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ZESTFUL INGENUITY: UNLEASHING THE HIDDEN POTENTIAL OF CITRUS PEELS IN A WORLD OF CULINARY AND SUSTAINABLE WONDERS

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ABSTRACT

Citrus fruits, part of the Rutaceae family, include orange, tangerine, lime, lemon, sour orange, and grapefruit. Apart from their culinary use, they contribute significantly to processing industries, yielding products like marmalade, jams, juice, and jellies. However, this processing generates substantial peel and seed waste, raising environmental concerns. Efforts to minimize waste impact involve transforming it into candies, unlocking nutritional benefits. The bitterness of citrus peels poses a challenge, affecting demand. Despite global research exploring ways to utilize these discarded elements, considerable untapped potential remains. This article synthesizes international research, shedding light on the underexplored possibilities of citrus waste and strategies for optimizing its utilization.

INTRODUCTION

Citrus, a globally esteemed fruit crop, is rich in essential phytochemicals that contributes towards human health. Despite its nutritional richness, citrus peel, containing abundant antioxidants and vitamin C, often faces wasteful disposal, adding to the staggering annual global discard of 144 million metric tons of peel waste. These peels encompass not only the vibrant outer layer (epicarp) but also the softer inner layer (mesocarp), both repositories of polyphenols, essential oils, and compounds like auraptene and bergamottin, known for their health-enhancing properties (fig.1). The management of citrus waste presents intricate challenges, particularly in countries such as India. Here, the escalating waste production strains landfill capacities due to population growth and industrialization. Globally, approximately 30–40% of fruit and vegetable production goes to waste, influenced by factors like household sizes, income disparities, and inadequate waste management systems.

Addressing waste challenges involves initiatives to recycle and extract optimal value. Current waste management falls short, leading to environmental degradation, exacerbated by overflowing landfills due to household organic waste. Urgent intervention is needed to rectify disposal practices, especially indiscriminate dumping. One solution is producing eco-enzymes from fruit and vegetable waste, transforming organic matter into versatile products. Scaling up eco-enzyme production is crucial for efficiently managing rising waste volumes. Embracing a zero-waste framework advocates for reduction, reuse, and recycling, fostering a circular system. Citrus waste utilization in various sectors is crucial, from animal feed to eco-friendly solvents and antibiotics production (fig. 2). Proper utilization reduces environmental impact and generates renewable bio-based products, emphasizing the need for effective waste management. However, optimizing citrus waste utilization not only addresses environmental challenges but also yields valuable bio-based products, emphasizing the urgent need for efficient waste management strategies.

BIOACTIVE AND NUTRITIONAL COMPOSITION

Discarded citrus components, including peel, seeds, juice vesicles, and membrane, represent a substantial and economically valuable source of high-added-value compounds such as dietary fibre, flavonoids, polyphenols, sugars, carotenoids, ascorbic acids, and essential oils. These citrus wastes, with their elevated sugar levels, prove crucial for processes like fermentation in bioethanol production and serve as substrates for solid-state fermentation (Khan *et al.*, 2021) (Table 1).

Table 1 Different bio-active compound and their benefits of citrus based products

Bioactive compound(S)	Potential benefits/uses	Citrus based sources
Dietary fibre	Integral in diet, lowers disease risk (cardiovascular, diabetic), aids weight loss, reduces hypertension, prevents heart disease.	Pulp and peel
Phenolics	Phenolics: potent antioxidants prevent cancer, tumors, and shield cells from free radical damage traditionally.	Peel and pulp
Essential oils.	Acts as a commercial antimicrobial agent, preserving food by inhibiting deterioration, possessing antifungal, insecticidal, antibacterial properties.	Peel
Carotenoids.	Vital in animal feed, nutraceuticals, pharmaceuticals, and as colorants in foods and cosmetic products.	Peel and pulp
Pectin	Pectin stabilizes and gels food, prevents poisoning, and aids diabetes and reflux.	Peel

BY-PRODUCT UTILIZATION

The primary challenge in citrus production is harshness, prompting analysts to explore by-product utilization, specifically rind and seeds, to improve overall citrus utilization. The major processing by-products, including all citrus fruits, peel, and pomace, constitute 55-60 per cent of the fresh fruit. These by-products serve various purposes, acting as insecticides, fumigants, and insect pest repellents. They also play major roles in recovering and purifying volatile oil and seed oil, processing pelletized dry peels as cattle feed, and repurposing citrus peel (Table 2).

Table 2 Potential health, economic and environmental benefits from citrus by-product utilization

Utilizing citrus by product as	**Potential health, economic and environmental benefits**
Dietary fibre	Citrus fruits, rich in both soluble (gum, pectin) and insoluble (lignin, cellulose, hemicellulose) dietary fibre, inhibit meat lipid oxidation, extending shelf life. Orange juice fibre, sourced from seeds, pulp, and peel, acts as a fat substitute in ice cream, thanks to its outstanding oil and water retention. These resistant polysaccharides provide unique health benefits and aid digestion.
Pectin production	Citrus rind contains pectin, a soluble fibre widely used in jams, jellies, medications, and juices as a gelling agent. Pectin's versatility extends to eco-friendly food packaging as edible films, showcasing biocompatibility and biodegradability. Extracted from citrus, it acts as a stabilizing, thickening agent in various products, from baked goods to confectionery.
Peel utilization	About 30-34% of fruit peel becomes a significant byproduct during citrus juice processing. This peel waste is repurposed for extracting polyphenolic compounds, creating value-added products known for their potential as sources of phenolic blends with beneficial antioxidant and antimicrobial properties. Peel Powder: The powder, obtained by drying kinnow rind through mechanical and solar methods, meets standard parameters. Candied Peel: Achieving the best colour and desirable caramelized appearance, candies are prepared by cooking at 70 degrees Celsius for 25 minutes in a syrup solution of 60 degrees brix (Rafiq *et al.*, 2018).

Seed oil	Citrus seeds and peels stand out as valuable sources for oils with diverse applications. The extracted seed oil, boasting 98.6% carboxylic acid and abundant tocopherols like alpha and gamma-tocopherols, features essential fatty acids such as palmitic and linoleic acids. With attributes like an iodine number of 104.80 g I/100 g of oil, a refractive index of 1.465 at 40°C, and a specific gravity of 0.927 mg/ml at 25°C, this oil finds utility in ear drops, disinfectants, and medicinal formulations for respiratory diseases.
Repellent	The volatile oil extracted from citrus waste serves as an insect repellent. However, the precise mechanisms behind repellents in various arthropods remain uncertain and even contradictory within scientific literature. Monounsaturated fatty acid and linoleic acid have been shown to trigger death aversion in cockroaches, leading to the suggestion of a 'necromone' as the compound responsible for this behaviour.
Insecticide and fumigant	Volatile oils from well-known sources like lime, sweet orange, and lemon exhibit insecticidal or repellent properties. Understanding their mechanisms is crucial for effective insect control, but practical large-scale application faces challenges due to the physical properties of volatile oils.
Biofuel production	Citrus fruit waste, rich in soluble and insoluble carbohydrate polymers, holds promise for biofuel conversion like biogas and ethanol. Anaerobic digestion with mesophilic bacteria offers an affordable means to produce methane from orange peel pressing liquid and citrus waste. Commercial-scale anaerobic reactors present an eco-friendly solution for processing stored waste with lower environmental impact and operational costs than treating fresh citrus waste.
Animal feed	Citrus processing waste, a valuable by-product, finds utilization in animal feed industries due to its abundant bioactive compounds, acting as a nutritious supplement while preventing the growth of harmful bacteria like salmonella and Escherichia coli. These waste materials offer a rich source of structural fibre, delivering essential nutrients for animal production, maintenance, growth, and reproduction.
Eco-enzyme	Eco-enzymes, derived from fruit peels, brown sugar, and water, serve as potent

	cleaning agents. The choice of raw materials significantly influences eco-enzyme production, aiming to reduce landfill waste while creating economic value. This eco-friendly liquid finds multiple uses from waste treatment to air purification and biopesticide/fertilizer roles after three-month fermentation.
Disinfectant	With a pH of 4 and a citrus aroma, it's an excellent disinfectant (Benny et al., 2023). By utilizing fruit peels instead of chemicals, these disinfectants align with eco-friendly practices, fostering waste reduction and recycling at the household level. This collective effort helps diminish waste until reaching near-zero levels.

FUTURE PROSPECTIVE

Citrus processing waste, abundant in plant-derived natural supplements, is positioned to substitute synthetic additives in the food industry. The increasing awareness of its health benefits is expected to propel the demand for natural ingredients, especially in food, cosmetics, and pharmaceuticals. The functional compounds present in this waste will experience heightened utilization across diverse sectors, contributing to the production of value-added chemicals. By harnessing citrus waste, not only is environmental damage mitigated, but waste accumulation is also reduced, signalling a shift towards prioritizing resource utilization over disposal.

CONCLUSION

Citrus waste, encompassing wastewater and peels, is crucial in the pharmaceutical, cosmetic, and food industries. Effectively managing this waste offers economic gains by enriching the soil as a natural conditioner and animal feed. Loaded with bioactive compounds, it combats inflammation, infections, and thrombosis for better health outcomes. However, disposal poses environmental and economic challenges. Utilizing citrus pulp as an adsorbent material effectively purifies industrial effluents. Our strong advocacy can end citrus waste disposal, promoting awareness of its diverse benefits. This strategy curtails waste accumulation, encourages healthier practices, and reduces reliance on synthetic products, promising multifaceted benefits for health and the environment.

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