The potential bioactive components in fruits wastes as value-added products from the fruit processing industry :A review

ABSTRACT

Fruits are an important source of nutrition as most of them contain sufficient amounts of minerals, vitamins, and antioxidants. However, processing these fruits results in enormous waste, accounting for around 40% of total food output. Fruit processing industry waste includes discarded pods, peels, pulp, stones, and seedsall of which can pose environmental and sustainability challenges. Importance of discovering the potential of fruit processing waste into value added products lies in the fact thatthe fruit processing industries generates substantial waste, contributing to environmental pollution, greenhouse gas emissions, and resource depletion. The solid waste generated by the fruit processing industry may include toxic biological components that contaminate aqueous media, degrade drinking water quality, and cause gastrointestinal disorders in animals.However, Fruit processing waste or byproducts have the potential to be converted into value-added goods of economic importance like candied peel, oils, pectin, reformed fruit fragments, enzymes, and wine/vinegar candied peel. Converting this waste into valuable products can mitigate these issues, while also creating new revenue streams, jobs, and industries. Furthermore, value-added products from fruit processing waste can enhance food security, nutrition, and sustainability, supporting the United Nations' Sustainable Development Goals (SDGs). Additionally, research in this area can also lead to technological innovations, improved efficiencyand scalability, enabling companies to gain a competitive edge in the growing market for sustainable products. This article provides an overview of all common andpossible consumer friendly uses of fruit processing wastesand deriving value added products out of it.

Key words: Fruit processing, Biofuel, Phenolic compound, Food Additives, Essential oil

1.Introduction

The global fruit processing industry, driven by increasing demand for nutritious food, generates substantial waste, accounting for approximately 40% of total food production (Sweta et al., 2023). Annually, over 470 million metric tons of fruits, including apples (84.63 MMT), bananas (114.08 MMT), citrus (124.73 MMT), grapes (74.49 MMT), mangoes (45.22 MMT), and pineapples (25.43 MMT), are harvested (FAO, 2022). However, this productive industry comes with significant environmental and sustainability challenges as fruit processing waste poses serious risks to environmental protection.The solid waste produced by the fruit processing industries often may contain some biological components that can be harmful due to phytotoxic effects. These wastes can contaminate aqueous media, degrade drinking water quality, interfere with plant growth, kill delicate marine species, and impede seed germination if disposal is not done properly. These substances also can cause gastrointestinal problems in animals if they are fed to them (Patra et. al., 2022).Thus Reducing food loss and waste is a crucial strategy for enhancing the efficiency, safety, quality, and sustainability of our food systems (Agilah*et al.*, 2023).Thus, researching the potential of fruit processing wastes to produce value-added products is crucial as it has multifaceted benefits. This approach can reduce food waste and create more resilient food systems. Additionally, it recovers valuable nutrients, addresses nutritional deficiencies, and contributes to food security. By exploring waste conversion techniques, industries can reduce their ecological footprint while unlocking economic, social, and environmental value, ultimately contributing to a more sustainable and responsible food processing sector.

Numerous researchers have explored the potential of fruit processing wastes, yielding promising results. Dos Santos et al. (2023) extracted bioactive compounds from citrus waste, demonstrating antioxidant and antimicrobial properties. Byproducts from fruit and fruit processing industries contain bioactive substances including phenolic and antioxidant substances which can improve meal stability (Dos Santos et al. 2023). Thus, these residues can be used to increase the nutritive value of poor people's diets and to help people reduce dietary deficiencies. Kumar et al. (2022) developed a process for essential oil extraction from orange peels, showcasing fragrant and antimicrobial applications. Nirmal et al. (2023) converted apple pomace into functional food ingredients, including dietary fibers and proteins. Sweta et al. (2023) employed enzyme-assisted extraction to recover phenolic compounds from grapefruit waste. Bhat et al. (2020) utilized pineapple waste to produce cosmetics with antioxidant and anti-inflammatory properties. Mirabella et al. (2014) investigated biofuel production from fruit waste, highlighting the potential for sustainable energy. Singh et al. (2022) optimized pectin extraction from citrus waste, demonstrating its potential as a valuable polysaccharide. Kamm et al. (2018) explored ultrasound-assisted processing for enhanced waste valorization. These studies demonstrate the vast potential for value-added product development from fruit processing wastes, underscoring the need for continued research and commercialization

However, existing management practices and research efforts have significant knowledge gaps which include the need for efficient bioactive compound extraction methods, cost-effective technologies, developing market-driven products beyond traditional options; comprehensive cost-benefit analysis, characterizing waste composition variability; understanding bioactive compound stability and bioavailability, insufficient attention to circular economy principles and sustainable waste management etc.. Additionally, gaps exist in technology transfer, standardization, quality control, market development, and consumer education, highlighting the requirement for interdisciplinary research to bridge these gaps and to achieveeconomic growth and improved environmental and social well-being ultimately contributing to a more circular and environmentally conscious food system.By aligning with the United Nations' Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action), this paper seeks to unlock the potential of fruit processing waste, promoting a more sustainable and circular bioeconomy.

2. Sources and Characteristics of Waste from the Fruit Processing Industry

A significant amount of by-products are generated during the processing of fruits including a large amount of waste from juice industry. Fruit processing waste can bedivided into two categories: liquid waste (juice and washed water) which are produced in small quantities and solid rubbish (peel, skin, seeds, stones, etc.) which are produced in larger quantities. Solid waste from fruit processing industries contain high amount of bioactive compounds, eg. polysaccharides such as starch, cellulose, pectin etc.(Bas-Bellver et.al.,2023) and phytochemicals such as flavonoid, anthocyanin, carotenoid, phenolic acid etc.(Machado et al., 2018). Most of the wastes are produced during the process of post-harvest handling like cleaning, sorting, and processing.The primary sources of waste from the fruit processing industries include waste likefruit washing water, leftover fruit after sorting, and peel, seed, and pomace after juice extraction.Waste like Peel, rag, and seed are produced during the processing of citrus fruits; Pomace from apples and pear; Peel and stone in mangoes; Rind and seeds of jackfruit: Core and peel in guava, overripe and blemished fruit from cranberries, Stone from Stone fruits (Gray, 2006).Numerous types and quantities of waste produced by fruit processing activities are presented in Table. 1

Table1: Typesandquantityofwastegeneratedfromfruitprocessingindustrie

Fruit	Quantity	Type of waste produced
Apple	12–50	Peel, pomace, and seed
Pineapple	32–65	Peel, skin, core, and coarse solid
Mango	45–70	Peel, pulp, and stone
Peach	11–25	Stone
Pear	4–47	Peel, pomace
Citrus fruit	55–60	Peel, rag, and seed
Banana	–	Peel
Apricot	11–35	Stone

Source: Bisht et al, 2020

3. Fruit waste disposal and management and disposal challenges

Many types of waste material are produced by fruit processing industries, either already loaded with large numbers of microbes or have the potential to alter quickly through microbial activity e.g. maggots of molds The breakdown of protein is always characterized by the generation of strong odours. The water content of fruits and vegetables ranged between 70 to 99% by mass. High water content increases transport costs of the waste and reduces the life of waste Mechanically removing the water through the use of a press can lead to further problems with wastewater disposal, due to the high level of organic material in the water. Waste with a high-fat content is susceptible to oxidation, which leads to the release of foul-smelling fatty acids. In many types of waste arising from vegetables and fruits, enzymes remain active for a longer time, which accelerates or intensifies the reactions involved in spoilage.

Large amounts of liquid and solid waste are produced in fruit processing industries which may cause environmental pollutionif not utilized or disposed off properly. Unmanaged solid wastes have been seen asa major threat to the environment and cause ahigh risk to human healthas some of the wastes from fruit processing industries may contain some harmful phytotoxin that can have adetrimental impact on human health as well well on the environment.However, most of these solid wastes (peel, stone, rag, seed, core, etc) are biodegradable and easily converted into valuable resources (William, 2005). The full utilization of horticultural produce is a requirement and a demand that needs to be met by countries wishing to implement low-waste technology in their agribusiness.

4. Value added products from fruit wastes

There are some new products derived from fruit wastethat are gaining popularity day by day. These products are highly rich in nutrient and mineral content and can be used in different ways. The six most widely used common products prepared from fruit wastes can be considered as candied peel, oils, pectin, reformed fruit pieces, enzymes, and wine/vinegar. Some of the important products which are commonly produced from fruit processing wastes are listed in Table 2.

Table 2: Potential value-added products from fruits and vegetables wastes

Fruit	Type of waste used	Value added product produced

Pineapple	Pomaces, peel	Biogas,ethanol,hydrogen,lacticacid, citric acid, ascorbic acid, ferulic acid, furaneol, vanillin, fiber
Grape	Seed, pomaces	Phenoliccompounds,essentialoil(Oleic and linoleic acid), tartaric acid, lactic acid, hydrolytic enzymes, Polyhydroxyalkanoates, anthocyanin
Banana	Banana bracts,	Single-cell protein, polymers (lignin, hemicellulose, pectin), sterols, anthocyanin, carotenoids, phenolic compound,ascorbicacid,bioethanol, amylase
Pomegranate	Peel	Single-cellprotein,phenoliccompounds, ascorbic acid, dietary fiber, ferulic acid
Orangewaste	Peel	Single-cellprotein,pectin,pectinase, ascorbic acid, ferulic acid, curdlan
Watermelon	Peel, seed	Single-cellprotein,ascorbicacid
Coconut	Husk, coconut water	Xanthan,curdlan, ascorbic acid,phenolic compounds, cocopeat
Datepalm	Date fruit pomaces	Xanthan,curdlan, citric acid
Apricot	Peel, seed	Succinicacid,lacticacid, polyhydroxyalkanoates
Cherries	Peel, seed	Lacticacid,succinicacid
Apple	Pomace, peel, seed	Ascorbic acid, flavonoids, flavonols, pectin, anthocyanin, enzymes, single-cell protein, aroma compound, ethanol, organic acid, livestock feed
Mango	Peel, pulp, and stone	Carotenoid,dietaryfiberAscorbicacid Furaneol Oleic and linoleic acid Livestock feed
Citrus	Peel	Pectin,pectinase,flavonol,phenolic acid, livestock feed

Source: Shrestha et al.,2001

4.1. Candied peel.

Peel of Citrus fruits like lime, grapefruit, lemon, and citrons are used to make candied peel. Candying citrus is incredibly simple consisting ofthree easy steps: preparing, blanching, and then simmering citrus peels in sugar syrup. This process removes the astringency and bitter taste of the peel making it sweet and soft. Sweet candied peel of citrus fruitis further used either in baked goods or as a snack food. In addition, shreds of peel are used in marmalades. Candy of other fruit peels and shreds like melons and root vegetables can also be used in baked goods.

4.2. Essential Oils

“The oils contained in various portions of wasted fruit are collected and refined usingvarious processes. Cold pressing, hot pressing, maceration, distillation, Soxhlet, or solvent extraction are some traditional techniques for edible oil extraction while 80 supercritical liquid extraction and pretreatment techniques such as enzyme, microwave, or pulsed electric field-assisted extractions and ultrasound are some example of modern oil extraction techniques”(Paul and Radhakrishnan 2020). “Citrus essential oil is commonly used in alcoholic beverages, confectioneries, soft drinks, perfumes, soaps, cosmetics, and home items due to its aromatic flavor. It is also used to disguise the bitter flavor of pharmaceutical products” (Ngeorge, 2005). It alsoextends the shelf life of fresh fruits

(Lanciotti et al., 2005)and has broad-spectrum antimicrobial activity (Javed et al., 2011). “Sweet and bitter orange oils are utilized in tea formulations as well as stomachic, carminative, and laxative remedies. D-limonene isolated from lemon essential oil are effective in boosting immunity, can cure occasional depression, promotes clarity of thought and purpose, energizes and stimulates the mind and body, opens and releases emotional blocks, promotes skin health, and reduces wrinkle appearance” (Sharon et al. 2008).

Stone fruits like mango, apricot, and peaches contain a good amount of oil in their stone with desirable properties which can be used for culinary or perfumery/toiletry applications. Moreover, oil can also be extracted from seeds of fruits like grapes. papaya and passionwhich may be used in medicinal industries. According to the study reported by (Pereira et al. 2017), the yellow (*Passifora edulis* Sims var. flavicarpa) passion fruit seeds contain about 30% oil by weightwhich can be used in foods to add more texture, flavor, and palatability. Consuming seed oil has several benefits as it reduced risk of developing several degenerative and chronic diseases, including diabetes, cancer, and cardiovascular disease. These beneficial effects are due to fatty acids and bioactive elements present in the seed oil. As a result, seed oil is more widely used for nutraceutical and pharmaceutical purposes (Kaseke et al. 2020).

4.3. Pectin

“Pectin is an abundant complex polysaccharide obtained from various plants. Safe, biodegradable, and edible pectin has been extensively utilized in the food industry as a gelling agent, thickener, and colloid stabilizer. Pectin is found in greater or lesser extent in most of fruits. Commercially, pectin is extracted from citrus peelsuch as lemon, orange, lime grapefruit, and apple pomaces in little extent” (Roy et al., 2023). The high levels of pectin are also reported in passion fruit. In most developing countries pectin is imported from Europe or the USA and superficially at least there would seem to be a good market for supplying local fruit processors with pectin to substitute for imports.

4.4. Reformed fruit pieces

Fruit pulp can be recovered and converted into synthetic fruit pieces. It is a reasonably easy process, but demand for this product is unlikely to be substantial, thus an assessment of the potential market is to be needed beforestarting any work. This product is made by boiling fruit pulp to concentrate and sterilize it. Sugar can also be added. A gelling ingredient, sodium alginate, is then added to the cooled pulp, which is subsequently combined with a strong calcium chloride solution. All substances are safe to consume and are approved as food additives in most countries. Calcium and alginates combine to form a firm gel structure, which allows the pulp to be reformed into fruit pieces. The most common way is to pour it into fruit-shapedmolds and allow it to set. It is also possible to allow drops of the fruit/ alginate mixture to fall into a bath of calcium chloride solution where they form small grains of reformed fruit which can be used in baked goods. Commercially, the most common product of this type is glace cherries.

4.5. Enzymes

“Papain, bromelain, and ficin are the most prevalent enzymes that are derived fromprocessing waste of papaya, pineapple, and fig and are utilized in meat tenderizers, washing powders, leather training, andbeer brewing. Trimmings and peels of horticultural leftovers may contain a variety of enzymes with numerous applications in the food industry” (Krishna and Chandrasekaran, 1996). Kinnow pulp and wheat bran may be used for filter paper cellulase (FPase). Apple pomace can be used to produce lignin, manganese peroxidase, and laccase. Sapota and citrus peels can be utilized to produce pectinase (Saravanan and Viruthagin, 2012). However, it is unlikely to be cost-effective to obtain these from waste fruit or even from efficient collection of whole fresh fruits.In addition, there are moves to phase out the use of these enzymes in food products in Europe and the USA and their market is therefore declining. In summary, these are not recommended as a means of income from waste utilization.

4.6. Wine/vinegar

"Generally, these products are produced from fresh, high-quality fruit juices to obtain high-quality products, it is technically feasible to produce them from both solid and liquid fruit wastes. Apple pomaces are generally used to producecider. The possibility of making wine from dried culled and surplus apples, grapes, oranges, and other fruits has also been explored. Vinegar can also be prepared from fruit wastes. The fruit waste is initially subjected to alcoholic fermentation followed by acetic acid fermentation by Acetobacter bacteria, which produces acetic acid. Vinegar production by fermenting waste from pineapple juice and orange peel juice has been reported. Apple pomace extract can also be mixed with molasses to produce vinegar" (Gautam &Guleria, 2007). "Fresh guavira (Campomanesiapubescens) is mostly used as a flavoring agent by the beverage industry due to its high acidity and presence of ascorbic acid, minerals, dietary fiber, and monoterpene hydrocarbons in substantial amounts" (Valillo et al., 2006). Solid wastes should be shredded and then boiled for 20-30 minutes to extract the sugars from the fruit and to sterilize the liquid. Several batches of waste can be cooked in the same liquid to enhance sugar content. This is then strained through a boiling cloth to remove any solid particles and chilled before being inoculated with yeast. During manufacturing, liquid wastes should be segregated to keep fruit juice separate from wash water (for example, juice might be drained from a peeling/slicing table into a separate drum. The juice is then cooked for 10-15 minutes and handled as before.

5. Potential value-added product for future prospect

The fruit and vegetable wastes or by-products of both in the organized and unorganized sectors are rich sources of bioactive compounds, which can be extracted and utilized in food, pharmaceutical, and biofuel industries. Among them few are important and potential value-added products and their utilities are discussed below-

5.1.Polyphenolic compounds

"Polyphenolic compounds are the naturally occurring chemicals produced by plants. Fruit wastes can be successfully used for the extraction of phenolic compounds. Varieties of fruit waste such as residue of grape, olive, citrus, apple, pomegranate, mango, banana, etc., can be worthy sources of phenolic compounds" (Kumar et al. 2017). "The concentration of total phenolic compounds in the peels, pulp/pomace, and seeds of citrus fruits, apples, peaches, pears, yellow and white flesh nectarines, banana, pomegranate, mulberry, blackberry, tomatoes, sugar beet, etc is more than twice the amount present in edible tissue. Apple and grape pomace are rich in proanthocyanidins and flavonoids, and bananas in catechin and gallocatechin" (Puravankara and Sharma, 2000)."Flavonoids are the largest group of plant phenolics, having few molecular compounds.Anthocyanins are another most common and widely found flavonoid which are accountable for the blue, red, and violet colors of some FV, although the red color of orange and tomato is due to carotenoid. In ripe berries, five classes of phenolic compounds such as phenolic acid, flavonol, flavones, flavanonols, and anthocyanins are well present. In different types of grapes, different phenolic compounds are found. For example, red grapes have anthocyanins, whereas white grapes have flavonols. The most common citrus fruits have only rutinosides that are non-bitter but pummelo and sour oranges have only flavanone neohesperidosides giving bitter taste.The kinnow peel, litchi pericarp, litchi seeds, and grape seeds can serve as potential sources of antioxidants for use in the food and pharmaceutical industries" (Babbar et al., 2011). Tannins are the third important group of phenolics and have relatively high molecular weight and include hydrolyzable and condensed tannins (Balasundram et al. 2006). Phenolic compounds are used as dietarysupplements and food fortification for health benefits and prefer natural sources that are not able to synthesize chemically and need to be extracted from original plant material (Schieber et al., 2001). Polyphenols reduce the incidence of cardiovascular diseases and are thought to inhibit the oxidation of LDL. The phenolic compounds act as antioxidants and as a substrate for oxidation reactions.

5.2. Edible oils

"The mango seed kernel is rich source of edible oil and its fatty acid and triglyceride profiles are similar to cocoa butter. Seeds of Guava and passion fruit usually discarded during the processing of juice have a good amount of essential fatty acids" (Adsule and Kadam, 1995). Palm kernel oil is well-established as both cooking and industrial oil.

5.3. Pigments and flavoringagents

"Pigments are naturally produced coloring agentsproducedby plants. Anthocyanin and carotenoids are the most common pigments found in fruits, which can be easily extracted from fruit parts like banana bract and beetroot pulp. The carotenoid pigment is found in extensively colored Fruits like peach, papaya, and citrus fruits.They are free radical scavengers that prevent biological molecules from being oxidised by both active oxygen and free radicals. Several studies have been published on the use of fruit and vegetable wastes as a substrate for the manufacture of carotenoids, including kinnow peel powder, apple pomace" (Joshi et al, 2003 & Dev et al, 2012), date (Moriel et al, 2005) etc.

Fruit processing waste can also be used to produce flavouring agents and aromas. Many natural flavouring compounds can be derived from fruit processing wasteusing biological reactions. Furaneol is an important aromatic molecule that produces the flavour of caramelised pineapple and may be extracted from fruits such as pineapples, strawberries, mangoes, raspberries, etc. It imparts fruity and strawberry flavor at low concentrations, whereas at high concentrations it gives caramel and burnt sugar flavor.

5.4. Food additives

"The use of horticulture wastes to produce food additives or supplements with high nutritional value is gaining popularity. Food additives are rich source of sugars, minerals, organic acid, dietary fiber and phenolics which have a wide range of actions which Includes anti tumoral, antiviral, antibacterial, cardioprotective and antimutagenic activities in the food industry Synthetic antioxidants, such as butylated hydroxyanisole and butylated hydroxytoluene, have long been used in the food industry as antioxidant additives to preserve and stabilize the freshness, nutritive value, flavor, and color of food.Now it can be substituted by natural food additives derived from fruit wastes. The antioxidant compounds from waste products of the food industry could be used for protecting the oxidative damage in living systems by scavenging oxygen free radicals, and also for increasing the stability of foods by preventing lipid peroxidation" (Makris, Boskou and Andrikopoulos, 2007)

5.5. Dietary fibre

"Dietary fibers from fruits and vegetables are believed to have a better impacton human health than cereal fiber because horticulturalfiber is soluble, whereas cereal fiber contains more insoluble cellulose and hemicelluloses. Fruit and vegetable wastes such as apple, pear, orange, peach, blackcurrant, cherry, artichoke, asparagus, onion and carrot pomace, mango peels, and cauliflower trimmings are used to enhance refined foods with nutritional fiber.Citrus and apple fiber are of higher quality than other dietary fibers because they include related bioactive components such as flavonoids, polyphenols, and carotenes" (Sharoba et al. 2013).Mango peel fiberis considered to have a goodpotential in dietary fiber-richfood preparation (Koubala et al.,2013) as it has a good hydration capacity. The peel and pulp of guava fruits could also be used as a source of antioxidant dietary fiber (Jimenez-Escrig et al. 2001)."Ripe berries include five different types of phenolic compounds: phenolic acid, flavonol, flavones, flavanonols, and anthocyanin. Grape cultivars include a wide range of phenolic compounds. For example, red grapes contain anthocyanins, whereas white grapes have flavonols. The most common citrus fruits contain only non-bitter rutinosides, but pummelo and sour oranges contain only flavanone neohesperidosides, which have a bitter taste. Certain citrus fruits, including grapefruit, contain both neohesperidosides and flavanone rutinoside. Sulfur dioxide bleaching has little effect on phenolic compounds such as malvidin glycosides, which form during wine maturation. Cinnamic acid accounts for the bulk of phenolic compounds discovered in citrus fruits" (Robards et al. 1999)."Phenolic compounds are used as dietary supplements and food fortification for health benefits and prefer natural sources that are not able to synthesize chemically and need to be extracted from original plant material" (Schieber et al. 2001).

5.6. Organic acids

"Organic acids are most commonly utilized in food and pharmaceutical industries. Citric acid is the most common organic acid derived from fruit waste. Citric acid has been produced for many years by fermenting starch or molasses. Citric acid has recently been produced from fruit and vegetable pomace, like apple pomace, pineapple waste, and mosambi waste are used in citric acid production as well as cassava bagasse"(Couto 2008). Citric acid was also generated from date extract/molasses using A. niger ATCC 6275 & 9642 (Mehyar et al, 2005) and date wastes using A. niger ANSS-B5 (Acourene et al., 2012).

"Acetic acid can also be derived from fruit processing waste. It is most widely used as vinegar, however the acetic acid content varies in vinegar. Vinegar manufactured in Canada contains acetic acid concentrations ranging from 4.1 to 12.3% (Panda et al. 2016). The acetic acid bacteria family comprises Endobacter, Acetobacter, Gluconobacter, Acidomonas, Bombella, Commensalibacter, and Gluconacetobacter. Acetobacter, Gluconacetobacter, Gluconobacter, and Acidomonas are recommended for vinegar production because they have a high oxidation rate of sugar, sugar alcohol, and ethanol. These bacteria are unaffected by acetic acid found in fermentation conditions" (Gomes et al. 2018).

"Lactic acid holds a significant position in the carboxylic acid family due to its use in both food and non-food industries. In the food industry, it is used as a preservative as well as an acidulant. However, commercial manufacturing of lactic acid is expensive due to the high cost of raw materials needed. It may be made at a low cost by using pineapple trash. The possibility of mango peel as a low-cost substrate for the synthesis of lactic acid has also been examined, with mango peel fermented directly utilizing bacteria capable of both amylolysis and lactic acid production" (Puligundla et al.,2014)."To lower the cost of lactic acid manufacturing, low cost affordable raw materials such as sapota, banana, and papayawere investigated. All substrates were found to support lactic acid growth and production. Sapota peel fermentation resulted in an efficient lactic acid concentration of 72 g/l" (Kumar et al., 2004). Nancib et al. (2001) employed date juice as a substrate to produce lactic acid using L. casei subsp. rhamnosus or Lactobacillus delbrucki (Yadav *et al*., 2011).

Ferulic acid is the most abundant hydroxycinnamic acid found in plant cell walls. This phenolic antioxidant is widely used in the food and cosmetic industries. Ferulic acid can be extracted from the peels of pineapple, orange, and pomegranate (Tilay et al. 2008)The major polyphenols in pineapple peels were found to be gallic acid (31.76 mg/100 g dry extracts), catechin (58.51 mg/100 g), epicatechin (50.00 mg/100 g), and ferulic acid (19.50 mg/100 g) (Li et al, 2005). Ferulic acid promotes sperm survival and motility in both fertile and infertile individuals, probably by lowering lipid peroxidative damage to sperm membranes and raising intracellular cAMP and cGMP levels. Thus, organic acid manufacturing from fruit waste serves two purposes: lowering raw material costs and recycling garbage, thereby reducing pollution..

5.7. Biofuel production

"The major quantities of waste can be used in the production of biofuel in both the form of solid andliquid. Bioethanol, biomethane, biodiesel, and biohydrogen are some of the biofuels that can be produced from fruit waste. Among them, ethanol is a major important form of waste production, it is generally produced by the use of many wastes like potato peel, apple pomace, banana waste, beet waste, and peach waste" (Sandhu et al., 2012; Oberoi et al., 2011). Jackfruit peel waste can also be used to produce bio-oil via a pyrolysis process in a fixed bed reactor, which was studied by Soetardji et al.

"In general, only a small percentage of fruit waste (0.5%) gets turned into valuable products, while the rest is discarded. Fruit waste is used to make biogas utilising anaerobic batch digester reactors with rice bran and cow dung. Cow dung influences the digestion of fruit wastes and produces the maximum output (405 mg) of biogas" (Narayani and Priya 2012). Dasa and Mondalb (2013) attempted to generate bio-methane from fruit and vegetable waste using anaerobic digestion which was found to be successful.

"Biodiesel is a sustainable, clean-burning liquid biofuel made up of low aliphatic alcohols and alkyl esters with high fatty acid content. Biodiesel is made from lipid- and oil-rich fruits and vegetables such as rapeseed, palm, soybean, and canola" (Lee et al. 2010; Muniraj et al. 2015). The choice of feedstocks is essential in determining diesel cost (Singh et al., 2012).

5.8. Single cell protein

"Single cell protein can be produced through the bioconversion of fruit waste, which may assist to address the global food protein shortfall by producing an affordable product for food and feed. It is also known as biomass, bioprotein, or microbial protein, and refers to proteins isolated from pure microbial cell cultures. It is made from bacteria, fungi, algae, or yeasts. Filamentous fungus (Aspergillus, Fusarium, Rhizopus, etc.), algae (Spirullina, Chlorella, etc.), bacterial species (Bacillus, Lactobacillus, Pseudomonas, etc.), and yeasts (S. cerevisiae) are widely utilised for single cell protein (SCP) production" (Bhalla et al, 1999). "In addition to its high protein content (60-82% dry cell weight), SCP contains lipids, carbs, nucleic acids, vitamins, and minerals, as well as lysine and methionine, which are limited in most plant and animal foods. The fruit and vegetable processing wastes are useful substrates for the production of SCP. Single cell proteins can be produced from dried and pectin-extracted apple pomace" (Gautam and Guleria, 2007).SCP can be manufactured from dried and pectin-extracted apple pomace using Trichoderma viride and A. niger (Devaranjan et al., 2004). "Pomegranate waste, orange trash, banana waste, and watermelon waste were employed as the only carbon source for preparing fermentation substrate on which S. cerevisiae yeast strains were used to create SCP 9" (Uchakalwar, 2014). Citrus peel juice has also been utilised to produce SCP via Fusarium. Papaya processing waste (PPW) acted as a substrate for S. cerevisiae. The product had 45% crude protein. Mango-peel extract has been used for SCP synthesis with Pichia pinus.

5.9. vermicomposting

"Horticultural waste can be composted and utilised to replace a considerable portion of mineral nitrogen fertilisation, with nitrogen recovery rates ranging from 6 to 22 percent. Long-term usage of horticultural waste resulted in considerable carbon accumulation in the top soil, improving soil nitrogen status and nutrient availability" (Tits et al., 2012).

Conclusion

Numerous useful components can be found in abundance in the waste from the fruit processing industry. This has grown to be a significant issue as fruit and vegetable production rises and pollutes the environment. It must therefore be appropriately used and maintained. Because of growing environmental concerns and the world's growing population, further exploitation of fruit processing by-products as sources of functional components and potential applications has emerged as a promising field and global necessity. By fusing technical advancement with health benefits, natural functional chemicals derived from fruit processing wastes can be used to substitute synthetic additives, introducing multifunctional notions. The best concentrations of bioactive chemicals and other economically significant compounds should be extracted from fruit wastes using innovative scientific and alternative technologies. The massive amounts of fruit waste that have accumulated worldwide would be significantly decreased by the combined efforts of waste minimization and sustainable byproduct utilization.

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