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Review on preand postharvest waste utilization of Banana and Papaya fruit crops

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Abstract

Fruit waste management has evolved into a multifaceted challenge for the agriculture andfood processing industry, exacerbated by increasingly stringent environmental legislationgoverning waste disposal and sustainability practices. This waste can be transformed andrepurposed as viable sources for food, animal feed, and agricultural fodder, among othervaluable applications. The byproducts derived from food processing operations are rich in awide array of essential resources that hold immense nutritional and industrial significance.These byproducts encompass a diverse spectrum of components, including but not limited todietary fiber, carbohydrates, minerals, organic acids, and a variety of bioactive componentsincluding polyphenols, protein isolates, biofuels, and other useful materials. The advent oftechnologicalinnovations, coupled with scientific advancements, offers promising avenuesfor redefining food waste from a problem to an opportunity.The current review focuses on the use ofbanana and papaya byproducts such as peels, leaves, pseudostem, pseudostem juice, stalk, and inflorescence in various industries as a thickening agent, an alternative source of renewable energy, nutraceuticals, livestock feed, natural fibers, colouring agents, bioactive compounds, and bio-fertilizers.In conclusion, food waste management within food processing industries represents a multifaceted challenge intertwined with environmental, economic, and social factors.Addressing this challenge requires a concerted effort, integrating innovative technologies, sustainable practices, and a shift in the mindset toward waste as a valuable resource.

Keywords: Waste utilization, Pre-harvest, Post-harvest, Banana, Papaya, Bioactive compounds

1. Introduction

The market for raw fruit resources is abundant in India. However, raw fruit is not often consumed directly by people and requires processing to separate the intended value product from other ingredients, resulting in a considerable amount of waste (Bisht *et al.*, 2019). The fruit processing industry often disposes of significant quantities of fruit waste in landfills or rivers, leading to environmental hazards. Thus, there is a pressing need for disposal methods that recycle this waste, generating livestock feed resources, or extracting and developing value-added products. (Wadhwa and Bakshi, 2013);However, owing to inadequate management of raw materials and insufficient infrastructure, we experience an annual loss of around 30-35% of our fruit commodities. Postharvest production losses in India are estimated to range from Rs 75,000 crore to Rs 1,000,000 crore each year(Bisht *et al.*, 2013).As of January 1st, 2019, India possesses a limited number of modest fruit processing infrastructure facilities, with only 5166 fruit and vegetable processing plants nationwide. Unfortunately, these units lack adequate waste management and disposal procedures (Joshi and Sharma, 2011; Bisht *et al.*, 2015). As fruit production and processing have expanded, the disposal and utilization of waste materials have emerged as significant challenges. However, traditional methods like drying, storing, transporting, and shipping byproducts have become cost-prohibitive (Varzakas*et al.*,2016; Arvanitoyannis *and*Varzakas, 2008),Fruits and byproducts from the fruit industry are notable reservoirs of bioactive compounds, including phenolic and antioxidant substances. These compounds play a vital role in enhancing food stability by mitigating lipid peroxidation (Makris *et al.*,2007). Numerous studies indicate that the residues of certain fruits exhibit higher antioxidant activity compared to fresh fruit pulp (Gorinstein*et al.*,2001). Aside from bioactive substances, research indicates that food processing byproducts have diverse potential applications across various sectors (Kodagoda and Marapana, 2017). Food processing byproducts frequently possess untapped potential. Rather than being discarded, they can be repurposed for various purposes. For example, leftovers from fruit processing, such as cuttings and shreds, can serve as animal feed. Furthermore, fruit wastes can undergo processing to extract valuable substances like starch, pectin, natural coloring matter, essential oils, and other nutrients. This strategy not only minimizes waste but also generates additional value from materials that would otherwise be considered waste. This study provides an overview of the composition, preservation techniques, nutritional content, and utilization of various types of fruit waste. (Helkar*et al.*, 2016).It also covers aspects related to the use of fruit waste and the possible generation of value-added products.

2. What is waste?

Materials that are undesirable or unsuitable waste are any substance that is abandoned after its primary purpose or that is worthless, faulty, or useless. A byproduct, on the other hand, is a joint product with low economic value. In the old days, waste is wasted in two ways. One way is to use it as fertilizer and use it as cattle feed example: after eating the banana pulp, the peel is removed. Peel is used as cow feed, or it is dumped with cow dung, after which it is used as fertilizer.

3. What is fruit waste utilization?

Waste processing fruits are two types of solid waste (peel, skin, seeds, stones, etc.), and liquid waste (Juice and washed water) in horticulture fruit waste is a very serious problem, attracting flies, unwanted microbial growth, and rats, which is a major problem in the field unit as well as the processing unit (Fig. 1). The possible products we can obtain from waste products includethe candied peel, oils, pectin, reformed fruit piece enzymes, compost, single-cell protein, biogas, edible oils, polyphenol compounds, fiber, mushroom growing media, bioplastics, medical drugs, etc. (Bisht *et al*., 2019).

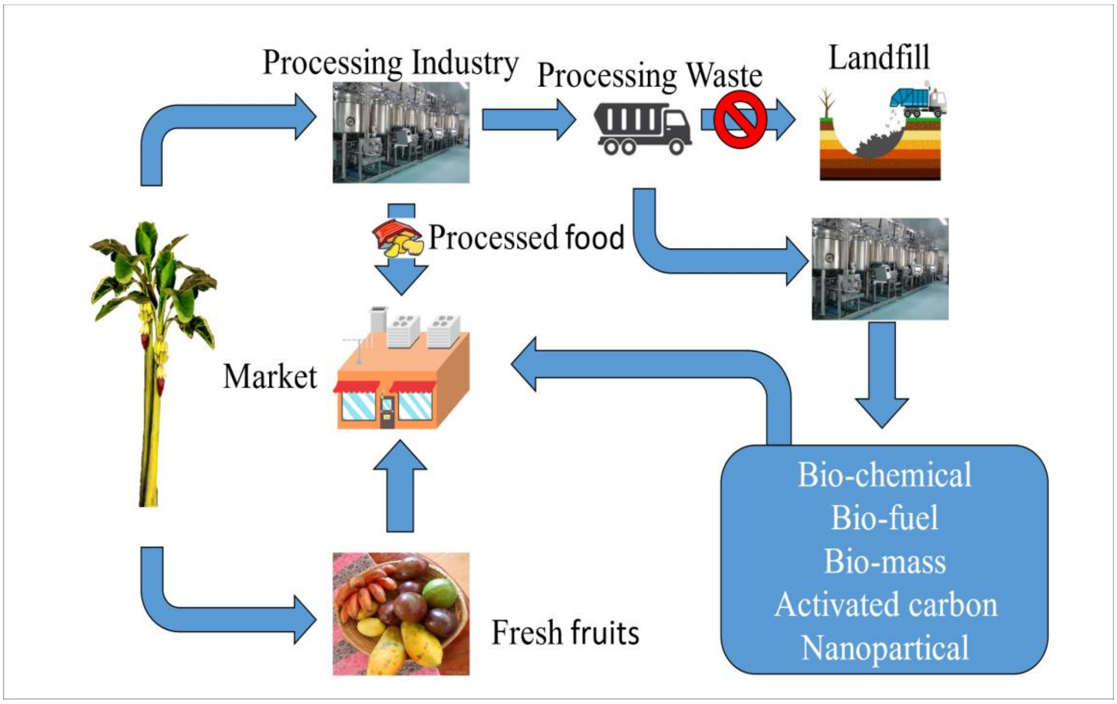

Fig 1. Concept of the utilization of waste

4. Pre and postharvest waste utilization of banana

Bananas are a tropical fruit grown in more than 122 countries around the world. By 2004, the total cultivated area reached 3.8 million hectares, resulting in a production of 56.4 million metric tonnes of fruit. This solidified its rank as the fourth most produced agricultural commodity globally, trailing behind rice, corn, and milk (Chai *et al*.,2004; Arumugam and Manikandan, 2011).Recently, the utilization of banana peels has expanded across various industries including biofuel production, biosorbents, pulp and paper manufacturing, cosmetics, energy-related projects, organic fertilizer production, environmental remediation, and biotechnology-related processes (Llori*et al*.,2007). Over the past few decades, the mass production and global consumption of bananas have led to their rise as the second-largest fruit crop in the world. Current estimates indicate that the total production has exceeded 139 million tonnes.(Fao, 2010).India, China, Uganda, Ecuador, the Philippines, and Nigeria are recognized as the leading global producers of bananas and plantains. These fruits have been extensively utilized by indigenous communities for various purposes apart from being a food source, showcasing their versatility in everyday life. Nevertheless, the large-scale banana plantations, which occupy significant land areas, pose environmental contamination risks. Following the harvest, trees are frequently felled and left abandoned in fields, exacerbating problems like the spread of Sigatoka disease(Chillet, *et al*., 2009).

4.1 Extraction of fiber from the leaves of banana plants

Fiber can be extracted from waste banana leaves through enzymatic and nonenzymatic methods(Chauhan and Sharma, 2014). The thick midribs of the waste banana leaves were acquired from the vegetable market. Moreover, leaves that were directly cut from the plant in the field can also be utilized in the enzymatic approach. In this particular procedure, a commercially available pectinase enzyme was utilizedto yield a percentage of the extracted fiber formula.

$$\text{Yield (\%)} = \frac{\text{OD weight of the extracted fiber}}{\text{OD weight of the plant part used for the extraction}} \times 100$$

Fibers were extracted from the mid-rib section of discarded banana leaves, with the midribs being separated prior to additional processing. The fiber yield showed a notable difference between enzyme-treated leaves and control leaves, as enzyme-treated leaves yielded 23% while untreated leaves yielded 8.94%. The banana fiber extracted was then utilized for the production of handmade paper. However, the banana fiber obtained from untreated banana ribs was unsatisfactory and contained a substantial amount of dust, pith, and trash. As a result, the waste produced after fiber extraction from untreated banana ribs underwent open digestion with 4% NaOH for 3-4 hours to facilitate further processing. Interestingly, pulps created from waste leftover from enzyme-treated fiber extraction displayed weaker strength qualities compared to those created from waste leftover from control fiber extraction. This suggested that the enzymatic approach resulted in less fibrous waste in comparison to the untreated method (control), where a significant amount of fiber was lost in the generated trash(Chauhan and Sharma, 2014).

Fig.2 Procedure for the extraction of fiber from leaves

4.2 Extraction of fiber from the green stem and trunk of the banana plant

The process of extracting fiber from the banana trunk and stem involves pretreating the green stem and trunk with pectinases. This pretreatment was found to enhance the fiber extraction process significantly. Fiber quality and yield from both the banana trunk and stem were improved with enzyme soaking compared to the zero-hour stage, which corresponds to the conventional fiber extraction process. Furthermore, the quality of fiber extracted from the banana trunk was superior to that extracted from the banana stem(Subagyo and Chafidz, 2018).

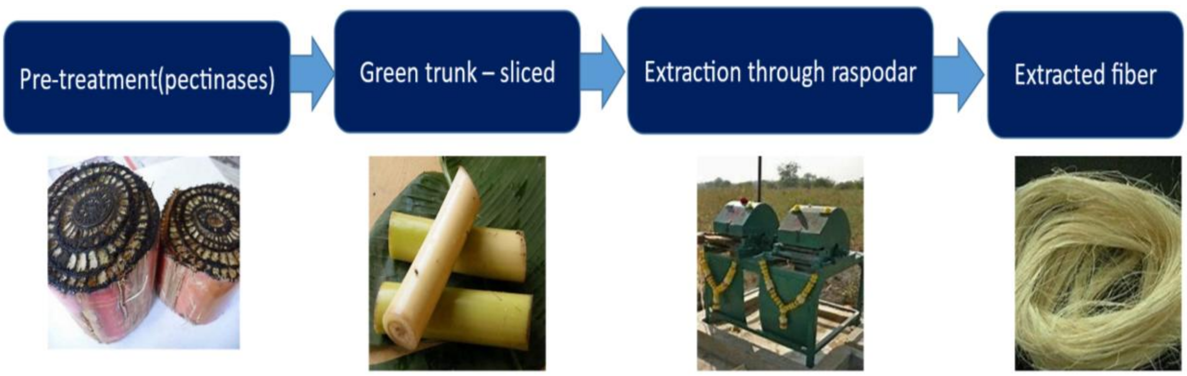

Fig.3 Procedure for the extraction of fibers from green trunks

4.3 Banana waste used as growing media

The brown oyster mushroom is greatly appreciated for its value as a food source, emphasizing the importance of developing economically viable cultivation methods. The availability of plentiful plants and industrial waste, such as dried banana leaves and tofu dregs, presents promising opportunities for utilizing these resources as growth substrates in the cultivation of edible mushrooms(Mtaki*et al*., 2023). Undoubtedly, dried banana leaves and tofu dregs have proven to be rich sources of nutrients for the ideal cultivation and progress of oyster mushrooms. Scientists have extensively examined the impact of these substances on the growth and productivity of brown oyster mushrooms through a meticulously designed randomized factorial experiment. The prescribed amount of tofu flour was precisely 50 g per baglog and a total of 150 g. Among the various treatments analyzed, the combination of 100 g of dried banana leaves with 250 g of tofu dregs exhibited the most favorable outcomes, showcasing remarkable fresh weight and biological efficiency(Dian Indratmi*et al.*, 2021).

4.4 Antibacterial activity of ethanolic and aqueous extracts of banana peels

Banana peel extracts, whether ethanolic or aqueous, possess antibacterial properties. Moreover, banana flowers have been traditionally used to treat a variety of ailments such as bronchitis, dysentery, and ulcers. Cooked banana flowers are particularly recommended for individuals with diabetes. The astringent sap derived from the banana plant is employed in the treatment of various conditions including hysteria, epilepsy, leprosy, fever, hemorrhage, acute dysentery, and diarrhea. Additionally, it is applied topically to alleviate symptoms associated with hemorrhoids, insect bites, and other stings. Young banana leaves are commonly utilized as poultices for diverse purposes(Ehiowemwenguan*et al*., 2014).

4.5 Production of cellulase from banana peel waste

Agricultural wastes primarily consist of cellulose, hemicellulose, pectin, starch, and other polymers. Hydrolyzing these substrates yields fermentable sugars, which can serve as valuable chemical feedstock or fuel. Given the growing focus on renewable energy resources, there's a pressing need for their efficient utilization (Baig*et al*.,2003).Among the 127 fungi isolated from banana crop soil, 12 were found to utilize cellulose as a carbon source. Notably, Trichoderma lignorum demonstrated considerable cellulolytic activity. It produced cellulase, β-glucosidase, and xylanase in carboxymethyl cellulose peptone media, as well as in an agro-waste-based medium comprising powdered leaves, stems, and rhizomes. In leaf-based media, the presence of 0.45 U/ml lignin resulted in the highest enzyme production.

4.6 Use of banana peel as a biosorbent for the treatment of water

In general, Overall, groundwater in the country is typically safe for drinking and various other purposes. However, certain contaminants like arsenic, fluoride, and iron are naturally occurring, primarily originating from interactions between rocks and water (geogenic sources). On the other hand, nitrates, phosphates, heavy metals, and other pollutants stem from human activities such as domestic sewage, agricultural practices, and industrial effluents(Reddy *et al*.,2015).The study explored the potential of employing banana peels as a biosorbent for the removal of nitrate from drinking water. Given the severity of nitrate pollution in water and the need for cost-effective and safe treatment methods, biosorption emerges as a promising approach. Biosorption offers advantages such as utilizing inexpensive adsorbents that can be reused, employing a straightforward process with minimal waste generation, and achieving high efficiency overall. The investigation delved into various factors including contact time, adsorbent size fraction, adsorbent dose, and nitrate content to assess the effectiveness of banana peel as a biosorbent. In the study, 0.05 g of banana peel powder with a particle size of 106 micrometers was utilized as an adsorbent to treat 100 ml of water samples containing 200 ppm of nitrate. The removal efficiency achieved was approximately 80%, with a final concentration of 40 ppm after 0.5 hours of contact time.

Furthermore, the culture media for synthesizing cellulolytic enzymes by Trichoderma lignum consisted of banana agro-waste, including pseudostems and leaves. When banana leaves were used as a carbon source, the enzyme activity was measured at 0.20 u/ml for cellulase, 0.41 u/ml for xylanase, and 0.24 u/ml for glucosidase. Soy peptone was identified as the optimal nitrogen source for enzyme synthesis. The optimal pH of the medium was found to be in the range of 5.6-5.8, while the optimal temperature for enzyme production was 45°C.

4.7 Production of paper from banana pseudostems

Bananas are increasingly being explored for the production of paper and various products due to their favorable characteristics. Following fruit harvesting, the banana stem typically becomes redundant(Jayaprabha*et al.*,2011). Pulping techniques are utilized to separate fibers from lignin and hemicelluloses, which can be accomplished through chemical, mechanical, or hybrid processes. Chemical pulping involves the use of chemicals to remove lignin from lignocellulosic materials while maintaining fiber length. This technique assesses the degree of lignin elimination during the cooking stage by considering factors like the kappa number, yield, and viscosity limit index (cm^3/gm). A recent study illustrated that pulp could be effectively generated from discarded banana stems, with a yield of 58% pre-bleaching and 43.33% post-bleaching. This highlights the potential of utilizing banana stems as a valuable resource for pulp production, promoting the sustainable use of agricultural waste (Mohapatra *et al.*, 2010). The sample underwent pulping at 120 degrees Celsius and atmospheric pressure, a significantly lower condition compared to the industrial standards of 170 degrees Celsius and 7 atm pressure for traditional raw materials in the kraft pulping process. Sheets were then produced using various combinations of virgin banana pulp and recycled university-cutting paper.

Type 1 sheets, made entirely of virgin banana pulp, exhibited a burst factor of 30.04, indicating high bursting strength. Type 2 sheets, composed entirely of recycled pulp, had a burst factor of 18.84. Type 3 sheets, comprising 50% virgin banana and 50% recycled pulp, showed the highest burst factor of 40.57.The findings revealed that the Type 1 sheet, solely made from banana fibers, displayed superior bursting strength compared to Type 2, emphasizing the strength of banana fiber sheets over recycled pulp sheets. Moreover, blending banana fibers with recycled fibers resulted in increased strength.

Despite the high moisture content being a drawback, growing bananas near mill sites could potentially mitigate this issue. Overall, these findings suggest that banana pseudo stems hold promise as a viable alternative raw material for the paper industry, offering high strength properties and potential environmental benefits through the utilization of agricultural waste (Girish *et al*., 2019).

Table 2: Results of different types of tests on paper made from pseudostems

Test	**Type 1**	**Type 2**	**Type 3**
Gsm	213	240	138
Bursting strength(kg/cm^2)	6.4	2.6	5.6
Burst factor	30.04	18.84	40.57
Burst index(kpa/g)	2.9466	1.06	4.3

5. Papaya

Papaya (*Carica papaya* L.), originally native to Mexico and northern South America, has spread and naturalized in numerous regions worldwide, particularly in tropical and subtropical areas. Global papaya production is projected to grow steadily, with an estimated annual increase of 2.1%, reaching a total of 16.6 million tons by 2029 (FAO, 2020). The distribution of papaya waste components typically includes approximately 12% papaya peel waste, 8.5% papaya seed waste, and 8.5% fruit weigh (Pathak *et al*., 2019). Papaya, a semi-herbaceous plant, can grow as tall as 8 feet and has hollow, cylindrical stems. It is known by different names in various regions and languages worldwide. Papaya is renowned for its abundant supply of vital nutrients such as vitamin A, C, and E, minerals like potassium and magnesium, carotenoids, phenolic compounds, fiber, and folate. Throughout numerous cultures, papaya has long been valued for its nutritional and health advantages. It is frequently used in conjunction with other herbs in traditional medicine to address a range of ailments(Anuar*et al*., 2008). As an antimalarial herbal blend with other plants in Cameroon (Tarkang*et al*., 2013), aboriginal Australians described leaf decoctions as anticancer remedies (Nguyen *et al*., 2016).

Indeed, papaya is renowned for its richness in the digestive enzyme papain, which finds applications in cosmetics, brewing, meat tenderization, and medicine due to its proteolytic properties. Additionally, the unripe fruit of papaya exhibits laxative properties.

Furthermore, when combined with the leaves, papaya fruit has been found effective in treating conditions such as pyrexia, diabetes, syphilis, and wounds, reflecting its diverse therapeutic uses in traditional medicine. (Sudhakar and Theivanai Vidhya,2014) Papaya fruit and leaf extracts are known to have medicinal properties that can help in the treatment of dengue fever and aid in increasing blood platelet counts. (Ahmad *et al*., 2011; Dharmarathna*et al*., 2013). Indeed, papaya trees have been demonstrated to possess a range of health benefits beyond their nutritional value. Studies have shown that papaya has properties that contribute to improved wound healing, immunomodulation (regulation of the immune system), and management of conditions such as hypolipidemia (high levels of lipids in the blood) and hypoglycemia (low blood sugar levels). These findings further highlight the potential therapeutic uses of papaya in promoting overall health and well-being (Nayak *et al*., 2007; Juárez-Rojo*et al*., 2012; Pandey *et al*., 2016; Santana *et al*., 2019).The reported remedial properties of various parts of Carica papaya include a wide array of beneficial effects. These include antihypertensive (lowering blood pressure), antibacterial, diuretic (increasing urine production), antifungal, and antitumor effects. These diverse properties highlight the potential medicinal value of different components of the papaya plant in managing various health conditions. The reported remedial properties of various parts of *C. papaya* include antihypertensive, antibacterial, diuretic, antifungal, antifungal, and antitumor effects (Vij and Prashar., 2015; Singh *et al*.,2020).

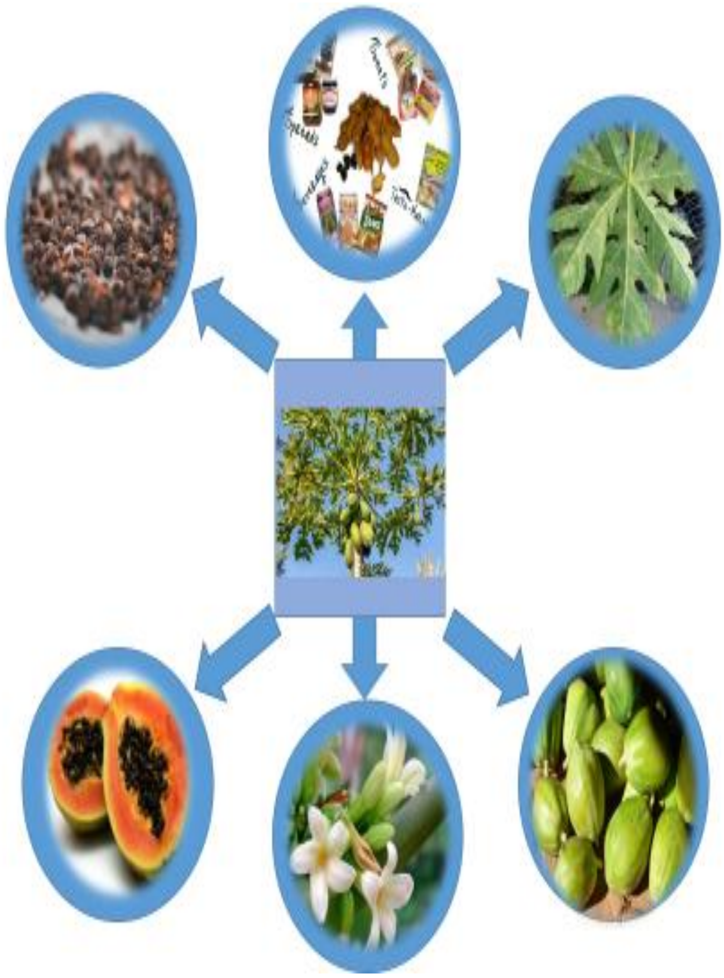

Fig. 6: Various applications of papaya and its products

Table 3 -Medical use of different parts of the papaya plant (Krishna *et al*., 2008)

Part	Medicinal property
Latex	Uesd to treat Anathematic, relieves dyspepsia, cures diarrhea, the pain of a burn and topical use, bleeding hemorrhoids, stomachic, whooping cough
Ripe fruit	Used to treat Stomachic, digestive, carminative diuretic, dysentery, and chronic diarrhea, expectorant, sedative, and tonic, relieves obesity, bleeding piles, wound of the urinary tract, ringworm, and skin disease psoriasis
Unripe fruit	Used to treat Laxative, diuretic, dried fruit reduces enlarged spleen and liver, use snakebit to remove poison, abortifacient, anti-implantation activity, and antibacterial activity
Seeds	Used to treat Carminative, emmenagogue, vermifuge, abortifacient, anti-irritant, used as a paste to treat ringworm and psoriasis, anti-fertility agent in malic acid
Seed juice	Used to treat Swollen liver and pectoral properties, as well as bleeding piles
Root	Used to treat Abortifacient, diuretic, checks irregular uterine bleeding, piles,

	antifungal activity
Flower	Used to treat Jaundice, emmenagogue, febrifuge, and pectoral properties
Steam bark	Used to treat Jaundice, anti-hemolytic activity, std, store teeth(inner bark), anti-fungal activity

5.1 Antioxidant activity

Many chronic health disorders are linked to free radicals, prompting research into antioxidants to prevent their production. Currently, studies aim to identify safe and commercially viable natural sources of antioxidants. Research has shown that the hexane fraction of male Papaya flowers exhibits significant antioxidant activity, as indicated by its low ic50 value (100.81, 1.180) (Chakraborty *et al*., 2015; Koleva*et al*., 2002). According to Oloyede*et al*. (2016), The antioxidant effects are attributed to the ethyl acetate extract obtained from unripe fruit, containing sitosterol and quercetin. Recently, researchers evaluated the antioxidant potential of the methanolic seed extract using a depth-free radical scavenging activity test(Singh *et al*., 2020a, 2020b, 2020c)(Nisa*et al*.,2019).The antioxidant potential of various types and maturity levels of papaya leaves was investigated using different extraction solvents, such as water, methanol, and 70% ethanol. Results revealed that mature leaves extracted with water demonstrated superior antioxidant activity in comparison to other leaf types

Table 4: Antioxidant activities of papaya

Part	Type of extract	Method used	Responsible phytochemical	Reference
Leaves	Methanol(CH_3OH)	Peroxynitrite scavenging assay	Kaempferol 3-(2crhamnosylrutinoside)	(Nugroho*et al*., 2017)
Leaves	Ethanol(C_2H_6O), methanol(CH_3OH), water(H_2O)	DPPH, FRAP	Flavonoids	(Nisa*et al*., 2019)

Leaves	Methanol(CH_3OH)	DPPH	Carpaine, kaempferol 3-(2 g-glucosylrutinoside), kaempferol 3-(2". Rhamnosylgalactoside), 7-rhamnoside, kaempferol 3-rhamnosyl-(1-> 2)-galactoside-7-rhamnoside, luteolin 7-galactosyl-(1-> 6) galactoside, orientin 7-o-rhamnoside, 11-hydroperoxy-12,13-epox-9-octadecenoic acid, palmitic amide, and 2-hexaprenyl-6-methoxyphenyl	(Soib*et al*., 2020)
Flower	Ethanol(C_2H_6O)	DPPH	Triterpenoid/steroids	(Sianipar*et al*., 2018)
Fruit	Papaya juice powder	FRAP, Orac, specific ros scavenging activities		(Jarisarapurin*et al*., 2019)
Peel	Aqueous	DPPH, ABTS assay	Proteins and phenolic groups	(Kokila *et al*., 2016)

5.2 Antidiarrheal responses

It was documented that a chloroform extract derived from fresh *Carica papaya* (25 mg/ml) and an acetone extract obtained from mature *Carica papaya* (25-0.39 mg/ml) exhibited notable effectiveness in treating diarrhea caused by intestinal pathogens(Prabhu*et al*., 2017). Extensive testing has been conducted on the mature *Carica papaya* extract to confirm its antidiarrheal properties. According to (Akindele *et al*., 2011), During trials on mice, das77, a natural mixture derived from dried *C. papaya* root and young *Mangiferaindica* bark, showed promise in alleviating diarrhea symptoms. A separate investigation also supported its effectiveness in treating diarrhea. Likewise, the antidiarrheal capabilities of papaya leaf water extract were tested on rats, indicating notable efficacy and safety at a 200 mg/kg dosage(Zanna *et al*., 2017).

5.3 Anticancer activity

Papaya possesses anticancer effects according to in vitro research. Papain includes an enzyme called papain, which is found in papaya and is particularly beneficial in cancer therapy. Fibrin is broken down into amino acids by papain, which coats tumor cells. Lycopene is a pigment found within papain that is highly reactive to free radicals and oxygen. Isothiocyanate, found in papaya, protects against breast, prostate, pancreas, lung, leukemia, and colon cancer (Fauziyaand Krishnamurthy, 2013). According to one study, black seeds from ripe yellow papaya directly impact the growth of prostate cancer cells. Researchers investigated the effect of methanolic extracts from black seeds (ripe papaya) and white seeds (unripe papaya) on a prostate cancer cell line. Previous research indicates that black seed extract is beneficial against prostate cancer cells, while white seed extract can stimulate existing prostate cancer cells. Papaya leaf juice demonstrates an inhibitory effect on the growth of prostate cancer cells (Pandey *et al*., 2018).

Table 5: Effect of *Carica papaya* extract on various cancer cell lines

Cancer cell lines	Preparation–plant part	Effects	Reference
Prostate cancer cell	Papaya leaf juice	Anti-proliferative effect on prostate cancer cell	Pandey *et al*., 2018
Mcf7 breast cancer cell line	Aqueous extract of *C. Papaya* flesh	Antiproliferative effect on mcf7 breast cancer cell line	García-sols *et al*., 2009
Prostate cancer cell	Methanolic extract of black seed	Inhibition of prostate cancer cell line	Alotaibi *et al*., 2017
Breast cancer cell line (t47d)	Protein fraction containing rips isolated from leaves	Cytotoxic effect: ic50 = 2.8 mg/ml	Hirose *et al*., 1998
Leukemia cell line hl-60	Aqueous extract of c. Papaya seed	Induce apoptosis	Nakamura *et al*., 2007
Human colon ccd-18co cells	Aqueous extract of c. Papaya fruit	Cytotoxic effect	Miyoshi *et al*., 2007
Cancerous cell lines	Aqueous extract of	Concentration-	Morimoto and dang,

of lung, colon, ovarian, lymphoma, breast, neuroblastoma, uterine, liver, pancreatic and stomach cancer	papaya leaves	dependent anticancer effect on each of the cancerous cell lines and by suppressing DNA synthesis.	2006

5.4 Antimalarial activity

Various reports support the antimalarial activity ofPapaya, along with other plants, is used to treat malaria and related symptoms (Suleiman *et al*., 2018). Leaf extracts were evaluated against Two strains ofPlasmodium *falciparum*, 3d7 and dd2. In dichloromethane leaf extract, caprine was the most potent alkaloid extract, with ic50 values of 2.19 at 0.60 g/ml (4.57 m) and 2.01 at 0.18 g/ml (4.21 m) against both Plasmodium falciparum strains. This alkaloid is not harmful to healthy, uninfected red blood cells and is very selective against the parasite (Teng *et al*., 2019).The antiplasmodial efficacy of methanol, chloroform, and petroleum ether extracts of papaya fruit rinds and roots against *Plasmodium berghei* in mice was investigated. The findings revealed that petroleum ether and chloroform extracts of Papayafruit rinds have significant antiplasmodial effects in a dose-dependent manner, with petroleum ether extract having the greatest antimalarial activity (Zeleke*et al*., 2017).

5.5 Anti-dengue activity

According to Chandrasekaran *et al*., 2018, the larvicidal efficacy of chloroform, methanol, and aqueous extracts of Papaya latex against larvae of *C. quinquefasciatus* and *Aedes aegypti* was dosedependent.Five dengue patients were given two teaspoons of papaya leaf juice three times a day after six hours of preparation using the customary technique. Platelet counts were demonstrated to significantly rise after treatment with leaf juice in just 24 hours. (Kala, 2012).

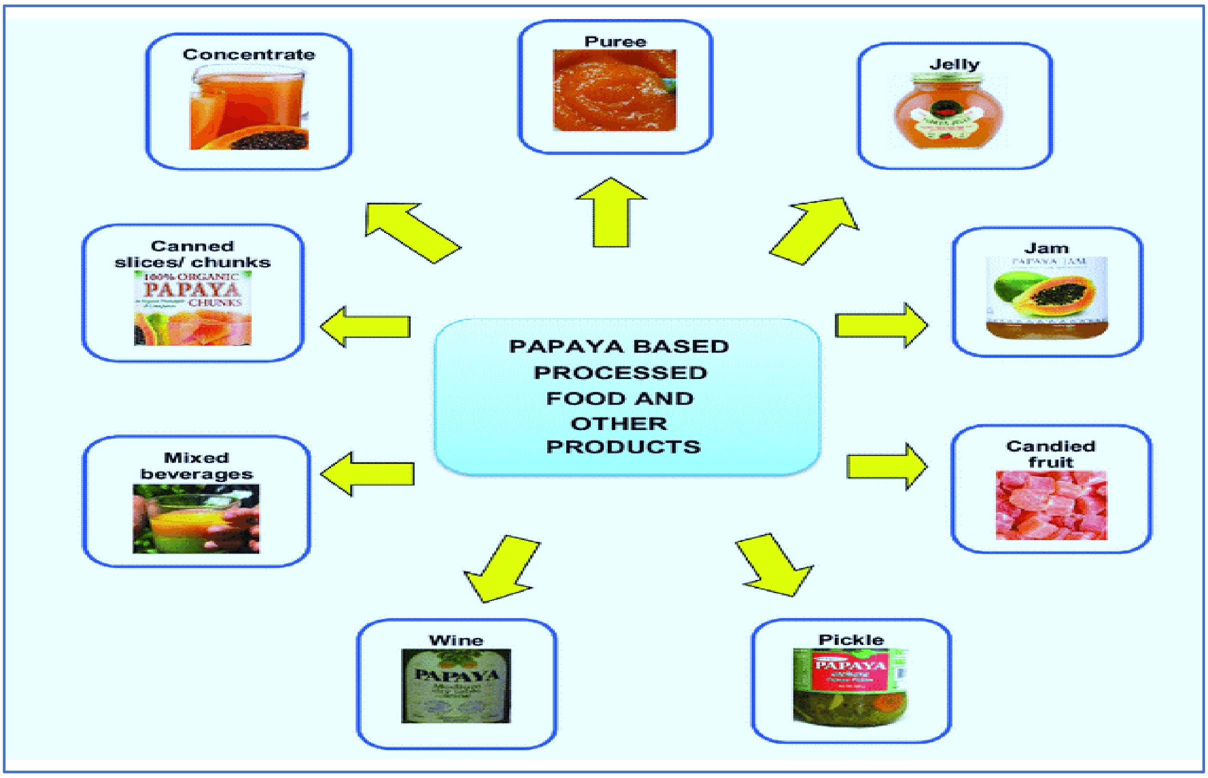

Fig.7: Papaya-based processed food and other products

When a patient received a *C. papaya* leaf extract pill three times a day for five days, there was an elevation in PLT, which may have been caused by the platelet-activating factor receptor gene being expressed.

5.6 Papaya usage in processed food and beverages

The papaya fruit is known to develop very quickly, to be produced year-round, and to have a high output rate. As a result, the primary concern is figuring out how to consume entire products before they decay. Papaya fruits are not commonly used on a global basis. Thus, to increase the shelf life of papaya fruit, it can be used to make processed foods and other related items. Many studies have been published on this topic; for example, papaya is used to make jam with other components(Aziz, 2020).

Table 6: Processed food and beverages of papaya

papaya Jam	Aziz,2020; Cruz *et al*., 2019; Parsi- ros,1976; Teangpook and Paosantong,2013
Papaya Jelly	Hunaldo*et al*., 2020; Mie,2013;Yi- zhuo*et al*., 2013

Papaya Pickel	Kumar *et al*., 2019; Nurul and Asmah, 2012; Su and liu, 2006
Candied fruit of papaya	Ahmad *et al*., 2005; Cherian and Cheriyan,2003; Jadhav *et al*., 2012; Kumar*et al*., 2019
Mixed beverage of papaya	Atif and Mishra, 2019; Bahnas*et al*., 2019
Papaya Ice cream	Omar *et al*., 2020
Papaya Puree	Ocoró- zamora and Ayala- aponte,2013; Tulamandi*et al*., 2016
Papaya Wine	Cholassery*et al*., 2019

5.7 Use of papaya fruit waste

Vitamins found in papaya peel include vitamin A, vitamin C, riboflavin, thiamine, and niacin. It contains phenols, alkaloids, flavonoids, tannins, and saponins (Chukwuka*et al*., 2013). It also contains a variety of valuable minerals, such as calcium, sodium, potassium, phosphorus, and magnesium (Asghar *et al*., 2016). Because of its high vitamin, mineral, and phytochemical content, papaya peel is used for a variety of purposes, including cosmetics (Aravind *et al*., 2013). Papaya seed oil contains 47.7% oleic acid, 37.3% linoleic acid, and 6% palmitic acid and is used to generate biodiesel (Agunbiade and Adewole, 2014; Anwar *et al*., 2018).

5.8 Enzymatic Method for MeatTenderness

In animal flesh, an endogenous tenderization mechanism is activated and controlled by calpain systems. Because the action of exogenous enzymes is temperature dependent, minimal activity is observed in frozen and cold products. However.The quality of tenderized meat varies substantially according to the enzyme utilized. This article goes into further detail on the uses of plant-based proteases, and the expensive cost of legitimate enzymes isolated from microbial and animal sources has limited their usage in comparison to plant proteases. Plant proteases used for softness include papain, bromelain, ficin, actinidin zingiber, and cucumin, among others. (Bekhit*et al*.,2014), and papain is extracted from the raw papaya fruit.

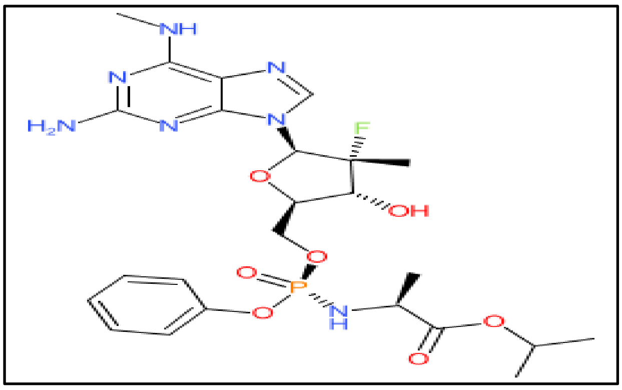

Fig. 7 Structure of papain($C_{19}H_{29}n_7O_6$)

Table 7: Papain Enzyme extraction methods from Latex of papaya, leaves of papaya

Extraction method	Significance	Reference
Aqueous two-phase (ATP) extraction system	At pH 5, ATP containing 8% (w/w) PEG and 15% (w/w) $NH4)_2SO_4$ obtained a maximum recovery of 88% and 100% purity from papaya latex containing 20-40 mg protein/ml. Other proteins were not found in the extracted papain.	Nitsawang*et al.* 2006
Ionic liquid aqueous two-phase (LATE) extraction technology	The [CnPy]Cl(n = 2,4,6)-K_2HPO_4 system produced high-purity and high-activity papain via late. Under the conditions of 0.35 g/ml K_2HPO_4, 0.25 g/ml [C4Py]Cl, pH 7.87, and papain dosage of 2.17 mg/ml at 30°c, the optimal result of overall desirability was 0.8985. The specific activity of papain was determined to be 4120.17 U/mg	Zhu and Zhang,(2019)
Peg-based aqueous two-phase systems	The ATPS of PEG400+$(NH_4)2So_4$ + H_2O was used to separate and purify papain from papaya latex by adding various il, with tetramethyl ammonium bromide ([N1111]br) in the ATPS with 20% (NH4)2	Yu and Zhaing(2020)

(ATPS) using quaternary ammonium ionic liquids (IL) as adjuvants	So_4 and 20% PEG400 at pH 7.0 and 60 c yielding the maximum papain purity. According to SDS-page analysis, adding 4 wt% il enhanced the crude papain purification factor (13.51) and papain recovery rate (96.46%).	
Reverse micellar extraction	The cetyltrimethylammonium bromide (CTAB) + isooctane + hexanol + butanol system is utilized to optimize forward and backward extraction of papain, with 61.0% and 90.52% efficiency at pH 11 and 6, isopropyl alcohol (%) of 6 and 19.938, and KCL of 20 (% v/v) and 0.729 m, respectively.	Prabhu*et al*., (2017)

As a result of papain's dominant action on mucoproteins and collagen in connective tissue, collagen suspensions are transformed into compact gels (Lonescu*et al*., 2008). Even though papain increases softness, it also reduces juiciness and imparts a bitter flavor due to bitter peptides generated by proteolytic breakdown, limiting its usage in the premium quality meat sector (Gerelt*et al*., 2000) because the enzyme can only be inactivated under high circumstances, such as 900 mpa and 80 degrees Celsius for 22 minutes, and the tenderization process continues long after the meat has been cooked (Passos*et al.*, 2016).

5.9 Anthelmintic properties

The antihelmintic effect of papaya seeds has been attributed mostly to carpaine (an alkaloid) and carpasemine (later identified as benzyl thiourea). Carpaine has a strongly bitter flavor and a significant depressive effect on the body. It may be found in papaya leaves as well as in fruit and seeds. According to pharmacological studies, papaya seeds contain benzilsothiocyanate, an anthelmintic biosubstance (Kermanshai*et al*., 2001). The combination of air-dried papaya seeds and honey has a considerable effect on human intestinal parasites, with no apparent negative effects. The consumption of papaya seeds is inexpensive, natural, safe, widely available, and mono-therapeutic and prevents intestinal parasitosis, particularly in tropical populations (Okeniyi*et al*., 2007). However, normal eating of ripe papaya during pregnancy may not be harmful; unripe or semi-ripe papaya (which has a large quantity of latex, which causes severe uterine contractions) may be harmful during pregnancy (Krishna *et al*., 2008).

Conclusion

The vast array of potential applications resulting from the innovative utilization of banana and papaya waste pre- and post-harvesting highlights the significant opportunity for minimizing agricultural waste in various industries. By extracting fibers from discarded banana leaves and stems and repurposing banana waste as a growth substrate and fiber, not only can environmental harm be minimized, but there are also opportunities for enhancing value and optimizing resources in agricultural settings. Furthermore, the investigation into the antibacterial, antioxidant, antidiarrheal, anticancer, antimalarial, and anti-dengue properties present in different parts of papaya plants underscores their essential role in the pharmaceutical and healthcare sectors. These discoveries broaden the scope of natural remedies accessible and offer sustainable alternatives to conventional pharmaceutical treatments, bridging the gap between traditional and modern medical approaches. Additionally, the conversion of banana peel waste into cellulase highlights the considerable potential for waste valorization in industrial processes, providing sustainable avenues for enzyme production and reducing dependence on finite fossil-based resources. Similarly, utilizing banana peel as a biosorbent for water treatment demonstrates its adaptability in addressing environmental issues, proving effective in eliminating pollutants and assisting in environmental restoration endeavors. In the domain of papaya, its diverse applications in processed foods and beverages showcase its culinary versatility and nutritional value, further enhanced by its ability to enzymatically tenderize meat. Moreover, the anthelmintic properties of papaya play a vital role in offering natural solutions for controlling parasitic infections in human intestinal parasites. The broad range of uses resulting from the creative utilization of banana and papaya waste highlights the substantial potential for sustainable practices and resource optimization across various sectors. thereby propelling sustainable development, environmental stewardship, and enhanced livelihoods across diverse sectors and communities on a global scale.

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