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A review: Antimicrobial activity and toxicity analysis of the peel of banana, pomegranate, papaya, and citrus fruits (lemon and orange)

Nik Khairunnisa Khir Juhari, Nurul Bahiyah Abd Wahid and Suzita Ramli*

Department of Biology, Faculty of Science and Mathematics,
Sultan Idris Education University, 35900 Tanjung Malim, Perak, Malaysia.
Email: suzita@fsmt.upsi.edu.my

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ABSTRACT

Fruits have nutrients and health-promoting compounds and usually fruits are eaten fresh with minimally processed. To meet rising demand, the production and processing of horticultural crops of fruits have grown massively in response to the population and changing dietary habits. It is rarely known that some fruit wastes, including peel, actually have their own advantages to humans as well as industry. In fact, these fruit wastes, including fruit peel, should be handled and used to minimise the environmental impacts. The functional properties of the peel of banana, pomegranate, papaya, and citrus fruits such as lemon and orange can beneficially help in the production of new health products and in food industries. Antimicrobial compounds in fruit peel play an important role in inhibiting the microbial growth, specifically pathogenic microorganisms such as *Escherichia coli*, *Bacillus aureus*, *Campylobacter*, *Salmonella*, *and Staphylococcus aureus*. The antimicrobial compounds present in the fruit peel are typically secondary metabolites consisting, in particular, of phenolic compounds, steroids and alkaloids, which give certain functional effects on human health. It has been reported that every fruit peel has its own antimicrobial compounds which are responsible for inhibiting microbial growth. These fruit peel, despite their beneficial effects, have also been shown to have toxicity effects on their consumption depending on the amount of doses used in the implementation. This review covers physiological properties, chemical properties, antimicrobial activity, and the toxicity analysis of the fruit peels from banana, pomegranate, papaya, and citrus fruits.

Keywords: Fruit peel, physiological, chemical composition, antimicrobial activity, toxicity

INTRODUCTION

During the last few decades, the food processing economy has recorded rapid growth around the world, but it has also experienced significant losses and pollution (Sagar *et al.*, 2018). Fruit waste has a major environmental effect because it is commonly used only to produce particular products in the food or pharmaceutical industries. Therefore, fruit wastes including fruit peel should be managed and utilised properly to reduce the impact towards the environment. Waste products that are released into the atmosphere have a high antimicrobial potential (Joshi *et al.*, 2012). According to Ayala-Zavala *et al.* (2010), the perishable nature of fresh-cut fruit products, as well as the large percentage of by-products produced by different stages of the industrial process, such as peels, seeds, and unused flesh, is dealt with by the fresh-cut fruit industry. In certain situations, discarded by-products have antioxidant and antimicrobial compounds that are equal to or even higher than the finished product. Besides, increased sales of fresh-cut fruits have been favored by the international public health programs and encourage fruit consumption, thus increasing the market for easy-to-eat foods (Hodge, 2003).

Antimicrobial compounds play an important role in inhibiting the microbial growth specifically pathogenic microorganisms as they are known as the naturally occurring or synthetic compounds (Singh *et al.*, 2018). These are new, safe, and cost-effective sources of antimicrobics and antioxidants that can be used to prevent diseases caused by pathogenic microbes (Joshi *et al.*, 2012). Hence, their presence may defend against diseases namely foodborne illnesses and food spoilage and they are normally secondary metabolites that consist of phenolic compounds, steroids and alkaloids particularly which gives positive and functional effects on human health (Singh *et al.*, 2018).

There have been various resolutions made in relevance the ways of re-using fruits and vegetables wastes (Duda-chodak and Tarko, 2007). As such, in the nutraceutical, cosmetic, pharmaceutical, and agribusiness

***Corresponding author**

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industries, research and production of new functional foods and health products from low-cost raw materials is crucial (Attanzio *et al.*, 2018). Mavani *et al.* (2020) mentioned that as organic substances decompose during fermentation, secondary metabolites known as bioactive compounds or phytochemicals are produced, further enhancing the antibacterial properties of fruit peel.

On a wide variety of microorganisms, the antimicrobial capacity of these widely available fruits peel waste (banana, pomegranate, papaya, lemon, and orange) has been assessed. Therefore, this review discusses the physiological activities of banana, pomegranate, papaya, and citrus fruit (lemon and orange) fruit peel, which are more specific in their functional properties. These fruits were selected in this review article because they are among the most widely consumed fruits around the world, and most people are only aware of the benefits of the flesh such as antioxidants. Besides, people are also ignorant of the antimicrobial properties of fruit peels since they are only discarded as fruit waste. The presence of the bioactive compounds will be discussed, focusing mainly on the antimicrobial activity and the toxicity analysis. On top of that, the focus on the type of extraction and the concentration needed to acquire the optimum results for the antimicrobial test will be narrowed. This information may be a good help for the food or pharmaceutical industry to be referred to as if any initiative is to be taken for some product relating these fruit peels are to be used in the future as a food additive, food preservative, and also a toxic-free food grade sanitizer.

BANANA PEEL

Physiological properties

Banana (*Musa*) which belongs to the family *Musaceae*, is one of the most popular tropical fruits in the world and known to be high in dietary fibre, protein, essential amino acids, polyunsaturated fatty acids and potassium (Parashar *et al.*, 2014). In Thailand, 200 tons of banana peels are produced every day, and this trend is expected to continue (Pangnakorn, 2006). The peel of the banana, which contributes to about 30% of the fruit, makes them to be a major by-product of the fruit and the high amount of nitrogen and phosphorus may become an environmental issue, as well as its high water content, which makes it susceptible to contamination of microorganism (González-Montelongo *et al*., 2010). The peel of a banana contains pectin, which is a strong soluble dietary fibre, and carrying out an extraction of the peel is one of the ways to utilise the waste to get the benefits from its valuable antimicrobial compounds.

In a study by Maneerat *et al*. (2017), the determination of the properties of pectin from the Nam Wa banana which is also called as *Musa* (ABB group) 'Kluai Nam Wa' peel has been conducted, and the action of that banana peel's pectin in replacing the fats in a salad cream by applying different extraction conditions have been displayed. Despite the fact that the water-extracted banana peel pectin contains a larger oil droplet size and a greater degree of droplet flocculation, the reduced-fat samples were both observed to be stable during the cream separation process, which was in 3-weeks storage. This indicates that it has the ability to substitute fat in food products.

Banana peel has many advantages as they are an effective source of soluble and insoluble fibre, and antioxidants. It is useful to combat cholesterol, protect eyesight, and have other uses such as meat tenderizer, teeth whitening, and polishing agent (Hussein *et al.*, 2019). Banana peel has also been used by the yeast *Saccharomyces cerevisiaee* to produce bioethanol since the nutrients present in a banana peel are vital and rapidly break down (Gebregergs *et al.*, 2016). In addition, Kokab *et al.* (2003) reported that banana peel has been used for the production of α-amylase using *Bacillus subtilis* through bioprocessing and a possible production of some fermented products could be produce from the banana peel, according to Patel *et al*. (2012). Glucose obtained from cellulose hydrolysis can be quickly fermented into useful products such as ethanol, lactic acid, single cell protein, and other value-added products (Chandra *et al.*, 2009). Alpha amylase is a hydrolytic enzyme, and due to its widespread use in the food, clothing, baking, and detergent industries, interest in its microbial production has grown in recent years (Asghar *et al.*, 2000).

In terms of energy recovery, the current study by Nathoa *et al.* (2014) has successfully demonstrated that two-stage banana peel fermentation is more effective than one-stage fermentation. When compared to one-stage fermentation, the total energy recovery from sequential hydrogen and methane fermentation increased by 81%, making it efficient to treat and extract hydrogen and methane from agricultural waste containing high complex organic molecules (Nathoa *et al.*, 2014).

Chemical properties

There have been more than 40 compounds identified from banana peel which can be generally classified into four sub-groups namely, hydroxycinnamic acids, flavonols, flavan-3-ols and catecholamines (Table 1) (Vu *et al*., 2018). They are essentially involved in processes of plant defence and are also considered to have various effects that promote health (Tsamo *et al*., 2015). Besides, Tsamo *et al*. (2015) also mentioned that they work as antioxidants and enzyme expression modulators, helping to relieve a broad range of chronic diseases, including cancer, diabetes, skin damage, allergies, atherosclerosis and viral infections. Banana peel is also known to contain vitamin A, vitamin C, gallocatechin, dopamine, vitamin E, vitamin B6, sitosterol, malic acid, succinic acid, palmatic acid, magnesium, potassium, phosphorus, iron, and fibre (Table 1) (Prakash *et al*., 2017).

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Table 1: Compounds present in banana peel and their functions.

Compound	Function
Hydroxycinnamic acids, flavonols, flavan-3-ols and catecholamines	Plant defence, promotes health, antioxidants, and enzyme expression modulators
Vitamin A, B6, C, and E Gallocatechin, dopamine, sitosterol, malic acid, succinic acid, palmatic acid, magnesium, potassium, phosphorus, iron, and fibre	Nutraceuticals

Kanazawa and Sakakibara (2000), Sundaram *et al*. (2011) and Fatemeh *et al*. (2012) have reported that the maturity of the fruit notably influences the phenolic content of the peel, whereby it is found that a decrease in total phenolic content occurs along with the ripening process. The percentage of the phenolic compound has been recorded regarding to this topic whereby an over-ripened fruit peel contains 52% less, whereas the ripe one contains 15–45% less phenolic content compared to that of the unripe fruit peel (Sundaram *et al*., 2011; Fatemeh *et al*., 2012).

Antimicrobial properties

In order to prevent and reduce the growth of microorganisms, antimicrobial compounds appear to exist as biological agents in certain plants and fruits. The hybrid of *Musa acuminata* with *Musa balbisiana* which is also known as Yellow *kepok* banana, contains flavonoids, tannins, alkaloids which are antibacterial compounds, and they are mainly found in Indonesia (Sutanti *et al*., 2020). Other phytochemicals or secondary metabolites found in banana peels include phlobatannins, glycosides, and terpenoids, which are responsible for the peel's antibacterial function (Imam and Akter, 2011).

According to Parashar *et al*. (2014), the peel of the green banana displayed a high antimicrobial activity by its water soluble and ethyl acetate fraction of the peel. A study conducted on the antimicrobial activity of banana peel in four different solvents like distilled water, methanol, ethanol and ethyl acetate showed that banana peel extract displays antimicrobial activity against all the tested bacteria namely *Pseudomonas aeruginosa, Klebsiella pneumoniae, Serratia marcescens, Escherichia coli, Proteus vulgaris, Salmonella typhi, Staphylococcus aureus, Enterococcus faecalis, Aeromonas hydrophila, Streptococcus pyogenes, Listeria monocytogenes,* and *Lactobacillus casei,* although some of them are slightly inhibited (Saleem and Saeed, 2020). Inhibition zone diameters of 19 mm and 17 mm against *E. coli* and *S. aureus* respectively have been shown in the assessment of antibacterial activity of banana peel solutions using the agar disc diffusion process (Bashir *et al*., 2020). The fresh banana peel extract demonstrated a substantial activity against *S. aureus* (13.55 ± 0.04) mm and *P. aeruginosa* (14.5 ± 0.00) mm, a moderate activity against *B. subtilis* (12.5 ± 0.04) mm and *E. coli* (10.51 ± 0.02) mm, whereas no activity was displayed by the dried banana peel extract against *S. aureus* (Kavitha *et al*., 2019).

In particular, the dried Kadali banana peel ash extract has been shown to exhibit antifungal activity against *Aspergillus niger* with an inhibition zone of 26 mm (Prakash *et al*., 2017). In contrast to a study by Bashir *et al*. (2020), banana (*Musa acuminate*) peel used in the application of therapeutic treatments were not successful to exhibit antifungal activity because the test solutions examined against *A. niger* were found to be ineffective as the peel solutions on potato dextrose agar did not inhibit fungal growth.

Toxicity

The toxicity of the banana peel is yet to be broadly investigated by the researchers. Mokbel and Hashinaga (2005) said that banana fruits are free from apparent toxicity as they have been consumed widely as food. Despite this, Ehigiator *et al*. (2019) conducted a study in which a methanolic extract of *Musa paradisiaca* was administered orally to Sprague Dawley rats at three separate doses of 100, 200, and 400 mg/kg with the aim of assessing the peel extract's protection, anti-inflammatory, and analgesic impact. The dose had no major (p>0.05) effects on the Sprague Dawley rats' liver, kidney, or serum lipids, consisting of organ weight, serum alkaline phosphatase, aminotransferases, conjugated bilirubin, total bilirubin, total cholesterol, triglyceride, low density lipoprotein, high density lipoprotein, glucose, creatinine, urea, uric acid, total protein, albumin, and serum electrolytes, when compared with control.

POMEGRANATE PEEL

Physiological properties

Pomegranate peel (*Punica granatum*) has been widely studied by researchers these days in science as there are still many functional properties to be revealed. Pomegranate peel extract-compatible active films have already been created (Kanatt *et al.*, 2012; Qin *et al.*, 2015). The use of pomegranate peel extract (PPE; 1% w/v) in edible coatings based on chitosan (1% w/v) and alginate (2% w/v) were observed to be effective in preserving the quality of guavas (cv. Allahabad Safeda) over a 20-days period of storage at low temperatures (Nair *et al.*, 2018). For samples coated with chitosan enriched with PPE at the end of storage, the ascorbic acid, total phenolics, total flavonoids contents, and antioxidant activity were measured with confined losses of 29%, 8%, 12%, 12% (DPPH), and 9% (FRAP),

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respectively. The main advantages of edible active coatings are that they retain the consistency of fresh fruits and prolong their shelf life while also preventing microbial spoilage.

Pomegranate peel is also used as a natural component to maintain the quality and stability of some meat products such as poultry products, goat meat, beef meat, pork meat and aquatic meat where it is claimed to be potentially effective in inhibiting the lipid oxidation and performing the degradation of meat pigments (Smaoui *et al*., 2019). In line with microbiological, sensory and oxidative analysis, the shelf life of the aqueous pomegranate peel treated chicken products is found to be extended up to 2 to 3 weeks (Kanatt *et al*., 2010). Zhuang *et al*. (2019) has discussed that the microbiota and the quality of bighead carp (*Aristichthys nobilis*) fillets which was stored at 4 °C have shown some changes after being applied by the aqueous pomegranate peel and ethanolic pomegranate peel extracts and this showed that the deterioration of sensory quality and colour of flesh have been retarded, the spoilage bacteria growth has been inhibited, and the production of biogenic amines, total volatile basic nitrogen (TVB-N) as well as the degradation of ATP-related compounds have been reduced. This may be supported by the fact that the strong activity of punicalagin isolated from pomegranate peel against *Candida albicans* and *C*. *parapsilosis* were shown, which proves its ability in inhibiting antimicrobial activity, as well as the combination of punicalagin and fluconazole, has showed a very effective synergistic interaction, as mentioned by Endo *et al*. (2010). Duman *et al*. (2009) reported that the importance of pomegranate's physicochemical properties to antimicrobial activity was related to their fruit phenolic and anthocyanin content.

Chemical properties

Pomegranates peel are very rich in bioactive compounds, especially antioxidants, which can be used for various applications, such as food, cosmetics, and pharmaceuticals, if properly extracted (Alexandre *et al*., 2017). In a study conducted by Kharchou *et al*. (2018), 40–50 percent of the total weight of pomegranate fruit is represented by its peel, which is a good source of bioactive compounds, namely hydrolysable tannins, consisting of core polyol molecules of gallic acid and ellagic acid esters (Table 2). These phenolic compounds, in which the hydrolysable tannins are mostly found in the fruit peel and mesocarp, are said to exploit their free radical scavenging and antioxidant capacity (Fischer *et al*., 2011). The presence of 61 total compounds containing gallic acid, ellagic acid, punicalin, punicalagin, malic acid, and so forth have been acquired as the major functional components during the chromatographic analysis of pomegranate peel's individual polyphenols (Table 2) (Al-Rawahi *et al*., 2014). Punicalagin is unique to pomegranate and is part of an ellagitannin family that includes the smaller tannins called punicalin and gallagic acid, distinguished by good solubility in water. Under normal physiological conditions, orally ingested ellagitannins are led to microbial hydrolysis of comparatively smaller compounds, such as ellagic acid, by intestinal microflora, and urolithins after further bacterial metabolism (Akhtar *et al*., 2015).

Pomegranates peel are known to have plenty of polyphenols which are phenolic acids, tannins and flavonoids specifically anthocyanins and these compounds have been confirmed to be effective against the pathogenic microorganisms (Table 2) (Singh *et al.*, 2018). Flavonoids such as quercetin, rutin, luteolin, pelargonidin, rodelphinidin, apigenin as well as tannins namely gallic acid, ellagic acid, punicalagin, ellagitannin (Table 2) are found to be the main antifungal components in the pomegranate peel aqueous extract as mentioned by Rongai *et al*. (2017). The flavonoid composition of pomegranate peel changes as it ages, and it also depends on the concentration of flavonols and flavones, which varies by cultivar (Singh *et al*., 2018).

Antimicrobial properties

Since pomegranates have been shown to have antimicrobial, antiviral, anti-cancer, active antioxidant, and anti-mutagenic properties, their popularity has skyrocketed in recent years (Çam and Hısıl, 2010). This fruit peel has been predominantly consumed as the natural resource against infectious diseases (Howell and Souza, 2013). The fruit pericarp (peel) of the pomegranate (*Punica granatum* L.) is one of those that contain high molecular weight phenolic compounds with good antimicrobial properties (Al-Zoreky, 2009). The antibacterial activity of the pomegranate peel is triggered by a variety of phenolic compounds, including flavonoids and tannins such as punicalagins, punicalins, gallic acid, ellagic acid, and gallic acid, which form a synergistic effect against microorganisms (Kharchou *et al*., 2018).

Table 2: Compounds present in pomegranate peel and their functions.

Compound	Function
Hydrolysable tannins (gallic acid and ellagic acid)	Free radical scavenging and antioxidant capacity
Polyphenols (phenolic acids, tannins and flavonoids)	Effective against pathogenic microorganisms
Flavonoids (quercetin, rutin, luteolin, pelargonidin, rodelphinidin, and apigenin) Tannins (gallic acid, ellagic acid, punicalagin, ellagitannin)	Antifungal agents

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In a study conducted by Prashanth *et al*. (2001), pomegranate is found to be the most effective against the tested microorganisms, in particular, against *P. vulgaris* and *B. subtilis* in the methanolic extract. Based on the 'Gabsi' accession carried out by Mansour *et al*. (2013) using methanol and water extraction, the antibacterial activity of the extracts against *Staphylococcus aureus, S. epidermidis, Salmonella typhimurium, E. coli* and *Enterococcus faecalis* by the disc diffusion method displayed with notable efficacy. Methanol and water extracts are proved to be good in inhibiting the aimed microorganisms at higher concentrations but the water extract which is shown by the viability assay in the liquid medium proved that it is able to reduce the bacterial growth and also yeast populations up to 3.15 log units (Kharchou *et al*., 2018).

Toxicity

Singh *et al.* (2018) reported that polyphenols present in the pomegranates peel act in fighting the microbial pathogens that leads to least or no toxicity to the host organism. Therefore, the toxicity of the fruit peel extract of *P. granatum* has been determined in a study conducted by Salwe *et al*. (2015) during the evaluation of the fruit peel on its antidiabetic, hypolipedimic and antioxidant activity of hydroalcoholic extract of fruit peel of *P. granatum* in male Wistar albino rats which has led to a result that shows no observation on the toxicity even though 10 times of higher doses are used and there are no changes occur when it was exceedingly used. In addition, pomegranate peel ethanol extract has been graded safe based on the Organisation for Economic Co-operation and Development (OECD) aquatic toxicity classification with LC50 of 196,037 ± 9,2 µg/mL, and the prediction of toxicity has showed that brevifolin was recognized as the safest substance among other substances found in pomegranate peel ethanol extract (Wibowo *et al*., 2018).

PAPAYA PEEL

Physiological properties

Papaya (*Carica papaya*) is recognised as a tropical fruit and also commonly known as the “medicine tree” or “melon of health” because of the parts of the fruit including the peel which are good in curing the diseases by having some bioactive compounds. People just want the flesh of papayas, so the peel is often discarded, and overproduction can pose environmental risks if the fruit peel is not used. For the treatment of indigestion, diarrhoea, lung swelling, preventing urination, blindness, tachycardia, ringworm and alopecia, the fruit, leaves, latex and stem are commonly used (Srivastava *et al*., 2016). While most of the papayas peel (~20% of the fruit weight) is mainly used in animal feed or fertiliser and has a few other commercial uses such cosmetics (Zhang *et al*., 2017; Pathak *et al.,* 2019).

As a result, using papaya peel for the active packaging of a food product is a smart option for reducing waste. Hanani *et al*. (2018) incorporated the papaya peel extract into the fish gelatin film-forming solutions before being deposited on a polyethylene (PE) layer. This led them to significantly (p<0.05) increase the thickness and moisture content of the film yet the solubility of the films decreased, giving the final appearance to be opaque and yellowish in colour. The microparticles of papaya peel powder with 7.5% concentration were proven to be effective in improving the tensile strength as well as the Young’s modulus (de Moraes *et al*., 2018). In regards to that, the active barrier of the food packaging that was improved with the lower content of peroxides (3.47 mEq/kg) was quantified after 22 days of the experiment conducted (de Moraes *et al*., 2018).

On the other hand, the *Carica papaya* L. var. Formosa peel extract showed a high content of cell wall polysaccharides and the glass transition temperature was at 38 °C which is considered high, giving it a chance to produce a dietary fibre concentrate to be applied as antioxidant concentrate with required conditions. It was determined that a 15 min extraction with 2.9 mL ethanol/g papaya peel followed by 40 °C drying provided the dietary fibre concentrates with optimal values.

Chemical properties

By-products such as the fruit peel can contain various useful compounds such as carotenoids, flavonoids, and phenolics (Table 3) (Jamal *et al*., 2017), as well as tannins as stated in Table 3, which are plentiful in papaya peel extract (Fasoyinu *et al*., 2019). Phenolic compounds found in papaya peel namely vitamins A, B, C, pantothenic acid, minerals, folate and fibre which also have antioxidant characteristics may boost the health of the human body (Table 3) (Pathak *et al*., 2019). Besides, a potential source of the polysaccharide which is pectin, as stated in Table 3, have been found during the isolation of the papaya peel’s cell wall and it contains a low degree of methyl-esterification as well as having homogalacturonans as their most abundant pectic polysaccharides in the plant cell wall (Koubala *et al*., 2014).

Table 3: Compounds present in papaya peel and their functions.

Compound	Function
Caretenoids, flavonoids, and phenolics, Tannins Vitamins A, B, C, pantothenic acid, minerals, folate and fibre	Antioxidants
Pectin	Soluble fibre

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Antimicrobial properties

Papaya peel is also known to have certain natural antimicrobial active ingredients that can improve human health and thus, its usage could save the environmental waste. The petroleum ether peel extract of *Carica papaya* cv. Sekaki/Hong Kong has been used as sample to get its phytochemicals to evaluate its antibacterial activities towards *Corynebacterium diphtheriae* and *Streptococcus pneumonia* which showed the average inhibition with MIC of 5.63 mg/mL and 1.40 mg/mL, respectively (Sani *et al*., 2017). It is stated that the microbial activity of the papaya peel extract reacts depending on the extraction solvent used. For example, *C. papaya* peel extract is more effective in petroleum ether and 1% hydrochloric acid (HCl) compared to aqueous extract like water. This might be because the solubility of the active components is better in petroleum ether and HCl (Orhue and Momoh, 2014).

These days, the fruit peel extract has been used to synthesize nanoparticles as a biological medium is such an environmentally-safe and evolving scientific trend. A study has been carried out by Kokila *et al*. (2016) by using *C. papaya* peel extract as antimicrobial agents of the nanoparticles toward different human pathogens. This study proved the ability of the papaya fruit peel to be potent against the inaccessible multi-drug human pathogens including Gram positive bacteria namely *S. aureus, B. subtilis* and Gram negative bacteria namely *K. pneumonia* and *E. coli* in which these Gram negative bacteria both have shown the maximum zone of inhibition in the analysis. In addition, the analysis on the antibacterial activity of the ethanolic papaya peel extract against *Pseudomonas aeruginosa* also exhibits a small inhibition zone (Rodrigo and Perera, 2018). According to Agarwal *et al*. (2015), the synergistic effect of the secondary metabolites which derived from the green papaya peel such as alkaloids, terpenoids, saponins, tannins, flavonoids are the ones that contributes to the boosting of the antimicrobial activity of the silver nanoparticles.

Toxicity

In terms of its application, papaya peel is rarely used in the food or even pharmaceutical industries because papaya peel is regarded as a part of the fruit waste by-product without further purpose uses. Therefore, there still is a lack of studies on the toxicity of papaya peel. Consequently, Ovie *et al*. (2019) have conducted a study on the peel of *C. papaya* to test the testes and sperm morphology of adult male Wistar rats in a four weeks duration and the LD50 of the peel showed to be toxic at 1000 mg with an instant death. Histological analysis and the sperm morphology test were used to analyse the data from the routine oral administration of *C. papaya* peel extract for 30 days. This summarises the fact that papaya fruit peel cannot be used in the treatment of fertility problems. Reddy *et al*. (2020) performed an oral acute toxicity analysis in Alzheimer's Wistar albino rats in conjunction with Organisation for Economic Co-operation and Development (OECD) Guidelines 423 and found no adverse effects or substantial changes in behavioural parameters at a single dose of 2000 mg/kg papaya peel extract.

CITRUS FRUIT PEEL (LEMON AND ORANGE)

Physiological properties

Peels were a major by-product of citrus fruit production and a possible environmental hazard if not treated properly (Ramful *et al*., 2011). Despite the lack of understanding regarding the mechanisms of medicinal properties used in folk medicine to treat certain degenerative diseases, citrus fruit peels such as lemon (*Citrus limon*) and orange (*Citrus sinensis*) peel are still used as natural additives because they have good results and are environmentally friendly (Ademosun *et al*., 2018). Peel of citrus fruits are rich in essential oils that have antibacterial properties, especially limonene (30–80%) (Sharma *et al*., 2019).

When compared to other sources of dietary fibre, such as cereals, the key benefit of dietary fibre from orange peel was its higher proportion of soluble dietary fibre (Wang *et al*., 2015). Natural pectin, found in fruits and vegetables, is a food ingredient that also serves as soluble dietary fibre (Zhang *et al*., 2015). Wang *et al*. (2015) reported that under ideal conditions (0.8% H_2SO_4 concentration, 0.8 MPa steam pressure and residence time 7 min), the coupled pre-treatment of orange peel with steam explosion (SE) and sulfuric-acid soaking (SAS) was an effective method for increasing soluble dietary fibre yield and physicochemical properties. Whereas in the finding by Garcia-Amezquita *et al*. (2019) stated that extrusion altered the dietary fibre profile of orange peel, modified its technical versatility and increased its applicability in the food industry.

Orange peel, as a food waste, can also be used as a source of essential oil because the valorisation of food waste is becoming a point of interest, as said by Gavahian *et al*. (2018). Dávila *et al*. (2015) also discussed that the processing of citrus provides a significant quantity of residues that can be utilised to manufacture intermediate compounds which can be used in the synthesis of industrial fine chemicals, fragrances, flavourings, herbicides and pharmaceuticals.

Besides, diets rich in orange bagasse fruit peel fiber decreased serum triglycerides and hepatic cholesterol levels while also helping to suppress postprandial glycemia (Macagnan *et al.*, 2015). When compared to the control animals, the male Wistar rats (21 days old) fed by the orange bagasse fruit peel diets for 34 days had significantly lower fasting blood glucose levels.

Dietary fibre, which accounts for 55–60 percent of the fresh fruit weight, is the main by-product of these industries from citrus fruits, including lemon peel (Zhang *et al*., 2020). Hashemipour *et al.* (2016) used citrus flavonoid and vitamin C from *Citrus aurantifolia* (lemon) as the dominant portion of a test to minimize lipid and

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lipoprotein levels, as well as to delay the progression of atherosclerosis and endothelial dysfunction. The use of these high-value ingredients is expected to boost food quality and encourage the creation of new food applications.

To boost the functional properties of the citrus fibre obtained from a lemon peel, alkali was combined with high-speed homogenization (chemo-mechanical treatment) in a study by Zhang *et al*. (2020). The water swelling power of the chemo-mechanically treated fibre was dramatically improved to 35.56 mL/g (from 4.86 mL/g), significantly higher than that of the commercial one, AQ Plus (28.25 mL/g), as a control. Its water holding capacity was increased from 8.24 g/g to 25.52 g/g, which is equivalent to the commercial one, AQ Plus (25.28 g/g).

Besides, essential oils from lemon and orange peels were discovered to be potential anti-diabetic and anti-hypertensive agents. The aim of a study by Oboh *et al.* (2017) was to see how essential oils from orange (*C. sinensis* L. Osbeck) and lemon (*C. limon*) peels affected enzymes linked to type-2 diabetes (α-amylase and α-glucosidase) and hypertension (angiotensin-I-converting enzyme [ACE]). The finding study revealed that the inhibitory effect of lemon peel essential oil (IC_{50} = 26.17 g/mL) was greater than that of orange peel (IC_{50} = 31.79 g/mL). Both essential oils from orange and lemon peels reduced hypertension (angiotensin-I-converting enzyme [ACE] function), with lemon peels having a greater inhibitory ability on ACE than orange peels. Numerous studies have linked bioactive compounds like terpenoids and flavonoids' ACE inhibitory activities to their ability to compete with the enzyme's substrate and chelate zinc metal ions at the active site (Zouari *et al.*, 2011).

Chemical properties

Lemon is one of the citrus fruits in which its peel is highly recognised to have flavonoids, which are good antioxidative agents, essential oil and also other functional compounds (Table 4.1) (Miyake and Hiramitsu, 2011). Ali *et al*. (2017) has investigated the presence of alkaloids, saponin, flavonoids, carbohydrates, glycosides, citric acids and tannins in lemon (Table 4.1) by carrying out the phytochemical analysis on methanolic extract of the dried *C. limon.* Besides, the citrus olive oil has been classified as nutraceuticals because of the existence of carotenoids, naringenin and minor phenolics as their functional compounds (Table 4.1) (Ascrizzi *et al*., 2019). Nutraceutical is defined as a nutrient derived from food or part of food that provides functional advantage or protection against prolonged disease (Varzakas *et al*., 2016).

On the other hand, the valuable peel of orange which contains hesperetin, naringenin, apigenin, neohesperidin, hesperidin, and naringin as their main phytoconstituent flavonoid (Table 4.2), as well as hydroxycinnamic acids (HCA), such as p-coumaric acid, caffeic acid, and ferulic acid 18 as their major phenolic compounds (Table 4.2), can be greatly industrialized into good value added products despite its low-priced resources (Rehan *et al*., 2018). Citrus bagasse, which is mostly composed of peel, comprises essential oils and phenolic compounds that have a variety of biological functions (Table 4.2) (Barrales *et al*., 2018).

The process of drying citrus fruit peel could affect the degree of bioactive compounds such as ascorbic acid, β-carotene, and flavonoids in ripened and fresh orange peel (*Citrus valencia* and *Citrus balady*) and tangerine (*Citrus reticulate*) (Abou-Arab *et al*., 2016). Depending on the species, there is a contrasting composition of hydrocarbons, sesquiterpenes, alcohols, aldehydes, esters, and even other oxygenated citrus peel extract derivatives (Table 4.2) (Asikin *et al*., 2012).

Table 4.1: Compounds present in lemon peel and its function.

Compound	Function
Limonene	Volatile aroma compound, antioxidant
Flavonoid Alkaloids, saponin, flavonoids, carbohydrates, glycosides, citric acids and tannins	Antioxidative agent
Carotenoids, naringenin and minor phenolics	Nutraceuticals

Table 4.2: Compounds present in orange peel and its function.

Compound	Function
Limonene	Volatile aroma compound, antioxidant
Flavonoid (hesperetin, naringenin, apigenin, neohesperidin, hesperidin, and naringin)	Antioxidants
Phenolic compounds (hydroxycinnamic acids (HCA), such as P-coumaric acid, caffeic acid, and ferulic acid 18) Essential oils	Biological functions
Hydrocarbons, sesquiterpenes, alcohols, aldehydes, and esters	Radical scavenging activity

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Citrus fruits often show their own volatile aroma components with a special composition, such as limonene (Tables 4.1 and 4.2), as the key component of unripe Shiikuwasha 'Ogimi kugani' (*Citrus depressa* Hayata) flavedo extracts, preceded by γ-terpinene, p-cymene, alpha-pinene and β-pinene, and their quantity depends on the method of extraction (Asikin *et al*., 2012). Although the limonene content of Shiikuwasha flavedo peel is lower than that of other widely known citrus peel, it is possible to increase the amount of phenolic compounds and the antioxidant activity of the extract by increasing the free phenolic acid fraction (Xu *et al*., 2008).

Antimicrobial properties

Every fruit have their own antibacterial or antimicrobial compounds which have a role in inhibiting bacterial or microbial growth. Hindi and Chabuck (2013) reported that the limonoids which are present in the *Citrus* species such as *Citrus limon* has the ability to inhibit the bacterial activity. On top of that, Henderson *et al*. (2017) also reported that flavonoid and essential oil are one of the plenty nutrients found in the lemon (*C. limon*) peel that can be consumed for its antimicrobial and anticancer activity. Therefore, an analysis on the antimicrobial activity of ethanolic extract of the *C. limon* peel of 25%, 50%, 75% and 100% have been conducted against *E. coli* using the disc diffusion method which results in 15.03 mm, 16.17 mm, 15.83 mm, 18.77 mm of the average inhibition zone respectively, thus summarise that those four different percentages of ethanolic extracts have strong antimicrobial activity against *E. coli.*

The extraction of citrus fruit juice is typically the main product required in the country's processing industry. Hence, the citrus fruit waste is left as waste products like peel, seeds and pulps. Thus, the peel extracts of lemon and orange have been used in the enquiries which was conducted by Afroja *et al*. (2017) to evaluate their antibacterial activities. The findings show that lemon and orange peel extracts have the best antibacterial activity against *B. cereus* in methanol and ethyl acetate, resulting in a MIC value to be equal to MBC value (31.25 µg/mL).

Toxicity

Papaya mealybug (*Paracoccus marginatus*) is very common as a pest of papaya (*Carica papaya* L.). According to Gowtham *et al*. (2019), an analysis on the toxic property of the methanolic peel extracts of *Citrus sinensis* (L.) Osbeck performing its insecticidal activity on the papaya mealybug were carried out and showed a minimum concentration of 0.57% methanolic citrus peel extract contributes to 50 percent mortality of *P. marginatus*. The topical application method proved to be the most successful against *P. marginatus*, with the lowest LC50 values, of the three different toxicity methods tested using methanol extract of *C. sinensis* peels against *P. marginatus*. The methanolic peel extract is toxic to *P. marginatus* nymphs, according to the results of this analysis.

At a concentration of 250 mg/g, the toxicity of lemon peel extract was tested in the natural diet (lemon slices endocarp) of the Mediterranean fruit fly, *Ceratitis capitata* larvae (Salvatore *et al*., 2004). To monitor for phototoxicity, female adults of *C. capitata* fed with diets containing additional amounts of ether extract, 5,7-dimethoxycoumarin, and linalool were subjected to multiple photoperiods. The treatment was toxic and had an effect on females' oviposition potential, which was influenced by photoperiod. Salvatore *et al*. (2014) also mentioned that small amounts of citral or 5,7-dimethoxycoumarin, as well as linalool, applied to the stored lemon peel extract will restore the toxicity levels to those of fresh lemon extracts.

CONCLUSION

In conclusion, fruit peel is considered a by-product of fruits that have been widely thrown away due to many individuals unaware of their benefits. In this review, fruit peels of banana, pomegranate, papaya, and citrus fruits have been shown to have an abundance of antimicrobial compounds that may be useful for pharmacological or medicinal purposes. Fruit peel from banana, pomegranate, papaya, and citrus fruit (lemon and orange) tend to have a lot of functional value either as a source of antimicrobial agents for use in food and pharmaceutical products, or as a traditional medicine. A research into these benefits is still also going on to discover new products as a food additive, food preservative, and also a toxic-free food grade sanitizer. The existence of bioactive compounds, especially phenolic compounds, steroids, and alkaloids has been shown in this article to be useful and can have a range of functional effects on human health. Despite their health benefits, these fruit peels have been shown to cause toxicity when consumed, depending on the doses used, and an overdosing on the extract may result in mild and uncommon medical complications. Therefore, the utilization of fruit residues (peel) into essential substances or products may not only provide potential research opportunities, but it may also help to prevent current environmental risks.

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