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**Review Article**

# Utilization of Orange Peel Waste as a Functional Ingredient For Sustainable Environment: A Review

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**ABSTRACT**

A huge quantity of orange peel waste (OPW) is generating worldwide. Although orange peels have numerous economic benefits however inappropriate valorisation or malpractice produces risk for environment and public health. Herein, we reported the processing of Orange peel, its handling, and valorisation for manufacturing that can be used in food, in cosmetic and in pharmaceutical industries. Moreover, herein we have discussed the valorisation of OPW for bioethanol and adsorbents preparation. Our write-up also reported value-added products developed from these peels like edible film coatings, carbon dots, biochips, and microbiological media for agronomic and industrial interests have been also discussed.

## INTRODUCTION

According to Chinese literature, orange is originated in the regions of Asia in 2200 BC [1]. Furthermore, few literatures stated that sweet oranges have origin in India, and are known for a very popular and highly consumed. Orange trees are cultivated extensively around the world with tropical and subtropical climates in areas with latitudes of 35° north and 35° south [2]. Oranges are thirst-quenching fruits that attract all age groups with their multi folds health benefits mainly consumed fresh or juice. Though, before using fruit, the thick bitter peels are removed and produce large quantity of orange peel waste as a by product in the fruit juice industry [3]. Oranges gained global popularity in the human diet however their processing leads to the generation of waste which is one of the largest foods processing waste. These wastes pollute areas near production facilities before being used as a raw material in animal feed or burned, incurring management costs. Zema et al. reported 10 million Metric Ton of waste each year, creating a serious ecological issue. Several applications for orange processing leftovers were researched in order to reduce management costs while also preventing environmental and human health issues [4]. Over the previous decade, over 1000 scientific articles have been published, with about 90% of them focusing on the various OPW valorization pathways around the world [5].

The current review emphasizes on global overview of world production, processing chain, waste management, and utilization of OPW. The goal is to educate farmers and inform emerging scientists, industry leaders in the fruit processing sector, and the audience about the best solutions for the utilization of OPW.

## WORLD PRODUCTION OF ORANGE FRUIT AND PEELS

Orange is an important fruit crop, with global production of approximately 49.01 million metric tons in 2021-22; nevertheless, global production is increasing as a result of increased consumption (Figure 1). It is grown in various nations across the world with tropical and subtropical climates in areas roughly centered between the latitudes of 35° north and 35° south. The top ten producers of oranges worldwide in the year 2021 are Brazil, China, India, Mexico, Egypt, the United States, Spain, Turkey, Italy, and Iran (Figure 1). Around 8–20 million tons of orange wastes are produced every year during orange juice production [6, 7].

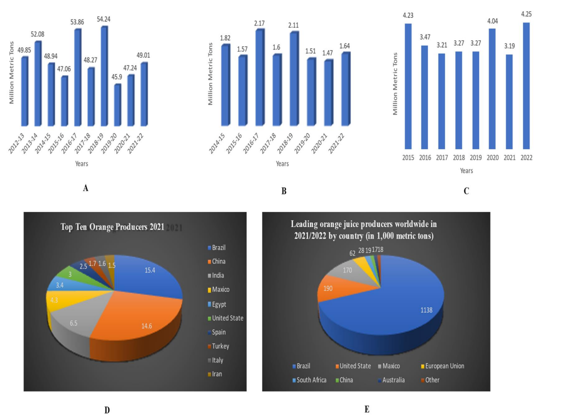

**Fig. 1.** A-Worldwide orange production from 2012/2013 to 2021/2022 (in million metric tons). B- Orange juice production volume worldwide from 2014/15 to 2021/22 (in million metric tons). C- Production of Orange fruit in India between the financial year 2015 and 2021 (in million metric tons). D- Top ten orange producer countries 2021. E-Leading orange juice producer countries worldwide in 2021/2022 (in thousand metric tons).

## ORANGE PROCESSING CHAIN

Before oranges arrive in the processing industry, there are three main stages: harvesting, temporary storage at farms, and transportation (Figure 2) [9, 10].

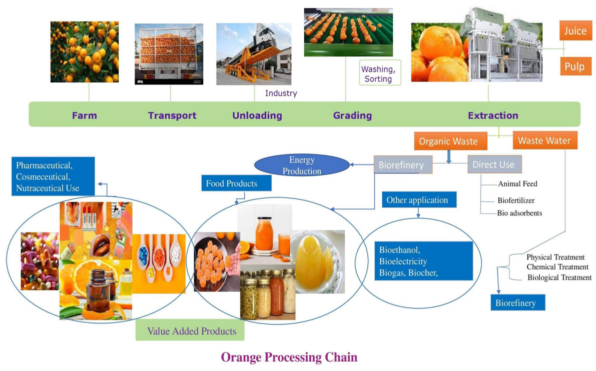


**Fig. 2.** Orange Processing Chain.

As the production, consumption, and processing of orange fruit increase worldwide, it's better to create more and more a pathway for the effective utilization of OPW that meets Sustainable Development Goal No. 12: Sustainable production and consumption. This objective aims to help developing countries switch to more sustainable consumption practices by 2030 by addressing the key challenge of sustainable use of natural resources and waste management. Using OPW more effectively in the food and non-food industries is a step in the right direction toward resource conservation that will promote sustainability and the circular economy [8].

### Orange Peel Waste Problems/Risks

Currently, standard OPW management options are not economically viable due to numerous limitations. Approximately 15-25 million tonnes of peel trash end up in landfills without being recycled or composted. The transported garbage is disposed of in landfills or burnt. Dumping these peels on a site can endanger both the environment and human health. During the wet season, they may degrade, emit bad odors, cause microbial infestation, attract flies, and represent a danger of disease transmission. OPW is now discouraged from being used as animal feed due to the high energy demand for the dehydration process, its bitterness, and its low nutritional content. Composting is economically costly, and the compost generated is frequently of no interest to the local market [11]. Nonetheless, these by-products contain high levels of vitamin C, thiamine, niacin, pyridoxine, phosphorus, calcium, iron, magnesium, and potassium, soluble and insoluble dietary fibers, the bioactive phytochemicals pectin, essential oil, polyphenolic- flavonoids disposed of intentionally or unintentionally, which are becoming increasingly impractical due to environmental concerns such as the emission of $CH_4$ as a greenhouse gas from landfilling, possible discharge [12-14]. These fruit peels, which are generated as waste in enormous quantities, also represent a biomass resource that can be collected for future use rather than being disposed of using impracticable conventional procedures. It is a growing concern that affects every aspect of waste management. OPW scientific initiatives (Figure 2) can contribute to the reduction of environmental difficulties. To establish long-term solutions, all parties in the food supply chain, including industry, agriculture, merchants, collection to disposal systems, and consumers, must collaborate.

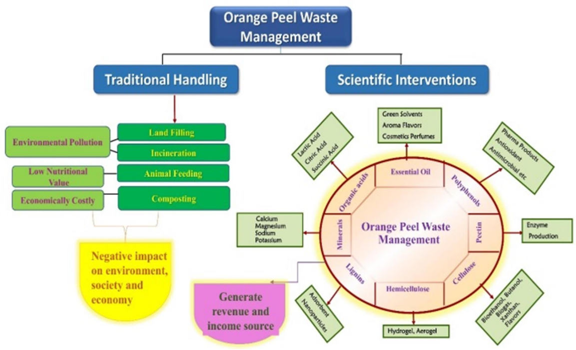


**Fig. 3.** Orange peel Waste Management

## CAPTIVATING BIOACTIVE COMPOUNDS

The bioactive phytochemicals including carotenoids, dietary fiber, essential oil, pectin, polyphenolic-flavonoids, organic acids, and vitamins are present in OPW. In an attempt to use processed fruit waste for environmentally sustainable and clean production, many researchers have been working in an original, affordable, and productive way. The scientific world is highly interested in the extraction processes used for sample setup and processing [15]. Recovery of bioactive compounds is primarily done by extraction, isolation and characterization. Care should be taken that potential bioactive compounds are not destroyed, lost, or distorted during the extraction process [16]. Recently, Several techniques such as green extraction, thermochemical, physicochemical and biological have been conducted for the valorisation of orange peel for the recovery of bioactive components.

## UTILIZATION OF ORANGE PEELS WASTE

Waste valorization is becoming a growing concern where cultivation is a major industry. The application of waste orange peels in various sectors is discussed and summarized as follows.

### Food Additives

Orange rind and peel are commonly used as food additives in the preparation of candied items for the confectionary, bread and other food sectors due to their distinctive flavour, colour, and nutritional value [17]. The combination of candied orange peel (COP) and OPP was investigated as a taste additive in frozen yogurt. The medium-fat frozen yoghurt mix was created by combining the yoghurt foundation with ice cream mix (25:75, w/w). COP and OPP were utilized as flavour enhancers at 8.0 and 2.5% by weight of mixtures, respectively. The results showed that including peel solids produced frozen yoghurts with significantly higher protein, carbohydrate, ash, and total solids content. The prepared frozen yogurt had significantly larger levels of β-carotene and dietary fibre (37.20 and 240.0%, respectively) [18]. Saini and Sharma conducted another study to prepare a smoothies made with sand pear, beetroot juice, and orange peel in order to improve the product's functional and sensory features while also utilizing trash. Smoothies are a great and practical way to consume fruits, and they are well-known for their antioxidant properties [19]. Results demonstrated that antioxidant activity, appearance, and flavour are positively affected by the concentration of orange peel and beet root juice, and this combination disguised the dull color and taste of the

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smoothies, proving a better way to use orange peel to generate value-added smoothies

Jaiswal and Paul successfully developed and evaluated Edible Bowl with orange peel powder (upto 10%) along with other ingredients without affecting sensory attributes [20]. In proximate analysis, moisture content 9.86%, ash 3.37%, crude fiber 2.07g, carbohydrates 59.49g, fat 1.51g, protein 11.71g, calcium 44.61mg and iron 4.58mg in edible bowl per 100 gm was noted. Author further concluded that proximate composition was increased due to incorporation of orange peel for the preparation of edible bowl

Sicari et al. studied the nutritional quality of orange peel-enriched jam after 90 days of storage at 15 and 30°C [21]. The test results demonstrated that using orange peels in jam kept its functional qualities throughout storage while also improving its nutritional profile. It is best stored at 15°C, and the polyphenol content ranged from 83.44 to 126.22 mg/100 g for control samples and from 125.12 to 171.02 mg/100 g for orange peel-enriched jam. Furthermore, bioactive substances like ascorbic acid, carotenoids, and phenolic compounds have antioxidant activity, which could improve the jam's functional characteristics

In another study, biscuits were prepared by substituting wheat flour with orange 10% peel and 10 % pulp flour. It has been observed that biscuit samples containing 10 % orange pulp had higher fiber content than the biscuit containing 10 % peel flour [22]. Furthermore, sweet orange peel powder in marmalade enhanced phenolic content and thus antioxidant capacity, however reduction in pH, treatable acidity, and anthocyanin content were noted [23].

**Prebiotic**

Orange peel pectin has been used to make jam, jellies, and marmalades has powerful prebiotic benefits. The pectic oligosaccharides (POS) are the emerging prebiotic derived from orange peel waste. Pectin made from orange peel-based fibre by enzymatic hydrolysis was reported to have more prebiotic activity than pectin from commercial markets [24].

In a recent study, composite fruit peel powder (pineapple, orange and passion fruit) was used in different proportions i.e., 0.7%, 1% and 0.5% (w/v), respectively, to develop fat and sugar-free probiotic set yogurt. The prebiotic effects of citrus waste dietary fibre were examined in an *in vitro* pig gastrointestinal tract model. The study reported a higher acetate ratio Pectic oligosaccharides derived from citrus trash can therefore be used as emerging prebiotics with increased activity. The use of probiotics in food formulation (Fermented food) is a traditional practice. Incorporating prebiotics into a daily diet can help combat nutrient deficiency and contribute to malnutrition mitigation with the reduction of agro-waste [25].

**Single-Cell Protein**

Mondal et al. investigated the generation of single-cell protein from discarded orange and cucumber peels using submerged fermentation with *Saccharomyces cerevisiae* [26]. The compounds generated from the biotransformation of such peel waste are both economically and nutritionally rich in protein Carranza-Méndez et al. investigated the use of orange peel as the sole carbon and energy source for *Candida utilis,* as well as the evaluation and optimization of SCP synthesis through submerged fermentation [27]. The results showed that orange peel waste is a good source of nutrients, particularly carbs, for producing single-cell protein. Orange peel's high sugar content makes it an ideal fermentation substrate for the growth of *C. utilis*. These few investigations strongly suggested that the orange peel has a high potential for producing single-cell protein

**Livestock Feed**

Pourhossein et al. found that feeding orange peel to broiler chicks increased the concentrations of white blood cells, lymphocytes, immunoglobulin G, and immunoglobulin [28]. Ciftci et al. revealed that adding orange peel extract to Quail diets increased body weight, decreased triglyceride levels, and enhanced feed conversion ratios [29]. Seidavi et al. proposed using orange peel waste as a healthy, affordable, and hygienic feed for chicken diets [30]. However, because too much orange peel waste might upset the digestive tract of livestock, it is recommended to use it in moderation in animal feed Souza et al. evaluated growth performance, bone characteristics, intestinal morphometry, and organ biometrics in broilers fed a diet containing orange (*Citrus sinensis L.*) essential oil and discovered that adding orange peel essential oil to diets promotes the improvement of productive variables (weight gain, feed intake, and feed conversion) in broilers during the

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pre-starter phase [31].. The studies cited above clearly show that using the appropriate proportions of orange waste and by-products as a supplement in the chicken feed can result in a healthy, antibiotic-free product with no dangerous residues for human consumption

**Pharma Drug**

Crude extract and isolated chemicals from orange peels showed a variety of pharmacological effects, including antibacterial, antiparasitic, insecticidal, antioxidant, antiproliferative, and antifungal properties, as well as aiding in the management of obesity, cholesterol, osteoporosis, and neurological illnesses. Orange peel polymethoxyflavones, including tangeretin and nobiletin have been shown to improve cognitive function in various experimental models, including Alzheimer's disease, Parkinson's disease, and cardiovascular dementia. These compounds modulate pathological features like Aβ/tau pathology, oxidative stress, and neuroinflammation, as well as improve synaptic plasticity. Furthermore, flavanones such as hesperidin, naringin, and narirutin exert neuroprotection in various neurodegenerative disease models [32]. *Citrus sinensis* essential oil was found in clinical investigations to reduce anxiety levels in patients awaiting dental treatment as well as healthy volunteers exposed to an anxiogenic scenario [33]. Naringin prevents and reduces plasma cytokine levels of IL-1β, IL-10, TNF-α, and IFN-γ in SARS-CoV-2 patients. Hesperetin has been shown to bind to the ACE2 protein, which may help reduce COVID-19 infection. According to recent research, *Citrus sinensis* supplementation may be beneficial as a preventative medication against SARS-CoV-2 infection and as a supplemental treatment for COVID-infected individuals [34]. These few examples demonstrated the usefulness of nutritious orange peels in everyday life.

**Bio-Adsorbents**

Orange peel bio-absorbent and silicon sand were used successfully to retain the salt from seawater [35]. Mafra et al. investigated the impact of orange peel physical characteristics on dye adsorption [36]. The greatest adsorption uptake in study which used powdered orange peel as an adsorbent to remove the dye Remazol Brilliant Blue R from organic wastes was 11.62 mg/g. Numerous studies indicate that base treatment of orange peel increases the carboxylates and binding sites of the peel

**Bioethanol**

OPW was used to produce bioethanol through simultaneous acid-catalyzed steam explosion, separate enzymatic hydrolysis, and fermentation with *Saccharomyces cerevisiae*. The study reported an ethanol production of 0.495 g/g and productivity of 4.85 g/Lh [37]. Taghizadeh-Alisaraei et al. employed an equal quantity of rice hull and orange peel (RHOP) trash to manufacture bioethanol by acid hydrolysis technique [38]. Three quantities of sulfuric acid (1, 2, and 3%) were utilized, with hydrolysis at 121 °C for 20, 40, and 60 minutes in the reactor. 55 g of Saccharomyces cerevisiae was utilized in the fermentation process, with periods ranging from 4 to 32 hours. The optimal setting yielded 22.77 g of bioethanol per L of RHOP substrate. The experiment's optimal circumstances resulted in a bioethanol production yield of 0.295 L/kg of RHOP dry matter. Singh et al. found that *S. cerevisiae* produces the highest output of bioethanol at 40ºC, 4.07% (v/v) for orange peel after 48 hours of incubation [39]. Bioethanol is created by digesting reducing carbohydrates.

Ojewumi et al. isolated pectin from orange peel (OP) and then turned it into ethanol using bacteria and fungi. OP of 802 g was used to make 1,770 mL of pectin [40]. A blend of pectin, *E. coli*, and *S. cerevisiae*, as well as a sample pectin-*E. coli* combination, produced a promising volume of ethanol. The quantity of energy included in the gross ethanol produced was 1526.6 btu. This can be blended with purified gasoline to achieve the ideal energy content that can be used to run an indigenous processing plant for citrus fruit in Nigeria.

**Skin/Hair Care Products**

Recent research has concentrated on determining the anti-tyrosinase activity of orange peel extract. Orange peel exhibited strong anti-tyrosinase activity, with an $IC_{50}$ value of 255.10 μg/ml. Whitening lotion made from orange peel waste (2%) weight by weight could reduce melanin pigment by 17.33% [41]. Borse et al. developed and tested two layered soaps using orange peel extract and found that orange peel soap improved skin color more than soap base [42]. The skin melanin content was reduced after one month of using orange peel soap. It was concluded that the use of orange oil as an anti-aging, whitening, and flavoring agent in one layer of soap, followed by the use of peel cake remains as a scrubbing agent in the second layer of soap, is the most suitable for the production of two layered soap, which provided potential skin benefits from an economic perspective An anti-acne composition using *C. sinensis* (3%), *Ocimum basilicum L* (5%) essential oils, and acetic acid (12%) inhibited *Propionibacterium* acnes. This antibacterial effect is mostly owing to the 94.0% of limonene in *C. sinensis*, and limonene (2.54%), linalool (21.0%), and eugenol (7.17%) in *O. basilicum L* [43]. Orange peel cold-pressed oil, which is high in polymethoxy-flavones (PMFs), has been shown in mice to inhibit UVB-induced skin damage. Orange CPO treatment effectively inhibits skin collagen degeneration by regulating TIMPs and MMPs mRNA and protein expression in mouse skin, as well as alleviating oxidation and inflammation-related bioindicator abnormalities in mice, thereby protecting the skin from UVB-induced photoaging. Orange peel (70%) was combined with *Zingiber officinale* roots, *Linum usitatissimum* seeds, *Nigella sativa*, and *Trigonella foenum-graecum* to create this herbal hair serum. Herbal hair serum that has been prepared has shown good hair growth and is effective in increasing hair consistency. Herbal cosmetics are still extensively utilized by normal citizens due to less side effects and a stronger protection and safety profile [44].

## ORANGE PEELS BASED VALUE ADDED PRODUCTS

### Orange Peel Based Edible Films/Coatings

Al-Anbari et al. used orange peel as edible films and applied them to cupcakes discovered positive results, including a rise in peroxide value and a reduction in microbial growth [45]. The effect of chitosan films mixed with 2% orange peel essential oil (*Citrus sinensis (L.) Osbeck*) on the shelf life of deepwater pink shrimp by *Parapenaeus longirostris Lucas* in 1846 was investigated Edible chitosan coatings combined with OPEO protected the shrimps and extended the shelf life during refrigerated storage [46]. The quality of deep-water pink shrimp was investigated using a gelatin-based film coating containing essential oil produced from orange (*Citrus sinensis (L.) Osbeck*) peel. It was claimed that gelatin and orange peel essential oil kept shrimp's sensory characteristics within acceptable limits during preservation. Combined coating reduced the growth of bacteria that cause shrimp deterioration and demonstrated effective antimicrobial properties throughout storage. It was also discovered that combining gelatin film forming solution with orange peel essential oil results in an efficient coating that may be used as a natural preservative for shrimp in refrigerated storage while maintaining quality [47]. Blood orange coated with carnauba wax and montmorillonite nanoclay (MMT) had the least deformation and dissolved solid, as well as the maximum acidity, when compared to other treatments. Fruits coated with MMT demonstrated improved brightness [48]. Orange slices were stored at 4ºC for 17 days, and the effect of pectin-based edible coatings containing orange peel essential oil at 0.5 and 1.0% concentrations was studied. The findings indicated that OPEO-containing edible coatings based on nanoemulsions can extend the shelf life of orange slices without altering their sensory attributes [49]. The edible film was made by combining blood orange peel pectin with fish gelatin. An edible film made up of 50% orange peel pectin and 50% fish gelatin shown exceptional tensile strength, antioxidant, and antibacterial properties. The created edible film was also utilized to coat cheese using the wrapping method. The results demonstrated increased physicochemical, textural, and microbiological stability of the cheese (ricotta) covered with mixed edible film [50].

### Orange Peel-Based Carbon Dots

The hydrothermal corbonization method was used at a low temperature (180ºC) to synthesize fluorescent carbon dots from discarded peels in a simple and straightforward one-pot reaction. The synthesized carbon dots demonstrated photocatalytic activity with several advantages, including green production, excellent solubility in an aqueous media, and luminescence [51]. Orange peels were employed as a precursor to produce carbon quantum dots (CQDs) using a simple and inexpensive carbonization technique. The produced carbon quantum dots have proven to be outstanding in extremely practical applications [52].

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**Table 1:** Orange peel based edible films/coating with their applications.

| Matrix | Applied on Food Items | Technique Used | Beneficial Effects | Reference |
|---|---|---|---|---|
| Chitosan film | Deep water pink shrimp | Casting | The combination of chitosan film with 2% orange peel essential oil concentration proved successful in extending the shelf life of fresh shrimps to 15 days. | [46] |
| Gelatin | Shrimps | ND | Gelatin coating mixed with orange peel essential oil protected shrimp quality during cold storage, extending shelf-life by approximately 6 days. | [47] |
| Carnauba wax, montmorillonite nano clay | Blood orange | ND | Blood orange coated with carnauba wax and montmorillonite nano clay (MMT) had the least deformation and dissolved solid, as well as the maximum acidity, when compared to other treatments. Fruits coated with MMT demonstrated improved brightness. | [48] |
| Pectin-coating | Fresh-cut orange | ND | The results demonstrated that the Nano emulsion-based edible coatings containing orange peel essential oil can enhance the shelf life of orange slices without having any negative effects on sensory qualities. | [49] |
| 50% of orange peel pectin and 50% of fish gelatin | Cheese | Wrapping | The results demonstrated increased physicochemical, textural, and microbiological stability of the cheese (ricotta) covered with mixed edible film. | [50] |

**Orange Peel Based Metallic Nanoparticles**

Silver nanoparticles produced from orange peel were found to be effective at inhibiting both *Staphylococcus aureus* and *Proteus vulgaris* bacterial strains. The bacterial activity is considered to be related to the changes generated in the membrane structure of the microbial cell because of its interaction with the rooted silver nanoparticles, which leads to an increase in the permeability of the cell membrane and, ultimately, leading to their death [53].

Silver nanoparticles derived from sun-dried *Citrus sinensis* peel extracts demonstrated effective antibacterial action against *Pseudomonas aeruginosa*, *E. coli*, and *Salmonella typhimurium* [54]. Silver nanoparticles produced using orange peel extract shown photocatalytic activity against methylene blue [55]. The activities of silver nanoparticles synthesized with orange peel extract were tested with human pathogens (*Salmonella, E. coli,* and *Pseudomonas*), plant pathogens (Fusarium), and marine pathogens (*Aeromonas hydrophila*), as well as the scavenging effect and anticancer properties against MCF-7 cell lines. These studies demonstrated that it has excellent antibacterial activity against human, plant, and marine diseases, as well as significant anticancer activity against human breast cancer cell (MCF-7) lines, which promotes the use of these nanoparticles in therapeutic applications [56]. Antimicrobial activity was determined using minimum inhibitory concentration assays against the bacteria Xanthomonas axonopodis pv. citri (Xac). The results showed that AgNPs produced using orange (*C. sinensis*) peel extract demonstrated strong antibacterial activity [57].

**Orange Peel Based Microbiological Media**

Cultivation of microorganisms in the laboratory necessitates a nutritional environment that provides nutrients for growth. Replacing nutritional media with alternatives such as scrap orange peel in media formulation. *E. coli*, *Pseudomonas sp*., and *Serratia sp*. grew well in the prepared media [58]. OPW was employed as a liquid medium for biodiesel production with oleaginous yeasts. *Cryptococcus laurentii* UCD 68-201 and *Rhodosporidium toruloides* NRRL 1091 strains produced 31.9% and 36.9% of biodiesel, respectively [59].

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**Orange Peel Derived Biochar And Its Applications**

Pyrolysis of orange peels was performed at various temperatures to produce biochar, which was subsequently tested as an adsorbent in palm oil mill effluent treatment. The results showed that pyrolysis has the potential to turn orange peel into value-added bio char that may be used as an adsorbent to remediate palm oil mill effluents. The recovery of bio chars from fruit waste has a number of advantages over standard landfill disposal procedures [60]. Biochar from orange peel were made at 300°C for 2 hours. Bio chars made from orange peel had the highest NH4+ adsorption capabilities (4.71 mg/g). To summarize, fruit peel-derived biochar can be employed as an alternative to conventional sorbents in water treatment [61].

**Conclusion/Future Prospective**

OPW are commercially valuable in the medicinal, agricultural, and industrial sectors. Because of their nutritional value, orange by-products have been successfully incorporated into the production of functional foods, according to studies. The usage of such low-cost fruit peel waste will benefit not only the formulation of healthy value-added food products, but also the management of fruit peel trash. The study of OPW valorisation and its applications in diverse industries remains a hotspot for scientific inquiry, necessitating a thorough examination of the mechanisms and long-term dangers of valorisation. Furthermore, there is a long way to go until optimum OPW valorisation and environmental protection.

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**DECLARATION OF COMPETING INTEREST**

The authors declare that they have no competing interests.

**REFERENCES**

1. Shima Y, Rasha A, Islam K et al. Citrus sinensis (sweet oranges) wastes: the orange wealth. Mediterranean Fruits Bio-wastes. 2022;261-285. doi.org/10.1007/978-3-030-84436-3_10.
2. Russell R, Pilar P, Fatima J. Historical review of citrus flavour research during past 100 years. J Agric Food Chem. 2009;57(18):8115-8124. doi: 10.1021/jf900112y.
3. Yadav S, Sharma CS. Novel and green processes for citrus peel extract: A natural solvent to source of carbon. Polym. Bull.2018;75:5133-5142.doi.org/10.1007/s00289-018-2310-5.
4. Zema DA, Calabrò PS A, Folino A et al. Valorization of citrus processing waste: A review. J Waste Manag. 2018;80:252-273.
5. Rezzadoria K, Benedettia S, Amanteb ER. Proposals for the residues recovery: Orange waste as raw material for new products. Food Bioprod. Process. 2012;90: 606-614.
6. Sebastiano S, Stefania B, Mario DiG et al. Sweet Orange: Evolution, Characterization. Varities and breeding perspectives. Agriculture. 2023;13:L264.
7. Mohsin A, Hussain H, Zaman Q et al. Advances in sustainable approaches utilizing orange peel waste to produce highly value-added bioproducts. *Crit Rev Biotechnol.* 2021;42(8):1284-1303. DOI: 10.1080/07388551.2021.2002805
8. Suri S, Singh A, Nema PK. Current applications of citrus fruit processing waste: A scientific outlook. *Appl. Food Res*. 2022;2(1):10050.
9. Jennifer S, Mary A, Linda H. Oranges: Safe Methods to Store, Preserve, and Enjoy. ANR Publication 8199. 2006. pp-1-12. DOI 10.3733/ucanr.8199
10. Juliana Maria de Mello Andrade, Erna Vogt de Jong , Amélia Teresinha Henriques. Byproducts of orange extraction: influence of different treatments in fiber composition and physical and chemical parameters. Braz J Pharm Sci. 2014; 50(3):473-482. http://dx.doi.org/10.1590/S1984-82502014000300005
11. Viviana N, Bernardo R, Debora F et al. Life cycle assessment of orange peel waste management. *Resour Conserv Recycl.*2017;127:148-158.
12. Ruviaro A, Barbosa PDM, Macedo G. Enzyme-Assisted Biotransformation Increases Hesperetin Content in Citrus

Juice by-products. *Food Res Int.* 2019;124:213–221. doi:10.1016/j.foodres.2018.05.004.

13. Ani P, Abel H. Nutrient, Phytochemical, and Antinutrient Composition of Citrus Maxima Fruit Juice and Peel Extract. Food Sci Nutr. 2018;6:653–658. doi: 10.1002/fsn3.604.
14. Sial TA, Lan Z, Khan MN et al. Evaluation of orange peel waste and its biochar on greenhouse gas emissions and soil biochemical properties within a loess soil. Waste Manage. 2019;15(87):125-134. doi:10.1016/j.wasman.2019.01.042.
15. Wang X, Chen Q, Lu X. Pectin extracted from apple pomace and citrus peel by subcritical water. Food Hydrocoll. 2014;38:129–137. 10.1016/j.foodhyd.2013.12.003.
16. Sasidharan S, Chen Y, Saravanan D et al. Extraction, isolation and characterization of bioactive compounds from plants' extracts. AJTCAM. 2011;8(1):1–10. 10.4314/ajtcam.v8i1.60483
17. Fadda SH, Attalla RF, Zaher MM. Impact of Food Values of Dried Orange Peel in Feeding the Nile Tilapia. EJABF. 2021;25(5):447–461.
18. Kotsou K, Chatzimitakos T, Athanasiadis V et al. Waste Orange Peels as a Feed Additive for the Enhancement of the Nutritional Value of Tenebrio molitor Foods. 2023;12(4):783. doi: 10.3390/foods12040783.
19. Saini D, Sharma SK. Utilization of sand pear and orange peel to develop value added smoothie. J Pharm Innov. 2020;9(6):200-202.
20. Jaiswal S, Paul V. Development and Standardisation of Edible Bowls by Utilization of Citrus Peel and Pulp. IJRES. 2022;10(9):502-504.
21. Sicari V, Loizzo MR, Romeo R et al. Addition of Orange By-Products (Dry Peel) in Orange Jam: Evaluation of Physicochemical Characteristics, Bioactive Compounds and Antioxidant Activity. Med Sci Forum. 2021;2:11.
22. Thliza BA, Kolo MT, Dawi HA et al. Production and Storage Properties of Biscuit from Orange Peels and Pulps. J Sci Eng Res. 2021;8(8):98-109.
23. Sicari V, Pellicanò TM, Laganà V et al. Use of Orange By-Products (Dry Peel) as an Alternative Gelling Agent for Marmalade Production: Evaluation of Antioxidant Activity and Inhibition of HMF Formation during Different Storage Temperature. J Food Process Preser. 2018;42:e13429. **DOI :** 10.1111/jfpp.13429
24. Míguez B, Gómez B, Gullón P, et al. Pectic Oligosaccharides and Other Emerging Prebiotics. Probiotics and Prebiotics in Human Nutrition and Health. Rao V, Rao LG. editors. 2016. DOI: 10.5772/62830.
25. Pgi D, Jwa S, Rmusk R. Formulation and development of composite fruit peel powder incorporated fat and sugar-free probiotic set yogurt. GSCBPS. 2020;11:93–99. **DOI :** https://doi.org/10.30574/gscbps.2020.11.1.0084
26. Mondal AK, Sengupta S, Bhowal J et al. Utilization of Fruit Wastes in Producing Single Cell Protein. IJEST. 2022;1:430–438.
27. Carranza-Méndez RC, Chavez-Gonzalez ML, Sepulveda-Torre L et al. Production of single cell protein from orange peel residue by Candida utilis. ISBAB. 2022; 40:102298. https://doi.org/10.1016/j.bcab.2022.102298.
28. Pourhossein Z, Qotbi AA, Seidavi A et al. Feeding of dried sweet orange (Citrus sinensis) peel on humoral immune response of broiler chickens. IJROWA. 2019; 8:361–367 https://doi.org/10.1007/s40093-019-0272-8
29. Ciftci, M., Simsek, U. G., Dalkilic, B., Azman, M. A., Yilmaz, O., Mutlu, S. I. Effect of dietary orange peel extract on physiological, biochemical, and metabolic responses of Japanese quail reared under low ambient temperature. *Turk* J Vet Anim Sci. 2016; 40(3):288–297. 10.3906/vet-1504-11.
30. Seidavi A, Zaker-Esteghamati H, Salem AZ. A review on practical applications of Citrus sinensis by-products and waste in poultry feeding. Agrofor Syst. 2020; 94(4):1581–1589. 10.1007/s10457-018-0319-2.
31. Souza CS, Vieites FM, Justino LR et al. Orange essential oil in the diet of broilers: performance, organ biometrics, bone characteristics, and intestinal morphometry. Braz J Anim Sci. 2021; 50:e20200097. https://doi.org/10.37496/rbz5020200097.
32. Matsuzaki K, Nakajima A, Guo Y, Ohizumi, Y. A Narrative Review of the Effects of Citrus Peels and Extracts on Human Brain Health and Metabolism. Nutrients. 2022; 14(9):1847. https://doi.org/10.3390/ nu14091847
33. Mannucci C, Calapai F, Cardia L et al. Clinical Pharmacology of Citrus aurantium and Citrus sinensis for the Treatment of Anxiety. eCAM. 2018;1-18. https://doi.org/10.1155/2018/3624094.
34. Hamimed S, Jebli N, Hamimed R et al._Phytochemicals

candidates as promising preventives and/or curatives for COVID-19 Infection: A brief review. Insights boil med. 2021;5:001-006. DOI: 10.29328/journal.ibm.1001019

35. Falcó M, Garcia J, Arnal O. Study of the influence of a bioabsorbent derived from orange peel on a filtering soil using seawater irrigation by capillarity. IJOEAR. 2021; 7(3):8-17. http://hdl.handle.net/2117/344013
36. Mafra MR, Igarashi-Mafra L, Zuim DR et al. Adsorption of remazol brilliant blue on an orange peel adsorbent. Braz. J. Chem. Eng. 2013; 30:657–665.
37. Santi G, Crognale S, D'Annibale, AA et al. Orange peel pretreatment in a novel lab-scale direct steam-injection apparatus for ethanol production. Biomass bioenergy 2014;61:146 -156. http://dx.doi.org/10.1016/j.biombioe.2013.12.007.
38. Taghizadeh-Alisaraei A, Ahmad Abbaszadeh-Mayvan, A, Hassan Hosseini, SBio-ethanol production from a mixture of rice hull and orange peel wastes, Biofuels. . 2022; 13(2):171-175, DOI: 10.1080/17597269.2019.1655214
39. Singh ARP, Singh AK, Charan AI, Production of Bioethanol by Banana and Orange peel using Sacchromyces cerevisiae. Bio Sci Trends. 2022;7(1):904-907.
40. Ojewumi ME, Oyekunle DT, Amaefule CV et al. Investigation into Alternative Energy Sources from Waste Citrus Peel (Orange): Approach to Environmental Protection. J Physics. 2019; 1378:022066. doi:10.1088/1742-6596/1378/2/022066
41. Wuttisin N, Boonmark J, Thaipitak V et al. Anti-tyrosinage activity of orange peel extract and cosmetic formulation. Int Food Res J. 2017;24(5):2128-2132.
42. Borse SL, Badwara MR, Laxmikant B et al. Formulation and Evaluation of Two Layered Soap Containing Orange Peel Extract. J Pharm Sci Res. 2019;11(6):2190-2192.
43. Matiz G. Osorio MR, Camacho F et al. Effectiveness of antimicrobial formulations for acne based on orange (Citrus sinensis) and sweet basil (Ocimum basilicum L.) essential oils. Biomedica. 2012;32:125–133. doi:10.1590/S0120-41572012000100014.
44. Li U, Tan F, Zhang Q et al. Protective effects of polymethoxyflavone-rich cold-pressed orange peel oil against ultraviolet B-induced photoaging on mouse skin. J Funct Foods. 2020;67:103834. https://doi.org/10.1016/j.jff.2020.103834.
45. Al-Anbari IH, Dakhel AM, Adnan A. The effect of adding local orange peel powder to microbial inhibition and oxidative reaction within edible film component. Plant Arc. 2019;19:1006–1012.
46. Alparslan Y, Baygar T. Effect of Chitosan Film Coating Combined with Orange Peel Essential Oil on the Shelf Life of Deepwater Pink Shrimp. FABT. 2017; 10:842–853. DOI:10.1007/s11947-017-1862-y
47. Alparslan Y. Metin C, Yapıcı HH, et al. Combined effect of orange peel essential oil and gelatin coating on the quality and shelf life of shrimps. J Food Safety and Food Quality. 2017;68:69–78. DOI:10.2376/0003-925X-68-69
48. Nasirifar SZ, Maghsoudlou A, Oliyaei N. Effect of active lipid-based coating incorporated with nanoclay and orange peel essential oil on physicochemical properties of Citrus sinensis. *J Food Safety Food* Nutr. 2018;6:1508–1518. doi: 10.1002/fsn3.681
49. Radi M, Akhavan HR, Amiri S et al. The use of orange peel essential oil microemulsion and nanoemulsion in pectin-based coating to extend the shelf life of fresh-cut orange. J. Food Process Preserv. 2017;42(2): pp.e13441. DOI:10.1111/jfpp.13441
50. Jridi M, Abdelhedi O, Salem A et al. Physico-chemical, antioxidant and antibacterial properties of fish gelatin-based edible films enriched with orange peel pectin: Wrapping application. Food Hydrocoll. 2020;103:105688 https://doi.org/10.1016/j.foodhyd.2020.105688.
51. Prasannan A, Imae T. One-Pot Synthesis of Fluorescent Carbon Dots from Orange Waste Peels. Ind Eng Chem Res. 2013; 52:15673–15678. https://doi.org/10.1021/ie402421s
52. Chatzimitakos T, Kasouni A, Sygellou L et al. Two of a kind but different: Luminescent carbon quantum dots from Citrus peels for iron and tartrazine sensing and cell imaging. Talanta. 2017;175:305–312. doi: 10.1016/j.talanta.2017.07.053
53. Shet AR, Tantri S, Bennal A. Economical biosynthesis of silver nanoparticles using fruit waste. J Chem Pharm Sci. 2016; 9:2306–2311.
54. Reena M, Menon AS. Synthesis of Silver Nanoparticles from Different Citrus Fruit Peel Extracts and a Comparative Analysis on its Antibacterial Activity. IJCMAS. 2017;6:2358–2365.

55. Skiba MI, Vorobyova VI. Synthesis of Silver Nanoparticles Using Orange Peel Extract Prepared by Plasmochemical Extraction Method and Degradation of Methylene Blue under Solar Irradiation. *Adv Mater Sci Eng.* 2019;1–8. https://doi.org/10.1155/2019/8306015
56. Naganathan K, Thirunavukkarasu S. Green way genesis of silver nanoparticles using multiple fruit peels waste and its antimicrobial, anti-oxidant and anti-tumor cell line studies. Mater Sci Eng. 2017;191(1):012009. DOI:10.1088/1757-899X/191/1/012009
57. Barros CHN, Cruz GCF, Mayrink W et al. Bio-based synthesis of silver nanoparticles from orange waste: Effects of distinct biomolecule coatings on size, morphology, and antimicrobial activity. Nanotechnol Sci Appl. 2018;11:1–14. doi: 10.2147/NSA.S156115.
58. Jadhav P, Sonne M, Kadam A et al. Formulation of cost effective alternative bacterial culture media using fruit and vegetables waste. IJCRR. 2018; 10:6–15. DOI: 10.7324/IJCRR.2018.1022
59. Carota E, Petruccioli M, D'Annibale A et al. Orange peel waste–based liquid medium for biodiesel production by oleaginous yeasts. Appl Microbiol Biotechnol. 2020; 104(10):4617–4628. DOI: 10.1007/s00253-020-10579-y
60. Lam SS, Liew RK, Cheng CK et al. Pyrolysis production of fruit peel biochar for potential use in treatment of palm oil mill effluent. J Environ Manag. 2018;213:400–408. DOI: 10.1016/j.jenvman.2018.02.092
61. Hu X, Zhang X, Ngo HH et al. Comparison study on the ammonium adsorption of the bio chars derived from different kinds of fruit peel. Sci Total Environ. 2020; 707:135544. DOI: 10.1016/j.scitotenv.2019.135544.