethanol	92.6 mg GAE/g	22.2 mg RE/g	Kim et al., (2010)
Mangifera indica peel (Ripe)	Ethanol	70.1 mg GAE/g	21.2 mg RE/g	
Mango peel (Langra)	Methanol	116.8 mg/g	90.89 mg/g	Sultana et al., (2012)
Mango peel (Chonsa)	Methanol	122.6 mg/g	92.55 mg/g	
Papaya peel	n-Hexane	7.32 mg GAE/g	1.10 mg CE/g	Asghar et al., (2016)
	Dichloromethane	21.15 mg GAE/g	1.23 mg CE/g	
	n-Butanol	24.80 mg GAE/g	3.72 mg CE/g	
	Ethyl acetate	27.21 mg GAE/g	8.57 mg CE/g	
	water	32.23 mg GAE/g	12.93 mg CE/g	
	Methanol	35.15 mg GAE/g	13.92 mg CE/g	
	Ethanol	43.79 mg GAE/g	19.81 mg CE/g	
Papaya peel	Acetone	4.22 GAE/ g	247.70 meq/quertin	Lydia et al., 2016b
	Ethanol	3.92 GAE/ g	0.83 meq/quertin	
	Aqueous	4.84 GAE/ g	15.48 meq/quertin	
Apple peels	Acetone	7.68 mg/g	5.34 mg/g	Massini et al., (2013)
	Ethanol	6.35 mg/g	4.76 mg/g	

Table 1 (continued)

Name of fruit peels	Extraction solvent	Total phenolic content	Total flavonoid content	References
Apple peels	methanol/water/acetic acid	32.3 mg GAE/g	-	Agourram et al., (2013)
	ethanol/water	20.1 mg GAE/g	-	
	acetone/water	61.3 mg GAE/g	-	
Apple peels	Ethanol	24.94 mg GAE/g	8.85 mg CE/g	Lee et al., (2016)

GAE/g- Gallic Acid Equivalents/gram; CE/g- Catechin Equivalents/gram; RE- Rutin Equivalent;

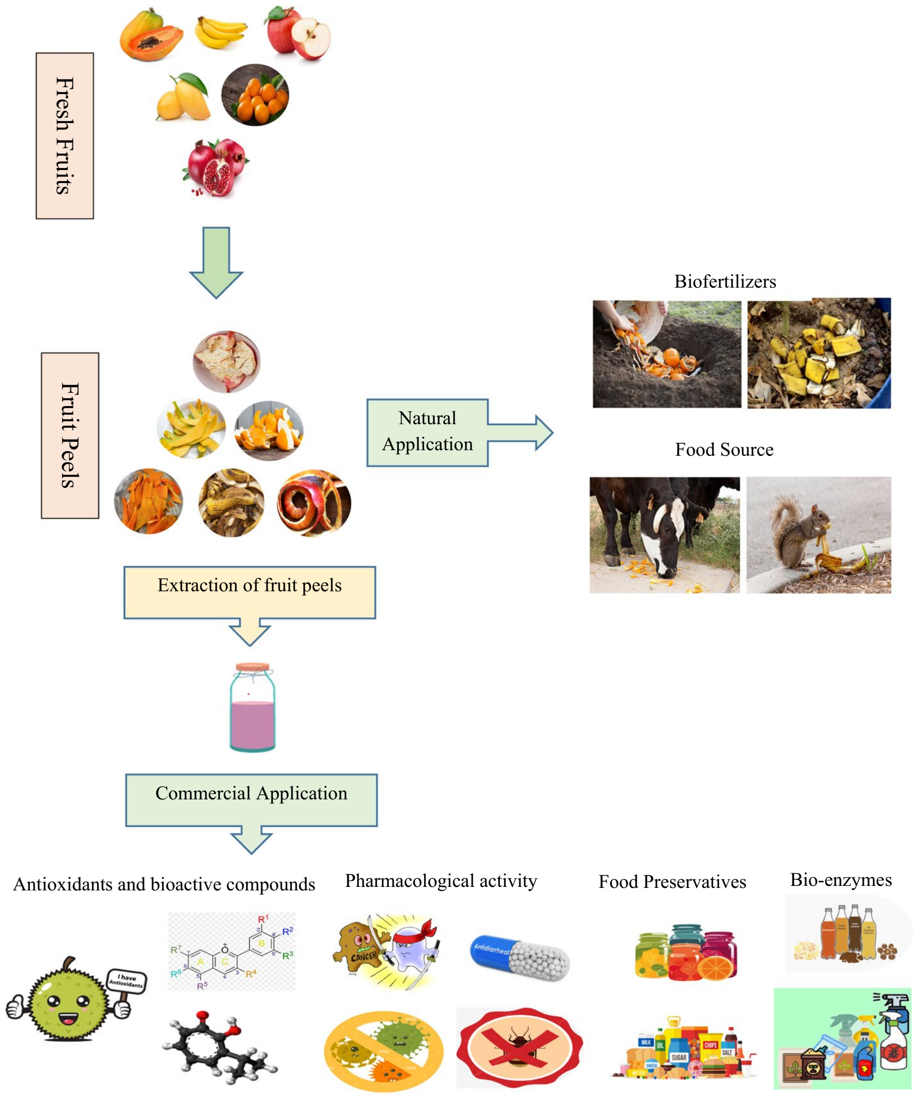

Fig. 1 Fruit peels and their uses in various fields

The main goal of this study is to provide a pathway for more effective use of waste from fruit processing that satisfies Sustainable Development Goal No. 12 of the UN: "Sustainable production and consumption". This objective covers the primary difficulty of effectively managing waste and using natural resources to assist poor countries in transitioning to more sustainable patterns of consumption by 2030. If any action is to be done for a product connected to these fruit peels being utilized in the future as food additives, food preservatives, and toxic-free food grade disinfectants, the food or pharmaceutical industries may find this information to be productive. Given the present issues surrounding the usage of antibiotics, interest in plants possessing

Table 2 Antioxidant capacity of different fruit peels by using different radical scavenging assay

Name of fruit peels	Scavenging assay	IC_{50}	References
Pomegranate	DPPH	4.9 µg/mL	Kanatt et al., (2010)
	Butylated hydroxy toluene	21.2 µg/mL	
Pomegranate	DPPH	0.003 mg/ml	Okonogi et al., (2007)
	ABTS	4.59 mM/mg	
Citrus reticulata	NO	1.98 mg/ml	Ho & Lin, (2008)
	DPPH	371 µg/mL	
Citrus paradissi	DPPH	1.4 mg/ml	Oboh & Ademosun, (2012)
	$.OH^{-}$	5.1 mg/ml	
	Fe^{2+}	0.63 mg/ml	
	LPO	151.8 µg/ml	
Citrus maxima	DPPH	1.6 mg/ml	
	$.OH^{-}$	5.6 mg/ml	
	Fe^{2+}	0.71 mg/ml	
	LPO	156.1 µg/ml	
Citrus hystrix	DPPH	53.83 mg/ml	Wijaya et al., (2017)
Citrus sinensis	DPPH	13.96 mg TE/g	Liew et al., (2018)
	FRAP	275.62 mmol Fe (II)/ g	
	ORAC	0.73 mol TE/ g	
Citrus clementina	DPPH	63.4 µg/mL	Saratale et al., (2018)
	ABTS	49.6 µg/mL	
Banana peel	DPPH	0.031 mg/ml	Okonogi et al., (2007)
	ABTS	1.80 mM/mg	
Banana peel	DPPH	8.45 µg/mL	Pathak et al., (2017)
Banana peel	Phosphomolybdenum	23.86 mg AAE/g	Hanafy et al., (2021)
Mangifera indica (Raw)	DPPH	1.98 µg of GAE	Ajila et al., (2007)
	LPO	4.59 µg of GAE	
	Soybean Lipoxygenase	5.14 µg of GAE	
Mangifera indica (Ripe)	DPPH	1..83 µg of GAE	
	LPO	3.13 µg of GAE	
	Soybean Lipoxygenase	5.24 µg of GAE	
Apple peel	ABTS	0.71 µM TE/g dry weight	Agourram et al., (2013)
Apple peel	DPPH	12.11 mg/g	Massini et al., (2013)
	FRAP	13.26 mg/g	
Apple peel	DPPH	9.86 mg AAE/g	Lee et al., (2016)
	ABTS	26.30 mM TE/g	

IC_{50}-Inhibition concentration; DPPH- 2,2-diphenyl-1-picrylhydrazyl; ABTS-2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); NO-Nitric Oxide;$.OH^{-}$ Hydroxyl radical; LPO-Lipid peroxidation; FRAP-Ferric Reducing Antioxidant Power; ORAC-Oxygen Radical Absorbance Capacity; Fe^{2+} Chelation Assay; TE- Trolox Equivalents; mg AAE/g milligram Ascorbic Acid Equivalent/gram (dry weight); GAE- Gallic Acid Equivalents

antibacterial characteristics has increased. Thus, the aim of this research is to shed light on the biotechnological methods employed to extract the numerous phytochemicals and beneficial compounds from fruit waste. The present review paper provides all

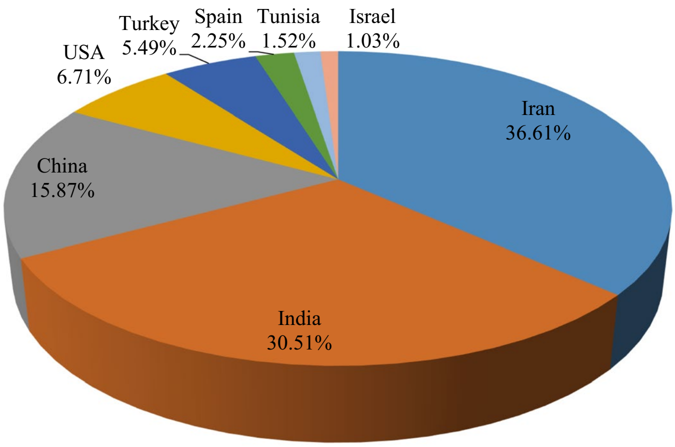

Fig. 2 Pomegranate fruit production across the world in 2020

the related details of biological activities in a concise manner to the community and readers as well.

2 Antioxidant property

Gallic acid and ellagic acid possess strong anti-free radical properties and they reduce the levels of superoxide anion and hydrogen peroxide and detoxify the liver enzymes such as catalase, peroxidase, and superoxide dismutase (Chidambara Murthy et al., 2002).

2.1 Pomegranate peel

Due to the antioxidant property of pomegranate, it helps in stabilizing sunflower oil and provides thermal stability (Iqbal et al., 2008). The fruit skins of pomegranates include phenolic compounds such as flavonoids (anthocyanin, catechins) and tannins (punicalin, pedunculagin, punicalagin, ellagic and gallic acid) (Ismail et al., 2012).

2.2 Citrus peel

The reports demonstrate that the ethanol-based extract of orange peel exhibits a considerable number of phenolic compounds and there is a close correlation between the total phenolic content and the reducing power (Hegazy & Ibrahium, 2012). A new strategy for the treatment of type 2 diabetes mellitus may be offered by the polyphenolic chemicals derived from *Citrus limetta* peel extract that have both antihyperglycemic and antioxidant effects (Padilla-Camberos et al., 2014). *Citrus maxima* contain many phytochemicals such as flavonoids, alkaloids and phenols and it is a reliable source of nutrients (Ani & Abel, 2018). The antioxidant capacity of phenolic and flavonoid content in plants is the main contributor to the specific biological actions in disease prevention and treatment, according to statistically substantial association between TPC, TFC and the antioxidant assays such findings support the hypothesis that *C. sinensis* extracts have some antioxidant activity (Liew et al., 2018).

2.3 Mango peel

Kim et al. (2010) stated that antioxidant and antiproliferative characteristics of mango peel may be related to the bioactive chemicals that are present there working in concert. The extraction solvent, however, is the most crucial element among the optimal circumstances. The temperature of the extraction process also affects the effectiveness of the process; in particular, temperatures between 50 and 75°C favour the ability of mango peel extracts to suppress lipid peroxidation (Dorta et al., 2012). The results of an HPLC examination showed that the chemical composition of mango peel extract consisted of five primary components: caffeic acid, chlorogenic acid, gallic acid, procyanidin B2, and oleanolic acid, vanillic aldehyde (Bai et al., 2018) (Fig. 3).

2.4 Papaya peels

Chukwuka et al. (2013) evaluated the nutritional value of papaya fruit at three distinct stages: unripe, hard ripe and very ripe. Carbohydrate, fat, vitamins, protein, fiber content, calcium, potassium, magnesium, and vitamin-C content decreased as papaya's ripening. However, vitamin A, riboflavin, moisture content was increases as papaya's ripening process. Aqueous extract of papaya peels possesses antioxidant activity (Pawpaw, 2016). Jamal et al. (2017) investigated that *Carica papaya* has the ability to serve as an antioxidant and prevent our body from diseases linked to free radical damage.

2.5 Banana peels

Mokbel and Hashinaga (2005) stated that a green peel extract had more significant activity in various solvent extracts than a yellow peel extract. Individual banana peel phenolic compounds, such as dopamine, ferulic acid, and catechins, also have strong antioxidant and antibacterial properties and may be used as food preservatives (Vu et al., 2018).

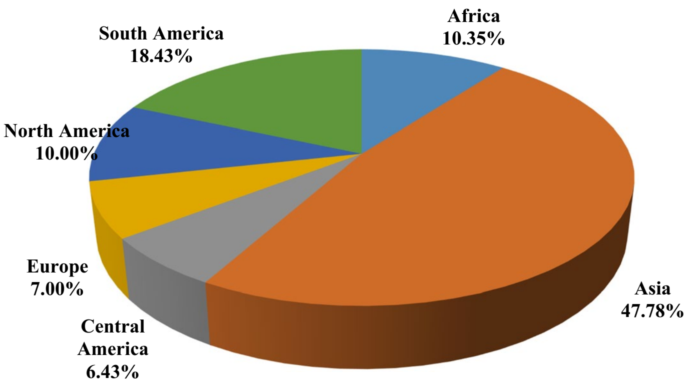

Fig. 3 *Citrus* fruit production across the world in 2020

2.6 Apple peels

The apple peel has the highest concentrations of phenolic chemicals than pulp. Peels possess many phytochemical compounds such as catechins and flavonol glycosides, particulasrly Rutin (Escarpa & Gonzalez, 1998). Eberhardt et al. (2000) stated that apple fruit has antioxidant activity as 100 gm of fresh apple is equivalent to 1500 mg of vitamin C. In the apple fruit, the compounds, rutin (27.43%), epicatechin (24.93%), dicaffeoylquinic acid (16.14%) and caffeic acid (15.3%) are the most abundant phenolics (Freatianni et al., 2011). The peels had a greater overall concentration of phenolic and flavonoid compounds than the flesh-peel combination or the flesh alone. Apple peels are a valuable source of antioxidants and can provide health advantages when taken due to their high phenolic component concentration and antioxidant activity (Parashar et al., 2014). Apple juice processing generates a huge amount of leftover, known as apple pomace, which consists primarily of peels, seeds, and pulp; and additionally, it supplies bioactive compounds include 114 dietary fibre, protein, biopolymers, and natural antioxidants Cargnin and Gnoatto (2017) (Fig. 4).

3 Medicinal values

3.1 Pomegranate peel

Pomegranate peels may be a desirable alternative in pharmaceuticals as it exhibits anti-inflammatory, anti-allergic (Mastrogiovanni et al., 2019; Panichayupakaranant et al., 2010), anti-ulcerogenic (Moghaddam et al., 2013), anti-cancer (Asmaa et al., 2015), and anti-diarrheal activities (Zhao et al., 2018). *Punica granatum* peel and seed oil extracts have a hepatoprotective effect against the rat liver injury caused by diethylnitrosamine (DEN) and phenobarbital (PB) (Shaban et al., 2013). Pomegranate *(Punica granatum* L) is valued for its high content of polyphenols including ellagic acid, ursolic acid, oleanolic and gallic acids and other flavonoids. Glucose level in blood, total cholesterol and triglycerides maintained under the effect of peel extract and shows the valuable

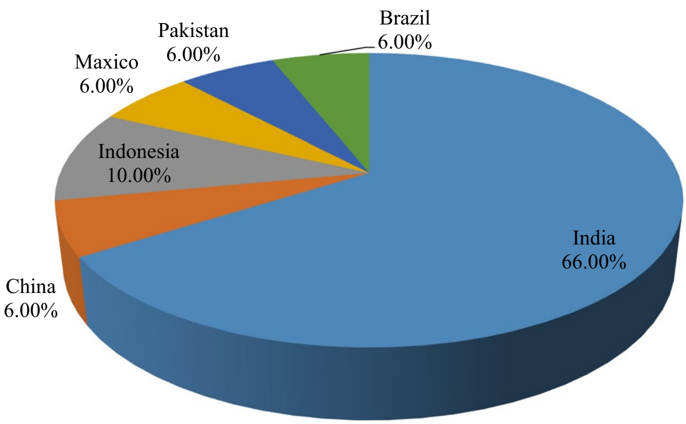

Fig. 4 Mango fruit production across the world in 2020

effect in coronary heart disease (Dos Santos et al., 2016). The action of pomegranate peel extract (PPE) potently suppressed the proliferation of thyroid cancer cell lines and induced apoptosis in cancer cells (Li et al., 2016) (Fig. 5).

PPE reduced the formation of reactive oxygen species (ROS), inflammatory cytokine expression, and cell adhesion molecules in THP-1 monocytic cells (human acute monocytic leukemia cell line) exposed to PM10 as well as avoided inflammatory events brought on by particulate matter (Park et al., 2016). In triple negative breast cancer (TNBC) cells, PPE lowered vimentin, ZEB1, and β-catenin gene expression while increasing E-cadherin expression and caused apoptosis in cells at quite high doses (500, 1000 μg/mL) (Bagheri et al., 2018). It also helps in maintaining the blood pressure in patients of diabetes mellitus type-2 (Grabež et al., 2020).

3.2 Citrus peel

Citrus microcarpa (Kalamansi) shows hepato-protective activity against acetaminophen-induced liver damage in male Sprague Dawley rats (Casimiro et al., 2010). Extract of *Citrus limetta* fruit peel using methanol exhibited anticancer efficacy in Swiss albino mice suffering from Ehrlich ascites cancer (Kundu Sen et al., 2012). In male albino mice, *Citrus unshiu* peel extract alleviate hyperglycemia by increasing insulin/glucagon secretion and decreasing hepatic PEPCK gene expression and interaction (Park et al., 2013). Disturbing in insulin secretion in pancreatic cells leading to diabetes, is the most common disease in India. Hydroethanolic extract of *Citrus reticulata* shows anti-diabetic property (Ali et al., 2020). *Citrus sinensis* possesses anti-diabetic and anti-hypercholestermic activity (Muhtadi et al., 2015). *Citrus* species shows anticancer activity (Nair et al., 2018) and silver nanoparticles of orange peel extract (*Citrus clementina*) shows cytotoxicity against tumour rat glial C6 cells (Saratale et al., 2018).

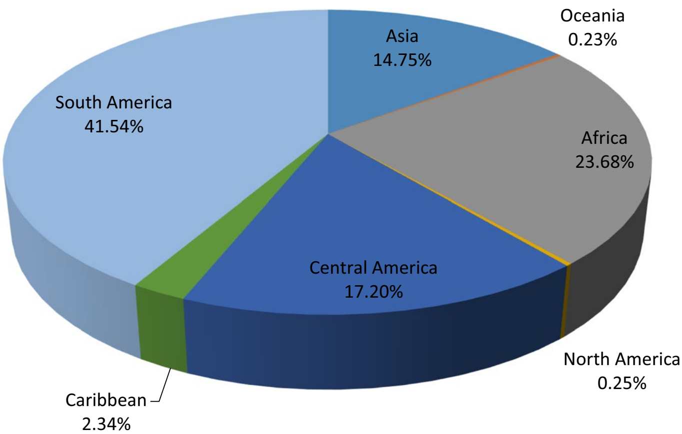

Fig. 5 Papaya fruit production across the world in 2020

3.3 Mango peel

Lipid per oxidation, membrane protein degradation, morphological changes and oxidative stress can be protected by using mango peel extract (Ajila & Rao, 2008). Mango peels are also used in fermentation process to produce polygalacturonase using *Aspergillus fumigates* (Garg & Ashfaque, 2010). The extract exhibits various kinds of activities such as anti-proliferative (Ali et al., 2012; Kim et al., 2012) and antidiabetic properties (Gondi & Rao, 2015).

3.4 Papaya peels

A live micro-organism that can be consumed as health supplements and provides health benefits is called probiotics. Production of *Lactobacillus acidophilus*, (a probiotic) can be possible with the help of papaya peel extract (Hardia & Iqbal, 2014). John et al. (2021) reported that silver nanoparticles of methanol extract of *Carica papaya* peels possesses antibacterial and anticancer activities (Fig. 6).

3.5 Banana peels

Inner peel extract of four species of banana; *Musa sapientum, M. paradisiaca, M. cavendish and M. acuminata,* was evaluated for antioxidant and antihyperglycemic activities. Out of these *M. cavendish and M. acuminata* exhibited higher antihyperglycemic activity (Navghare & Dhawale, 2017). Ethanol extract of banana peels lowers the cholesterol level and is helpful in the treatment of obesity (Berawi & Bimandama, 2018). Banana fruit peel extract also possesses anticancer activity, and it may prove beneficial to hematological parameters as there is significant elevation in RBCs, Hb, HCT, MCV, WBCs (Kamal et al., 2019).

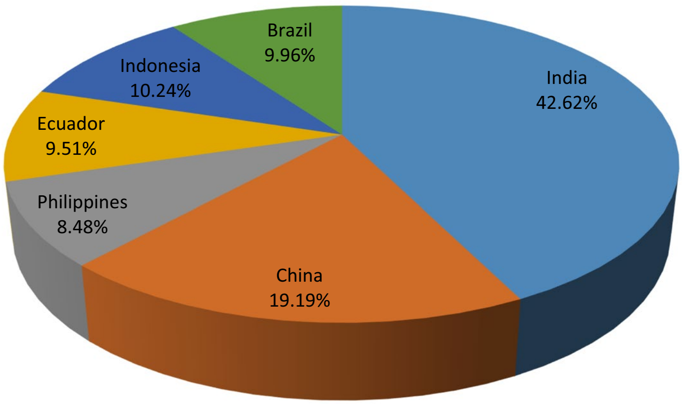

Fig. 6 Banana fruit production across the world in 2020

3.6 Apple peels

In the Western world, colorectal cancer is a primary causes of cancer-related fatalities. Colo-rectal cancer is thought to be caused by a combination of variables including diet and lifestyle. Phenolic compounds isolated from apple peel extract are beneficially altered three colo-rectal cancer risk indicators without causing cytotoxicity as it protects DNA degeneration, increase barrier function, and prevent invasion by using HT29, HT115 and CaCo-2 cell lines in vitro (McCann et al., 2007). Against HepG2 human liver cancer cells, MCF-7 human breast cancer cells, and Caco-2 human colon cancer cells, most triterpenoids extracted from apple peels demonstrated highly potent antiproliferative activity (He & Liu, 2008).

Balasuriya and Rupasinghe (2012) analysed that flavonoid rich apple peel inhibits angiotensin converting enzyme (ACE) which is helpful in treatment of high blood pressure. EtOH-AcOEt Extract of apple peel possesses ursolic acid which is responsible for anti-inflammatory activity and used in treatment of arthritis (Pádua et al., 2014). Hashemi and Yousefzadeh (2015) stated that extract of apple peels possesses triterpenoids (Ursolic acid and Oleanoilic acid), out of which Oleanoilic acid shows powerful anti-cancer activity on human B cell lymphoma. Activated carbon is prepared from apple peels, which is used in wastewater treatment (Enniya et al., 2018). Along with valuable source of antioxidant property, phenolic containing extract of apple peel also shows cyto-protective effect in Insulin-producing RINm5F cells (Yassin et al., 2018). In a hyperlipidemic rat model, the apple peels extract could operate as an antihyperlipidemic agent by lowering LDL and raising HDL levels (Susilowati et al., 2020) (Fig. 7).

4 Anti-pathogenicity

4.1 Pomegranate peel

Worm-borne illnesses are often persistent and frequently have higher mortality rates. Helminth infections caused by soil-transmitted helminths (STH) affect many people in developing countries, especially in rural areas. Pomegranate peel extract possesses

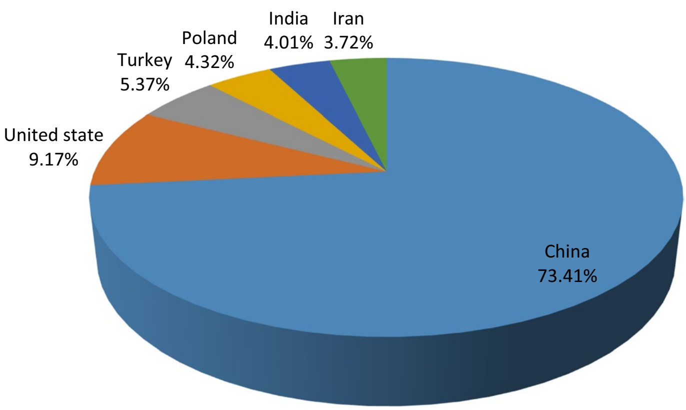

Fig. 7 Apple fruit production across the world in 2020

anthelmintic activity against female *Ascaris suum* (Amelia et al., 2017) under in-vitro conditions, earth worm (*Allolobophora caliginosa*) at the concentration of 300 mg/mL and shows anticoccidial activity against *Eimeria papillata* (Dkhil, 2013). One of the most prevalent gastrointestinal nematode, *Ascaridia galli*, affects a wide spectrum of domestic and wild birds around the world. The infection causes a reduction in body mass. Aqueous extract of pomegranate fruit peels shows anthelmintic property against *Ascaridia galli* (Aziz et al., 2018). Apart from these qualities, pomegranate fruit peel also contains antibacterial and insecticidal capabilities (Tables 3 and 4).

4.2 Citrus peel

Insect-borne diseases are still a major cause of sickness and death across the world. Ethanolic extract of *Citrus sinensis* exhibits insecticidal properties against the first instar larvae of *Anopheles stephensi, Aedes aegypti* and *Culex quinquefasciatus* with LC_{50} values 182.4, 204.87 and 244.70 ppm, respectively (Murugan et al., 2012). Silver nanoparticles of *Citrus limetta* peel aqueous extract exhibits antimicrobial properties against five bacteria viz. *Micrococcus luteus*, *Staphylococcus aureus*, *S. epidermidis*, *Streptococcus mutans* and *Escherichia coli* with IC_{50} values 4.28, 4.28, 4.28, 4.28 and 4.28 µg/ml, respectively and four yeast fungi, viz. *Candida albicans*, *C. glabrata*, *C. parapsilosis* and *C. tropicalis* with IC_{50} values 4.75, 5.94, 4.75 and 5.94 µg/ml, accordingly (Dutta et al., 2020). In addition to these properties, *Citrus* fruit peel extracts have antibacterial properties, as demonstrated in Tables 5.

4.3 Mango peel

Dorta et al. (2016) discovered antibiotic action against significant yeast species that cause food spoilage, including *Dekkera anomala, Hanseniaspora uvarum, Zygosaccharomtces bailii, Z. bisporus,* and *Z. rouxii,* as well as human infections by *Candida bracarensis, C. glabrata, C. nivariensis,* and *C. parapsilosis*. According to Xing et al. (2021), bactericidal action against *S. aureus* was more effective than against *E. coli* because silver nanoparticles prepared from mango peel extract, can sterilize by destroying cell walls, preventing enzyme respiration, and harming the DNA replication pathway. According to Table 6, mango peel extract has antimicrobial properties against a variety of bacteria, fungi, and viruses.

4.4 Papaya peels

Papaya is rich in vitamin A, B, and C as well as proteolytic enzymes like papain and chymopapain, which have antiviral, antifungal, and antibacterial activities (Orhue & Momoh, 2013). Aqueous extract of papaya peel shows insecticidal activity against *Aedes aegypti* (Hayatie et al., 2015). Due to the synergistic action of secondary metabolites like alkaloids, terpenoids, saponins, tannins, and flavonoids, the silver nanoparticles of green papaya peels exhibit an increase in the antibacterial activity (Agarwal et al., 2015). Papaya also has antibacterial and antiviral properties in addition to its insecticidal properties (Table 7).

Table 3 Antimicrobial properties of pomegranate peels extract prepared by using different solvents

Extraction Solvent	Target organism	Toxicity value	References
Aqueous	*Staphylococcus aureus, Escherichia coli and Aspergillus niger*	10.7, 340.5, 17.3 µg/ mL	Anesini and Perez (1993)
Aqueous	*Salmonella typhi*	73.4 µg/mL	Perez and Anesini, (1994)
Aqueous, hexane, and alcohol	*Bacillus subtilis, Proteus bulgaris, Salmonella typhimurium, Pseudomonas aeruginosa, Escherichia coli and Staphylococcus aureus*	–	Ahmad et al. (1998)
Ethanol	*Staphylococcus aureus*	61.5 µg/mL	Machado et al. (2002)
Acetone[a], Methanol[b] and Aqueous[c]	*Bacillus cereus, Bacillus subtilis, B. coagulens, Staphylococcus aureus, E. coli, and Pseudomonas aeruginosa*	200, 150, 187.5, 200,200 and 200[a] ppm 250, 250, 250, 350, 500 & 250[b] ppm 400, 500, 600, 450, 700 & 400[c] ppm	Negi and Jayaprakasha (2003)
Aqueous and methanol	*Escherichia coli, Shigella and Salmonella*	–	Alanis et al. (2005)
Carbopol, water and triethanolamine	*Streptococcus mutans, Streptococcus sanguis, Streptococcus mitis and Candida albicans*	–	Vasconcelos et al. (2006)
Aqueous	*S. aureus, B. subtilis, E. coli, Ps. aeruginosa and P. mirabilis*	–	McCarrell et al. (2008)
Di ethyl ether, Methanol & Aqueous	*Listeria monocytogenes,Staphylococcus aureus,Bacillus subtilis,Escherichia coli,Pseudomonas aeruginosa, Klebsiella pneumoniae, Yersinia enterocolitica,Candida utilis,Saccharomy cerevisae, Aspergillus niger*	–	Al-Zoreky (2009)
Methanol	*Plasmodium*	4.2 µg/mL	Dell'Agli et al. (2009)
Ethanol, Methanol, Water and Imazalil	*Penicillium digitatum*	20.0, 15.0, 22.5 and 27.5 mg/L	Tayel et al. (2009)
Methanol	*Aspergillus niger, P. citrinum, R. oryzae, T. reesei and M. indicus, Staphylococcus aureus, Bacilus spp., E. coli, Klebsiella. pneumoniae and Pseudomonas aeruginosa*	–	Dahham et al. (2010)

Table 3 (continued)

Extraction Solvent	Target organism	Toxicity value	References
Ethanol	*Candida albicans and C. parapsilosis*	3.9, 3.9 µg/mL	Endo et al. (2010)
Ethanol	*Staphylococcus aureus, Escherichia coli, Aspergillus niger and Saccharomyces cerevisiae*	–	Ibrahium (2010)
Aqueous	*Staphylococcus aureus, Bacilus cereus, Pseudomonas*	–	Kanatt et al. (2010)
Methanol	*Propionibacterium acnes, Staphylococcus epidermidis and S. aureus*	15.6, 7.81 and 7.81 µg/mL	Panichayupakaranant et al. (2010)
Aqueous, Ethanol & Methanol	*Candida albicans*	15.0, 10.0 and 7.5 mg/L	Tayel and El-Tras (2010)
Methanol	*Streptococcus mutans, Streptococcus sanguinis, Streptococcus salivarius, Staphylococcus aureus, Staphylococcus epidermidis, Actinomyces viscosus, Lactobacillus acidophilus and Candida albicans*	–	Abdollahzadeh et al. (2011)
Ethanol	*Salmonella strains-S. typhii, S. paratyphi, S. entritidis, S. typhimurium, S. dubin, S. derby, S. choleraesuis, S. gallinarum*	250, 62.5, 1000, 1000, 500, 500, 62.5, 62.5 µg/mL	Choi et al.(2011)
Aqueous, Methanol and ethanol	*Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa*	–	Khan & Hanee, 2011
Aqueous	*Staphylococcus aureus, Escherichia coli, Salmonella Enteritidis, A.parasiticus, and A.parasiticus*	–	Oraki et al., 2011
Ethanol and Aqueous	*Vibrio cholera, Vibrio parahemolyticus, species of Shigella, Salmonella, Enteropathogenic Escherichia.coli, Aeromonas hydrophila, and Candida albicans*	–	Pai et al., 2011
Aqueous and methanol	*S. aureus, P. aeruginosa, C. albicans*	–	Sadeghian et al., 2011

Table 3 (continued)

Extraction Solvent	Target organism	Toxicity value	References
Aqueous[a] and methanol[b]	*Penicillium italicum, Rhizopus stolonifer and Botrytis cinerea*	17.86, 30.29, 30.92[a] 28.46, 42.29, 42.77[b] ppm	Tehranifar et al., 2011
Aqueous	*E. coli, Bacillus subtilis, Bacillus indicus, Enterbacter aerogens, Serratia marcescens, Brucella spp., Staphylococcus spp., Saccharomyces cerevisiae, Rhodotorula glutinis*	–	Yehia et al., 2011
Ethanol	*Trichomonas tenax*	–	El-Sherbini & Shoukry, 2012
Aqueous[a] and Methanol[b]	*E. coli, K. pneumoniae, B. subtilis and S. aureus*	> 12.50, > 12.50, > 12.50 and > 12.50[a] 0.78, 0.20, 0.39 and 0.39[b] mg/mL	Fawole et al., 2012
Aqueous	*Alternaria alternaria, Penicillium digitatum, P. expansum, Botrytis cineria, Stenophylium botryosum and Fusarium spp.*	–	Glazer et al., 2012
Methanol	*Staphylococcus aureus*, *Enterococcus faecalis*, *Bacillus cereus*, *Clostridium perfringens*, *Listeria monocytogenes*, *Escherichia coli*, *Pasteurella multocida*, *Pseudomonas aeroginosa*, *Salmonella typhimurium* and *Yersinia entrocolitica*	15.6, 31.3, 31.3, 31.3, 31.3, 83.3, 83.3, > 62.5, 83.3 and 31.3 mg/mL	Naziri et al., 2012
Aqueous[a], Ethanol[b] & Acetone[c]	*B. subtilis, S. aureus, E. coli and S. typhimurium//*	< 104, < 104, 207 and < 104[a] 242, 242, 499 and 242[b] 444, 444, 3500 and < 222[c] mg/mL	Nuamsetti et al., 2012
Ethanol, Methanol and Aqueous	*Bacillus cereus, S. aureus, B. subtilis, and Escherichia coli*	–	Hayrapetyan et al., 2012
Methanol	*Candida albicans*	250 mg/mL	Shafighi et al., 2012
Aqueous	*Pseudomonas*	–	Devatkal et al., 2013

Table 3 (continued)

Extraction Solvent	Target organism	Toxicity value	References
Ethanol	*(Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus Streptococcus faecalis, Erwinia cartovora and Xanthomonase campestris*	–	Hassan et al., 2013
Ethanol	*Escherichia coli, Pseudomonas aeruginosa, Morganella sp. Staphylococcus aureus, and Micrococcus sp., Candida albicans, Aspergillus niger, Alternaria alternata and Fusarium sp., Penicillium sp.*	–	Eldiasty et al., 2014
Hydro-alcoholic	*Staphylococcus aureus, Bacillus subtilis, Pseudomonas aeruginosa, Escherichia coli, Trichophyton mentagrophytes, T. rubrum, Microsporum canis, and M. gypseum*	62.5, 62.5, 250, > 1000, 125, 125, 250 and 250 µg/mL	Foss et al., 2014
Ethanol, Methanol and Aqueous	*Staphylococcus aureus, Enterobacter aerogenes, Salmonella typhi and Klebsiella pneumoniae*	–	Malviya et al., 2014
Methanol	*Staphylococcus aureus and Escherichia coli*	125 and 250 ppm	Emam-Djomeh et al. (2015)
Ethanol, Methanol and Aqueous	*Botrytis cinerea, Fusarium sambucinum, Penicillium digitatum and A. niger*	–	Hamunda et al. (2015)
Ethanol and Aqueous	*Staphylococcus aureus*	650 and 650 µg/mL	Marchi et al., 2015
Aqueous	*A. Niger and A. flavus, E. coli, P aeruginosa, S. aureus and S. typhii*	–	Bharani and Namasivayam (2016)
Methanol	*Fusarium sambucinum*	20 mg/mL	Elsherbiny et al., (2016)
Acetone[a], Aqueous[b], Ethanol[c] and Methanol[d]	*B. subtilis, E. coli, S. aureus, P. aeruginosa, S. typhimurium and A. niger*	0.25, 0.46, 0.36, 0.41, 0.66 and 0.55[a] 0.43, 0.84, 0.66, 0.72, 1.30 and 1.19[b] 0.35, 0.52, 0.45, 0.57, 0.83 and 0.89[c] 0.31, 0.54, 0.42, 0.48, 0.78 and 0.69[d] mg/mL	Ismail et al., 2016

Table 3 (continued)

Extraction Solvent	Target organism	Toxicity value	References
Hexane	*Penicillium digitatum and Penicillium italicum, Penicillium expansum and Botrytis cinerea*	–	Nicosia et al., 2016
Methanol	*Giardia lamblia*	–	Al-Margin (2017
Aqueous	*Fusarium oxysporum*	–	Rongai et al., 2017
Methanol	*Salmonella enterica, Escherichia coli, Shigella sonnei, Enterococcus faecalis, Staphylococcus aureus, Bacillus subtilis*	171, 255, 171, 255, 182 and 171 µg/mL	Rosas-Burgos et al. (2017)
Methanol and Aqueous	*Staphylococcus aureus, Bacillus sp and Streptococcus pneumonia, Escherichia coli, Klebsiella sp, Shigella sp, and Pseudomonas sp*	–	Hassan et al., 2018
Aqueous[a] and Methanol[b]	*Pseudomonas putida, Saccharomyces cerevisiae and Penicillium digitatum,*	0.072, –; 0.180[a] 0.061, 0.152 and 0.061[b] g/mL	Kharchoufi et al., 2018
Aqueous	*Bacillus cereus, Staphylococcus aureus, Listeria monocytogenes, Salmonella enteritidis, Pseudomonas aeruginosa and Escherichia coli*	15.63, 15.63, 31.25, 62.5, 62.5 and 62.5 mg/mL	Alexandre et al., 2019
Starch film)	*S. aureus, and Salmonella*	–	Ali et al., 2019
Ethanol	*Influenza virus*	6.4 µg/mL	Moradi et al., 2019
Methanol	*Cronobacter sakazakii*	6.67 mg/mL	Polat Yemis et al., 2019
Aqueous, Ethanol, hydro-ethanol and Methanol	*F. oxysporum*	–	Rongai et al., 2019
Aqueous	*Monilinia fructigena and Monilinia laxa*	9.93 and 12.84 mg/mL	El Khetabi et al., 2020

a, b, c, d are toxicity values of respective solvents

Table 4 Insecticidal properties of pomegranate peels extract prepared by using different solvents

Solvent	Target organism	Toxicity value	References
Ethanol	*Culex pipiens*	1253.9 ppm	Eldiasty et al., 2014
Aqueous, Ethanol & Methanol	*Tribolium castaneum*	–	Hamunda et al. 2014
Aqueous, Ethanol & Methanol	*Myzus persicae* and *Pthorimaea* operculella	–	Hamunda et al. (2015)

4.5 Banana peels

Chabuck et al. (2013), stated that aqueous extracts of fresh yellow banana peels could be utilized in place of synthetic medications in the treatment of bacterial illnesses. These extracts are effective against both Gram positive and negative bacteria. Bagul et al. (2017) extracted 3-carboxycoumarins compound from the waste of banana peels and used as biological agent for antibacterial, anticancer and cosmetics properties. According to Behiry et al. (2019), the methanolic extract from *Musa paradisiaca* peels demonstrated potential as a wood-biofungicide against the development of *Fusarium culmorum* and *Rhizoctonia solani*, moreover a bactericide against *Agrobacterium tumefaciens*, which might be regarded as a natural preservative for wood. Table 8 below discusses the antibacterial properties of banana peels.

4.6 Apple peels

Du et al. (2011) observed antibacterial activity of apple fruit skin against *Listeria monocytogenes* and *Escherichia coli.* According to Prakash et al. (2013), aqueous extract of apple peel shows the antibacterial activity against *Bacillus, Pseudomonas, Escherichia coli,* and *Klebsiella.* Lee et al. (2016) stated that organic solvent extracts of apple peel possess antimicrobial activity against *Salmonella enterica, Shigella flexneri, Listeria monocytogenes* and *Staphylococcus aureus.* Table 9 below discusses the antibacterial properties of apple peels.

5 Food preservative

5.1 Pomegranate peel

Pomegranate peel exhibits many bioactive compounds; hence, its by-products are used as preservative in food industry, it helps in preservation of many fruits such as strawberry (Zhang et al., 2010), citrus fruits (Pangallo et al., 2021) and it can also increase the shelf life of edible oils (El-Hadary and Taha, 2020). It also improves the characteristic of juices (Trigo et al., 2020) and pomegranate peel extract (PPE) added to popular chicken meat products to extend their shelf life in cold storage by 2–3 weeks, PPE also worked well in preventing oxidative degradation in these chicken products (Kanatt et al., 2010).

Table 5 Antimicrobial properties of Citrus peels Extracts

Species of citrus	Solvent	Target organism	Toxicity value	References
Citrus sinensis	Aqueous	*Aspergillus niger*	15.6 µg/mL	Anesini and Perez (1993)
C. sinensis	Aqueous	*Salmonella typhi*	10.3 µg/mL	Perez and Anesini (1994)
Citrus limon	Acetone, ethanol and methanol	*Pseudomonas aeruginosa*, *Salmonella typhimurium*, and *Micrococcus aureus*	–	Dhanavade et al. (2011)
Citrus sinensis, C. maxima and *C. reticulate*	Aqueous, ethanolic and chloroform	*Aspergillus niger, Candida albicans, S. aureus, and S. pyogens*	–	Mathur et al. (2011)
C. sinensis	Methanol	*Escherichia coli*	0.78 µg/mL	Dhiman et al. (2012)
Citrus limon and C. limetta	Aqueous	*Staphylococcus aureus, S. epidermidis, Streptococcus pneumoniae, S. pyogenes, S. agalactiae, Enterococcus faecalis, Escherichia coli, Enterobacter aerogenes, Klebsiella pneumoniae, Proteus spp., Salmonella Typhi, Acinetobacter spp., Moraxella catarrhalis, Pseudomonas aeruginosa* and *Candida albicans* (yeast)	–	Hindi and Chabuck (2013)
Citrus unshiu	Ethanol	*B. cereus*, *S. aureus*, and *L. monocytogenes*	20, 10 and 10 mg/mL	Min et al. (2014)

Table 5 (continued)

Species of citrus	Solvent	Target organism	Toxicity value	References
C. Limon and *C. reticulata*	Hexane, Ethyl Acetate, Acetone, Methanol and Water	*Bacillus megaterium, B. subtilis, Corynebacterium rubrum, Staphylococcus aureus, S. epidermidis, Citrobacter freundii, Enterobacter aerogenes, Klebsiella pneumoniae, Proteus mirabilis, Salmonella typhimurium, Candida albicans, C. glabrata, C. neoformans* and *C. epicola*	–	Rakholiya et al. (2014)
C. limon, *C. reticulata* and *C. sinensis*	Ethanol	*Bacillus subtilis, Enterococcus faecalis, Staphylococcus aureus, Listeria innocua, L. monocytogenes, Clostridium sporogenes, C. difficile, Acinetobacter lwoffii, A. junii, A. pittii, A. baumannii, Klebsiella spp., E. coli, Proteus vulgaris, Salmonella typhimurium*, *Pseudomonas spp.* and *Cronobacter sakazakii*	–	Casquete et al. (2015)
Citrus limetta	Aqueous	*E. coli*, *Staphylococcus aureus*, *Sterptococcus pyogens*, *Salmonella typhi, Pseudomonas aeruginosa, Aspergillus niger*, *Fusarium* and *Cladosporium*	–	Saramanda and Kaparapu (2017)
Citrus clementina	Aqueous	*Escherichia coli, Bacillus cereus,* and *Staphylococcus aureus*	40.0, 40.0 and 50.0 µg/mL	Saratale et al., 2018

Table 5 (continued)

Species of citrus	Solvent	Target organism	Toxicity value	References
C. sinensis	Methanol[a] and Aqueous[b]	*Pseudomonas aeruginosa, Klebsiella pneumoniae, Serratia marcescens, Escherichia coli, Proteus vulgaris, Salmonella typhi, Staphylococcus aureus, Enterococcus faecalis, Aeromonas hydrophila, Streptococcus pyogenes, Listeria monocytogenes, Lactobacillus casei, Aspergillus niger and Penicillium citrinum, Candida albicans* and *Saccharomyces cerevisiae*	350, 310, 280, 320, 290, 280, 420, 400, 410, 370, 510, 520, > 1000, > 1000, > 1000 and > 1000[a] And 210, 200, 250, 270, 210, 220, 340, 260, 400, 340, 470, 510, 950, > 1000, > 1000 and 930[b] μg/mL	Saleem and Saeed (2020)
C. Limonia Osbeck	Methanol[a] and Aqueous[b]	*Pseudomonas aeruginosa, Klebsiella pneumoniae, Serratia marcescens, Escherichia coli, Proteus vulgaris, Salmonella typhi, Staphylococcus aureus, Enterococcus faecalis, Aeromonas hydrophila, Streptococcus pyogenes, Listeria monocytogenes, Lactobacillus casei, Aspergillus niger and Penicillium citrinum, Candida albicans and Saccharomyces cerevisiae*	210, 140, 200, 220, 220, 250, 320, 260, 280, 210, 340, 270, 960, > 1000, > 1000 and 660[a] And 160, 130, 150, 140, 130, 210, 270, 140, 280,250, 300, 320, 900, 960, 920 and 960[b] μg/mL	Saleem and Saeed (2020)

a, b are toxicity values of respective solvents

Table 6 Antimicrobial properties of Mango peels Extracts prepared by using different solvents

Extraction solvent	Target organism	Toxicity value	References
Ethanol	*S. aureus Strains*	–	Oliveira et al. (2016)
Aqueous	*B. cereus, B. megaterium, B. subtilis, Corynebacterium rubrum, L. monocytogenes, Micrococcus flavus, S. albus, E. coli, Klebsiella aerogenes, Enterobacter aerogenes, Proteus mirabilis, Pseudomonas aeruginosa, Candida albicans,* and *C. neoformans*	–	Rakholiya et al. (2014)
Aqueous, Ethanol and Acetone	*E.coli, Salmonella typhi, Enterobacter Shigella species* and *Aspergillus Niger*	–	Thambi et al. (2016)
Methanol	*S. Aureus, E. coli, E. faecalis, B. subtillis* and *B. cereus*	–	Falusi et al. (2017)
Ethanol	*Staphylococcus aureus, Escherichia coli, Pseudomonas aerogenes,, Bacillus cereus* and *Candida albicans*	–	El-Desoukey et al. (2020)
Ethanol	*Colletotrichum gloeosporioides, Mucor, Sclerotinia sclerotiorum* and *Fusarium oxysporum*	702.239, 757.178, 1275.7 and 930.07 ppm	Rojas et al. (2020)
Aqueous	*S. Aureus* and *E. coli*	1.557 and 2.335 mg/mL	Xing et al. (2021)

Table 7 Antimicrobial properties of Papaya peels Extracts prepared by using different solvents

Extraction solvent	Target organism	Toxicity value	References
Ethanol	*Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, Proteus species* and *Enterococcus faecalis*	–	Akujobi et al. (2010)
Aqueous, 70% ethanol, 80% methanol and Acetone	*Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, Aspergilus niger, Candita albicans* and *Trichophyton rubrum*	–	Khan et al. (2012)
Water[a], Ethanol[b], 1% HCl[c], Acetone[d] and Petroleum Ether[e]	*S. aureus, E. coli* and *Pseudomonas aeruginosa*	30, 30, 0.0[a] 28, 28, 28[b] 9.6, 9.6,15.6[c] 24, 30, 30[d] 2.0, 2.0, 2.0[e] mg/mL	Orhue and Momoh (2013)
Hexane, Ethyl Acetate, Acetone, Methanol and Water	*Bacillus megaterium, B. subtilis, Corynebacterium rubrum, Staphylococcus aureus, S. epidermidis, Citrobacter freundii, Enterobacter aerogenes, Klebsiella pneumoniae, Proteus mirabilis, Salmonella typhimurium, Candida albicans, C. glabrata, C. neoformans* and *C. epicola*	–	Rakholiya et al. (2014)
Methanol, Ethanol, Ethyl Acetate, Dichloromethane, n-Butanol and n-hexane	*Staphylococcus aureus, and Bacillus cereus, Escherichia coli* and *Pasteurellamultocida*	–	Asghar et al. (2016)
Aqueous and Ethanol	*Escherichia coli, Staphylococcus aureus* and *Pseudomonas aeruginosa*	–	Egbuonu et al. (2016)
Aqueous[a] and Acetone[b]	*Bacillus subtilis, E.coli, Klebsiella pneumoniae, Staphylococcus aureus* and *Aspergillus flavus*	10, 10, 1.25, 1.25 and 500 mg/μL[a] 1.25, 1.25, 2.5, 1.25 and 500 mg/μL[b]	Lydia et al. (2016b)
Ethanol	*S. aureus, B. subtilis, P. aeruginsa,* and *E. coli*	–	Siddique et al. (2018)
Methanol	*E. coli, S. aureus, Klebsiella pneumonia* and *Pseudomonas aeruginosa*	19.90, 51.94, 3.489 and 5.805 μL/mL	John et al. (2021)

a, b, c, d are toxicity values of respective solvents

Table 8 Antimicrobial properties of Banana peels extracts prepared in different solvent

Extraction Solvent	Target organism	Toxicity value	References
Acetone	*Bacillus cereus*, *Salmonella enteritidis*, *Escherichia coli*, *Bacillus subtilis* and *Staphylococcus aureus*	250, 350, 300, 270 and 330 ppm	Mokbel and Hashinaga (2005)
Aqueous	*S. aureus, S. pyogenes, E. aerogenes, K. pneumoniae, E. coli, M. catarrhalis* and *candida albicanis*	–	Chabuck et al. (2013)
Ethanol[a] and Aqueous[b]	*Bacillus subtilis, Staphylococcus aureus, Micrococcus leutus, Klebsiella Pneumoniae, Pseudomonas aeruginosa, Escherichia coli* and *Salmonella typhi*	512.5, 512.5, 256, 32, 128, 64 and 16[a] and 1025, nil, nil, 128, 512, 64 and nil[b] mg/mL	Ehiowemwenguan et al. (2014)
Hexane, Ethyl Acetate, Acetone, Methanol and Water	*Bacillus megaterium, B. subtilis, Corynebacterium rubrum, Staphylococcus aureus, S. epidermidis, Citrobacter freundii, Enterobacter aerogenes, Klebsiella pneumoniae, Proteus mirabilis, Salmonella typhimurium, Candida albicans, C. glabrata, C. neoformans* and *C. epicola*	–	Rakholiya et al. (2014)
Isopropyl alcohol	*Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans*	–	Kapadia et al. (2015)
Aqueous	*S. aureus, B. subtilis, P. aeruginsa, E. coli*	–	Siddique et al. (2018)
Methanol	*Agrobacterium tumefaciens, Dickeya solani, Erwinia amylovora, Pseudomonas cichorii, Serratia pylmuthica, Fusarium culmorum* and *Rhizoctonia solani*	–	Behiry et al. (2019)
Ethyl acetate and Aqueous	*Pseudomonas aeruginosa, Klebsiella pneumoniae, Serratia marcescens, Escherichia coli, Proteus vulgaris, Salmonella typhi, Staphylococcus aureus, Enterococcus faecalis, Aeromonas hydrophila, Streptococcus pyogenes, Listeria monocytogenes, Lactobacillus casei, Aspergillus niger and Penicillium citrinum, Candida albicans and Saccharomyces cerevisiae*	410, 370, 500, 520, 300, 310, 790, > 1000, 670, 720, 780, 600, 980, > 1000, 540 and 670[a] And 380, 350, 290, 490, 280, > 1000, 650, > 1000, 630, 590, 670, 570, 970, > 1000, 510 and 530[b] µg/mL	Saleem and Saeed (2020)

a, b are toxicity values of respective solvents

Table 9 Antimicrobial properties of Apple peels extracts prepared from different solvent

Extraction solvent	Target organism	Toxicity value	References
Acetone: Water: Acetic acid; Ethyl acetate: Methanol: Water and Ethanol: Water	*Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Enterococcus faecalis* and *Listeria monocytogenes*	–	Alberto et al. (2006)
Styrene–divinylbenzene	*Helicobacter pylori*	31.4 µg/mL	Pastene et al. (2009)
Aqueous	*Listeria monocytogenes* and *Escherichia coli*	–	Du et al. (2011)
Ethanol	*Bacillus cereus*, *Escherichia coli*	2.50 µg/g	Freatianni et al. (2011)
Aqueous	*Bacillus, Pseudomonas, Escherichia coli, and Klebsiella*	–	Prakash et al. (2013)
Acetic acid, Tartaric acid, Citric acid, Propionic acid and Lactic acid	*Salmonella enterica, Shigella flexneri, Listeria monocytogenes* and *Staphylococcus aureus*	0.80, 0.80, 6.25 and 6.25[a] 1.07, 1.07, 6.25 and 6.25[b] 1.07, 1.07, 10.42 and 12.50[c] 0.67, 0.80, 6.25 and 6.25[d] 1.33, 1.33, 6.25 and 8.33[e]	Lee et al. (2016)

a, b, c, d, e are toxicity values of respective solvents

5.2 Citrus peel

The pectin from citrus peels may be used as a natural and inexpensive binder in dosage forms. It may prove to be a superior to commercially available synthetic binders (Khule et al., 2012). Pectin is mostly used in food as a gelling, thickening and stabilizing agent. The most common use is to give jams, jellies, and marmalades a jelly-like consistency when they would otherwise be sweet liquids. The presence and extraction of pectin from the sweet lime peel was confirmed by Devi et al. (2014).

5.3 Mango peel

Mango peel extract-containing PVA-cyclodextrin-gelatin film is a feasible solution for the creation of active food packaging that may be utilised as the main packaging material (Kanatt & Chawla, 2018). Mango waste product components are being proposed as novel sources of sustainable packaging materials, and they can also be used as active ingredients (Oliver-Simancas et al., 2021).

6 Production of bio-enzymes

Fruit wastes may be readily used in homes to create a crude solution of the hydrolytic enzymes, often known as bioenzymes or trash enzymes. Bio-composites are inexpensive materials that have the ability to increase plant production, improve soil texture, enrich the soil's nutritional quality, and prevent the formation of diseases.

6.1 Citrus peel

The production of pectinases, cellulases, and hemicellulases from *Citrus limetta* peels and endopolygalacturonase is made from *Citrus limon* peels demonstrated to be a superior substrate (Pathak et al., 2017). The eco-enzyme solutions are inexpensive since they are made from fruit waste, which is plentiful in supply. They offer significant promise for treating home wastewater as well as decreasing the burden on managing organic solid waste. Additionally, the eco-enzyme solutions created in this manner have demonstrated utility for cleaning, various residential, and agricultural uses (Patel et al., 2021).

6.2 Banana peels

According to Kokab et al. (2003), with the help of banana peel and solid-state fermentation (SSF), *Bacillus subtilis* synthesized alpha amylase. Many beneficial substances were isolated from banana peels (pectin, beta-cryptoxanthin, phenolic antioxidants, trans α carotene, trans β carotene, beta-tocopherol, vitamin E, phenolic compounds, gallic acid, ketones sterols, lipids, esters, pigments, glucose, fructose, amines, and ethylene) (Pathak et al., 2016). Banana Peels used as a substrate to produce enzymes such as α-amylase, cellulase, xylanase, laccase, manganese peroxidase and lipase (Pathak et al., 2017).

7 Other uses

7.1 Pomegranate peel

Pomegranate peel extracts possess many kinds of activities such as it inhibits the melanosis formation in white shrimp (Fang et al., 2013), inhibits mild steel corrosion in hydrochloric acid conditions. The efficiency of inhibition increased as the extract concentration was raised and the effect was attributed to the chemical components found in the extract solution adsorbing on the mild steel surface (Ashassi-Sorkhabi et al., 2015). The ZnO nanoparticles prepared from fruit peel extract of pomegranates were used as reducing and stabilizing agents in synthesis process, which also exhibits antibacterial and anticancer properties (Sukri et al., 2019).

7.2 Citrus peel

Several bacteria (*Actinobacillus succinogenes, Anaerobiospirillum succiniciproducens, Mannheimia succiniciproducens*), yeast (*S. cerevisiae*), and fungi (*Byssochlamys nivea, Aspergillus* etc.) were employed to produce succinic acid from Orange, Mausami, and Lemon Peels. Orange peel is also used to prepare citric acid and lactic acid as natural sources (Pathak et al., 2017).

7.3 Papaya peels

Biogas is renewable fuel which is produced by organic breakdown of agricultural, animal and food wastes. It is a mixture of gases, as methane and carbon dioxide are the major constituents. It can be used in different fields such as heating and electricity generation and used for vehicle fuel. Dahunsi et al., (2017) used the extract of papaya peel waste in successful production of biogas. Chaubey et al., (2018) reported the hydrochloric acid (HCl) extract of *Carica papaya* peel to inhibit the corrosion effect in aluminum alloy.

7.4 Banana peels

Banana peels are helpful to remove cadmium ions from industrial wastewater, thus they may be employed in wastewater treatment (Memon et al., 2008). The release of liquid petroleum hydrocarbon into the marine ecosystem due to human activity, causes pollution to the environment, and is called oil spill. Banana peels can be used as oil spill cleanup due to its satisfactory results on sorption capacity for gas oil (El-Din et al., 2018). In water and wastewater treatment turbidity arises due to colloidal and suspended particles, and it can be removed by coagulation–flocculation method. The aqueous extract of banana peel extract acts as natural coagulants to remove turbidity from stimulated turbid water (Deverey et al., 2019).

7.4.1 Extraction techniques

A useful resource to produce dietary supplements, nutritional additives, and therapeutic foods is bioactive chemicals. It has been shown that the majority of these bioactive compounds might have health-promoting properties, including anti-cancer, cardioprotective, antimicrobial, antiseptic, and anti-obesity properties. The bioactive compounds being extracted may need different extraction techniques. The separation processes can be impacted by several factors, including heat, plant components, pressure, and solvent type (Milovanovic et al., 2022). Flow-chart of extraction techniques listed in Fig. 8.

Conventional processes are referred to as usual ways since they have been in use for an extended period. The three conventional extraction techniques are found to be hydro-distillation, Soxhlet extraction, and maceration (Ali et al., 2022). Even nevertheless, these methods were initially devised just for lipid extraction, significant bioactive chemicals have long been extracted from a number of plant sections using Soxhlet extraction. As a standard technique for isolating essential oil, hydro-distillation is an established process. A common method for obtaining medicinal plants is maceration, which is typically used to herbal remedies (Khoddami et al., 2013).

Reduce the amount of organic solvent used, speed up the extraction process, and are easy to use in innovative methods of extraction. Methods for extracting bioactive ingredients that are primarily focussed on enzyme-assisted extraction, solvent extraction (SE), solid–liquid extraction, pulsed electric field (PEF), microwave-assisted extraction (MAE),

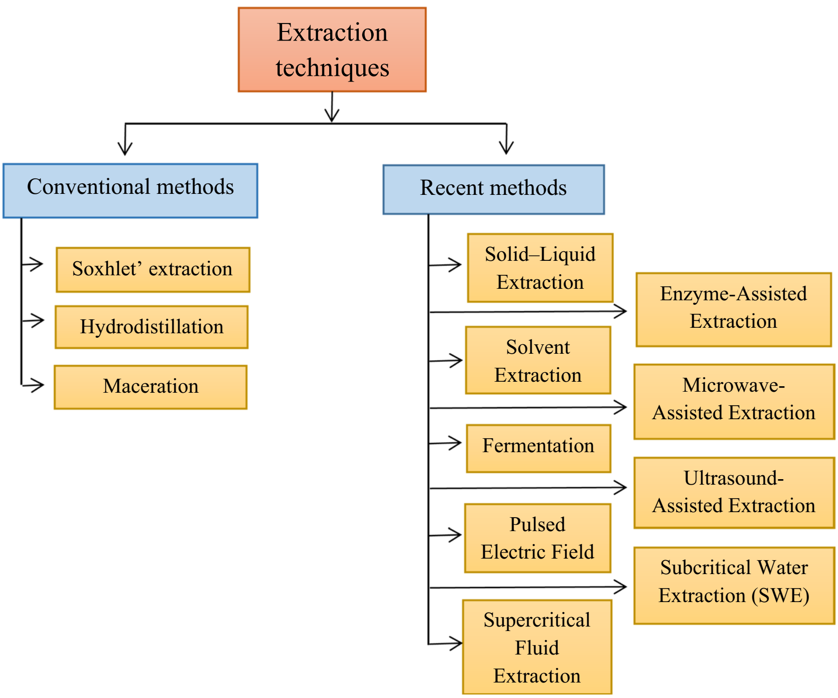

Fig. 8 Schematic representation of different techniques of extraction

subcritical water extraction (SCW), ultrasound-assisted extraction (UAE), and supercritical fluid extraction (SFE) (Ali et al., 2022). Solid–liquid extraction is one of the most widely applied techniques for phenolic chemical extraction from agricultural and culinary waste. It does, however, come with a cost, restricted output, lengthy processing periods, and the use of organic solvents, which are excellent for extracting phenolic substances but have several drawbacks of their own, including toxicity, heating, and non-biodegradability (Welton, 2015). In solvent extraction, solvents need less energy and are recyclable, non-volatile, biodegradable, and non-toxic. The selection of a solvent affects the extraction process. The best option would be a solvent with a low boiling point, rapid mass transfer, and little toxicity. Solvent extraction is a better approach than other comparable ones because of its low operating costs and ease of usage (Ali et al., 2022). Frequently, enzymes are employed in enzyme-assisted extraction to extract beneficial compounds from food waste. Because it uses water (solvent) instead of organic solvents, enzyme-aided extraction is thought to be a more environmentally benign method of extracting bioactive chemicals and oil. The foundation is in the capacity of enzymes to facilitate interactions in aqueous environments with mild processing conditions (Khoddami et al., 2013; Nadar et al., 2018). Using microorganisms to transform food waste products into useful products, fermentation is one of the first product-specific processes. Solid-state fermentation is the method of fermentation wherein microbes develop on solid substrates without encountering liquid. The process of liquefying or fermenting a medium in an environment of water is known as submerged fermentation (Sadh et al., 2018). Fruit wastes and remains may presently be transformed into valuable chemicals using a new and creative method called pulsed electric field (PEF). To achieve this remarkable separation method, a material is "sandwiched" between two electrodes and exposed to high-voltage microsecond pulses. PEF is a wonderful way to separate compounds that are heat-sensitive (Barba et al., 2015). Heat is produced inside the substance during due to the fact that microwave-assisted extraction (MAE) conductivity of ions and dipolar rotation of the interior molecules. Requiring fewer organic solvents, requiring shorter time for extraction (usually less than 30 min), and producing higher extraction yields are some benefits of using MAE procedures (Khoddami et al., 2013). Liquid solvents are used to extract chemical and inorganic components derived from solid matrices more easily by using ultrasonic radiation, which has frequencies higher than 20 kHz. Like MAE, ultrasound-aided extraction (UAE) reduces the quantity of solvent and time needed for successfully extracting phenolic chemicals from agri-food residues (Ali et al., 2022). A supercritical fluid extraction is a kind of solvent that develops when the fluid's temperature and pressure rise over its critical values. Moreover, compared to other procedures, there is a much-reduced chance of contaminating the sample with solvent contaminants and the deterioration of extracted chemicals may be prevented in the absence of light and air (Khoddami et al., 2013). Subcritical water extraction (SCWE) is additional eco-friendly extraction techniques that has been effectively used to separate phenolic chemicals. It has been shown that SCWE treatment is strong enough to remove a variety of polar to low-polar molecules. For the extraction of significant volumes of phenolic chemicals without leaving harmful organic solvent residues, SCWE may be a useful substitute industrial technique (Khoddami et al., 2013).

7.4.2 Risk assessment study

Another aspect of this review is the risk assessment study of these fruit peels. Pomegranate fruit peels do not significantly alter the body mass, haematological, cytotoxic, or genotoxic characteristics of Swiss mice (Vale et al., 2020). The levels of albumin, total protein, alkaline phosphatase (ALK-P), aspartate amino transferase (AST), and alanine amino transferase (ALT) remained largely unchanged when Wistar rats were compared to the normal control group using aqueous extracts of banana fruit peels (Edenta et al., 2017). Like this, Ehigiator et al. (2018) conducted the study demonstrating the negligible impact of banana peel extracts on the liver, kidney, or serum lipids in Sprague Dawley rats. The parameters included in this study were organ weight, serum alkaline phosphatase, aminotransferases, total cholesterol, conjugated bilirubin, total bilirubin, urea, uric acid, creatinine, glucose, low density lipoprotein, high density lipoprotein, and triglycerides total protein, albumin, and serum electrolytes. According to Organisation for Economic Co-operation and Development (OECD) Guidelines 423, Reddy et al. (2020) conducted an oral acute toxicity analysis in Alzheimer's Wistar albino rats and observed no significant changes in behavioural parameters or unfavourable effects from a single dosage of 2000 mg/kg papaya peel extract. Thus, turning fruit leftovers (peel) into necessary materials or goods might not only open new research avenues but also assist mitigate existing environmental problems.

7.4.3 Uncertainties affecting the scalability and commercialization of fruit peels

The scalability of common fruit peels waste management using their pharmaceutical and insecticidal attributes can be significantly affected by various uncertainties. Here is a breakdown of the key uncertainties and their potential impacts:

a) Resource availability and variability

Fluctuations in fruit production, seasonality, and pest infestations can impact the consistent availability of fruit peels in enormous quantities. Variations in peel quality (e.g., ripeness, pesticide residues) may influence how well bioactive chemicals are extracted and how effective they are. Extraction of bioactive substances in large quantities might require dedicated land for peel drying or composting, potentially competing with agricultural or other land uses. Water scarcity in certain regions could limit the feasibility of washing and processing copious quantities of peels.

b) Technical uncertainties

Efficient and scalable techniques used to extract bioactive substances from fruit peels are crucial for economic viability. Scaling up lab-scale processes to industrial levels might encounter unforeseen challenges, leading to reduced yields or increased processing costs. Formulating bioactive extracts into stable and effective pharmaceuticals or insecticides can be challenging. Uncertainties regarding shelf life, compatibility with other ingredients, and potential deterioration in different environmental circumstances can affect product marketability and long-term efficacy.

c) Regulatory and market uncertainties

Extensive safety and efficacy testing is required for commercializing pharmaceuticals and insecticides derived from fruit peels. Regulatory hurdles and lengthy approval processes can significantly delay or even prevent market entry.

Public perception and acceptance of natural products generated from waste items such as fruit peels can be uncertain. The market for these goods might be in need of be lower than anticipated, affecting the economic viability of scaling up waste management efforts.

d) Environmental and sustainability uncertainties

The environmental impact of large-scale peel processing needs careful consideration. Increased water and energy consumption, potential generation of hazardous waste during extraction, and transportation and storage-related greenhouse gas emissions are all aspects that can undermine the sustainability of the waste management approach. Fruit peel waste management using their bioactive properties might compete with existing practices like composting or anaerobic digestion. Careful evaluation of the environmental and economic benefits compared to existing options is crucial to ensure optimal waste management strategies.

Overall, addressing these uncertainties through comprehensive research, pilot projects, and robust economic and environmental assessments is essential for realizing the full potential of scaling up common fruit peels waste management using their valuable pharmaceutical and insecticidal attributes. By proactively addressing these uncertainties, researchers, entrepreneurs, and policymakers can contribute to developing sustainable and scalable solutions for fruit peel waste management, while simultaneously unlocking the potential of these natural resources for pharmaceutical and insecticidal applications.

8 Conclusion

India generates a staggering quantity of garbage every day, with fruit peel trash accounting for twenty to fifty percent of the waste generated by the fruit processing industry. These days, it's rare to find opportunities to recover useful components from fruit peel waste that able to be employed as a feedstock. The initial components and all processing stages possess an effect on the waste's composition, amount, and quality. Increased sustainability in the use of all resources (such as water, fertilisers, preserving soil health, and effective land management) would result from more thorough and efficient use of biomass related to food production. The findings of this review show that peel extracts have various therapeutic effects in addition to being high in flavonoids and polyphenols. These fruit peel extracts are quite effective in treating ailments, especially considering their plant origin and minimal environmental impact. Therefore, it makes sense to suggest turning fruit peels—which are now underutilized—into more commercially viable raw materials in order to make greater use of them. A byproduct called peel extract may be added to dietary supplements and pharmaceutical products. A recent report found that extracts from pomegranate peels have the strongest antibacterial properties of any frequently consumed fruit. The present review, therefore, demonstrated that fruit peels have a great deal of promise to act as a prototype for future antibacterial therapies that are safer, more effective, and better. Moreover, these natural fruit-based medicines can be disposed of safely than conventional drugs. It also increases the food items' shelf life as well as is a highly nutritious supplement. Apple pomace has a great deal of potential for use as a source of novel, strong, safe, and superior antioxidant and antibacterial chemicals, according to the findings of numerous fruit peel studies. Furthermore, there is still a lot of uncharted territory to be covered and the majority of action mechanisms that need to be explained, despite the fact that many of study has been done in previously, few years regarding the possible health advantages of chemicals that have been reported. Considering the current review, fruit peels have a considerable therapeutic potential and provide a number of health advantages for both humans and animals.

Therefore, the potential uses of fruit peel extracts as an inexpensive and abundant source of phenolic chemicals depend on clearly defined goals for future research: (a) the creation of inexpensive, effective techniques for phenolic compound recovery; (b) the potential application of phenolic compounds as beneficial ingredients in food or medicine; (c) the production of valuable goods; and (d) a decrease in environmental pollution. Fruit peels are suggested for use in a number of disciplines. An overview of sophisticated extraction methods for isolating and purifying phenolics from plant-based sources was given in this paper, along with outlines on certain sophisticated approaches for plant phenolic separation and identification. Subcritical water extraction has a number of benefits over conventional extraction techniques, including less expensive extracting agents, quicker extraction times, higher-quality extract, and a more environmental friendly process. The administration of fruit peel extracts in this particular scenario did not result in significant organ damage; nevertheless, the observed changes might be attributed to the extracts' low toxicity when used over an extended period of time. In addition to helping to develop scalable and sustainable methods for managing fruit peel waste, searchers, entrepreneurs, and legislators can unlock the potential of these natural resources for use in pharmaceutical and insecticidal applications by taking proactive steps to address these uncertainties.

Acknowledgements We would like to express our gratitude to all authors of the references included in this review article, as it contains information that was gathered from a variety of published sources.

Author contributions L. Mohan and S. Gupta: Conceptualization and Methodology, S. Gupta: Writing-Original Draft, S. Sharma: Writing-Review & Editing, A. P. Sikarwar and N. Loach: Investigation, L. Mohan: Supervision and Writing-Review & Editing.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability The data will be made available on the request.

Declarations

Conflict of interest There is no conflict of interest to the authors.

Involvement of human/animal in the article In this review article, there is no participation or involvement of any human/animal.

References

Abdollahzadeh, S. H., Mashouf, R. Y., Mortazavi, H., Moghaddam, M. H., Roozbahani, N., & Vahedi, M. (2011). Antibacterial and antifungal activities of *Punica granatum* peel extracts against oral pathogens. *Journal of Dentistry (tehran, Iran), 8*(1), 1.

Agarwal, R., Garg, N., Kashyap, S. R., & Chauhan, R. P. (2015). Antibacterial finish of textile using papaya peels derived silver nanoparticles. *Indian Journal of Fibre and Textile Research (IJFTR), 40*(1), 105–107. https://doi.org/10.56042/ijftr.v40i1.4947

Agourram, A., Ghirardello, D., Rantsiou, K., Zeppa, G., Belviso, S., Romane, A., & Giordano, M. (2013). Phenolic content, antioxidant potential, and antimicrobial activities of fruit and vegetable by-product extracts. *International Journal of Food Properties, 16*(5), 1092–1104.

Ahmad, I., Mehmood, Z., & Mohammad, F. (1998). Screening of some Indian medicinal plants for their antimicrobial properties. *Journal of Ethnopharmacology, 62*(2), 183–193.

Ajila, C. M., Naidu, K. A., Bhat, S. G., & Rao, U. P. (2007). Bioactive compounds and antioxidant potential of mango peel extract. *Food Chemistry, 105*(3), 982–988.

Ajila, C. M., & Rao, U. P. (2008). Protection against hydrogen peroxide induced oxidative damage in rat erythrocytes by *Mangifera indica* L. peel extract. *Food and Chemical Toxicology, 46*(1), 303–309.

Akujobi, C. N., Ofodeme, C. N., & Enweani, C. A. (2010). Determination of antibacterial activity of *Carica papaya* (pawpaw) extracts. *Nigerian Journal of Clinical Practice, 13*(1), 55–57.

Alanis, A. D., Calzada, F., Cervantes, J. A., Torres, J., & Ceballos, G. M. (2005). Antibacterial properties of some plants used in Mexican traditional medicine for the treatment of gastrointestinal disorders. *Journal of Ethnopharmacology, 100*(1–2), 153–157.

Alberto, M. R., Rinsdahl Canavosio, M. A., & Manca de Nadra, M. C. (2006). Antimicrobial effect of polyphenols from apple skins on human bacterial pathogens. *Electronic Journal of Biotechnology*. https://doi.org/10.2225/vol9-issue3-fulltext-1

Alexandre, E. M., Silva, S., Santos, S. A., Silvestre, A. J., Duarte, M. F., Saraiva, J. A., & Pintado, M. (2019). Antimicrobial activity of pomegranate peel extracts performed by high pressure and enzymatic assisted extraction. *Food Research International, 115*, 167–176.

Ali, A., Chen, Y., Liu, H., Yu, L., Baloch, Z., Khalid, S., Zhu, J., & Chen, L. (2019). Starch-based antimicrobial films functionalized by pomegranate peel. *International Journal of Biological Macromolecules, 129*, 1120–1126.

Ali, A. M., Gabbar, M. A., Abdel-Twab, S. M., Fahmy, E. M., Ebaid, H., Alhazza, I. M., & Ahmed, O. M. (2020). Antidiabetic potency, antioxidant effects, and mode of actions of *Citrus reticulata* fruit peel hydroethanolic extract, hesperidin, and quercetin in nicotinamide/streptozotocin-induced wistar diabetic rats. *Oxidative Medicine and Cellular Longevity*. https://doi.org/10.1155/2020/1730492

Ali, A., Riaz, S., Sameen, A., Naumovski, N., Iqbal, M. W., Rehman, A., & Manzoor, M. F. (2022). The disposition of bioactive compounds from fruit waste, their extraction, and analysis using novel technologies: A review. *Processes, 10*(10), 2014.

Ali, M. R., Yong, M. J., Gyawali, R., Mosaddik, A., Ryu, Y. C., & Cho, S. K. (2012). Mango (*Mangifera indica* L.) peel extracts inhibit proliferation of HeLa human cervical carcinoma cells via induction of apoptosis. *Journal of the Korean Society for Applied Biological Chemistry, 55*(3), 397–405.

Al-Megrin, W. A. (2017). In vivo study of pomegranate (*Punica granatum*) peel extract efficacy against Giardia lamblia in infected experimental mice. *Asian Pacific Journal of Tropical Biomedicine, 7*(1), 59–63.

Al-Zoreky, N. S. (2009). Antimicrobial activity of pomegranate (*Punica granatum* L.) fruit peels. *International Journal of Food Microbiology, 134*(3), 244–248.

Amelia, M., Jasaputra, D. K., & Tjokropranoto, R. (2017). Effects of pomegranate peel (*Punica granatum* L.) extract as an anthelmintic. *Journal of Medicine and Health*, *1*(5).

Anesini, C., & Perez, C. (1993). Screening of plants used in Argentine folk medicine for antimicrobial activity. *Journal of Ethnopharmacology, 39*(2), 119–128.

Ani, P. N., & Abel, H. C. (2018). Nutrient, phytochemical, and antinutrient composition of *Citrus maxima* fruit juice and peel extract. *Food Science and Nutrition, 6*(3), 653–658.

Asghar, N., Naqvi, S. A. R., Hussain, Z., Rasool, N., Khan, Z. A., Shahzad, S. A., & Jaafar, H. Z. (2016). Compositional difference in antioxidant and antibacterial activity of all parts of the *Carica papaya* using different solvents. *Chemistry Central Journal, 10*(1), 1–11.

Ashassi-Sorkhabi, H., Mirzaee, S., Rostamikia, T., & Bagheri, R. (2015). Pomegranate (*Punica granatum*) peel extract as a green corrosion inhibitor for mild steel in hydrochloric acid solution. *International Journal of Corrosion*.

Asmaa, M. J. S., Ali, A. J. H., Farid, J. M., & Azman, S. (2015). Growth inhibitory effects of crude pomegranate peel extract on chronic myeloid leukemia, K562 cells. *International Journal of Applied and Basic Medical Research, 5*(2), 100.

Aziz, A. R. A., AbouLaila, M. R., Aziz, M., Omar, M. A., & Sultan, K. (2018). In vitro and in vivo anthelmintic activity of pumpkin seeds and pomegranate peels extracts against *Ascaridia galli*. *Beni-Suef University Journal of Basic and Applied Sciences, 7*(2), 231–234.

Bagheri, M., Fazli, M., Saeednia, S., Kor, A., & Ahmadiankia, N. (2018). Pomegranate peel extract inhibits expression of β-catenin, epithelial mesenchymal transition, and metastasis in triple negative breast cancer cells. *Cellular and Molecular Biology, 64*(7), 86–91.

Bagul, S. D., Rajput, J. D., & Bendre, R. S. (2017). Synthesis of 3-carboxycoumarins at room temperature in water extract of banana peels. *Environmental Chemistry Letters, 15*(4), 725–731.

Bai, X., Lai, T., Zhou, T., Li, Y., Li, X., & Zhang, H. (2018). In vitro antioxidant activities of phenols and oleanolic acid from mango peel and their cytotoxic effect on A549 cell line. *Molecules, 23*(6), 1395.

Balasuriya, N., & Rupasinghe, H. V. (2012). Antihypertensive properties of flavonoid-rich apple peel extract. *Food Chemistry, 135*(4), 2320–2325.

Barba, F. J., Parniakov, O., Pereira, S. A., Wiktor, A., Grimi, N., Boussetta, N., & Vorobiev, E. (2015). Current applications and new opportunities for the use of pulsed electric fields in food science and industry. *Food Research International, 77*, 773–798.

Behiry, S. I., Okla, M. K., Alamri, S. A., El-Hefny, M., Salem, M. Z., Alaraidh, I. A., & Salem, A. Z. (2019). Antifungal and antibacterial activities of *Musa paradisiaca* L. peel extract: HPLC analysis of phenolic and flavonoid contents. *Processes 7*(4), 215.

Berawi, K. N., & Bimandama, M. A. (2018). The effect of giving extract ethanol of Kepok banana peel (*Musa acuminata*) toward total cholesterol level on male mice (*Musa musculus* L.) strain Deutschland-denken-yoken (ddy) obese. *Biomedical and Pharmacology Journal*, *11*(2).

Bharani, R. A., & Namasivayam, S. K. R. (2016). Pomegranate (*Punica granatum* L.) peel extract-a study on potential source of pharmacological activities. *International Journal of Pharma and Bio Sciences, 7*(4), 282–290.

Cargnin, S. T., & Gnoatto, S. B. (2017). Ursolic acid from apple pomace and traditional plants: A valuable triterpenoid with functional properties. *Food Chemistry, 220*, 477–489.

Casimiro, M., Franchesca, M., Gutierrez, M., Leano, D. R., Judilynn, N., & Solidum, E. (2010). Evaluation of the hepatoprotective activity of *Citrus microcarpa* Bunge (Family Rutaceae) fruit peel against acetaminophen-induced liver damage in male BFAD-Sprague Dawley rats. *International Journal of Chemical and Environmental Engineering 1*(2).

Casquete, R., Castro, S. M., Martín, A., Ruiz-Moyano, S., Saraiva, J. A., Córdoba, M. G., & Teixeira, P. (2015). Evaluation of the effect of high pressure on total phenolic content, antioxidant, and antimicrobial activity of citrus peels. *Innovative Food Science and Emerging Technologies, 31*, 37–44.

Chabuck, Z. A. G., Al-Charrakh, A. H., Hindi, N. K. K., & Hindi, S. K. K. (2013). Antimicrobial effect of aqueous banana peel extract, Iraq. *Res. Gate. Pharm. Sci*, *1*, 73–5.

Chaubey, N., Singh, V. K., & Quraishi, M. A. (2018). Papaya peel extract as potential corrosion inhibitor for Aluminium alloy in 1 M HCl: Electrochemical and quantum chemical study. *Ain Shams Engineering Journal, 9*(4), 1131–1140.

Chidambara Murthy, K. N., Jayaprakasha, G. K., & Singh, R. P. (2002). Studies on antioxidant activity of pomegranate (*Punica granatum*) peel extract using in vivo models. *Journal of Agricultural and Food Chemistry, 50*(17), 4791–4795.

Choi, J. G., Kang, O. H., Lee, Y. S., Chae, H. S., Oh, Y. C., Brice, O. O., Kim, M.S., Sohn, D. H.., Kim, H. S., Park, H., Shin, D. W., Rho, J. R. & Kwon, D. Y., (2011). In vitro and in vivo antibacterial activity of *Punica granatum* peel ethanol extract against Salmonella. *Evidence-Based Complementary and Alternative Medicine*.

Chukwuka, K. S., Iwuagwu, M., & Uka, U. N. (2013). Evaluation of nutritional components of *Carica papaya* L. at dissimilar stages of ripening. *IOSR Journal of Pharmacy and Biological Sciences, 6*(4), 13–16.

Dahham, S. S., Ali, M. N., Tabassum, H., & Khan, M. (2010). Studies on antibacterial and antifungal activity of pomegranate (*Punica granatum* L.). *American-Eurasian Journal of Agricultural & Environmental Science, 9*(3), 273–281.

Dahunsi, S. O., Oranusi, S., & Efeovbokhan, V. E. (2017). Cleaner energy for cleaner production: Modeling and optimization of biogas generation from *Carica papaya* s (Pawpaw) fruit peels. *Journal of Cleaner Production, 156*, 19–29.

Daverey, A., Tiwari, N., & Dutta, K. (2019). Utilization of extracts of *Musa paradisica* (banana) peels and *Dolichos lablab* (Indian bean) seeds as low-cost natural coagulants for turbidity removal from water. *Environmental Science and Pollution Research, 26*(33), 34177–34183.

Dell'Agli, M., Galli, G. V., Corbett, Y., Taramelli, D., Lucantoni, L., Habluetzel, A., & Bosisio, E. (2009). Antiplasmodial activity of *Punica granatum* L. fruit rind. *Journal of Ethnopharmacology, 125*(2), 279–285.

Devatkal, S. K., Jaiswal, P., Jha, S. N., Bharadwaj, R., & Viswas, K. N. (2013). Antibacterial activity of aqueous extract of pomegranate peel against *Pseudomonas stutzeri* isolated from poultry meat. *Journal of Food Science and Technology, 50*(3), 555–560.

Devi, W. E., Kumar, R. S. K. B. A., & Mishra, A. A. (2014). Extraction of pectin from citrus fruit peel and its utilization in preparation of jelly. *International Journal of Engineering Research*, *3*(5).

Dhanavade, M. J., Jalkute, C. B., Ghosh, J. S., & Sonawane, K. D. (2011). Study antimicrobial activity of lemon (*Citrus lemon* L.) peel extract. *British Journal of Pharmacology and Toxicology, 2*(3), 119–122.

Dhiman, A., Nanda, A., Ahmad, S., & Narasimhan, B. (2012). In vitro antimicrobial status of methanolic extract of *Citrus sinensis* Linn. fruit peel. *Chronicles of Young Scientists*, *3*(3).

Dkhil, M. A. (2013). Anti-coccidial, anthelmintic and antioxidant activities of pomegranate (*Punica granatum*) peel extract. *Parasitology Research, 112*(7), 2639–2646.

Dorta, E., González, M., Lobo, M. G., & Laich, F. (2016). Antifungal activity of mango peel and seed extracts against clinically pathogenic and food spoilage yeasts. *Natural Product Research, 30*(22), 2598–2604.

Dorta, E., Lobo, M. G., & Gonzalez, M. (2012). Reutilization of mango byproducts: Study of the effect of extraction solvent and temperature on their antioxidant properties. *Journal of Food Science, 77*(1), C80–C88.

Dos Santos, R. L., Dellacqua, L. O., Delgado, N. T., Rouver, W. N., Podratz, P. L., Lima, L. C., Piccin, M. P., Meyrelles, S. S., Mauad, H., Graceli, J. B., & Moyses, M. R. (2016). Pomegranate peel extract attenuates oxidative stress by decreasing coronary angiotensin-converting enzyme (ACE) activity in hypertensive female rats. *Journal of Toxicology and Environmental Health, Part A, 79*(21), 998–1007.

Du, W. X., Olsen, C. W., Avena-Bustillos, R. J., Friedman, M., & McHugh, T. H. (2011). Physical and antibacterial properties of edible films formulated with apple skin polyphenols. *Journal of Food Science, 76*(2), M149–M155.

Dutta, T., Ghosh, N. N., Das, M., Adhikary, R., Mandal, V., & Chattopadhyay, A. P. (2020). Green synthesis of antibacterial and antifungal silver nanoparticles using *Citrus limetta* peel extract: Experimental and theoretical studies. *Journal of Environmental Chemical Engineering, 8*(4), 104019.

Eberhardt, M. V., Lee, C. Y., & Liu, R. H. (2000). Antioxidant activity of fresh apples. *Nature, 405*(6789), 903–904.

Edenta, C., Okoduwa, S. I., & Okpe, O. (2017). Effects of aqueous extract of three cultivars of banana (*Musa acuminata*) fruit peel on kidney and liver function indices in wistar rats. *Medicines, 4*(4), 77.

Egbuonu, A. C. C., Harry, E. M., & Orji, I. A. (2016). Comparative proximate and antibacterial properties of milled *Carica papaya* (pawpaw) peels and seeds. *BJPR, 12*(1), 1–8.

Ehigiator, B. E., Offonry, N. C., Adikwu, E., & Inemesit, B. O. (2018). Safety, anti-inflammatory and analgesic assessments of methanolic extract of Musa paradisiaca peel in Sprague Dawley rats. *African Journal of Pharmacology and Therapeutics, 7*(2), 46–52.

Ehiowemwenguan, G., Emoghene, A. O., & Inetianbor, J. E. (2014). Antibacterial and phytochemical analysis of Banana fruit peel. *IOSR Journal of Pharmacy, 4*(8), 18–25.

El Khetabi, A., Lahlali, R., Askarne, L., Ezrari, S., El Ghadaroui, L., Tahiri, A., Hrustic, A., & Amiri, S. (2020). Efficacy assessment of pomegranate peel aqueous extract for brown rot (*Monilinia* spp.) disease control. *Physiological and Molecular Plant Pathology, 110*, 101482.

El-Desoukey, R. M. A., Aljor, N. M., & Alaotibi, A. D. (2020). The phytochemical and antimicrobial effect of mango (*Mangifera indica* L.) peel extracts on some animal pathogens as eco-friendly. *Acta Scientific Microbiology, 3*(4), 34–39.

Eldiasty, J. G., Hassan, M. M., & Kamel, O. M. (2014). Evaluation of some agricultural waste extracts against mosquito larvae, and some types of microorganisms as insecticidal and antibiotic agents. *Egyptian Academic Journal of Biological Sciences, G. Microbiology, 6*(1), 1–16.

El-Din, G. A., Amer, A. A., Malsh, G., & Hussein, M. (2018). Study on the use of banana peels for oil spill removal. *Alexandria Engineering Journal, 57*(3), 2061–2068.

El-Hadary, A. E., & Taha, M. (2020). Pomegranate peel methanolic-extract improves the shelf-life of edible-oils under accelerated oxidation conditions. *Food Science and Nutrition, 8*(4), 1798–1811.

El-Sherbini, G. T., & Shoukry, N. M. (2012). In vitro effect of pomegranate peel extract on *Trichomonas tenax*. *Life Science Journal, 9*(3), 791–797.

Elsherbiny, E. A., Amin, B. H., & Baka, Z. A. (2016). Efficiency of pomegranate (*Punica granatum* L.) peels extract as a high potential natural tool towards *Fusarium* dry rot on potato tubers. *Post Harvest Biology and Technology, 111*, 256–263.

Emam-Djomeh, Z., Moghaddam, A., & Yasini Ardakani, S. A. (2015). Antimicrobial activity of pomegranate (*Punica granatum* L.) peel extract, physical, mechanical, barrier and antimicrobial properties of pomegranate peel extract-incorporated sodium caseinate film and application in packaging for ground beef. *Packaging Technology and Science, 28*(10), 869–881.

Endo, E. H., Cortez, D. A. G., Ueda-Nakamura, T., Nakamura, C. V., & Dias Filho, B. P. (2010). Potent antifungal activity of extracts and pure compound isolated from pomegranate peels and synergism with fluconazole against *Candida albicans*. *Research in Microbiology, 161*(7), 534–540.

Enniya, I., Rghioui, L., & Jourani, A. (2018). Adsorption of hexavalent chromium in aqueous solution on activated carbon prepared from apple peels. *Sustainable Chemistry and Pharmacy, 7*, 9–16.

Escarpa, A., & Gonzalez, M. C. (1998). High-performance liquid chromatography with diode-array detection for the determination of phenolic compounds in peel and pulp from different apple varieties. *Journal of Chromatography A, 823*(1–2), 331–337.

Falusi, V., Adesina, I., Aladejimokun, A., & Elehinafe, T. (2017). Phytochemical screening and antibacterial activity of methanolic extracts of ripe and unripe peels of mango (*Mangifera indica* L.). *Journal of Applied Life Sciences International, 14*, 1–7.

Fang, X. B., Sun, H. Y., Huang, B. Y., & Yuan, G. F. (2013). Effect of pomegranate peel extract on the melanosis of Pacific white shrimp (*Litopenaeus vannamei*) during iced storage. *Journal of Food, Agriculture and Environment, 11*(1), 105–109.

Fawole, O. A., Makunga, N. P., & Opara, U. L. (2012). Antibacterial, antioxidant and tyrosinase-inhibition activities of pomegranate fruit peel methanolic extract. *BMC Complementary and Alternative Medicine, 12*(1), 200.

Foss, S. R., Nakamura, C. V., Ueda-Nakamura, T., Cortez, D. A., Endo, E. H., & Dias Filho, B. P. (2014). Antifungal activity of pomegranate peel extract and isolated compound punicalagin against dermatophytes. *Annals of Clinical Microbiology and Antimicrobials, 13*(1), 1–6.

Fratianni, F., Coppola, R., & Nazzaro, F. (2011). Phenolic composition and antimicrobial and antiquorum sensing activity of an ethanolic extract of peels from the apple cultivar *Annurca*. *Journal of Medicinal Food, 14*(9), 957–963.

Garg, N., & Ashfaque, M. (2010). Mango peel as substrate for production of extra cellular polygalacturonase from *Aspergillus fumigatus*. *Indian Journal of Horticulture, 67*(1), 140–143.

Glazer, I., Masaphy, S., Marciano, P., Bar-Ilan, I., Holland, D., Kerem, Z., & Amir, R. (2012). Partial identification of antifungal compounds from *Punica granatum* peel extracts. *Journal of Agricultural and Food Chemistry, 60*(19), 4841–4848.

Gondi, M., & Rao, U. P. (2015). Ethanol extract of mango (*Mangifera indica* L.) peel inhibits α-amylase and α-glucosidase activities, and ameliorates diabetes related biochemical parameters in streptozotocin (STZ)-induced diabetic rats. *Journal of Food Science and Technology, 52*(12), 7883–7893.

Grabež, M., Škrbić, R., Stojiljković, M. P., Rudić-Grujić, V., Paunović, M., Arsić, A., Petrović, S., Vučić, V., Mirjanić-Azarić, B., Šavikin, K., Menković, K., Janković, Y., & Vasiljević, N. (2020). Beneficial effects of pomegranate peel extract on plasma lipid profile, fatty acids levels and blood pressure in patients with diabetes mellitus type-2: A randomized, double-blind, placebo-controlled study. *Journal of Functional Foods, 64*, 103692.

Hamouda, A. B., Chaieb, I., Daami-Remadi, M., & Laarif, A. (2015). In vitro evaluation of insecticidal and antifungal potencies of fruit peel extracts of pomegranate (*Punica granatum*). *Central European Journal of Experimental Biology, 4*(1), 11–15.

Hamouda, A. B., Mechi, A., Zarred, K., Chaieb, I., & Laarif, A. (2014). Insecticidal Activities of Fruit Peel Extracts of Pomegranate (*Punica granatum*) against the red flour beetle *Tribolium castaneum*. Tunis. *Tunisian Journal of Plant Protection, 9*(1), 91–100.

Hanafy, S. M., El-Shafea, A., Mohamed, Y., Saleh, W. D., & Fathy, H. M. (2021). Chemical profiling, in vitro antimicrobial and antioxidant activities of pomegranate, orange, and banana peel-extracts against pathogenic microorganisms. *Journal of Genetic Engineering and Biotechnology, 19*(1), 1–10.

Hardia, S., & Iqbal, S. (2014). Production of the best natural health supplements using fruit waste materials. *The International Journal of Innovative Research and Development, 3*(5), 131–133.

Hashemi, M., & Yousefzadeh, M. (2015). Anticancer effects of triterpenoid extracted from apple peel on human B cell lymphoma. In *International conference on plant, marine and environmental sciences-PMES* (pp. 1–2).

Hassan, N. A., El-Feky, G. S., & Elegami, H. M. (2013). Antibacterial activity of thirty-two pomegranate (*Punica granatum* L.) accessions growing in Egypt fruit peels. *World Applied Sciences Journal, 21*(7), 960–967.

Hassan, S. M., Hamad, A. K., & Farhan, A. (2018). The effect of pomegranate extracts on bacteria. *Journal of Raparin University-Vol, 5*(15), 5.

Hayatie, L., Biworo, A., & Suhartono, E. (2015). Aqueous extracts of seed and peel of *Carica papaya* against Aedes Aegypti. *Journal of Medical and Bioengineering 4*(5).

Hayrapetyan, H., Hazeleger, W. C., & Beumer, R. R. (2012). Inhibition of *Listeria monocytogenes* by pomegranate (*Punica granatum*) peel extract in meat paté at different temperatures. *Food Control, 23*(1), 66–72.

He, X., & Liu, R. H. (2008). Phytochemicals of apple peels: Isolation, structure elucidation, and their antiproliferative and antioxidant activities. *Journal of Agricultural and Food Chemistry, 56*(21), 9905–9910.

Hegazy, A. E., & Ibrahium, M. I. (2012). Antioxidant activities of orange peel extracts. *World Applied Sciences Journal, 18*(5), 684–688.

Hindi, N. K. K., & Chabuck, Z. A. G. (2013). Antimicrobial activity of different aqueous lemon extracts. *Journal of Applied Pharmaceutical Science, 3*(6), 074–078.

Ho, S. C., & Lin, C. C. (2008). Investigation of heat-treating conditions for enhancing the anti-inflammatory activity of citrus fruit (*Citrus reticulata*) peels. *Journal of Agricultural and Food Chemistry, 56*(17), 7976–7982.

Ibrahium, M. I. (2010). Efficiency of pomegranate peel extract as antimicrobial, antioxidant, and protective agents. *World Journal of Agricultural Sciences, 6*(4), 338–344.

Iqbal, S., Haleem, S., Akhtar, M., Zia-ul-Haq, M., & Akbar, J. (2008). Efficiency of pomegranate peel extracts in stabilization of sunflower oil under accelerated conditions. *Food Research International, 41*(2), 194–200.

Ismail, T., Akhtar, S., Sestili, P., Riaz, M., Ismail, A., & Labbe, R. G. (2016). Antioxidant, antimicrobial and urease inhibitory activities of phenolics-rich pomegranate peel hydro-alcoholic extracts. *Journal of Food Biochemistry, 40*(4), 550–558.

Ismail, T., Sestili, P., & Akhtar, S. (2012). Pomegranate peel and fruit extracts: A review of potential anti-inflammatory and anti-infective effects. *Journal of Ethnopharmacology, 143*(2), 397–405.

Jamal, P., Akbar, I., Jaswir, I., & Zuhanis, Y. (2017). Quantification of total phenolic compounds in papaya fruit peel. *Pertanika Journal of Tropical Agricultural Science*, *40*(1).

John, T., Parmar, K. A., Kotval, S. C., & Jadhav, J. (2021). Synthesis, characterization, antibacterial and anticancer properties of silver nanoparticles synthesized from *Carica papaya* peel extract. *International Journal of Nanoscience and Nanotechnology, 17*(1), 23–32.

Kamal, A. M., Taha, M. S., & Mousa, A. M. (2019). The radioprotective and anticancer effects of banana peels extract on male mice. *Journal of Food and Nutrition Research, 7*, 827–835.

Kanatt, S. R., Chander, R., & Sharma, A. (2010). Antioxidant and antimicrobial activity of pomegranate peel extract improves the shelf life of chicken products. *International Journal of Food Science and Technology, 45*(2), 216–222.

Kanatt, S. R., & Chawla, S. P. (2018). Shelf life extension of chicken packed in active film developed with mango peel extract. *Journal of Food Safety, 38*(1), e12385.

Kapadia, S. P., Pudakalkatti, P. S., & Shivanaikar, S. (2015). Detection of antimicrobial activity of banana peel (*Musa paradisiaca* L.) on Porphyromonas gingivalis and Aggregatibacter actinomycetemcomitans: An in vitro study. *Contemporary Clinical Dentistry, 6*(4), 496.

Khan, J. A., & Hanee, S. (2011). Antibacterial properties of *Punica granatum* peels. *International Journal of Applied Biology and Pharmaceutical Technology, 2*(3), 23–27.

Khan, J. A., Yadav, J., Srivastava, Y., & Pal, P. K. (2012). In vitro evaluation of antimicrobial properties of *Carica papaya*. *International Journal of Biology, Pharmacy and Allied Sciences, 1*(7), 933–945.

Kharchoufi, S., Licciardello, F., Siracusa, L., Muratore, G., Hamdi, M., & Restuccia, C. (2018). Antimicrobial and antioxidant features of 'Gabsi' pomegranate peel extracts. *Industrial Crops and Products, 111*, 345–352.

Khoddami, A., Wilkes, M. A., & Roberts, T. H. (2013). Techniques for analysis of plant phenolic compounds. *Molecules, 18*(2), 2328–2375.

Khule, N. R., Mahale, N. B., Shelar, D. S., Rokade, M. M., & Chaudhari, S. R. (2012). Extraction of pectin from citrus fruit peel and use as natural binder in paracetamol tablet. *Der Pharmacia Lettre, 4*(2), 558–564.

Kim, H., Kim, H., Mosaddik, A., Gyawali, R., Ahn, K. S., & Cho, S. K. (2012). Induction of apoptosis by ethanolic extract of mango peel and comparative analysis of the chemical constitutes of mango peel and flesh. *Food Chemistry, 133*(2), 416–422.

Kim, H., Moon, J. Y., Kim, H., Lee, D. S., Cho, M., Choi, H. K., & Cho, S. K. (2010). Antioxidant and antiproliferative activities of mango (*Mangifera indica* L.) flesh and peel. *Food Chemistry, 121*(2), 429–436.

Kokab, S., Asghar, M., Rehman, K., Asad, M. J., & Adedyo, O. (2003). Bioprocessing of banana peel for α-amylase production by *Bacillus subtilis*. *International Journal of Agriculture and Biology, 5*(1), 36–39.

Kumar, C. C., Mythily, R., & Chandraju, S. (2012). A rapid and sensitive extraction of sugars from papaya peels (*Carica papaya*). *Der Pharma Chem, 4*(4), 1631–1636.

KunduSen, S., Bala, A., Kar, B., Bhattacharya, S., Mazumder, U. K., Gupta, M., & Haldar, P. K. (2012). Antitumor potential of *Citrus limetta* fruit peel in Ehrlich ascites carcinoma bearing Swiss albino mice. *Alternative Medicine Studies, 2*(1), e10–e10.

Lee, S. E., Han, J. H., & Han, J. (2016). Development and evaluation of apple peel-and carboxymethylcellulose-based biodegradable films with antioxidant and antimicrobial properties. *Journal of Food Safety, 36*(3), 317–324.

Li, Y., Ye, T., Yang, F., Hu, M., Liang, L., He, H., Li, Z., Zeng, A., Li, Y., Yao, Y., Xie, Y., An, Z., & Li, S. (2016). *Punica granatum* (pomegranate) peel extract exerts potent antitumor and anti-metastasis activity in thyroid cancer. *RSC Advances, 6*(87), 84523–84535.

Liang, Z., Zhang, P., & Fang, Z. (2022). Modern technologies for extraction of aroma compounds from fruit peels: A review. *Critical Reviews in Food Science and Nutrition, 62*(5), 1284–1307.

Liew, S. S., Ho, W. Y., Yeap, S. K., & Sharifudin, S. A. B. (2018). Phytochemical composition and in vitro antioxidant activities of *Citrus sinensis* peel extracts. *PeerJ, 6*, e5331.

Lydia, E., John, S., Mohammed, R., & Sivapriya, T. (2016a). Investigation on the phytochemicals present in the Fruit peel of *Carica papaya* and evaluation of its antioxidant and antimicrobial property. *Research Journal of Pharmacognosy and Phytochemistry, 8*(4), 217–222.

Lydia, E., Riyazudin, M., John, S., & Thiyagarajan, S. (2016b). Investigation on the phytochemicals present in the fruit peel of *Carica papaya* and evaluation of its antioxidant properties. *International Journal of Health and Allied Science, 5*, 247–252.

Machado, T. D. B., Leal, I. C., Amaral, A. C. F., Santos, K., Silva, M. G. D., & Kuster, R. M. (2002). Antimicrobial ellagitannin of *Punica granatum* fruits. *Journal of the Brazilian Chemical Society, 13*(5), 606–610.

Malviya, S., Jha, A., & Hettiarachchy, N. (2014). Antioxidant and antibacterial potential of pomegranate peel extracts. *Journal of Food Science and Technology, 51*(12), 4132–4137.

Marchi, L. B., Monteiro, A. R., Mikcha, J., Santos, A., Chinelatto, M., Marques, D., Dacome, A., & Costa, S. C. (2015). Evaluation of antioxidant and antimicrobial capacity of pomegranate peel extract (*Punica granatum*l.) Under different drying temperatures. *Chemical Engineering Transactions, 44*, 121–126.

Marina, Z., & Noriham, A. (2014). Quantification of total phenolic compound and in vitro antioxidant potential of fruit peel extracts. *International Food Research Journal*, *21*(5).

Massini, L., Rico, D., Martin-Diana, A. B., & Barry-Ryan, C. (2013). Valorisation of apple peels. *European Journal of Food Research Review, 3*(1), 1–15.

Mastrogiovanni, F., Mukhopadhya, A., Lacetera, N., Ryan, M. T., Romani, A., Bernini, R., & Sweeney, T. (2019). Anti-inflammatory effects of pomegranate peel extracts on in vitro human intestinal caco-2 cells and ex vivo porcine colonic tissue explants. *Nutrients, 11*(3), 548.

Mathur, A., Verma, S. K., Purohit, R., Gupta, V., Dua, V. K., Prasad, G. B. K. S., Mathur, D., Singh, S. K., & Singh, S. (2011). Evaluation of in vitro antimicrobial and antioxidant activities of peel and pulp of some citrus fruits. *Journal of Biotechnology and Biotherapeutics, 1*(2), 1–17.

McCann, M. J., Gill, C. I. R., & O'brien, G., Rao, J. R., McRoberts, W. C., Hughes, P., McEntee, R. and Rowland, I. R. (2007). Anti-cancer properties of phenolics from apple waste on colon carcinogenesis in vitro. *Food and Chemical Toxicology, 45*(7), 1224–1230.

McCarrell, E. M., Gould, S. W., Fielder, M. D., Kelly, A. F., El Sankary, W., & Naughton, D. P. (2008). Antimicrobial activities of pomegranate rind extracts: Enhancement by addition of metal salts and vitamin C. *BMC Complementary and Alternative Medicine, 8*(1), 1–7.

Memon, J. R., Memon, S. Q., Bhanger, M. I., Memon, G. Z., El-Turki, A., & Allen, G. C. (2008). Characterization of banana peel by scanning electron microscopy and FT-IR spectroscopy and its use for cadmium removal. *Colloids and Surfaces b: Biointerfaces, 66*(2), 260–265.

Milovanovic, S., Lukic, I., Stamenic, M., Kamiński, P., Florkowski, G., Tyśkiewicz, K., & Konkol, M. (2022). The effect of equipment design and process scale-up on supercritical CO2 extraction: Case study for Silybum marianum seeds. *The Journal of Supercritical Fluids, 188*, 105676.

Min, K. Y., Kim, H. J., Lee, K. A., Kim, K. T., & Paik, H. D. (2014). Antimicrobial activity of acid-hydrolyzed *Citrus unshiu* peel extract in milk. *Journal of Dairy Science, 97*(4), 1955–1960.

Moghaddam, G., Sharifzadeh, M., Hassanzadeh, G., Khanavi, M., & Hajimahmoodi, M. (2013). Anti-ulcerogenic activity of the pomegranate peel (*Punica granatum*) methanol extract. *Food and Nutrition Sciences, 4*(10A), 43.

Mokbel, M. S., & Hashinaga, F. (2005). Antibacterial and antioxidant activities of banana (*Musa*, AAA cv. Cavendish) fruits peel. *American Journal of Biochemistry and Biotechnology, 1*(3), 125–131.

Moradi, M. T., Karimi, A., Shahrani, M., Hashemi, L., & Ghaffari-Goosheh, M. S. (2019). Anti-influenza virus activity and phenolic content of pomegranate (*Punica granatum* L.) Peel extract and fractions. *Avicenna Journal of Medical Biotechnology, 11*(4), 285.

Muhtadi, H., Azizah, T., Suhendi, A., & Yen, K. H. (2015). Antidiabetic and antihypercholesterolemic activities of *Citrus sinensis* peel: In vivo study. *National Journal of Physiology, Pharmacy and Pharmacology, 5*(5), 382–385.

Murugan, K., Kumar, P. M., Kovendan, K., Amerasan, D., Subrmaniam, J., & Hwang, J. S. (2012). Larvicidal, pupicidal, repellent and adulticidal activity of *Citrus sinensis* orange peel extract against *Anopheles stephensi, Aedes aegypti* and *Culex quinquefasciatus* (Diptera: Culicidae). *Parasitology Research, 111*(4), 1757–1769.

Nadar, S. S., Rao, P., & Rathod, V. K. (2018). Enzyme assisted extraction of biomolecules as an approach to novel extraction technology: A review. *Food Research International, 108*, 309–330.

Nair, A., Kurup, R., Sr., Nair, A. S., & Baby, S. (2018). Citrus peels prevent cancer. *Phytomedicine, 50*, 231–237.

Navghare, V. V., & Dhawale, S. C. (2017). In vitro antioxidant, hypoglycemic and oral glucose tolerance test of banana peels. *Alexandria Journal of Medicine, 53*(3), 237–243.

Naziri, Z., Rajaian, H., & Firouzi, R. (2012). Antibacterial effects of Iranian native sour and sweet pomegranate (*Punica granatum*) peel extracts against various pathogenic bacteria. *13*(4), 282–288.

Negi, P. S., & Jayaprakasha, G. K. (2003). Antioxidant and antibacterial activities of *Punica granatum* peel extracts. *Journal of Food Science, 68*(4), 1473–1477.

Nicosia, M. G. L. D., Pangallo, S., Raphael, G., Romeo, F. V., Strano, M. C., Rapisarda, P., Droby, S., & Schena, L. (2016). Control of postharvest fungal roots on citrus fruit and sweet cherries using a pomegranate peel extract. *Postharvest Biology and Technology, 114*, 54–61.

Nuamsetti, T., Dechayuenyong, P., & Tantipaibulvut, S. (2012). Antibacterial activity of pomegranate fruit peels and arils. *Science Asia, 38*(3), 319–322.

Oboh, G., & Ademosun, A. O. (2012). Characterization of the antioxidant properties of phenolic extracts from some citrus peels. *Journal of Food Science and Technology, 49*(6), 729–736.

Okonogi, S., Duangrat, C., Anuchpreeda, S., Tachakittirungrod, S., & Chowwanapoonpohn, S. (2007). Comparison of antioxidant capacities and cytotoxicities of certain fruit peels. *Food Chemistry, 103*(3), 839–846.

Oliveira, T. Í. S., Rosa, M. F., Cavalcante, F. L., Pereira, P. H. F., Moates, G. K., Wellner, N., & Azeredo, H. M. (2016). Optimization of pectin extraction from banana peels with citric acid by using response surface methodology. *Food Chemistry, 198*, 113–118.

Oliver-Simancas, R., Labrador-Fernandez, L., Díaz-Maroto, M. C., Pérez-Coello, M. S., & Alañón, M. E. (2021). Comprehensive research on mango by-products applications in food industry. *Trends in Food Science & Technology, 118*, 179–188.

Oraki, H. H., Demirci, A. Ş., & Gümüş, T. (2011). Antibacterial and antifungal activity of pomegranate (*Punica granatum* L. cv.) peel. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, *10*(3).

Orhue, P. O., & Momoh, A. R. M. (2013). Antibacterial activities of different solvent extracts of *Carica papaya* fruit parts on some gram positive and gram-negative organisms. *International Journal of Herbs and Pharmacological Research, 2*(4), 42–47.

Padilla-Camberos, E., Lazcano-Díaz, E., Flores-Fernandez, J. M., Owolabi, M. S., Allen, K., & Villanueva-Rodríguez, S. (2014). Evaluation of the inhibition of carbohydrate hydrolyzing enzymes, the antioxidant activity, and the polyphenolic content of *Citrus limetta* peel extract. *The Scientific World Journal*.

Pádua, T. A., de Abreu, B. S., Costa, T. E., Nakamura, M. J., Valente, L. M., Henriques, M. D. G., & Rosas, E. C. (2014). Anti-inflammatory effects of methyl ursolate obtained from a chemically derived crude extract of apple peels: Potential use in rheumatoid arthritis. *Archives of Pharmacal Research, 37*, 1487–1495.

Pai, V., Chanu, T. R., Chakraborty, R., Raju, B., Lobo, R., & Ballal, M. (2011). Evaluation of the antimicrobial activity of *Punica granatum* peel against enteric pathogens: An in vitro study. *Asian Journal of Plant Science and Research, 1*(2), 57–62.

Pangallo, S., Nicosia, L. D., & M. G., Scibetta, S., Strano, M. C., Cacciola, S. O., Belgacem, I., Agosteo, G. E. and Schena, L. (2021). Preharvest and postharvest applications of a pomegranate peel extract to control citrus fruit decay during storage and shelf life. *Plant Disease, 105*(4), 1013–1018.

Panichayupakaranant, P., Tewtrakul, S., & Yuenyongsawad, S. (2010). Antibacterial, anti-inflammatory, and anti-allergic activities of standardised pomegranate rind extract. *Food Chemistry, 123*(2), 400–403.

Parashar, S., Sharma, H., & Garg, M. (2014). Antimicrobial and antioxidant activities of fruits and vegetable peels: A review. *Journal of Pharmacognosy and Phytochemistry*, *3*(1).

Park, S., Seok, J. Kwak, J. Y., Suh, H. J., Kim, Y. M., & Boo, Y. C. (2016). Anti-inflammatory effects of pomegranate peel extract in THP-1 cells exposed to particulate matter PM10. *Evidence-Based Complementary and Alternative Medicine*.

Park, H. J., Jung, U. J., Cho, S. J., Jung, H. K., Shim, S., & Choi, M. S. (2013). *Citrus unshiu* peel extract ameliorates hyperglycemia and hepatic steatosis by altering inflammation and hepatic glucose-and lipid-regulating enzymes in db/db mice. *The Journal of Nutritional Biochemistry, 24*(2), 419–427.

Pastene, E., Speisky, H., Troncoso, M., Alarcon, J., & Figueroa, G. (2009). In vitro inhibitory effect of apple peel extract on the growth of *Helicobacter pylori* and respiratory burst induced on human neutrophils. *Journal of Agricultural and Food Chemistry, 57*(17), 7743–7749.

Patel, B. S., Solanki, B. R., & Mankad, A. U. (2021). Effect of eco-enzymes prepared from selected organic waste on domestic wastewater treatment. *World Journal of Advanced Research and Reviews, 10*(1), 323–333.

Pathak, P. D., Mandavgane, S. A., & Kulkarni, B. D. (2017). Fruit peel waste: characterization and its potential uses. *Current Science*, 444–454.

Pathak, P. D., Mandavgane, S. A., & Kulkarni, B. D. (2016). Valorization of banana peel: A biorefinery approach. *Reviews in Chemical Engineering, 32*(6), 651–666.

Pathak, P. D., Mandavgane, S. A., & Kulkarni, B. D. (2019). Waste to wealth: A case study of papaya peel. *Waste and Biomass Valorization, 10*(6), 1755–1766.

Pawpaw, E. O. U. (2016). Phytochemical and antioxidant analysis of aqueous extracts of unripe pawpaw (*Carica papaya* Linn.) fruit's peel and seed.
Perez, C., & Anesini, C. (1994). In vitro antibacterial activity of Argentine folk medicinal plants against *Salmonella typhi*. *Journal of Ethnopharmacology, 44*(1), 41–46.
Polat Yemis, G., Bach, S., & Delaquis, P. (2019). Antibacterial activity of polyphenol-rich pomegranate peel extract against *Cronobacter sakazakii*. *International Journal of Food Properties, 22*(1), 985–993.
Prakash, A., Mathur, K., Vishwakarma, A., Vuppu, S., & Mishra, B. (2013). Comparative assay of antioxidant and antibacterial properties of Indian culinary seasonal fruit peel extracts obtained from Vellore, Tamilnadu. *International Journal of Pharmaceutical Sciences Review and Research, 19*(1), 131–135.
Rakholiya, K., Kaneria, M., & Chanda, S. (2014). Inhibition of microbial pathogens using fruit and vege`table peel extracts. *International Journal of Food Sciences and Nutrition, 65*(6), 733–739.
Reddy, K. S., Likithasree, P., Peraman, R., Jyothi, M. V., Babu, C. N., Pradeepkumar, B., & Sudheer, A. (2020). Spatial long-term memory retention by banana and papaya peel extract: In silico and in vivo evaluation. *International Journal of Pharmaceutical Investigation, 10*(2), 202–207.
Rojas, R., Alvarez-Pérez, O. B., Contreras-Esquivel, J. C., Vicente, A., Flores, A., Sandoval, J., & Aguilar, C. N. (2020). Valorisation of mango peels: Extraction of pectin and antioxidant and antifungal polyphenols. *Waste and Biomass Valorization, 11*(1), 89–98.
Rongai, D., Pulcini, P., Di Lernia, G., Nota, P., Preka, P., & Milano, F. (2019). Punicalagin content and antifungal activity of different pomegranate (*Punica ganatum* L.) genotypes. *Horticulturae, 5*(3), 52.
Rongai, D., Pulcini, P., Pesce, B., & Milano, F. (2017). Antifungal activity of pomegranate peel extract against *fusarium* wilt of tomato. *European Journal of Plant Pathology, 147*(1), 229–238.
Rosas-Burgos, E. C., Burgos-Hernández, A., Noguera-Artiaga, L., Kačániová, M., Hernández-García, F., Cárdenas-López, J. L., & Carbonell-Barrachina, Á. A. (2017). Antimicrobial activity of pomegranate peel extracts as affected by cultivar. *Journal of the Science of Food and Agriculture, 97*(3), 802–810.
Sadeghian, A., Ghorbani, A., Mohamadi-Nejad, A., & Rakhshandeh, H. (2011). Antimicrobial activity of aqueous and methanolic extracts of pomegranate fruit skin. *Avicenna Journal of Phytomedicine, 1*(2), 67–73.
Sadh, P. K., Kumar, S., Chawla, P., & Duhan, J. S. (2018). Fermentation: A boon for production of bioactive compounds by processing of food industries wastes (by-products). *Molecules, 23*(10), 2560.
Saleem, M., & Saeed, M. T. (2020). Potential application of waste fruit peels (orange, yellow lemon, and banana) as wide range natural antimicrobial agent. *Journal of King Saud University-Science, 32*(1), 805–810.
Saramanda, G., & Kaparapu, J. (2017). Antimicrobial activity of fermented citrus fruit peel extract. *International Journal of Engineering Research and Applications, 7*, 25–28.
Saratale, R. G., Shin, H. S., Kumar, G., Benelli, G., Ghodake, G. S., Jiang, Y. Y., & Saratale, G. D. (2018). Exploiting fruit byproducts for eco-friendly nanosynthesis: *Citrus clementina* peel extract mediated fabrication of silver nanoparticles with high efficacy against microbial pathogens and rat glial tumor C6 cells. *Environmental Science and Pollution Research, 25*(11), 10250–10263.
Shaban, N. Z., El-Kersh, M. A., El-Rashidy, F. H., & Habashy, N. H. (2013). Protective role of *Punica granatum* (pomegranate) peel and seed oil extracts on diethylnitrosamine and phenobarbital-induced hepatic injury in male rats. *Food Chemistry, 141*(3), 1587–1596.
Shafighi, M., Amjad, L., & Madani, M. (2012). In vitro antifungal activity of methanolic extract of various parts of *Punica granatum* L. *International Journal of Scientific and Engineering Research, 3*(12), 2229–5518.
Shin, H. S., Kang, S. I., Ko, H. C., Kim, H. M., Hong, Y. S., Yoon, S. A., & Kim, S. J. (2011). Anti-inflammatory effect of the immature peel extract of Jinkyool (*Citrus sunki* Hort. ex Tanaka). *Food Science and Biotechnology, 20*(5), 1235–1241.
Siddique, S., Nawaz, S., Muhammad, F., Akhtar, B., & Aslam, B. (2018). Phytochemical screening and in-vitro evaluation of pharmacological activities of peels of *Musa sapientum* and *Carica papaya* fruit. *Natural Product Research, 32*(11), 1333–1336.
Sukri, S. N. A. M., Shameli, K., Wong, M. M. T., Teow, S. Y., Chew, J., & Ismail, N. A. (2019). Cytotoxicity and antibacterial activities of plant-mediated synthesized zinc oxide (ZnO) nanoparticles using *Punica granatum* (pomegranate) fruit peels extract. *Journal of Molecular Structure, 1189*, 57–65.
Sultana, B., Hussain, Z., Asif, M., & Munir, A. (2012). Investigation on the antioxidant activity of leaves, peels, stems bark, and kernel of mango (*Mangifera indica* L.). *Journal of Food Science, 77*(8), C849–C852.
Susilowati, R., Jannah, J., Maghfuroh, Z., & Kusuma, M. T. (2020). Antihyperlipidemic effects of apple peel extract in high-fat diet-induced hyperlipidemic rats. *Journal of Advanced Pharmaceutical Technology and Research, 11*(3), 128.

Tayel, A. A., El-Baz, A. F., Salem, M. F., & El-Hadary, M. H. (2009). Potential applications of pomegranate peel extract for the control of citrus green mould. *Journal of Plant Diseases and Protection, 116*(6), 252–256.

Tayel, A. A., & El-Tras, W. F. (2010). Anticandidal activity of pomegranate peel extract aerosol as an applicable sanitizing method. *Mycoses, 53*(2), 117–122.

Tehranifar, A., Selahvarzi, Y., Kharrazi, M., & Bakhsh, V. J. (2011). High potential of agro-industrial by-products of pomegranate (*Punica granatum* L.) as powerful antifungal and antioxidant substances. *Industrial Crops and Products, 34*(3), 1523–1527.

Thambi, P. A., John, S., Lydia, E., Iyer, P., & Monica, S. J. (2016). Antimicrobial efficacy of mango peel powder and formulation of recipes using mango peel powder (*Mangifera indica* L.). *International Journal of Home Science, 2*(2), 155–161.

Trigo, J. P., Alexandre, E. M., Silva, S., Costa, E., Saraiva, J. A., & Pintado, M. (2020). Study of viability of high-pressure extract from pomegranate peel to improve carrot juice characteristics. *Food and Function, 11*(4), 3410–3419.

Vale, E. P., & do Rego, L. R., Pureza, D. D. N., de Barros Silva, P. G., de Sousa, F. F. O., & Neto, M. D. A. B. M. (2020). Cytogenetic and toxicological effects of *Punica granatum* Linnaeus fruit peel hydroethanolic extract in mice. *South African Journal of Botany, 130*, 465–470.

Vasconcelos, L. C. D. S., Sampaio, F. C., Sampaio, M. C. C., Pereira, M. D. S. V., Higino, J. S., & Peixoto, M. H. P. (2006). Minimum inhibitory concentration of adherence of *Punica granatum* Linn (pomegranate) gel against *S. mutans, S. mitis* and *C. albicans*. *Brazilian Dental Journal*, *17*(3), 223–227.

Vel, T., & Stanley, S. A. (2015). Studies on the Effect of The Different Modes of Extraction on Enzyme Activity of Proteolytic Enzymes from the Peels of Three Fruit Samples *Carica papaya (*Papaya), *Ananas Comosus* (Pineapple) and *Actinidia Deliciosa* (Kiwi). *Compare*, *2*, 4.

Vu, H. T., Scarlett, C. J., & Vuong, Q. V. (2018). Phenolic compounds within banana peel and their potential uses: A review. *Journal of Functional Foods, 40*, 238–248.

Welton, T. (2015). Solvents and sustainable chemistry. *Proceedings of the Royal Society a: Mathematical, Physical and Engineering Sciences, 471*(2183), 20150502.

Wijaya, Y. A., Widyadinata, D., Irawaty, W., & Ayucitra, A. (2017). Fractionation of phenolic compounds from kaffir lime (*Citrus hystrix*) peel extract and evaluation of antioxidant activity. *Reaktor, 17*(3), 111–117.

Xing, Y., Liao, X., Liu, X., Li, W., Huang, R., Tang, J., & Yu, J. (2021). Characterization and antimicrobial activity of silver nanoparticles synthesized with the peel extract of mango. *Materials, 14*(19), 5878.

Yassin, L. S., Alberti, A., Ferreira Zielinski, A. A., da Rosa Oliveira-Emilio, H., & Nogueira, A. (2018). Cytoprotective effect of phenolic extract from brazilian apple peel in insulin-producing cells. *Current Nutrition and Food Science, 14*(2), 136–142.

Yehia, H. M., Elkhadragy, M. F., & Moneim, A. E. A. (2011). Antimicrobial activity of pomegranate rind peel extracts. *African Journal of Microbiology Research, 5*(22), 3664–3668.

Zhang, L., Zhang, Y., Cao, H., & Yang, X. (2010). Effects of pomegranate peel extract on keep-freshing of strawberry. *Transactions of the Chinese Society of Agricultural Engineering, 26*(2), 361–365.

Zhao, S. S., Ma, D. X., Zhu, Y., Zhao, J. H., Zhang, Y., Chen, J. Q., & Sheng, Z. L. (2018). Antidiarrheal effect of bioactivity-guided fractions and bioactive components of pomegranate (*Punica granatum* L.) peels. *Neurogastroenterology and Motility, 30*(7), e13364.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.