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Industrial Application of Orange Peel Waste; A Review

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ABSTRACT

Orange peel waste (OPW) is a byproduct generated in large quantities during the juice extraction process in the citrus industry. Due to its high content of bioactive compounds and organic matter, OPW has the potential to be used in various industrial applications, thus reducing the environmental impact associated with its disposal. One of the most promising applications of OPW is in the production of animal feed, where it can be used as a source of dietary fiber, pectin, and antioxidants. In addition, OPW can be used as a source of natural pigments and flavors in the food industry, particularly in the production of confectionery, bakery products, and beverages. Another potential application of OPW is in the production of biofuels and biochemicals. The high concentration of carbohydrates in OPW makes it a suitable substrate for the production of ethanol, which can be used as a fuel or a feedstock for the production of other chemicals. Furthermore, OPW can be used as a source of essential oils, which can be used in the fragrance and cosmetics industries. Other industrial applications of OPW include the production of biodegradable polymers, wastewater treatment, and the remediation of contaminated soils. However, the utilization of OPW in industrial applications is still limited by several factors, such as the high variability in composition and the lack of standardization in processing methods. In conclusion, OPW is a promising source of value-added products that can be used in various industrial applications. Further studies are needed to optimize the utilization of OPW and to overcome the challenges associated with its processing and standardization.

Key words: Pharmaceuticals Industry, Compost, Food Industry, Pectin, Biogas, Animal Feed.

INTRODUCTION

About 50% of the weight of citrus fruits, including peels, pulp, seeds, and membranes, is discarded during processing. Additionally, the albedo, which is the inner peel, accounts for around 17% of the total fruit weight, while the outer peel, or flavedo, accounts for about 10% of the total fruit weight. Roughly 30% of the total citrus production is utilized for processing, with a primary focus on juice production (Siddiqui et al., 2020). Oranges, which are mainly the sweet orange Citrus sinensis, but sometimes also the bitter orange Citrus aurantium, are the most commonly consumed citrus fruit, with an estimated global production of 72 million tonnes. As a result, orange peels constitute a significant portion of the roughly 25 million tonnes of citrus waste generated worldwide in 2016 (Zema et al., 2018). These waste materials consist of non-edible parts such as seeds and peels, which are typically discarded. In fact, the peels alone make up almost 50 to 70% of the total waste generated from processed citrus fruits. Improper disposal of these wastes in landfills can result in various environmental issues. This is concerning, given that the discarded peels and seeds of citrus fruits contain bioactive compounds such as sugar, carbohydrate, protein, fats, organic acids, flavonoids, oil, and pigments. As a result, there have been several initiatives to decrease the environmental impact of citrus waste disposal and instead, transform them into valuable resources (Khamsaw et al., 2022). It's worth noting that oranges are one of the most widely consumed citrus fruits globally, with an annual production of 75 million tonnes. Orange waste is similar to other citrus fruits, as it consists of 60 to 65% peels and 30 to 35% pulp and seeds (Liu et al., 2017).

Orange peels have numerous potential industrial applications due to their abundance, low cost, and high content of bioactive compounds. Here is a brief review of

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some of the most promising uses of orange peels in various industries. Overall, orange peels have a lot of potential for industrial applications, and their use is likely to become more widespread as research into their properties and potential applications continues. However, it is important to note that more research is needed to fully understand the optimal methods for extracting and using the bioactive compounds in orange peels for industrial purposes. At present, several conventional methods exist to handle excess OPW, which include incineration, landfilling, ensiling, and animal feeding. However, these approaches come with their own set of pros and cons. The utilization of renewable resources to generate bioproducts is believed to have significantly lower environmental impacts compared to the previously mentioned techniques, and can contribute to more eco-friendly environment (Yaradoddi et al., 2022).

Orange Peel as a Compost for Soil Improvement

Orange peels are high in nitrogen, phosphorus, and potassium, which are essential nutrients for plant growth. When added to a compost pile, the peels will break down and release these nutrients into the soil, helping to create a rich and fertile environment for plants. Composting orange peels can help to balance the pH levels of soil, which is essential for healthy plant growth. The acidity of orange peels can help to counterbalance the alkalinity of other materials in compost pile. Organic waste, such as food scraps, can contribute to methane emissions, which are harmful to the environment. Composting orange peels, along with other food scraps, is an eco-friendly way to reduce environmental impact (Negro et al., 2017). Utilizing OPW (OPW) can be done in two ways: by directly spreading it over agricultural land, or by composting it before use. The former method is cost-effective and can increase soil fertility by adding organic matter. Studies have shown that direct spreading of OPW does not have any adverse effects on the soil environment. Another approach to utilizing OPW is through the ensiling process, which preserves the raw substrate by reducing its moisture content and ensuring its availability year-round. This process involves the formation of lactic acid and a decrease in pH value due to the absence of oxygen, which inhibits the activity of certain enzymes. However, researchers have also discovered that some bioactive compounds in OPW, despite being abundant, can harm natural microorganisms in the soil after composting. Hence, more research is necessary to identify better applications of OPW (Nossier, 2021; Mohsin et al., 2022).

Orange Peel used in Animal Feed

The orange peel contains a range of nutrients that can be beneficial to animals, including fiber, carbohydrates, vitamins, and minerals. Additionally, the peel contains essential oils that can have antimicrobial and antioxidant properties, which can help improve animal health and welfare. Orange peel can be used as a partial replacement for traditional feed sources, such as corn or soybean meal, in ruminant and non-ruminant diets (Andrianou et al., 2023). In ruminants, the high fiber content of orange peel can stimulate rumen function and increase the production of microbial protein, which is an important source of protein for the animal. In non-ruminants, the digestibility of orange peel can be improved through various processing techniques, such as ensiling or drying. The use of orange peel as an animal feed has several potential benefits. Firstly, it can reduce the environmental impact of citrus processing waste by diverting it from landfills or other disposal methods. Secondly, it can provide a low-cost alternative to traditional feed sources, which can help reduce the cost of animal production. Finally, the use of orange peel as an animal feed can help improve animal health and welfare by providing additional nutrients and bioactive compounds (Kesbiç et al., 2022).

Citrus by-products are a low-cost nutritional supplement that can be added to cattle diets. Studies have suggested that incorporating citrus by-products into cattle diets can inhibit the growth of *Escherichia coli* and *Salmonella typhimurium* within mixed ruminal microorganism fluid media. This is due to the antimicrobial properties of essential oils found in citrus by-products, which can damage the cell wall of gram-negative bacteria and lead to a reduction in foodborne pathogens (Callaway et al., 2011). Furthermore, citrus by-products are a suitable feed for ruminants because they can be fermented in the rumen, which allows for the inclusion of high fibre feeds in their diets. However, there are also some challenges associated with the use of orange peel as an animal feed. For example, the high fiber content of orange peel can limit its digestibility, which can reduce the energy and nutrient content of the diet. Additionally, the essential oils in orange peel can have a bitter taste, which may reduce palatability and intake. Further research is needed to optimize the processing and use of orange peel in different animal diets and to assess its long-term effects on animal health and production (Kesbiç et al., 2022).

Orange Peel for Pectin Extraction

Orange peel contains a significant amount of pectin, a complex carbohydrate that is widely used in the food industry as a gelling agent, stabilizer, and thickener. Pectin can be extracted from orange peel through a variety of methods, including acid extraction, enzymatic hydrolysis, and microwave-assisted extraction. Acid extraction is the most common method of pectin extraction from orange peel. This method involves treating the orange peel with an acid solution, usually a mixture of citric acid and hydrochloric acid, under controlled conditions of temperature and time. The acid breaks down the cell walls of the orange peel and releases the pectin, which is then separated from the other components of the peel by filtration and precipitation (Maran et al., 2013).

Enzymatic hydrolysis is an alternative method of pectin extraction that involves using enzymes, such as pectinases, to break down the pectin molecules in the orange peel. This method is milder and less energy-intensive than acid extraction, and it results in a higher-quality pectin with a more consistent molecular weight (Mohsin et al., 2022). Microwave-assisted extraction is a newer method of pectin extraction that uses microwave energy to heat the orange peel and extract the pectin. This method is faster and more energy-efficient than traditional extraction methods, and it can also result in a higher yield of pectin. The pectin extracted from orange peel has a wide range of applications in the food industry, including as a gelling agent in jams, jellies, and other fruit products, as a stabilizer in dairy products and beverages, and as a thickener in sauces and dressings (Duwee et al., 2022). In addition, orange peel pectin has been found to have potential health benefits, such as reducing cholesterol levels and improving gut health. Further research is needed to optimize the extraction methods and explore new applications for orange peel pectin in the food and health industries.

Orange Peel for Essential Oil

Citrus peel glands with a diameter of 0.4 to 0.6 mm can yield a volatile and fragrant compound known as essential peel oil. OPW was found to contain a higher amount of essential oil d-limonene compared to other lignocellulose feedstocks. The positive sensory effects of flavor, aroma, and color make peel oil products a desirable ingredient in various industries, such as food, perfume, and pharmaceuticals. Peel oil has also been identified as a green insecticide by the United States Environmental Protection Agency, with effective results against several pests (Mohsin et al., 2022). Orange peel, also known as orange zest, is a byproduct of the citrus fruit industry that has been found to have a variety of uses beyond consumption. One such use is the production of essential oil, which can be extracted from the peel using various methods. Orange essential oil has a variety of applications, including aromatherapy, flavoring, and as an ingredient in personal care products. The essential oil in orange peel is primarily made up of monoterpenes, such as limonene, which is the most abundant compound in the oil. Limonene has been shown to have a variety of beneficial properties, including antioxidant, anti-inflammatory, and anti-cancer effects (Siddiqui et al., 2020). In addition, orange essential oil has been found to have antimicrobial properties, making it useful in the preservation of food and as a natural alternative to synthetic preservatives. The process of extracting essential oil from orange peel involves several steps, including washing, grinding, and distillation. The oil can also be extracted using cold-pressing, which involves pressing the peel to release the oil. This method is less efficient than distillation, but it produces a higher quality oil that is less likely to degrade due to heat exposure. One of the advantages of using orange peel for essential oil production is that it is a readily available and inexpensive raw material. In addition, the use of orange peel for essential oil production has the potential to reduce waste in the citrus fruit industry (Santos et al., 2022). However, the production of essential oil from orange peel is still a relatively small industry, and more research is needed to fully understand the potential benefits and drawbacks of this process.

Bioactive Compounds Extraction from Orange Peel

Orange peel contains a high amount of bioactive compounds such as flavonoids, carotenoids, and limonoids. These compounds have potential applications in the production of biochemicals such as antioxidants, antimicrobials, and nutraceuticals. Therefore, orange peel can be considered as a sustainable and inexpensive source for the production of value-added biochemicals. Another important biochemical that can be extracted from orange peel is limonene (Saini et al., 2022). Limonene is a monoterpene that has many industrial applications such as a solvent, flavoring agent, and precursor for the synthesis of other compounds. The extraction of limonene from orange peel involves steam distillation, and the extracted limonene can be used in various industries such as the fragrance, cosmetic, and pharmaceutical industries (Sharma et al., 2017).

In addition to pectin and limonene, other bioactive compounds such as flavonoids and carotenoids can also be extracted from orange peel. Flavonoids are a group of polyphenolic compounds that have antioxidant, anti-inflammatory, and antimicrobial activities. The extraction of flavonoids from orange peel involves solvent extraction, and the extracted flavonoids can be used in the food, cosmetic, and pharmaceutical industries. Carotenoids are a group of pigments that have antioxidant and anti-inflammatory activities (Lai et al., 2022). The extraction of carotenoids from orange peel involves solvent extraction, and the extracted carotenoids can be used in the food, cosmetic, and pharmaceutical industries. In conclusion, orange peel is a valuable source of bioactive compounds that can be used in the production of various biochemicals. The extraction of these compounds from orange peel can be done using simple and inexpensive methods, making it a sustainable and cost-effective alternative to traditional sources of these biochemicals. Therefore, the use of orange peel for the production of biochemicals has great potential for both economic and environmental benefits

The orange peel is a potential source of flavonoids and carotenoids, which are bioactive compounds with health-promoting effects. Flavonoids are a class of polyphenolic compounds that exhibit antioxidant, anti-inflammatory, and anti-carcinogenic properties. Carotenoids are a group of pigments that act as antioxidants and are involved in maintaining vision and immune function.

The production of flavonoids and carotenoids from orange peel can be achieved through various extraction techniques. The most common extraction techniques include solvent extraction, microwave-assisted extraction, and ultrasound-assisted extraction (Mohsin et al., 2022).

Solvent extraction involves the use of organic solvents to extract the bioactive compounds from the orange peel. The choice of solvent depends on the type of bioactive compound to be extracted. For example, methanol, ethanol, and acetone are commonly used solvents for flavonoid extraction, while hexane, acetone, and ethyl acetate are used for carotenoid extraction. Microwave-assisted extraction (MAE) is a fast and efficient method that involves the use of microwave radiation to extract the bioactive compounds from the orange peel. MAE has been shown to be effective in extracting both flavonoids and carotenoids from orange peel. Ultrasound-assisted extraction (UAE) is a non-thermal technique that involves the use of ultrasound waves to disrupt the cell walls of the orange peel and release the bioactive compounds. UAE has been shown to be an effective method for extracting flavonoids and carotenoids from orange peel (Mohsin et al., 2022).

After extraction, the crude extract is subjected to further processing to isolate and purify the bioactive compounds. This can be achieved through various techniques such as liquid-liquid partitioning, column chromatography, and high-performance liquid chromatography (HPLC). In conclusion, orange peel is a potential source of flavonoids and carotenoids, which are bioactive compounds with health-promoting effects. The production of these compounds can be achieved through various extraction techniques, followed by isolation and purification. The use of these compounds in food and pharmaceutical industries is expected to increase in the future due to their health-promoting properties (Saini et al., 2022).

Biofuels Production from OPW

OPW is a significant source of organic waste generated from citrus fruit processing industries. The disposal of this waste poses a significant environmental challenge, as it can cause water and soil pollution. However, OPW can also be used to produce biofuels, which can offer a sustainable alternative to traditional fossil fuels. Biofuels are derived from biomass, which includes plant materials, animal waste, and organic matter (Awogbemi et al., 2022). The production of biofuels from OPW involves several steps. First, the OPW is collected and dried to reduce its moisture content. Then, it is processed to extract the oil content present in the peel. This oil is rich in limonene, a compound commonly used in the fragrance and flavor industry. Limonene can be converted into biofuels through a process called hydrotreatment, which involves reacting the compound with hydrogen at high temperatures and pressures. This results in the production of limonene-based biofuels that can be used in various applications, such as transportation and heating (Devasan et al., 2023).

The production of biofuels from OPW has several advantages. Firstly, it reduces the amount of waste that would otherwise end up in landfills, reducing the environmental impact of citrus processing industries. Secondly, it provides a sustainable source of energy, reducing reliance on non-renewable fossil fuels. Thirdly, the use of biofuels derived from OPW can help reduce greenhouse gas emissions, as they have a lower carbon footprint compared to traditional fossil fuels (Mohsin et al., 2022). The production of biofuels from OPW is a promising solution for the sustainable production of energy. It not only provides a sustainable alternative to traditional fossil fuels but also helps to reduce the environmental impact of citrus processing industries. With further research and development, this technology has the potential to become a significant contributor to the renewable energy sector.

Biogas Production from OPW

OPW is a rich source of organic matter that can be used for biogas production. Biogas is a renewable energy source that is produced by the anaerobic digestion of organic matter, such as animal manure, food waste, and agricultural residues. The process of biogas production from OPW involves the decomposition of the organic matter in the presence of anaerobic bacteria. The OPW is first collected and then subjected to a pretreatment process to increase its biodegradability (Bouaita et al., 2022). The pretreatment process involves shredding the waste into small pieces and then mixing it with water to form a slurry. The slurry is then heated to a specific temperature, which helps to break down the complex organic compounds present in the waste, making it easier for the bacteria to digest. After pretreatment, the slurry is transferred to a bioreactor, which is a closed system that allows for the controlled digestion of the organic matter. The bioreactor is typically an airtight vessel that is filled with the slurry and the anaerobic bacteria. As the bacteria digest the organic matter, they produce biogas, which is a mixture of methane, carbon dioxide, and small amounts of other gases (Fazzino., 2022; Mohsin et al., 2022).

The biogas produced in the bioreactor is then collected and purified for use as a fuel. The purification process involves removing the carbon dioxide and other impurities, leaving behind a high-quality methane gas. This methane gas can be used to generate electricity, heat, or fuel for vehicles. Biogas production from OPW has several environmental and economic benefits. It provides a renewable energy source that reduces the dependence on fossil fuels and helps to mitigate climate change. Additionally, it provides a cost-effective solution for managing organic waste (Shao et al., 2022). Biogas production from OPW is a promising technology that has the potential to provide a sustainable source of energy while reducing the environmental impact of waste disposal.

Citric Acid Production from OPW

Citric acid is a key industrial chemical widely used in various industries including food and beverage, pharmaceutical, and cosmetic industries. Traditionally, citric acid has been produced through microbial fermentation of sugars, mainly sucrose or glucose, using the fungus *Aspergillus niger*. However, with the rising demand for sustainable and eco-friendly production methods, there has been a growing interest in the use of waste materials as feedstocks for citric acid production (Teigiserova et al., 2022). One such waste material is OPW, which is a byproduct of the orange juice industry. Orange peels are rich in sugars and contain a high amount of pectin and other polysaccharides, which can be hydrolyzed into fermentable sugars. Additionally, orange peels contain a high concentration of citric acid and other organic acids, making them an attractive feedstock for citric acid production. The process of citric acid production from OPW typically involves three main steps: pretreatment, hydrolysis, and fermentation. In the pretreatment step, the orange peels are washed and dried, and then ground into small particles. The hydrolysis step involves the use of enzymes, such as cellulase and pectinase, to break down the polysaccharides in the orange peels into simple sugars. The resulting sugar solution is then sterilized and inoculated with a suitable microorganism, such as *Aspergillus niger*, to initiate the fermentation process. During fermentation, the microorganism utilizes the sugars in the solution to produce citric acid (Torrado et al., 2011). Several studies have reported successful citric acid production from OPW, with yields ranging from 70 to 90 g/L. The economic feasibility of the process needs to be evaluated, taking into consideration the cost of waste collection and processing, enzyme and microorganism cost, and the cost of downstream processing. Citric acid production from OPW is a promising approach for sustainable and eco-friendly citric acid production. With further research and development, this process could become a viable alternative to traditional citric acid production methods (Mohsin et al., 2022).

Microbial Polysaccharide Production from OPW

OPW is a major byproduct of the orange juice industry, and its disposal has long been a challenge due to its high organic content. However, OPW can be a valuable source for the production of microbial polysaccharides, which have numerous applications in the cosmetic, food, and pharmaceutical industries. Microbial polysaccharides are high-molecular-weight polymers produced by various microorganisms such as bacteria, fungi, and algae. They have a wide range of physical and chemical characteristics, including high water-holding capacity, viscosity, and emulsifying properties (Davaritouchaee et al., 2023). These properties make them attractive for a numerous application, like thickeners, stabilizers, and gelling agents in the food industry, and as drug delivery systems in the pharmaceutical industry. OPW is rich in polysaccharides such as pectin and cellulose, which can serve as a carbon source for microbial growth and polysaccharide production. The process of microbial polysaccharide production involves the cultivation of microorganisms in a nutrient medium containing OPW as a carbon source, followed by the extraction and purification of the polysaccharide product (Mohsin et al., 2022).

Several microorganisms have been identified for their ability to produce polysaccharides from OPW. For example, the bacterium Bacillus subtilis has been shown to produce a polysaccharide called levan from OPW. Levan has a high molecular weight and can be used as a prebiotic, which promotes the growth of beneficial bacteria in the gut. In addition to providing a valuable use for OPW, the production of microbial polysaccharides from this waste stream has several environmental benefits (Padmanabhan et al., 2022). By diverting OPW from landfills, the production of microbial polysaccharides can reduce greenhouse gas emissions and minimize the environmental impact of waste disposal. Furthermore, the use of microbial polysaccharides in place of synthetic thickeners and stabilizers can reduce the demand for petroleum-based products and decrease the environmental impact of their production and disposal (Irshad et al., 2014).

Bakery Products Supplemented with OPW

Bakery products are a popular food item around the world, and the food industry is always looking for ways to improve the nutritional value of these products while also reducing waste. One promising solution is the addition of OPW to bakery products. OPW is a byproduct of the orange juice industry, and it is typically discarded as waste. However, this waste have high dietary fiber, flavonoids, and other bioactive compounds that can have numerous health benefits. By supplementing bakery products with OPW, food manufacturers can create a more nutritious product while also reducing waste (Gaonkar et al., 2022).

Several studies have investigated the effects of adding OPW to bakery products. One study found that adding OPW to bread increased the bread's fiber content and improved its overall quality. The researchers also found that the bread had a lower glycemic index, which is beneficial for people with diabetes. Another study found that adding OPW to biscuits improved their antioxidant content and extended their shelf life. The researchers also found that the biscuits had a better texture and flavor compared to those without the added OPW. In addition to its nutritional benefits, the addition of OPW to bakery products can also have environmental benefits (Mohsin et al., 2022).

Overall, the addition of OPW to bakery products has the potential to create a more nutritious and sustainable food product. As more research is conducted in this area, we can expect to see more bakery products supplemented with OPW on store shelves.

Conclusion

In conclusion, the industrial application of OPW has significant potential in various industries due to the abundance of the waste material and its diverse range of valuable components. Through various processes such as extraction, fermentation, and pyrolysis, OPW can be converted into valuable products such as essential oils, pectin, biofuels, and animal feed additives. These products not only provide a sustainable and cost-effective solution for waste management but also offer economic and environmental benefits to industries that utilize them. Additionally, the utilization of OPW can help to reduce the negative impacts of waste disposal on the environment.

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