Nutritional and Pharmacological Properties of Papaya Peel: A Comprehensive Review

Adeel Yousaf[1], Marwa Waheed[2], Muhammad Bilal Hussain[1], Sawera Asif[1], Nabeel Haris[1], Hafsa Muniba[1], Muhammad Sagheer[3], Muhammad Abu Bakar Iftikhar[1], Areeha Zulfiqar[1], Misbah Asim[2], Imama Zainab[1]
[1]Department of Food sciences, Government College University Faisalabad, Pakistan.
[2]Department of Food Science and Technology, Riphah International University, Faisalabad, Pakistan.
[3]Department of Chemistry, University of Agriculture, Faisalabad, Pakistan
***Correspondence:** abashaheed47@gmail.com

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Food waste is a significant problem with ecological, ethical, societal, and economic implications. The global papaya market is likely to grow significantly between 2022 and 2027, leading to an increase in organic and discarded leftovers like peels and seeds. Papaya is a profitable and nutritious fruit that is gaining acceptance in Pakistan. Papaya fruit pulp and its other parts, including leaves, peels, roots, and seeds, have nourishing and medicinal significance. The pulp of papaya fruit contains an abundance of vitamins and minerals, while many valuable bioactive compounds are available in fruit peels and seeds. These bioactive components have a vital role in pharmacological activities, including antibacterial, anticancer activity, antioxidant, anti-inflammatory, wound-healing, antidiabetic, and many more, which are due to the presence of some phytochemicals, including phenolic, flavonoids, and alkaloids. Additionally, the nutritive profile of papaya peel is under development because of its potential applications in the food and pharmaceutical industries. This review paper targets to highlight the nutritional and pharmacological properties of papaya peel, with an emphasis on promoting sustainable waste management in practical applications.

Keywords: Papaya Peel, Nutritional Value, Value-Added Products, Medicinal Properties, Pharmacological Characteristics

Introduction:

Carica papaya L. (papaya) is a highly valuable herbaceous fruit plant belonging to the family Caricaceae, cultivated throughout the year for its economic importance. It is also commonly known as pawpaw or papaw and is cultivated in tropical and subtropical regions[1]. India, Mexico, Brazil, and Nigeria are at the moment the leading producers of papaya. In 2017, global production was estimated at 13 million metric tonnes, with Brazil and India making up the greatest share of global production, followed by the Dominican Republic, Mexico, Indonesia, and Nigeria. Projections are for global papaya production to grow at an annual rate of 2.1 percent to reach 16.6 million tonnes in 2029[2] India maintains its first position in papaya production and is expected to increase its value in worldwide production from 59 to 61 percent in 2029[3] Papaya production in Pakistan was carried out on 1,663 ha and produced 7,630 tons, which was an average of 45.881 kg ha-1 in 2019[4]

According to FAO statistics, worldwide papaya production from 2000 to 2022 showed a steady increase on the demand, reaching about 13.8 million metric tonnes in 2022, a 1% decrease from the 2021 production which was about 14 million metric tonnes[5].

One of the common examples of staple crops of the general population is Carica papaya, a popular tropical fruit[6]. The fruit under normal conditions has a morphology that is approximately globular; specimens produced out of hermaphroditic individuals have an elongated, fusiform, or pyriform geometry. C. papaya fruit sizes also vary according to the cultivar, with the maximum weight of about 10kg to 0.1kg. When grown to full maturity, the edible, fleshy cortex (mesocarp) is approximately 2.5 or 3cm thick, but the seed cavity is the largest portion of the internal volume[7] There is a drastic change in the compositional makeup of papaya fruits during the postharvest transformation of the green to the ripe, which is reflected in the observable changes in the nutritional and organoleptic properties. The phenolic antioxidants are often found in high levels in immature fruits and very low levels in reducing sugars, and the conversion of starch to fermentable sugars during maturation is finally achieved in increased sweetness and energy density. Although the immature papaya can be used as a ingredient in culinary dishes, the safety profile of this food may be undermined by the occurrence of low-molecular-weight, possibly cytotoxic chemicals; thus, the consumption has to be assessed on a cultivar-by-compositional basis. C. papaya has been reported to have a variety of nutritive and bioactive properties in the botanical constituents of pericarp, rhizome, inflorescences, foliar tissue, latex, fruit and seed kernels[2]

Papaya is commonly described as a fruit that contains high amounts of nutrients due to its nutritional value[8]. It is a great source of phenolic, vitamins (A, C, E, B-complex), and minerals (magnesium, potassium, and folate)[3]. The fruit peel also contains bioactive compounds that can help to cure different diseases. In most cases, when people consume papaya, only the pulp is eaten while the peel is discarded, leading to environmental concerns from overproduction and improper disposal of papaya peels[9]. However, papaya peel comprises a huge range of phytochemicals, including phenolic compounds, carotenoids, vitamins, alkaloids, and flavonoids, which have substantial antioxidant and antimicrobial properties.

The major by-products of papaya are peels and seeds that form about 12 and 8.5 percent of the weight of the fruit, respectively[3]. These compounds are enhanced with bioactive compounds, which makes them appropriate as nutraceutical supplements, functional food ingredients, and precursors of novel alimentary and pharmaceutical preparations. In the past, papaya peel has been used in ruminant feed, cosmetic recipes, and a myriad of traditional remedies[10]. In addition, the food-processing industry uses papaya to produce jam, pectin, nectars, juices, and papain; thus producing high levels of waste products[11]. An intense, methodical categorization of the physical and chemical properties of papaya peel is thus necessary to streamline the use of the material and determine the potential of papaya peel at its utmost. Detailed studies on the fiber content, moisture content, mineral profile, and bioactive components of the peel provide essential information on the functional characteristics of the peel. Not only does such knowledge form the basis of valorisation approaches, but it also promotes environmentally friendly approaches to waste minimisation.

Nutritional Composition of Papaya Peel (PP):

The papaya peel and seed make about 50% of the total papaya weight, and the seeds make about 14 % of the total fruit mass[11]. Unlike the pulp, the peel contains higher amounts of bioactive nutrients like β-carotene, lycopene, anthocyanins, and flavonoids that have strong antioxidant potential and help to alleviate oxidative stress by neutralizing free radicals[12]. Additionally, the concentration of anti-nutritional compounds, such as flavonoids, phenols, tannins, alkaloids, and saponins, was likely to decrease as the fruit matured. The bitter taste of unripe papaya peels is attributed to saponins, which can have beneficial effects on the upper digestive tract[3]. Additionally, the peel contains alkaloids and tannins in trace amounts, offering various health-promoting properties[2].

The unripe papaya is a rich source of micro- and macronutrients, including carbohydrates, fiber, minerals, and vitamins; however, the levels of these nutrients decline as the fruit ripens[6][10][13]. It is an incredible source of dietary fiber, which helps to boost the human digestive system. Furthermore, PP consists of minerals that are important for electrolyte balance in the human body and support bone strength because of the presence of calcium, phosphorus, and magnesium[14][15][16]. Table 1 displays the proximate and nutritional composition of papaya pulp and peel.

Table 1. Proximate and nutritional composition of Papaya pulp and peel (unripe and ripe)[17]

Parameters	Papaya Pulp		Papaya Peel	
	(Unripe)	(Ripe)	(Unripe)	(Ripe)
Moisture Content (%)	81.39	89.21	54.48	68.39
Fat (%)	0.55	0.35	0.23	0.33
Crude Protein (%)	1.46	0.29	10.56	6.89
Crude Fiber (%)	11.62	6.18	14.52	9.67
Ash (%)	4.84	2.83	5.25	3.15
Carbohydrates (%)	18.47	9.65	30.35	20.04
Vitamin C (IU/mg)	150.12	112.00	71.01	65.70
Vitamin A (IU/mg)	1354.87	2085.13	731.28	1164.10
Riboflavin (mg)	0.04	0.07	0.05	0.08
Thiamine (mg)	0.086	0.125	0.04	0.06
Niacin (mg)	0.24	0.33	0.37	0.45
Calcium (mg)	58.78	14.69	46.67	30.73
Sodium (mg)	25.68	27.25	19.33	20.67
Potassium (mg)	58.67	36.00	98.93	96.80
Phosphorus (mg)	9..48	3.10	21.82	15.37
Magnesium (mg)	12.80	6.40	20.80	13.60
Phenol (%)	0.11	0.01	0.38	0.17
Alkaloid (%)	0.41	0.05	1.35	0.39
Flavonoid (%)	0.34	0.10	0.47	0.33
Tannin (%)	0.37	0.11	0.61	0.35
Saponin (%)	1.31	0.09	1.47	0.49

Pharmacological Properties of Papaya Peel:

The papaya peel has been receiving much publicity due to its abundance of pharmacological values, thus making it quite promising in medical applications. It is full of bioactive compounds, such as flavonoids, carotenoids, and phenols, and these compounds have such huge health benefits as antibacterial, anti-inflammatory, and antioxidant.

Table 2. Pharmacological properties of Papaya peel [41]

Pharmacological Property	Model	Investigation	Significance/ Result	References
Antioxidant effects	In vitro	E. coli and K. pneumonia were efficiently ↓ by both peel and seed extracts	DPPH activity (55.50 μg/mL) and β-carotene/linoleic acid assay (75.80 μg/mL) compared to the seed extract	[18]
		Papaya peel (PP) extract was inspected against human pathogens and evaluated for DPPH & ABTS+ assay.	The presence of active proteins and phenolic compounds showed inhibition of pathogens	[19]
Antitumor effects	In vitro cultures	Aqueous extract of green papaya peel and pulp to investigate rat pancreatic cells	Results showed ↓ the effect of Fe+2-induced lipid peroxidation	[20]
		PP extracts 50–250 μg/mL aqueous PSE against breast cancer cell line (ER-/Her-2)	Demonstrated anti-proliferative action against estrogen receptor-negative breast tumors	[21]
Antibacterial effect	In vitro	PP extract against C. diphtheriae and S. pneumoniae	The ↓ MIC was 5.63 mg/mL and 1.40 mg/mL, respectively	[22]
		Silver nanoparticles on papaya peel were investigated against two bacterial strains E. coli and S. aureus	Silver nanoparticles showed potent antibacterial activity against human pathogens	[23]
Anti-inflammatory and wound-healing effects	In vitro	PP extracts investigated against wound healing and anti-inflammatory activity	Extract treatment ↓ of inflammation-related oxidative damage and ↑ antioxidant activity	[24]
		PP extract against Azoxymethane AOM-induced cytotoxicity in rat colon	Papaya peel exhibited anti-inflammatory and anti-carcinogenic activity due to the presence of bioactive components	[25]
Antidiabetic effect	In vitro	The ethanolic extract of PP for hypoglycemic and antihyperlipidemic effects in alloxan-induced diabetic rats	The extracted ↓ blood glucose levels over 28 days and ↓ serum cholesterol and triglycerides, and HDL	[26]
	In vitro	PP aqueous extract of unripe fruit ↓ α-amylase and α-glucosidase activity	↑ Activities of α-glucosidase and α-amylase ↓ with IC50 values of 1.76 mg/mL and 0.87 mg/mL, respectively	[27]

Antioxidant Activity:

Free radicals are generated in the human body, increasing oxidative stress within cells, which can contribute to conditions such as arthritis, heart disease, and chronic illnesses, including skin cancer, colon cancer, and atherosclerosis, due to cellular damage caused by these free radicals[2]. Antioxidants can shield against the production of free radicals and lessen lipid peroxidation, DNA damage, immune system function, and transformation of cells to malignant[28]. Antioxidant capacity of primary phenolic compounds (ferulic, p-coumaric, and caffeic acid) in papaya peel can be analyzed. Whereas the concentration of ferulic and caffeic acid was decreased from 14.98% to 8.09% and from 6.92% to 6.22%, respectively[29]. Conversely, p-coumaric acid rose from 0.86% to 0.94%, indicating that the arrangement and concentration of individual molecules within the food matrix play a key role in determining antioxidant activity[30]. The phytochemical components in the peel and seed of unripe papaya were examined, and the results showed that the unripe papaya seed extract consisted of terpenoids, tannins, steroids, and saponins, whereas the unripe papaya peel extract contained flavonoids, steroids, and saponins[31].

The peel and seed tissues of papaya contain a wide variety of bioactive components that give them several therapeutic properties as reported in literature[32]. Their microbiological characteristics and antioxidative capacity have also been investigated. It is worth noting that the seed extract also exhibits a more pronounced antibacterial effect compared to the peel extract, effectively inhibiting the proliferation of pathogenic bacteria such as K. pneumoniae and E. coli. Therefore, papaya by-products have a high level of potential as a source of antibacterial and antioxidant properties in various industrial applications. Conversely, the peel extract was found to be better than the seed counterpart in the β-carotene/linoleic acid chelation (75.80 μg/mL) and DPPH radical scavenging (55.50 μg/mL) assays, highlighting its strong antioxidant ability[18].

Antimicrobial Activity:

Antimicrobial agents are chemical products that act either by destroying or suppressing the growth and development of microbial organisms. In most countries, the most common pathogen is Trichomonas vaginalis, which is the most common non-viral sexually transmitted disease (STI) in the world. It is an important health burden of the world, as the World Health Organization (WHO) has indicated that there were about 156 million cases in 2020 among persons aged 15 to 49 years. The research has indicated that papaya seeds have antibacterial effects against this pathogen[2].

Papaya peel also contains natural antimicrobial compounds that can promote human health and therefore support its potential applications. The activity of the papaya peel against the antibacterial activity of the bacteria, Streptococcus pneumoniae and Corynebacterium diphtheriae, revealed the inhibition with the MIC value of 1.40 mg/mL and 5.63 mg/mL, respectively[22]. Besides, the application of fruit-peel extract to form nanoparticles as a biological platform is a contemporary scientific innovation that is environmentally friendly. As it was reported in[19], a research that used papaya-peel nanoparticles demonstrated antimicrobial properties against various human diseases. The study also showed that the papaya peel has an anti-microbial activity against multidrug-resistant human pathogens, such as, but not limited to, E. coli and K. pneumoniae, which are gram-negative microbes that showed the highest inhibitory activities.

Antidiabetic Activity:

The challenge of managing hyperglycemia is the most important factor that can be used to reduce the risk of diabetes and its related complications[33]. As reported in[26], aqueous and ethanolic extracts of papaya have been indicated to regulate the lipid profile of diabetic rat models. The extract was subsequently observed to induce hypoglyceridemia and demonstrate antioxidant effects attributed to its various bioactive compounds. Additionally, the ethanolic extract of papaya fruit peel was found to reduce blood glucose levels and improve the lipid profile. Although the extract is nontoxic, it caused a dramatic change in body weight in rats between day 3 and day 28.

Papaya fruit peel may have an impact on glycemic metabolism by inhibiting important enzymes like α-amylase and α-glycosidase that aid in the digestion of carbohydrates[34]. According to a research study, α-amylase and α-glycosidase could be inhibited in a dose-dependent way by aqueous extracts of unripe green papaya fruit (0 to 2.0 mg/mL) [22].The most prominent inhibitory effect on both enzymes is observed when the seeds, pulp, and peel of the unripe fruit are combined in equal concentrations. Dietary complex carbohydrates are first broken down into smaller sugars by α-amylase and then into glucose by α-glycosidase. Slowing down the breakdown and absorption of carbohydrates allows these enzymes to work more gradually, causing glucose to enter the bloodstream at a slower rate. This controlled release helps reduce sudden increases in blood sugar, resulting in lower postprandial glucose levels[35].

Anti-inflammatory Activity:

The human body relies on anti-inflammatory substances to defend against infections and harmful external agents. However, chronic conditions such as cancer and obesity are often associated with persistent inflammation as an underlying factor. The enzyme cyclooxygenase-2 (COX-2) is mainly expressed in inflammatory cells, for instance, mast cells and macrophages[36]. Papaya fruit is rich in biologically active secondary metabolites, including phenolics, alkaloids, and flavonoids, as well as proteolytic enzymes (papain and chymopapain). These phytochemicals not only help in reducing chronic inflammation 2422 also modulate the activity of inflammatory markers[33]. Researchers are exploring the use of plant extracts in treating infections to combat antimicrobial drug resistance, with a focus on bioactive compounds of papaya in modifying immune-inflammatory indicators, despite the increase in antimicrobial drug resistance[37]. Papaya seed extract exhibits antibacterial activity against Trichomonas vaginalis; however, due to its toxic nature, caution is necessary when using it for the treatment of urogenital infections[38].

According to[39], papaya leaf extract showed effectiveness against E. coli and K. pneumoniae at a concentration of 1000 μg/disc. The extract also possessed antibacterial compounds that reduced the growth of wound-infection-causing bacteria under in vitro conditions. When cells are treated with papaya extract at a concentration of 200 μg/mL or lower, their survival or viability remains almost the same as that of cells not treated with any papaya extract. In other words, papaya extract at this concentration does not have any beneficial or harmful effect on the cells' ability to survive. Furthermore, compared to untreated cells, those treated with lipopolysaccharide (LPS) and papaya extracts showed increased production of intracellular ROS and NO. However, all papaya extracts, to varying extents, were able to inhibit LPS-induced ROS and NO generation. These inhibitory effects were observed to be stronger with seed extracts than with peel-pulp extracts, irrespective of ripeness[40].

Anticancer Activity:

Cancer is a major global public health concern that affects people worldwide. Several in vitro studies indicate that papaya fruit has anticancer potential, with the papain enzyme showing promise in cancer treatment. The papain enzyme breaks down fibrin that coats tumor cells, converting it into amino acids. Papaya also contains lycopene, a pigment highly sensitive to oxygen and free radicals. Additionally, papaya includes isothiocyanates, which protect against a variety of cancers such as leukemia (blood cancer), lung, breast, prostate, and colon cancer[7].

Key components of papaya fruit peel extract have demonstrated high antioxidant activity and reducing power. In one study, silver nanoparticles were synthesized using papaya peel extract as a reducing agent, and their anticancer properties were evaluated through various techniques. The nanoparticles are found to be crystalline and exhibit strong antibacterial properties against both gram-positive and gram-negative pathogens. The cytotoxic activity of these nanoparticles on Hep2 and MCF-7 cells is also observed[41]. Oxidative damage due to free radicals has a significant effect on many chronic diseases[42]. The apoptotic and antioxidant properties of papaya peel extract are investigated, and the extract is observed to exhibit apoptotic characteristics in HepG2 cells, decrease COX-2 activity and DNA breakage, and increase caspase-3 levels. This implies that the extracts cause apoptosis, which is most likely behind cancer cancer-fighting mechanism of the extracts. It is thus most probable that the joint mechanism of apoptosis initiation and the activation of antioxidant enzymes could be the reason for the anti-cancer effects of papaya peel extracts. Finally, the study concluded that the anticancer properties of papaya peel extracts can be attributed to their combined ability to induce apoptosis and activate antioxidant enzymes[37].

Wound-Healing Activity:

The wound and skin healing potential of papaya fruit has been investigated, with studies showing that wounds in rats treated with ethanolic papaya extract healed more rapidly. Additionally, it was shown that papaya leaf nanofibers exhibit antibacterial activity against Gram-negative E. coli and Gram-positive S. aureus, while also promoting wound healing. The aqueous extract from papaya root also demonstrated the effect of wound healing in an albino rat study as effectively as Framycetinsulpha cream[43].

The wound-healing potential of papaya has been extensively reviewed in studies investigating in vivo treatments for skin injuries. Early evidence of the administration of extracts of mature, although unripe, green papaya peel to murine subjects indicates an epidermal repair profile that is conspicuously enhanced when compared to extracts of fully ripened fruit peel[44]. A strict experimental protocol was used where healthy laboratory rats were subjected to thermomechanical insults to the integumentary surface, and then one of the three treatments was administered to the experimental rats: vehicle (vaseline), ethanolic extract, and the traditional antibiotic mupirocin. Serial clinical measures, which are conducted on a bi-daily basis during 13 days, showed that the seed-based extract elicits an astonishing improvement in wound healing kinetics. The seed extract shows an impressive ability to promote recovery after 13 days of treatment[13].

The research team had done a systematic analysis of the wound-healing abilities of the green and yellow papaya skin in controlled laboratory conditions. Quantitative measures of fibroblast motility in the injured dermis revealed that the opportunity to migrate in cells increased two to three times when exposed to skin extracts, compared to an untreated control group. This activity is an important mechanistic gateway in the healing of the cutaneous integrity, which highlights the therapeutic interest of papaya skin constituents in the regulation of post-traumatic tissue repair. In addition, green and yellow papaya seeds almost tripled the amount of collagen generated by fibroblast cells and may help the body to regenerate tissue. These findings highlight the potential of both green and yellow papaya extracts as effective agents for wound healing, particularly in diabetic wound care [45].

Food Applications of Papaya Peel:

According to the United Nations Food and Agriculture Organization, global papaya production is expected to increase by 2.1% per year, reaching 16.6 million tons by 2029[46]. In addition to phytochemicals, papaya peel serves as a source of soluble dietary fiber (SDF) and insoluble dietary fiber (IDF), as reported in research studies[47]. Dietary fiber in papaya adds some health benefits that include reduction in blood cholesterol, weight control, and decreased risk of heart diseases, cancer, and gastrointestinal disorders[48]. Unripe papaya peel powder has nutritional advantages when used in dairy products for health promotion since the peel contains a considerable quantity of fiber and bioactive chemicals that explain numerous therapeutic benefits[49]. Furthermore, pectin and sugars have been extracted from papaya peel. Pectin, a structural polysaccharide and source of dietary fiber, is used as a filling agent and stabilizer in food products. It also plays an important role in maintaining blood cholesterol levels in the human body[50]. Furthermore, using PP can produce numerous valuable products through fermentation (e.g., biofuels, biogas, methane, biomaterials, adsorbents, biomedicine, and dietary fiber)[3] [7].

Herbal cosmetics, which are free from chemicals, are increasingly in demand. These products, made from bio-based ingredients, are designed to be safe for the skin and hair[7]. The vitamins A and vitamin E found in papaya peel help in repairing and reconstructing damaged skin[6]. Apparently, papaya peel contains a fairly high amount of riboflavin to aid in the synthesis of associated coenzymes, which include flavin mononucleotide and flavin adenine dinucleotide that perform generic reduction and oxidation tasks[16]. Papaya waste from production can also be repurposed as a valuable food source for animals. It serves as a beneficial addition to animal feed due to its content of minerals and polyphenols, which support animal health. In aquaculture, the cultivators also feed their fish with commercial feed products which are produced from plant and animal origin and their products. Papaya peel was also used to obtain pectin through extraction. Pectin extracted from papaya peel demonstrates important properties for food industry applications, with its degree of esterification and methoxyl content affecting its stabilizing and gelling abilities, making it suitable for use in jellies, edible films, and jams. Pectin constitutes approximately 19% of the dry weight of papaya peel, making it a valuable commercial source [3][51][52].

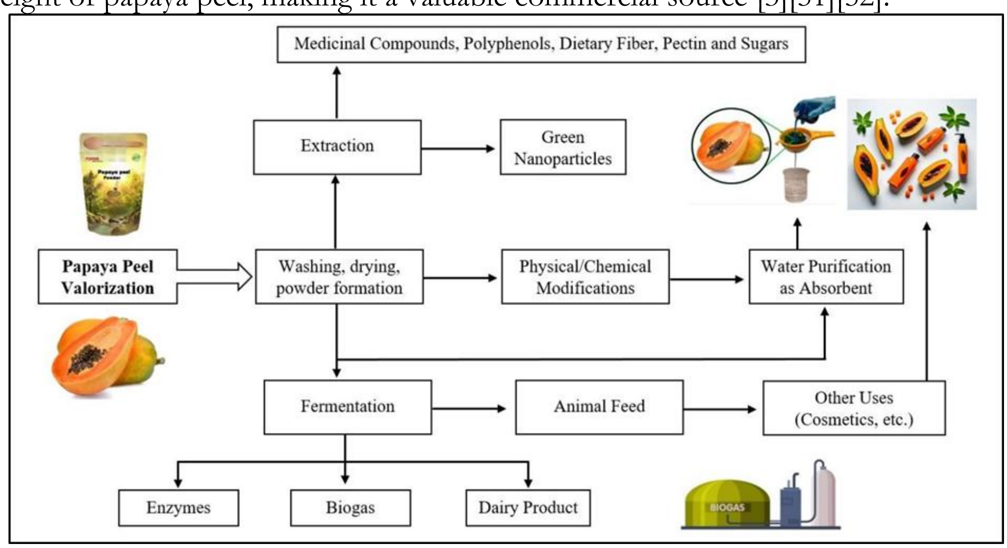

Figure 1. Food applications of Papaya [4]

Papaya Peel in Animal Feed:

Polyphenols and minerals are abundant in papaya peels and have many beneficial effects on animals; thus, fruit peel could be an extra constituent in animal feed. Papaya peel must be given importance as a wholesome supplement in livestock nutrition. Typically, farmers use commercial feeds that are prepared from several parts of plants and animals, together with their by-products[53]. A heavy amount of papaya peel is wasted during fruit[53] processing, even without a thought that it might be added to the feed of animals and poultry. Furthermore, proteases found in papaya peel promote the release of digestive enzymes. These enzymes improve fish digestion and nutrient absorption, which ultimately promotes M. rosenbergii PL (prawn) growth. Therefore, the consumption of papaya peels enhances the quality of prawns in terms of sodium, potassium, essential amino acids, fatty acids, vitamin C, and vitamin E[3]. Another study investigated the effect of dietary papaya peel performance on strongylus-infected lambs. Papaya peel consumption did not decrease the Strongylus spp. Infection levels in all the experimental sheep. However, it showed the capacity to maintain the level of Strongylus infection within an acceptable range. Moreover, the results showed that papaya peel silage of up to 75% replacing paddy straw has the possibility to function both as a feed supplement and as an anthelmintic agent[54].

Papaya Peel as Biofuel:

Waste-to-energy is a process of generating energy by converting waste into a fuel source[55]. In recent times, there has been an improved demand for fuels made from biomass (ethanol, biogas, and methane) because of their usage as fuel and in the synthesis of other important chemicals. These are renewable energy sources that can be produced by fermenting carbohydrates, in contrast to fossil fuels[56]. In some countries, ethanol is occasionally used as a substitute for certain types of gasoline. Studies have shown that fruit peels are particularly effective for fermentation-based ethanol production, as the sugars present in the peels can be readily utilized during the fermentation process. Therefore, the use of papaya peels may be of economic value when producing bioethanol in the manufacturing process. Fermentation-based ethanol manufacturing is affordable, and there is no toxic sludge or waste generated as a result of its production[57].

Additionally, a combination of organic waste (papaya peels, rice, coconut scrap, and potato peel) is used to make biogas. Seventeen days after the first feeding, the biogas generation process started. Subsequently, 40-42 days of anaerobic digestion with papaya peel, the maximum amount of biogas (~400 mL) is produced. After 41 days, reactors holding waste had just 1 mL of biogas. The range of 10-12% total solids in papaya peels makes it appropriate for anaerobic digestion[3]. Despite recent advances in food preservation techniques, fruits, vegetables, and root crops remain the most wasted products globally, accounting for 40–50% of total food waste. Each year, at least 35–40% of produced fruits and vegetables are either lost or discarded[58]. The maximum and frequently used microorganism for bioethanol production is Saccharomyces cerevisiae due to its long history of utilization for ethanol production. Saccharomyces cerevisiae has high ethanol yield and tolerance, low accumulation of by-products, as well as high fermentation rate[59].

Papaya Peel in Cosmetics:

Papaya peel is beneficial as a skin-bleaching agent. It can give a cooling effect to the skin and provide moisture when used in combination with honey[6]. Several researchers have demonstrated that the use of peel extract along with lemon juice and vinegar can be used to prevent dandruff. The mixture may be applied to the scalp after washing for twenty minutes. Similarly, various scientific studies show that lycopene in papaya peel and other related components have a strong impact on hair growth[60].

The bleaching and antioxidant properties of papaya peel can be utilized in the form of an anti-acne face pack of papaya peel[7]. Lanolin, mineral oil, stearic acid, and 0.1% potassium sorbate are heated slowly over a medium flame until they melt. The molten mixture is then slowly added to sterile distilled water with continuous stirring. After cooling to room temperature to obtain a semisolid, it is transferred into a container. Instead of potassium sorbate, 0.1% fruit peel extracts were used to make a face cream in a comparable formulation. The effectiveness of the face cream was measured through standard CTFA procedures, such as the Cosmetic, Toiletry, and Fragrance Association [61].

Papaya Peel Medicinal Uses:

In recent years, there has been a lot of research regarding the diagnostic potential of plants and natural food items as a remedy due to their pharmacological property. Other fruit products with proven health benefits have since been developed and successfully marketed[62]. Papaya peel is a good food, rich in vitamins, and has good nutritional value. Epidemiological studies found decreased chronic illness risk related to heart problems, aging, and cancer[63][64]. A study followed the antihyperlipidemic and antidiabetic effect of the ethanolic extract from papaya peel in rats on alloxan-induced diabetes. These results included the presence of alkaloids, flavonoids, tannins, saponins, and cardiac glycosides. Blood glucose, serum cholesterol, including triglycerides and LDL-C, dramatically dropped when diabetic rats were given PP ethanolic extract orally, whereas serum high-level lipoprotein (HDL-C) levels increased[26].

Papaya Peel in Wastewater Treatment:

Papaya peels can be used in the removal of pollutants from various water sources because of their characteristics as a commercial biosorbent. Papaya peel can be employed either in its natural form or following surface modification treatments[65]. Carbon obtained from papaya peel has proven effective as a bio-derived adsorbent for the removal of lead (Pb^{2+}) from contaminated water. Papaya peel can be utilized directly or after various surface modifications[65]. Carbon from papaya peel was known as a bio-sourced adsorbent in an aqueous system and intended for the extraction of lead Pb (II) from metal-polluted water. Pb (II) is a metal element that accumulates in living organisms over time through the food chain and causes chronic organ toxicity to the kidneys, nervous system, reproductive system, cancer, skin, and heart diseases[66][67].

Conclusion:

Papaya peel is often used as agricultural waste and has significant therapeutic properties that make it important in terms of utilization and attention. It is rich in bioactive compounds, which contribute to the following therapeutic properties, including antioxidant, anti-inflammatory, as well as wound-healing properties. Papaya peel is used as a raw material for the development of value-added products through sustainable procedures such as bio-refinery approaches and green synthesis. Its applications range from fermentation substrate and dietary fiber to the production of biomaterials, nanoparticles, pharmaceuticals, and biofuels, thus representing a zero-waste paradigm having environmental and economic benefits. Using papaya peel to its full potential could transform natural health solutions by producing affordable, easily accessible, and long-lasting medicinal ingredients. In addition to simply validating the effectiveness and safety of papaya peel-based therapeutic interventions, a more elaborate research agenda will help to integrate them into conventional medical paradigms, which will lead to sustainable development and improve health outcomes in the world

Table 3. The industrial and food applications of Papaya peel [4]

Usage	Investigation	Result	References
Animal feed	Papaya peel (PP) as silage and its effect on strongylus-infected lambs	Strongylus infection ↓, and worked as a feed supplement	[54]
	PP produces single-cell protein for animal feed.	PP waste can produce protein-rich biomass, which is valuable in animal feed.	[68]
Wastewater treatment	Bio-adsorbent from papaya peel and magnetic nanoparticles (Fe3O4) were developed to remove Pb (II) from aqueous media.	The bio-adsorbent effectively removes Pb (II) from water with an 86% recovery rate of wastewater.	[66]
	Papaya peel carbon (PPC) as an adsorbent for removing heavy metals (Pb, Cu, and Ni) from aqueous solution	Adsorption for Pb and Ni occurred at pH 6, while for Cu, it occurred at pH 5, showing PPC as an effective alternative adsorbent.	[67]
Biofuel and biogas production	Production of bioethanol from fruit peel (Mango, Papaya, Banana) using Saccharomyces cerevisiae	PP fermentation produces 96.11% pure bioethanol, which can further be used to feed livestock.	[59]
	Batch experiment in mesophilic conditions (30°C) at varying hydraulic retention times for papaya peels	PP formed the maximum biogas of 404.24 mL in 15 days.	
Cosmetics	Oil extraction and analysis from PP through GC-MS analysis	Different compounds were detected, including Oleic acid 65.82%, Palmitic acid 16.16%, Linoleic acid 6.08%, Lauric acid 6.05%, Stearic acid 4.73% and a minor amount of Linoleic acid	[69]
	Papaya peel, along with lycopene.	Shows a potent hair growth-stimulating activity	[70]
Medicinal Uses	Unripe papaya peel aqueous extract explores antioxidant and phytochemical potential.	Results revealed that peel contains saponin, steroids, flavonoids, and sterols, following antioxidants with higher ferric reducing power (112.35 mg AAE/100 g)	[60]
	Investigating the ethanolic extract of PP as a low-toxicity alternative to antidiabetic and anti-hyperlipidemic drugs in managing diabetes and hyperlipidemia	Showed ↓ in blood glucose and serum cholesterol, and ↑ in HDL-C levels in diabetic wistar rats	[31]

References:

[1] G. B. Mohammed Jafar, Gezu Degefa, Wakgari, Girma, "Adaptation Trial of Improved Papaya (Carica papaya L.) Varieties in East Hararghe, Oromia, Ethiopia," *Int.J.Agr.Sci. Tech*, vol. 4, no. 1, pp. 78–82, 2024, [Online]. Available: https://www.svedbergopen.com/files/1715395971_(9)_IJAGST25032024ZX5R_(p_78-82).pdf

[2] J. M. Dotto and S. A. Abihudi, "Nutraceutical value of Carica papaya: A review," *Sci. African*, vol. 13, p. e00933, Sep. 2021, doi: 10.1016/J.SCIAF.2021.E00933.

[3] P. D. Pathak, S. A. Mandavgane, and B. D. Kulkarni, "Waste to Wealth: A Case Study of Papaya Peel," *Waste and Biomass Valorization*, vol. 10, no. 6, pp. 1755–1766, Jan. 2019, doi: 10.1007/s12649-017-0181-x.

[4] S. T. Qazi, "Intensity of papaya ring spot disease in district Hyderabad Pakistan and its management using antiviral compounds," *Pure Appl. Biol.*, vol. 12, no. 2, Jun. 2023, doi: 10.19045/BSPAB.2023.120099.

[5] FAO, "Major Tropical Fruits Market Review – Preliminary results 2022," *Food Agric. Organ. United Nations Rome*, 2023, [Online]. Available: https://openknowledge.fao.org/server/api/core/bitstreams/852265a4-9006-4d54-a792-51f1d9c44673/content

[6] O. R. Alara, N. H. Abdurahman, and J. A. Alara, "Carica papaya: comprehensive overview of the nutritional values, phytochemicals and pharmacological activities," *Adv. Tradit. Med. 2020 221*, vol. 22, no. 1, pp. 17–47, Aug. 2020, doi: 10.1007/S13596-020-00481-3.

[7] A. Sharma, A. Bachheti, P. Sharma, R. K. Bachheti, and A. Husen, "Phytochemistry, pharmacological activities, nanoparticle fabrication, commercial products and waste utilization of Carica papaya L.: A comprehensive review," *Curr. Res. Biotechnol.*, vol. 2, pp. 145–160, Nov. 2020, doi: 10.1016/J.CRBIOT.2020.11.001.

[8] A. Hanif, S. Ahmad, M. J. Jaskani, and R. Ahmad, "Papaya treatment with putrescine maintained the overall quality and promoted the antioxidative enzyme activities of the stored fruit," *Sci. Hortic. (Amsterdam).*, vol. 268, p. 109367, Jun. 2020, doi: 10.1016/J.SCIENTA.2020.109367.

[9] N. K. K. Juhari, N. B. A. Wahid, and S. Ramli, "A review: Antimicrobial activity and toxicity analysis of the peel of banana, pomegranate, papaya, and citrus fruits (lemon and orange)," *Malays. J. Microbiol.*, vol. 17, no. 4, pp. 1–12, 2021, doi: 10.21161/mjm.201076.

[10] S. Kakkar, R. Tandon, and N. Tandon, "Papaya Seeds: Treasure of Nutrients and a Promising Preservative," *Glob. Emerg. Innov. Summit*, pp. 245–253, Jan. 2021, doi: 10.2174/9781681089010121010031.

[11] A. F. Vinha *et al.*, "High-Value Compounds in Papaya By-Products (Carica papaya L. var. Formosa and Aliança): Potential Sustainable Use and Exploitation," *Plants 2024, Vol. 13, Page 1009*, vol. 13, no. 7, p. 1009, Apr. 2024, doi: 10.3390/PLANTS13071009.

[12] C. . D. Jessie Suneetha W, "Nutritional Profiling of Papaya Peel Incorporated Chapathis," Researchgate. Accessed: Nov. 01, 2025. [Online]. Available: https://www.researchgate.net/publication/328562785_Nutritional_Profiling_of_Papaya_Peel_Incorporated_Chapathis

[13] S. KHAN *et al.*, "Carica papaya Therapeutic Properties In Disease Management: A Review," *PLANT CELL Biotechnol. Mol. Biol.*, pp. 1–14, Mar. 2022, doi: 10.56557/PCBMB/2022/V23I11-127504.

[14] * Chukwuka and Uka, "Evaluation of Nutritional Components of Carica papaya L. At Different Stages of Ripening," *IOSR J. Pharm. Biol. Sci. (IOSR-JPBS*, vol. 6, no. 4, pp. 13–16, Accessed: Nov. 11, 2025. [Online]. Available: www.iosrjournals.org

[15] N. Asghar *et al.*, "Compositional difference in antioxidant and antibacterial activity of all parts of the Carica papaya using different solvents," *Chem. Cent. J. 2016 101*, vol. 10, no. 1, pp. 1–11, Feb. 2016, doi: 10.1186/S13065-016-0149-0.

[16] J. K. Patra, H. S. Shin, I. J. Yang, L. T. H. Nguyen, and G. Das, "Sustainable Utilization of Food Biowaste (Papaya Peel) Extract for Gold Nanoparticle Biosynthesis and Investigation of Its Multi-Functional Potentials," *Antioxidants 2024, Vol. 13, Page 581*, vol. 13, no. 5, p. 581, May 2024, doi: 10.3390/ANTIOX13050581.
[17] E. L. Koffi, D. M. Koffi, H. K. Konan, and E. J. P. N. Kouadio, "Effect of the Ripening Stages on Some Biochemical and Nutritional Properties in Carica papaya L. (cv. Solo 8) Pulp, Skin, and Seeds," *Eur. J. Nutr. Food Saf.*, pp. 1–9, Oct. 2020, doi: 10.9734/EJNFS/2020/V12I1030297.
[18] U Dutta, "Antimicrobial and antioxidant properties of peel and seed extract of Carica papaya L.: Antimicrobial and antioxidant potential of papaya," *Indian J. Exp. Biol.*, 2024, [Online]. Available: https://scholar.google.com.pk/scholar?q=Antimicrobial+and+antioxidant+properties+of+peel+and+seed+extract+of+Carica+papaya+L.:+Antimicrobial+and+antioxidant&hl=en&as_sdt=0&as_vis=1&oi=scholart
[19] T. Kokila, P. S. Ramesh, and D. Geetha, "Biosynthesis of AgNPs using Carica Papaya peel extract and evaluation of its antioxidant and antimicrobial activities," *Ecotoxicol. Environ. Saf.*, vol. 134, pp. 467–473, Dec. 2016, doi: 10.1016/J.ECOENV.2016.03.021.
[20] G. Oboh, A. A. Olabiyi, and A. J. Akinyemi, "Inhibitory effect of aqueous extract of different parts of unripe pawpaw (Carica papaya) fruit on Fe2+-induced oxidative stress in rat pancreas in vitro," *Pharm. Biol.*, vol. 51, no. 9, pp. 1165–1174, Sep. 2013, doi: 10.3109/13880209.2013.782321;Requestedjournal:Journal:Iphb20;Wgroup:String:Publication.
[21] S. A. Hadadi, H. Li, R. Rafie, P. Kaseloo, S. M. Witiak, and R. A. Siddiqui, "Anti-oxidation properties of leaves, skin, pulp, and seeds extracts from green papaya and their anti-cancer activities in breast cancer cells," *J Cancer Metastasis Treat 2018;425.*, vol. 4, no. 0, p. N/A-N/A, May 2018, doi: 10.20517/2394-4722.2018.22.
[22] U Dutta, "Antibacterial composition of bioautographic fractions, characteristics, and stability of Carica papaya seed extract," *Indian J. Exp. Biol.*, vol. 62, no. 8, pp. 660–669, 2024.
[23] J. Balavijayalakshmi and V. Ramalakshmi, "Carica papaya peel mediated synthesis of silver nanoparticles and its antibacterial activity against human pathogens," *J. Appl. Res. Technol.*, vol. 15, no. 5, pp. 413–422, Jun. 2019, doi: 10.1016/J.JART.2017.03.010.
[24] A. B. Nafiu and M. T. Rahman, "Anti-inflammatory and antioxidant properties of unripe papaya extract in an excision wound model," *Pharm. Biol.*, vol. 53, no. 5, pp. 662–671, May 2015, doi: 10.3109/13880209.2014.936470;Requestedjournal:Journal:Iphb20;Wgroup:String:Publication.
[25] M. I. Waly *et al.*, "Amelioration of azoxymethane induced-carcinogenesis by reducing oxidative stress in rat colon by natural extracts," *BMC Complement. Altern. Med. 2014 141*, vol. 14, no. 1, pp. 1–10, Feb. 2014, doi: 10.1186/1472-6882-14-60.
[26] M. Haruna, Y. Abdulmumin, T. M. Abdulmumin, M. Murtala, and M. M. Dalhatu, "Hypoglycemic and Antihyperlipidemic Effects of Ethanolic Fruit Peel Extract of Carica papaya (pawpaw) in an Alloxan-induced Diabetic Rats," *J. Adv. Med. Pharm. Sci.*, pp. 31–41, Apr. 2022, doi: 10.9734/JAMPS/2022/V24I230285.
[27] P. H. Miranda-Osorio *et al.*, "Protective Action of Carica papaya on β-Cells in Streptozotocin-Induced Diabetic Rats," *Int. J. Environ. Res. Public Heal. 2016, Vol. 13, Page 446*, vol. 13, no. 5, p. 446, Apr. 2016, doi: 10.3390/IJERPH13050446.
[28] O. Kadiri, B. Olawoye, O. S. Fawale, and O. A. Adalumo, "Nutraceutical and Antioxidant Properties of the Seeds, Leaves and Fruits of Carica papaya: Potential Relevance to Humans Diet, the Food Industry and the Pharmaceutical Industry - A Review," *Turkish J. Agric. - Food Sci. Technol.*, vol. 4, no. 12, pp. 1039–1052, Nov. 2016, doi: 10.24925/TURJAF.V4I12.1039-1052.569.

[29] L. E. G.-G. Sancho, E. M. Yahia, G. A. González-Aguilar, L. E. G.-G. Sancho, E. M. Yahia, and G. A. González-Aguilar, "Contribution of Major Hydrophilic and Lipophilic Antioxidants from Papaya Fruit to Total Antioxidant Capacity," *Food Nutr. Sci.*, vol. 4, no. 8, pp. 93–100, Jul. 2013, doi: 10.4236/FNS.2013.48A012.

[30] N. Gogna, N. Hamid, and K. Dorai, "Metabolomic profiling of the phytomedicinal constituents of Carica papaya L. leaves and seeds by 1H NMR spectroscopy and multivariate statistical analysis," *J. Pharm. Biomed. Anal.*, vol. 115, pp. 74–85, Nov. 2015, doi: 10.1016/J.JPBA.2015.06.035.

[31] F. A. Dada, F. O. Nzewuji, A. Esan, S. Oyeleye, and V. B. Adegbola, "Phytochemical And Antioxidant Analysis Of Aqueous Extracts Of Unripe Pawpaw (Carica papaya Linn.) Fruit's Peel And Seed," 2016.

[32] S. Siddique, S. Nawaz, F. Muhammad, B. Akhtar, and B. Aslam, "Phytochemical screening and in-vitro evaluation of pharmacological activities of peels of Musa sapientum and Carica papaya fruit," *Nat. Prod. Res.*, vol. 32, no. 11, pp. 1333–1336, Jun. 2018, doi: 10.1080/14786419.2017.1342089;Requestedjournal:Journal:Gnpl20;Page:String: Article/Chapter.

[33] R. B, P. R, S. Pavani G, U. Fatima, and S. Begum, "Pharmacological Review of Carica Papaya," *Int. J. Sci. Res.*, vol. 11, no. 5, pp. 225–232, May 2022, doi: 10.21275/SR22415174422.

[34] D. Sarkar, A. Christopher, and K. Shetty, "Phenolic Bioactives From Plant-Based Foods for Glycemic Control," *Front. Endocrinol. (Lausanne).*, vol. 12, p. 727503, Jan. 2022, doi: 10.3389/FENDO.2021.727503/FULL.

[35] A. C. I. Lidiani F. Santana, "Nutraceutical Potential of Carica papaya in Metabolic Syndrome," *Nutrients*, vol. 11, no. 7, p. 1608, 2019, doi: https://doi.org/10.3390/nu11071608.

[36] S. Salla *et al.*, "Antioxidant and Apoptotic Activity of Papaya Peel Extracts in HepG2 Cells," *Food Nutr. Sci.*, vol. 7, no. 6, pp. 485–494, May 2016, doi: 10.4236/FNS.2016.76050.

[37] S. Pandey, P. J. Cabot, P. N. Shaw, and A. K. Hewavitharana, "Anti-inflammatory and immunomodulatory properties of Carica papaya," *J. Immunotoxicol.*, vol. 13, no. 4, pp. 590–602, Jul. 2016, doi: 10.3109/1547691X.2016.1149528; Journal:Iimt20;Wgroup:String:Publication.

[38] S. F. Van Vuuren, K. E. Motlhatlego, and V. Netshia, "Traditionally used polyherbals in a southern African therapeutic context," *J. Ethnopharmacol.*, vol. 288, p. 114977, 2022, doi: https://doi.org/10.1016/j.jep.2022.114977.

[39] R. Gharibi, H. Yeganeh, A. Rezapour-Lactoee, and Z. M. Hassan, "Stimulation of Wound Healing by Electroactive, Antibacterial, and Antioxidant Polyurethane/Siloxane Dressing Membranes: In Vitro and in Vivo Evaluations," *ACS Appl. Mater. Interfaces*, vol. 7, no. 43, pp. 24296–24311, Nov. 2015, doi: 10.1021/ACSAMI.5B08376.

[40] Y. A. Jeon, S. W. Chung, S. C. Kim, and Y. J. Lee, "Comprehensive Assessment of Antioxidant and Anti-Inflammatory Properties of Papaya Extracts," *Foods*, vol. 11, no. 20, p. 3211, Oct. 2022, doi: 10.3390/FOODS11203211/S1.

[41] T. John, K. A. Parmar, S. C. Kotval, and J. Jadhav, "Synthesis, Characterization, Antibacterial and Anticancer Properties of Silver Nanoparticles Synthesized from Carica Papaya Peel Extract," *Int. J. Nanosci. Nanotechnol.*, vol. 17, no. 1, pp. 23–32, Mar. 2021, Accessed: Nov. 11, 2025. [Online]. Available: https://www.ijnnonline.net/article_242800.html

[42] B. Koul *et al.*, "Carica papaya L.: A Tropical Fruit with Benefits beyond the Tropics," *Divers. 2022, Vol. 14, Page 683*, vol. 14, no. 8, p. 683, Aug. 2022, doi: 10.3390/D14080683.

[43] A. B. Wadekar *et al.*, "Morphology, phytochemistry and pharmacological aspects of Carica papaya, an review," *https://gsconlinepress.com/journals/gscbps/sites/default/files/GSCBPS-2021-*

0073.pdf, vol. 14, no. 3, pp. 234–248, Mar. 2021, doi: 10.30574/GSCBPS.2021.14.3.0073.

[44] S. Kumar, A. Kumar, R. Kumar, V. Kumar, N. Kumar, and A. Tyagi, "Phytochemical, Pharmacognostical and Pharmacological Activities of Carica papaya," *Int. J. Res. Appl. Sci. Biotechnol.*, vol. 9, no. 2, pp. 310–315, Apr. 2022, doi: 10.31033/IJRASB.9.2.27.

[45] H. Li *et al.*, "Characterization of Green and Yellow Papaya (Carica papaya) for Anti-Diabetic Activity in Liver and Myoblast Cells and Wound-Healing Activity in Fibroblast Cells," *Nutr. 2023, Vol. 15, Page 1929*, vol. 15, no. 8, p. 1929, Apr. 2023, doi: 10.3390/NU15081929.

[46] J. P. Rodrigues, C. C. de Souza Coelho, A. G. Soares, and O. Freitas-Silva, "Current technologies to control fungal diseases in postharvest papaya (Carica papaya L.)," *Biocatal. Agric. Biotechnol.*, vol. 36, p. 102128, Sep. 2021, doi: 10.1016/J.BCAB.2021.102128.

[47] J. E. Angulo-López *et al.*, "Antioxidant Dietary Fiber Sourced from Agroindustrial Byproducts and Its Applications," *Foods 2023, Vol. 12, Page 159*, vol. 12, no. 1, p. 159, Dec. 2022, doi: 10.3390/FOODS12010159.

[48] S. Hussain, I. Jõudu, and R. Bhat, "Dietary Fiber from Underutilized Plant Resources—A Positive Approach for Valorization of Fruit and Vegetable Wastes," *Sustain. 2020, Vol. 12, Page 5401*, vol. 12, no. 13, p. 5401, Jul. 2020, doi: 10.3390/SU12135401.

[49] S. Lal Bajya *et al.*, "Foodomics-based metabolites profiling of the Greek yogurt incorporated with unripened papaya peel powder," *Food Chem. Mol. Sci.*, vol. 8, p. 100199, Jul. 2024, doi: 10.1016/J.FOCHMS.2024.100199.

[50] T. Mada, R. Duraisamy, and F. Guesh, "Optimization and characterization of pectin extracted from banana and papaya mixed peels using response surface methodology," *Food Sci. Nutr.*, vol. 10, no. 4, pp. 1222–1238, Apr. 2022, doi: 10.1002/FSN3.2754.

[51] S. Wimalasiri, S., & Somasiri, "Ensiled Fruit Peels of Pineapple (Ananas comosus) and Papaya (Carica papaya) as an Animal Feed," *Conf. Proc. Int. Conf. Agric. Food Secur. Saf.*, vol. 2, no. 1, pp. 29–43, 2021, doi: https://doi.org/10.32789/agrofood.2021.1003.

[52] A. O. Akintunde *et al.*, "Evaluation of the Nutritive Values of Carica Papaya Fruit peels as A Potential Ingredient in Livestock Nutrition," *Anim. Prod.*, vol. 24, no. 2, pp. 104–113, Jul. 2022, doi: 10.20884/1.JAP.2022.24.2.129.

[53] S. S. Diarra, "Peel meals as feed ingredients in poultry diets: Chemical composition, dietary recommendations and prospects," *J. Anim. Physiol. Anim. Nutr. (Berl).*, 2018, doi: https://doi.org/10.1111/jpn.12954.

[54] M. Wanapat *et al.*, "The recycling of tropical fruit peel waste-products applied in feed additive for ruminants: Food manufacturing industries, phytonutrient properties, mechanisms, and future applications," *J. Agric. Food Res.*, vol. 17, p. 101234, Sep. 2024, doi: 10.1016/J.JAFR.2024.101234.

[55] O. K. Saheed, P. Jamal, and M. Z. Alam, "Fruit wastes: a potential carbon source for animal feed production," pp. 18–35, 2022.

[56] M. V. L. Chhandama, A. C. Chetia, K. B. Satyan, Supongsenla Ao, J. V. Ruatpuia, and S. L. Rokhum, "Valorisation of food waste to sustainable energy and other value-added products: A review," *Bioresour. Technol. Reports*, vol. 17, p. 100945, Feb. 2022, doi: 10.1016/J.BITEB.2022.100945.

[57] D. P. C. Favaretto *et al.*, "Fruit Residues as Biomass for Bioethanol Production Using Enzymatic Hydrolysis as Pretreatment," Jan. 2023, doi: 10.21203/RS.3.RS-2465028/V1.

[58] A. Tadesse and T. Yemata, "Production and Optimization of Bioethanol from Mixed Banana and Papaya Peels Using *Saccharomyces Cerevisiae*," *Am. J. Chem. Biochem. Eng. 2024, Vol. 8, Page 45*, vol. 8, no. 2, pp. 45–57, Sep. 2024, doi: 10.11648/J.AJCBE.20240802.12.

[59] A. A. Mitiku and T. M. Hatsa, "International Journal of Current Research and Academic Review Bioethanol Production from Decaying Fruits Peel Using Saccharomyces cerevisiae," *Int.J.Curr.Res.Aca.Rev*, vol. 8, no. 5, pp. 50–59, 2020, doi: 10.20546/ijcrar.2020.805.006.

[60] M. Deshpande, P. S. Parihar, S. Brahma, A. Shirole, E. Vahikar, and H. Agarwal,

"Benefits of Papaya Fruit and its Leaves to Treat Malaria or Dengue and Various Other Uses for Human Health," *Int. Res. J. Eng. Technol.*, vol. 08, no. 04, pp. 3460–3467, 2021, Accessed: Nov. 11, 2025. [Online]. Available: https://www.academia.edu/51470076/IRJET_Benefits_of_Papaya_Fruit_and_its_leaves_to_Treat_Malaria_or_Dengue_and_Various_Other_Uses_for_Human_Health

[61] T. Ashok Patil and L. Jain, "Natural Preservatives from Fruit Peels," *Acta Sci. Microbiol.*, vol. 3, no. 6, pp. 152–157, May 2020, doi: 10.31080/ASMI.2020.03.0623.

[62] R. Suhag *et al.*, "Fruit peel bioactives, valorisation into nanoparticles and potential applications: A review," *Crit. Rev. Food Sci. Nutr.*, vol. 63, no. 24, pp. 6757–6776, 2023, doi: 10.1080/10408398.2022.2043237;PAGE:STRING:ARTICLE/CHAPTER.

[63] E. O. S, N. J. D., and N. I. B., "Metals and Phytochemical Composition of Leaves and Peels of Pawpaw (Carica Papaya) Sold Within Port Harcourt, Rivers State, Nigeria," *Pharmacophore*, vol. 10, no. 4–2019, pp. 57–61, 2019, doi: 10.51847/UB5GN0A.

[64] Y. R. Kong *et al.*, "Beneficial Role of Carica papaya Extracts and Phytochemicals on Oxidative Stress and Related Diseases: A Mini Review," *Biol. 2021, Vol. 10, Page 287*, vol. 10, no. 4, p. 287, Apr. 2021, doi: 10.3390/BIOLOGY10040287.

[65] Y. L. Khee, P. L. Kiew, and Y. T. Chung, "Valorizing papaya seed waste for wastewater treatment: a review," *Int. J. Environ. Sci. Technol. 2022 202*, vol. 20, no. 2, pp. 2327–2346, May 2022, doi: 10.1007/S13762-022-04178-9.

[66] S. Abbaszadeh, H. R. Nodeh, and S. R. W. Alwi, "Bio-adsorbent derived from papaya peel waste and magnetic nanoparticles fabricated for lead determination," *Pure Appl. Chem.*, vol. 90, no. 1, pp. 79–92, Jan. 2018, doi: 10.1515/PAC-2017-0503/XML.

[67] S. Abbaszadeh, S. R. Wan Alwi, C. Webb, N. Ghasemi, and I. I. Muhamad, "Treatment of lead-contaminated water using activated carbon adsorbent from locally available papaya peel biowaste," *J. Clean. Prod.*, vol. 118, pp. 210–222, Apr. 2016, doi: 10.1016/J.JCLEPRO.2016.01.054.

[68] P. Thiviya, A. Gamage, R. Kapilan, O. Merah, and T. Madhujith, "Production of Single-Cell Protein from Fruit Peel Wastes Using Palmyrah Toddy Yeast," *Ferment. 2022, Vol. 8, Page 355*, vol. 8, no. 8, p. 355, Jul. 2022, doi: 10.3390/FERMENTATION8080355.

[69] U. Onthong and N. Juntarachat, "Evaluation of Biogas Production Potential from Raw and Processed Agricultural Wastes," *Energy Procedia*, vol. 138, pp. 205–210, Oct. 2017, doi: 10.1016/J.EGYPRO.2017.10.151.

[70] O. V. Enearepuadoh and O. Victor, "Extraction And Gc-Ms Analysis Of Oil Obtained From Ripe Carica Papaya l. Peels," *Adv. Ind. Pharm. Pharm. Sci.*, vol. 1, no. 1, pp. 1–14, Dec. 2021, doi: 10.23977/AIPPS.2021.010101.