Chapter 1

Introduction and literature review

1.1 Overall Introduction

Pineapple (*Ananas Comosus* L.) is called 'The King of Fruits' and is one of the commercially significant fruits of India. As a result of its excellent aroma, flavor, and taste, it is one of the most popular fruits in the world. The top eight nations producing pineapples worldwide were the Philippines, Costa Rica, Brazil, Indonesia, China, India, Thailand, and Nigeria with an annual production of 2702.55, 2624.12, 2455.692, 2447.24, 2220.26, 1799, 1553.25,1508.2 metric tons respectively during the year 2020-21 (Li et al., 2022). Numerous pineapple types with different colors, forms, sizes, and flavors are available today. Pineapple is made up of numerous fruitlets and has a characteristic maturation pattern from top to bottom and close to the crown of the fruit (Lobo et al., 2017). This is because pineapple is a non-climacteric tropical fruit, and its quality varies when it reaches different stages of maturity (Shamsudin et al., 2020).

(a) (b)

Fig. 1.1: (a) Raw pineapple (b) Pineapple waste

The fruit can be processed in a variety of ways and canned as well as eaten fresh. Generally, fresh pineapple fruit or fresh pineapple juice is consumed after removing the crown, leaf, rind, stem, eyes, and core from field-ripe fruits. In addition to being used as a complement to meat preparations, pineapple can also be eaten as canned pineapple, juiced, and in a variety of desserts, fruit salads, jams, yogurt, ice cream, and confectionery products. Typically, the functional, physico-chemical, and biochemical properties of fruits with appropriate essence and structural qualities are used to evaluate pineapple maturity indicators (Ali et al., 2023). Fresh pineapple contains many essential vitamins (vit A, B, and C) and minerals, including calcium, magnesium, potassium, and iron (Uthman et al., 2023). The health advantages are linked to various phytochemicals and functional bioactivities that support human health and metabolism (Jiang et al., 2021). Pineapple has recently expanded much prominence for its health-promoting properties like anti-inflammatory, antioxidant, and antimicrobial activity. Pineapple is also a good source of the digestive enzyme bromelain, and it possesses all the good organoleptic qualities. The predominant bioactive substances found in pineapple fruits are phenolic acid and flavonoids, both of which are found in the structural components of the fruits (Lobo et al., 2017). The pineapple is known as one of the most valuable tropical fruits for having bioactive compounds such as organic acids, the digestive enzyme bromelain, antioxidants, and phenolic acids based on its physicochemical parameters and nutritional qualities.

Industrial pineapple processing, including minor processing, produces a significant amount of by-products, which typically account for more than 20% of the fruit. The peel makes up a majority of these by-products, accounting for 25–35% of the pineapple fruit (Fouda-Mbanga et al., 2022). It is crucial to characterize and valorize these products, turning them into value-added products; this reduces the environmental effect and costs associated with treating the by-products of pineapple processing companies (such as core and rind). Due to the production of significant amounts of by-products from fruits and vegetable processing industries, including skin, seeds, pomace, leaves, and peel at various stages of the processing, their utilization has emerged as one of their most crucial and challenging elements (Rico et al., 2020; Gavahian et al., 2021). Numerous findings have verified the utilization of processing waste through various methods of extraction, purification, isolation, and fermentation as a new, affordable source of bioactive compounds such as dietary fiber, phenolic, antioxidants, proteolytic enzymes, organic acids, essential oils, etc.

Pineapple fruit has the possibility of more profitable and better markets for waste valorization. The valorization of processing waste explores the potential uses for pineapple waste and encourages comprehensive utilization of wastes rich in bioactive components. A wide range of waste processing products with significant economic value might be produced by utilizing pineapple to its full potential in both the food industry and other sectors. The upper crown of the pineapple, which generates about 3 billion tonnes of by-products annually, makes up around 25% of its overall weight in fruit waste (Nirmal et al., 2023). Despite recent technological advancements in the pineapple industry, the crown, core, leaf, and peel of the fruit are still thrown, despite the possibility that they could be commercialized for useful purposes. Nutrients such as dietary fiber, organic acids, volatile chemicals, and bioactive compounds are abundant in pineapple waste. A variety of biofuels is produced using pineapple waste. Additionally, pineapple waste offers a variety of possible food-based and waste-processing goods. A novel area to work on is the use of pineapple wastes for a circular bio-economy. This primary goal is to thoroughly understand the chemical composition, nutritional content, volatile chemicals, pineapple waste extraction and utilization, health advantages, and future applications of pineapple waste valorization which could be incorporated into diets. This information is provided by researchers and food producers with the foundational knowledge to consider new avenues for pineapple and pineapple waste products.

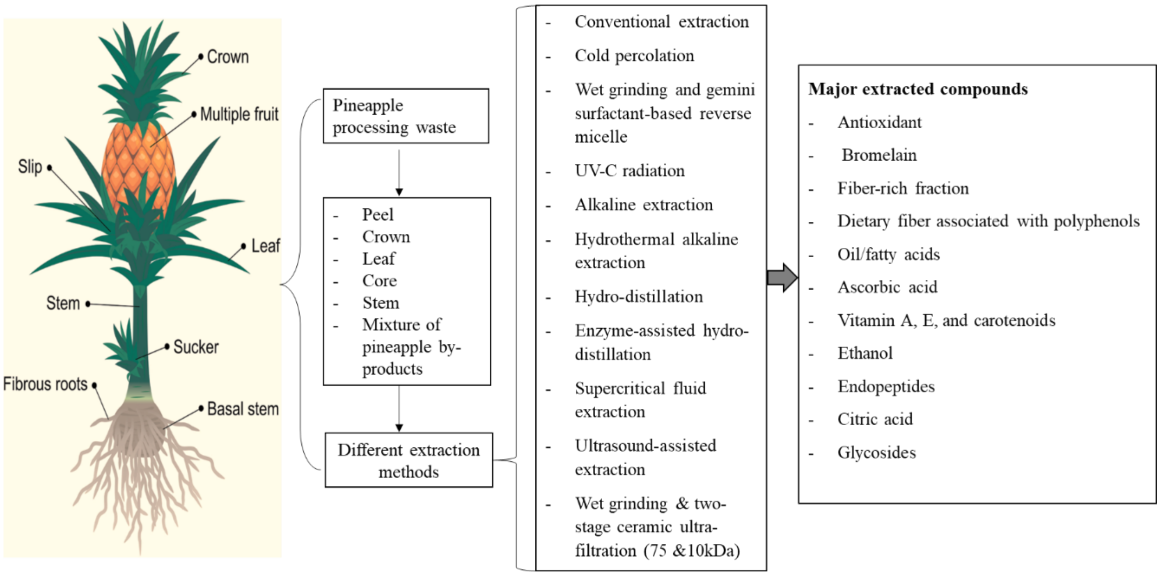

Fig. 1.2 Pineapple processing waste extraction methods

1.2 Economic importance of pineapple

Pineapples hold significant importance as a tropical fruit crop worldwide, ranking as the third most important after bananas and citrus. Over the years, pineapple production has seen substantial growth. According to the Food and Agriculture Organization (FAO) statistics, global pineapple production has increased from 0.3 million tons in 1961 to 3.3 million tonnes in 2022. Costa Rica, the second-largest pineapple producer globally, following the Philippines, plays a major role in the worldwide supply of raw pineapples. It accounts for nearly 70% of global shipments of raw pineapple. This highlights the country's dominance in the pineapple industry (Altendorf 2017). The production and consumption of pineapples have a significant impact on the economy (Campos et al., 2020). Consumers enjoy pineapples in various forms, including fresh fruit and processed products like juice, jams, syrup, and squash. Among the processed pineapple products, pineapple juice holds a prominent position, accounting for 50% of the total consumption of all processed pineapple products (Dorta et al., 2017). The canning industry plays a crucial role in utilizing the large-scale production of pineapples worldwide, while the consumption of fresh pineapples is relatively limited. Approximately 97% of the world's pineapple production is used by the pineapple processing industry (Chaudhary et al., 2019). However, the situation is different in India, where only around 10% of pineapples are processed. In contrast, other pineapple-cultivating countries prioritize processing, with about 95% of their pineapple production being utilized for processing (Banerjee et al., 2017).

This disparity in the processing of pineapples between countries highlights the variations in consumption patterns and market preferences. The processing industry allows for value addition, shelf-life extension, and the production of various pineapple-based products, catering to diverse consumer demands. Overall, pineapples have a significant economic impact, with production and consumption influencing local and global markets. The processing industry plays a major role in utilizing the bulk production of pineapples, while fresh fruit consumption and processing percentages vary between countries based on consumer preferences and market dynamics.

1.3 Impact of Pineapple Waste Utilization

Waste utilization can have both direct and indirect impacts on pineapple waste. Some potential effects are cost effect and diversification, environmental sustainability, resource efficiency, and circular economy. Waste utilization strategies, such as converting pineapple waste into by-products or energy sources, can help reduce production costs. By effectively utilizing waste, pineapple producers can lower their overall expenses, which may lead to more competitive pricing for their primary products. Waste utilization also can enable the creation of new products or by-products derived from pineapple waste, such as pineapple juice, jams, animal feed, or biofuels. This diversification can contribute to pineapple producers, potentially mitigating price fluctuations in primary products (Sarangi et al., 2023). In an era where consumers are increasingly concerned about sustainability and environmental impact, waste utilization can improve a company's sustainability credentials. By effectively managing waste and adopting eco-friendly practices, pineapple producers may attract environmentally conscious consumers who are willing to pay a premium for sustainably produced primary pineapple products (Sarangi et al., 2022). Waste utilization initiatives can also help pineapple producers differentiate themselves in the market. Utilizing waste in innovative ways and promoting sustainable practices can position a brand as socially responsible and environmentally friendly. This differentiation may allow producers to capture niche markets and potentially command higher prices for their primary pineapple products (Ghimire et al., 2015). Waste management regulations and standards may evolve, and producers who can effectively manage waste and comply with these requirements are more likely to maintain access to markets. By investing in waste utilization strategies, pineapple producers can ensure compliance and avoid potential penalties or restrictions that could impact their market value (Mayers and Butler, 2013). Pineapple waste, such as peels, crowns, and cores, can be converted into useful products, reducing the environmental impact of waste disposal. By utilizing these waste materials, the overall volume of waste sent to landfills is reduced, mitigating environmental pollution and methane emissions (Baidhe et al., 2021). Pineapple waste can be transformed into various valuable products, maximizing resource efficiency. For example, pineapple peels and cores can be used to extract enzymes, dietary fibre, and bioactive compounds, which can be utilized in various industries such as food, pharmaceuticals, and cosmetics. This reduces the need for additional raw materials, promoting sustainable resource management (Awasthi et al., 2022). Microbial biotechnology approaches for conversion of pineapple waste into an emerging source of healthy food for a sustainable environment. Waste utilization can also create economic opportunities by generating additional revenue streams and reducing production costs. For instance, pineapple waste can be processed into animal feed, contributing to the livestock industry, and reducing feed costs. Additionally, the extraction of valuable compounds from waste can lead to the development of new products and industries, generating employment and economic growth (Campos et al., 2020). Utilizing waste from primary pineapple products aligns with the principles of a circular economy. Instead of considering waste as a useless by-product, it becomes a valuable resource that can be reintroduced into the production cycle. This approach promotes a closed-loop system where waste is minimized, resources are optimized, and the overall environmental impact is reduced (Sarangi et al., 2023). It is important to note that the successful implementation of waste utilization strategies requires appropriate infrastructure, technological capabilities, and supportive policies. Collaboration between pineapple producers, researchers, government entities, and other stakeholders is crucial to harnessing the full potential of waste utilization and realizing its positive impacts (Khan et al., 2022).

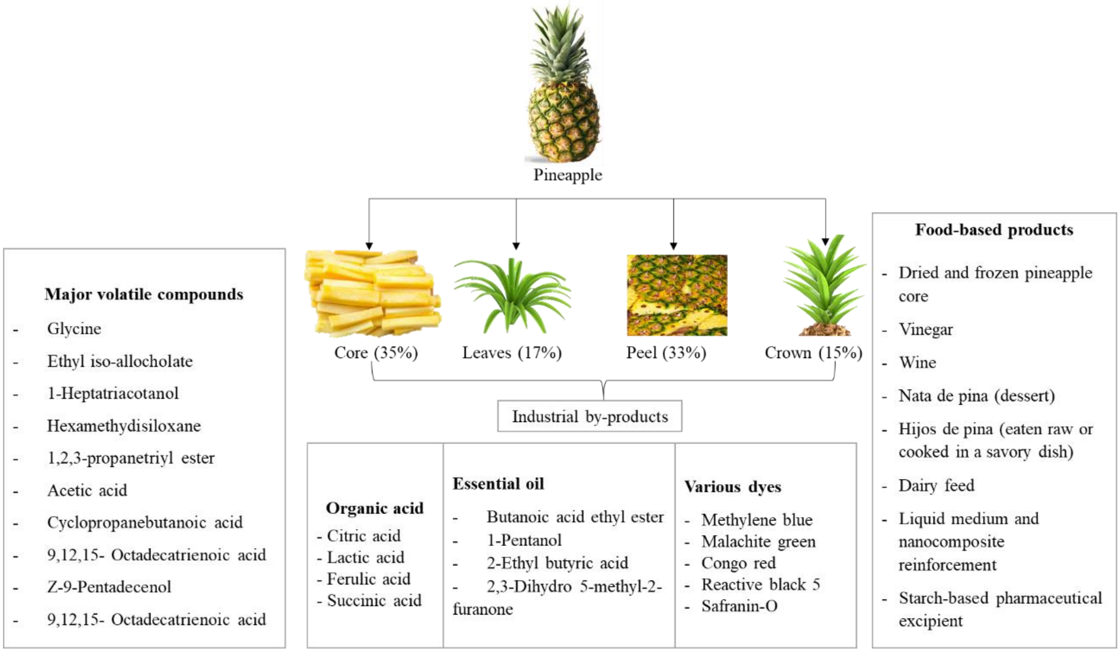

Fig. 1.3 Utilization of pineapple waste in the production of significant volatile compounds, as well as various food and industrial by-products

1.4. Physico-chemical composition and nutritional value of pineapple

Pineapple is a non-climacteric tropical fruit with excellent juiciness, pleasant aroma, flavor, and immense health-beneficial compounds. Despite the significant amount of phytochemicals, nutrients, and other desirable components present in pineapple. The production of pineapple has been on a rising trend in the lucrative food industry. Due to this scenario, pineapple nutrition and physicochemical composition investigations have advanced. The primary areas of interest for the food processing industry are the unusual properties of rich nutrients and the presence of functional composition. The primary nutrients in pineapple are water and carbohydrates along with some micronutrients, which are also important sources of dietary fiber, sugars, organic acids, vitamins (ascorbic acid, niacin, and thiamine), as well as minerals (magnesium, manganese, and copper) (Altendorf, 2017; Campos et al., 2020). The number of essential minerals such as manganese, a trace mineral for the development of bone as well as the production and activation of specific enzymes; and copper, another trace mineral that helps with iron absorption, controls high blood pressure, and improves heart rate are present in pineapple (Dorta and Sogi, 2017) A powerful antioxidant, ascorbic acid, or vitamin C, helps iron absorption and fights viral and bacterial infections. The recommended daily intake (RDI) of vitamin C is included in one cup of pineapple juice for an adult (Duque- Acevedo et al., 2022). The proteolytic enzyme bromelain, also found in pineapple fruit, is crucial for the digestion process of the bromelain and its therapeutic actions. Bromelain has several potential uses as an antioxidant, and anti-inflammatory activity, reducing swelling in inflammatory conditions such as acute sinusitis, sore throat, arthritis, gout, and cardio-protective agent (Chaudhary et al., 2019). Bromelain, found in pineapple, is also helpful for easing menstrual issues, by lowering excessive water retention in the body. However, taking antibiotics, barbiturates, benzodiazepines, or antidepressant medications should be cautious while consuming pineapple because it might interact negatively with several medications (Banerjee et al., 2017).

Pineapples generally produce a beneficial physicochemical composition, which mainly depends on the functional groups present in the structure and processing circumstances. The sensory attributes like aroma, flavor, and taste are directly related to the physicochemical characteristics of pineapple. The sensory characteristics, total soluble solids (TSS), titrable acidity (TA), pH and moisture content (MC), hardness, and translucency of the fruit pulp are major parameters to interfere with the physicochemical composition. Consumers judge a product based on its appearance, so color is also an important parameter in fruits (Ghimire et al., 2015).

The fibers of pineapple waste (crown, peel, pomace, leaf, and core) are cheap, renewable, biodegradable, and abundantly available (Nirmal et al., 2023). The chemical composition of pineapple fiber is diverse, with cellulose (79- 85%), lignin (5 to 12%), and ash content (1.3%) etc. Hemicellulose, cellulose, and pectin are the three main fibers found in pineapple. Due to the high cellulose concentration, pineapple fiber contains multicellular lignocellulose fiber and is hydrophilic, with excellent rigidity and tensile strength. A detailed outline of the chemical composition and nutrient value of pineapple and its different parts is presented in Table 1.1.

Table 1.1: Chemical composition of pineapple and its different parts

Chemical composition	Whole fruit	Fresh	Dry	Peel	Pomace	Pulp	Crown
Moisture (%)	72.49-74.12	71.07-73.31	27.43-28.18	92.21-93.50	37.65-39.08	-	21.25-23.82
Protein (%)	4.40-4.85	3.13-3.78	3.30-3.57	3.28-3.58	4.10-4.31	4.60-5.10	4.20-4.50
Ash (%)	0.70-0.91	3.88-3.97	4.10-4.58	10.60-11.07	0.60-1.98	0.20-0.89	0.40-0.78
Total solid (%)	27.51- 28.09	29.03-30.10	72.57-73.06	7.80-8.02	-	-	-
Volatile solid (%)	87.12-87.88	96.12-96.76	95.90-96.08	89.40-90.07	-	-	-
pH	4-4.01	4.70-4.78	4.70-4.81	-	-	4.00-4.09	-
Reducing sugar	6.50	25.80	27.80	-	-	-	-
Non-reducing sugar	5.20	5.70	4.90	-	-	-	-
Total sugar	11.7	31.50	32.70	-	-	-	-
Insoluble dietary fiber	22.40-22.80	16.20-17.02	18.50-18.92	87.32-88.19	66.21-66.31	-	91.20-91.87
Soluble dietary fiber	4.70	6.70	-	12.22-12.85	35.01-35.60		1.23-2.08

(Roda and Lambri; 2019; Ali et al., 2020)

1.5 Pineapple Waste Towards Circular Economy:

Pineapple waste harbours an array of functional groups including amines, hydroxyls, carboxyls, methoxyls, and phenolics. These groups play a pivotal role in facilitating diverse processes for the creation of bioenergy and biofuels, thus contributing to the establishment of a circular bio-economy. Moreover, the presence of hemicellulose, cellulose, and pectin compounds in pineapple waste bolsters the biorefinery concept. This approach not only takes into account environmental and social considerations but also strives for sustainable practices that yield a positive influence on both the local community and the ecosystem (Liu et al., 2023). There is a growing need for a sustainable and economically viable method to produce bio-economy. In this context, the synthesis of biohydrogen from pineapple wastes through anaerobic digestion and dark fermentation emerges as a promising solution (Duan et al., 2022). This innovative approach offers the potential to produce hydrogen in an eco-friendly manner while efficiently utilizing pineapple waste resources. Table 1.2 provides a list of some possible applications for pineapple waste as feedstocks for the production of biorefinery as a renewable energy source. Using pineapple waste as a feedstock for bioenergy production has many positive effects on the perspectives of waste management, pollution control, and circular bio-economy (Aili et al, 2021).

Table 1.2: Applications of pineapple waste in the production of biorefinery

Type of biorefinery	Waste type	Parameters	Yield
Bioethanol	Pineapple peel	Immobilized S. cerevisiae, pH 6, 32 ◦C, 7 days, 100 mL flask-scale	Ethanol yield of 6.4%
	Pineapple peel	S. cerevisiae, inoculum size of 2%, pH 5.6, 36 ◦ C, 72 h, 175 mL flask-scale	Ethanol concentration of 197.6 g/L
	Pineapple waste	Immobilized S. cerevisiae, 30 ◦C, 4 weeks, 50 mL flask-scale	Ethanol yield of 5.4%
	Pineapple peel and core	S. cerevisiae, pH 5, 28 ◦C, 72 h	0.43 g ethanol/g reducing sugar, ethanol yield of 5.4%

	Pineapple peel	S. cerevisiae, inoculum size of 3%, 13.5 g/L glucose equivalent concentration, pH 5, 30 ◦C, 48 h, 10 mL vial	Ethanol concentration of 4.9 g/L, fermentation efficiency 71.1%
	Pineapple peel	Metchnikowia sp. Y31, 30 ◦C, 7 days, flask-scale	0.43 g ethanol/g reducing sugar
Biogas	Pineapple waste	TS at 5 w/v%, 250 mL batch reactor, 86 days, 37 ◦C	Methane yield of 43.6 L/kg VS
Biohydrogen	Pineapple waste	150 mL reactor, wastewater sludge as inoculum, 35 ◦ C, pH 6	H2 yield of 3.9 mmol/g COD
	Pineapple peel	8.5 L upflow anaerobic contact filter, cow manure as inoculum, HRT greater than 5 d,	Biogas yield of 0.73 m /kg VS with H2 content of 63%
	Pineapple waste	Clostridium strain BOH3, media supplemented with 52.6 g TS/L fruit waste, 60 h, 37 ◦C, 300 rpm	H2 production of 10.7 L/L, yield of 360 mL/g TS consumed

(Casabar et al., 2020; Al-Maqtari et al., 2019; Seguí Gil and Fito Maupoey, 2018; Hemalatha and Brinda Lakshmi, 2021; Leong and Chang, 2022)

1.6 Pineapple waste-processing and potential value-added products:

Pineapple waste is a significant by-product of the pineapple industry and poses environmental challenges if not properly managed. However, with the application of industrial technologies, this waste can be effectively utilized, leading to various benefits such as resource recovery, environmental sustainability, and economic value (Nath et al., 2023). The fruit processing industry recognizes the significant nutritional value and diverse chemical compounds present in pineapples, making them an attractive ingredient for various culinary products. Moreover, the production and consumption of pineapples result in the generation of substantial amounts of solid waste, creating opportunities for the development of functional food products through waste processing (Polania et al., 2023). Researchers have explored the potential utilization of pineapple waste to produce valuable food-based products. Some of the notable products associated with pineapple waste are discussed in this section and summarized in Table 1.3.

Table 1.3: Pineapple waste extraction and utilization

Pineapple waste	Extraction method	Compounds	Utilization
Peel (Raw, oven dried, and freeze dried)	Conventional extraction, cold percolation Wet grinding, UV-C radiation, grinding and precipitation	Antioxidant compounds,	Phenolic compounds, ferulic acid, Vitamin A, Vitamin C, Vitamin E, carotenoids
	Grinding and precipitation, Wet grinding and gemini surfactant-based reverse micelle, Wet grinding and RME, Grinding and ATPS, Wet grinding (2 cultivars)	Bromelain	Extraction of bromelain enzyme
	Alkaline extraction, Hydrothermal alkaline extraction	Fiber-rich fraction	Extraction of insoluble and soluble fiber-rich fraction
	Conventional extraction, cold percolation Wet grinding, UV-C radiation, grinding and precipitation	Source of dietary fibrer associated with polyphenols	Fluor cereal bars carbon source during fermentation using bacteria with probiotic potential;
	Conventional extraction, cold percolation Wet grinding, UV-C radiation, grinding and precipitation, Alkaline extraction, Hydrothermal alkaline extraction	Source of bioactive compounds (fibre, antioxidants and prebiotic)	Development of lactic acid bacteria in cooked sausages; Probiotic yogurt fortified with fibre-rich pineapple peel powder; Phenolic antioxidant
	Hydro-dostillation, Enzyme-assisted hydro-distillation, Supercritical fluid extraction	Oil/fatty acids	Extraction of essential oil, Hydrosol

Core	Conventional extraction and UV-C radiation	Ascorbic acid, Vitamin A, E and carotenoids	Extraction of Proteolytic enzymes
		Ethanol	Vinegar production
	Wet grinding and RME; Wet grinding (2 cultivars)	Bromelain	Extraction of bromelain enzymes
Steam	Conventional extraction and UV-C radiation	Ascorbic acid	Extraction of Proteolytic enzymes
	Wet grinding and RME; Wet grinding (2 cultivars)	Bromelain	Extraction of bromelain enzymes
Crown	Extraction and RME, Wet grinding (2 cultivars)	Bromelain	Extraction of bromelain enzymes, Meat tenderization
Leaf		Endopeptides	Proteolytic enzymes
	Extraction and RME, Wet grinding (2 cultivars)	Bromelain	Extraction of bromelain enzymes
		Citric acid	Ethanol production
	Conventional extraction, cold percolation Wet grinding, UV-C radiation, grinding and precipitation, Alkaline extraction, Hydrothermal alkaline extraction	Bioactive compounds and glycosides	Phenolic antioxidant
Mixture of pineapple by-products	Conventional extraction (Soxhlet), Maceration, Conventional extraction, Ultrasound-assisted extraction; Hydrothermal extraction	Phenolic compounds	Phenolic antioxidant
	Wet grinding & precipitation; Wet grinding & two-stage ceramic ultra-filteration (75 &10kDa)	Bromelain	Extraction of bromelain enzymes, meat tenderization

(Khanvilkar and Nagarjee, 2021; Rico et al., 2020; Chaudhary et al., 2021; Nakthong et al., 2017)

One prominent industrial application is the extraction of valuable compounds from pineapple waste. Pineapple peels, cores, and other discarded parts contain bioactive compounds such as bromelain, phenolic compounds, and dietary fibres. Industrial technologies like extraction and purification processes can be employed to isolate these compounds, which have various applications in the food, pharmaceutical, and cosmetic industries. For instance, bromelain is a proteolytic enzyme with anti-inflammatory properties, making it useful in wound healing and skin care products (Rico et al., 2020). Additionally, pineapple waste can be utilized for bioenergy production. The waste material contains organic matter that can be converted into biogas or biofuels through anaerobic digestion or fermentation processes. Biogas, primarily composed of methane, can be used for heat and electricity generation, reducing the reliance on fossil fuels (Sarangi et al., 2022). Moreover, the digestion produced during the anaerobic digestion process can serve as a nutrient-rich fertilizer, promoting sustainable agriculture practices. Industrial technologies also enable the production of value-added products from pineapple waste. The cellulose and hemicellulose present in the pineapple waste can be converted into bio-based materials such as bioplastics or biofilms. These materials have potential applications in packaging, reducing the reliance on petroleum-based plastics and minimizing environmental impact (George et al., 2021). Furthermore, pineapple waste can be utilized as a substrate to produce enzymes, organic acids, and other biochemicals through fermentation processes, offering opportunities for the bio-based chemical industry (Cetecioglu et al., 2022).

Industrial technologies play a vital role in the utilization of pineapple waste, offering multiple applications and benefits. From extracting valuable compounds for the food and pharmaceutical industries to producing bioenergy, and value-added products, these technologies enable a sustainable and resource-efficient approach to managing pineapple waste. The utilization of pineapple waste to produce these valuable compounds has attracted the attention of researchers. It offers a sustainable approach to reduce waste and maximize the economic potential of pineapples. By converting waste into functional food ingredients, the food processing industry can create value-added products and contribute to waste reduction and sustainability.

1.7 Pineapple waste-based products

1.7.1 pineapple waste based food products

Pineapple peel and pulp are often utilized in a variety of foods, after the removal of flesh and core of thr pineapple. The flesh is rich in chemical components necessary for the human diet, including fiber, vitamins, and minerals (Mayers and Butler, 2013). Due to its sweet flavor and distinctive aroma, pineapple is primarily consumed as a fresh, canned, lightly processed fruit and a flavoring. In the Philippines, a classic dish called Nata de pina, a favorite treat is typically made using fermented pineapple juice. The high concentration of moisture, carbohydrates, and fibre is crucial for developing bacteria and acts as a nutritional medium for fermentation. The chewy texture and transparent gel, which practically turns it into a jelly-like meal, have earned the name pineapple gelatine in the dessert part. Nata de pina is used in fruit salads, ice cream, sweets, and other desserts because of its sour and sweet flavor. Hijos de pina, or young pineapple shoots, are vented as a vegetable to be consumed either fresh or prepared in a savoury recipe. In addition, a variety of processed pineapple products, such as canned pineapple, dried pineapple cubes, frozen pineapple, nectar, and pineapple juice, are offered on the commercial market (Baidhe et al., 2021). Consumers want pineapple that is fresh and of higher quality, so the fruit must be handled carefully during processing and storage to prevent any damage during processing (Chaudhary et al., 2019).

For sweet meals, pineapple is frequently used in various ways, including as a component in cakes, fudge, puddings, pies, and garnish. Although pineapple is primarily associated with desserts, it also works well in savory meals like curries and other meat dishes (Altendorf, 2017; Campos et al., 2020). When it comes to processed goods, the fruit's potential is translated into various items such as jams, syrups, toffees, powder, beverages, and preservers. The fruit's therapeutic, nutritional, and medicinal properties are assessed to be a key element in the food product to meet the demand for processed foods made from pineapple.

An enhancement in postharvest management could increase the efficient operation of the entire variety of processed foods due to the sturdy aroma that should not be lost while processing (Duque-Acevedo et al., 2022). Once pasteurized and stored, pineapple juice is known as processed goods. To optimize the processing parameters and conditions, a chemical reaction occurs during the juice processing that destroys the microorganisms (Khan et al., 2022). A substitute beverage made from pineapples and processed with sweeteners, organic acid, and water in a specified proportion for mixing (Ali et al., 2020). It is also possible to offer low-calorie pineapple beverages, improving the fruit's organoleptic properties.

In addition, pineapple jam is a different item made from fruit pulp and pomace, along with pectin, sweeteners, and organic acid (Ali et al., 2020). Pineapple jam is produced by drying, mixing, and chilling the fruit to a particular time-temperature combination. After that, the mixture is boiled pasteurized, and delivered for packing. Pineapple can be made into candies and toffees in bars or in conjunction with chocolates and nuts since it has a flavourful aroma. For customers adhering to a specific diet, pineapple bars are made with nutritious components to deliver minerals and energy as a replacement for sweetened items. Pineapple is frequently processed into powder as a flavoring agent and instant powder (Khanvilkar and Nagarjee, 2021). According to a study by (Ali et al., 2020), pineapple powder has favorable physical characteristics. It is appropriate for use as a binding agent and fragment for pharmaceutical excipients based on starch. Because pineapple powder has a long shelf life and may be used for many purposes in the food industry, it is a better binder material.

Additionally, pineapple converted into vinegar may be used for overripe, abandoned wastes, and surplus fruits. The alcohol, acetic acid, and other ingredients go through various fermentation processes, producing pineapple vinegar (Duque-Acevedo et al., 2022). Continuous aeration is used for several days to allow the acetic acid bacteria in the pineapple vinegar combination to convert ethanol. The study about wine production has investigated the several volatile chemicals in pineapple. Alcoholic pineapple wine is a product of naturally occurring yeast, sugar, and microbes in different ratios (Zdrojewicz et al., 2018). From the fermented juice of pineapple, wine is made by adding sugar and organic preservatives such as sulfur dioxide, sorbic acid, and potassium sorbate.

The use of pineapple waste peel flour enables the creation of a new product, giving cereal bars good technological properties like a lower pH level by increasing acidity and enhancing microbiological stability. The texture profile of cereal bars was consistent with the sensory assessment, and the sensory attributes of the bars only degraded at a 6% level of addition with pineapple waste peel flour. The starch from pineapple waste, mainly the stem, can be acquired by milling as an additional potential ingredient. By avoiding chemical and technological approaches, (Chakraborty et al., 2021) produced high-purity starch with distinct properties compared to rice, corn, and cassava. The pineapple stem starch (34.4%) contains a significant amount of amylose, which is more than twice as high as corn starch, more than double that of cassava starch (15.4%), and five times higher than rice starch (6.5%), was responsible for some technological properties such as high gelatinization temperature and enthalpy, as well as pasting temperature. The highest solubility percentage above 32% is therefore found in pineapple starch. Pineapple starch has the lowest viscosity under normal cooking circumstances. All these characteristics and distinctiveness support the fact that pineapple starch has a variety of uses in food, including potential use as a thermoplastic and resistant starch (Chakraborty et al., 2021).

Table 1.4: Food-based products using pineapple waste

Pineapple waste	Potential use	Reference
Pulp	Dried and frozen pineapple	Chaudhary et al., 2021
	Cakes, puddings, pies, compotes, and garnish (sweet dishes)	Ali et al., 2023 Ali et al., 2020
	Curry and meat dishes	
	Preservers, nectar, toffees, jam	
	Juice, beverage, syrup	Chaudhary et al., 2019
	Vinegar	Chaudhary et al., 2021
	Wine	Cannon and Ho, 2018
	Powder	Priyadarshani et al., 2019;
	Canned pineapple (slices, cubes)	Rahma et al., 2019
	Nata de pina (dessert)	
Young shoot	Fruit salad	Rahma et al., 2019
	Hijos de pina (eaten raw or cooked in a savoury dish)	
Peel	Methane gas for waste treatment	Rahma et al., 2019
	Dairy feed	Chaudhary et al., 2019
Crown	Dairy feed	Chaudhary et al., 2021
	Liquid medium and nanocomposite reinforcement	Prado and Spinac´e, 2019
Core	Dairy feed	Chaudhary et al., 2019
Stem	Starch-based pharmaceutical excipient	

1.7.2 Volatile compounds

The volatile pineapple component, which is highly significant in the sensory of fruit flavours, has received much attention. Pineapple variety and characteristic flavor reflected thorough information for ongoing fruit aroma research and desirable qualities for customers (Altendorf 2017; Campos et al., 2020). In particular, during storage, the shelf life of volatile components is useful for observing the quality of raw and processed products. Not all volatile substances are considered the primary sources of essence or aroma. Pineapple contains hundreds of volatile compounds; however, only a few aroma-active molecules were significantly related to the other volatile compounds based on the overall aroma. The efficacy of those aroma-active chemicals is influenced by the volatility, concentration, and aroma threshold (Siti Rashima et al., 2019). By using different methods such as gas chromatography, sniffing chromatography, aroma extract dilution analysis, active odor value calculation, odour specific magnitude estimate, and volatile compound recombination tests, it is possible to assess the importance of distinct volatile compounds (Cannon and Ho, 2018).

In general, volatile compound estimation requires laboratory equipment that is less penetrating than the human olfactory system. The volatile compound estimation is a complex method due to the sniffing out of aroma-active compounds using olfactometry, so trained panelists were frequently employed. However, given the changes that occur during the extraction of volatile components, the identification of flavor active compounds should be more than just the level of volatility (Liu et al., 2023). There has been a substantial advancement in volatile component analysis to control the difficulty in identifying flavors and volatile compounds. The majority of volatile components are the main reason for fruit flavor, based on the composition and quality of that fruit, which is quite complex. Modern volatile component extraction, separation, and identification methods provide complete details on the volatile distribution and constitution of the fruits. For various analytical purposes, the affinity of the volatile components in pineapple waste is carried out using a variety of techniques, including solid-phase microextraction, conventional extraction, headspace solid-state extraction, solvent-assisted flavor evaporation, electronic nose, gas chromatography, sensory evaluation, mass spectrometry etc. (Campos et al., 2020).

According to a prior study conducted by (Ghimire et al., 2015), the presence of ester in pineapple is high. The esters in pineapple are methyl-2-methyl butanoate, methyl hexanoate, methyl 3-(methylthiol)-propanoate, methyl octanoate, and 2-methoxy-4-vinyl phenol, which are connected to the flavor and aroma quality of pineapple. Table 1.4 below lists the major volatile substances found in varied pineapple waste.

Some of the common volatile compounds (Glycine, Acetic acid, Dimethylsilanediol, Stigmasterol, Ethyl iso-allocholate, 1-Heptatriacotanol, Oleic acid, 9,12,15- Octadecatrienoic acid) found in pineapple peel. A significant amount of ester concentrations over the active odour value were found in the volatile aromatic profiles of the wine sample made from pineapple waste, which was processed at a lower temperature (Choi et al., 2015). In the third stage, the organic acid fermentation process involves Acetobacteraceti converting ethanol to acetic acid. Acetic acid was produced through fermentation on a pilot size fermenter at 34°C for 30 days with hardly any presence of ethanol or acetaldehyde. Except for some ethyl esters and alcohols, volatile fatty acids, and some related ethyl esters and vinegar, the majority of the aromatic compounds suggestively decreased during this fermentation, according to the detailed characterization of the composition of pineapple waste wine and pineapple vinegar through GC-MS and UHPLC. In addition, some substances remained the same in pineapple waste wine and vinegar, while amino acids and phenolic acids were raised during the fermentation (Al-Maqtari et al., 2019). All the major volatile compounds from pineapple waste and their extraction method have been shown in Table 1.5.

Table 1.5: Major volatile compounds from pineapple waste

Pineapple waste	Compound name	Extraction method	Yield	Reference
Pineapple peel	Hydrosol - Glycine - Acetic acid - Dimethylsilanediol - Stigmasterol - Ethyl iso-allocholate - 1-Heptatriacotanol - Oleic acid - 9,12,15- Octadecatrienoic acid	Hydro-distillation	70.65-71.15	Ali et al., 2020 Zhang et al., 2020 Tan et al., 2020 Lasekan& Hussein, 2018

Pineapple peel	Hydrosol - Hexamethydisiloxane - 1,2,3-propanetriyl ester - Acetic acid - Cyclopropanebutanoic acid - 9,12,15- Octadecatrienoic acid - Z-9-Pentadecenol - Oleic acid - Ethyl iso-allocholate - 1-Heptatriacotanol	Hydro-distillation with enzyme assisted extraction	80.65-82.32	Mahmud et al., 2020 Lasekan& Hussein, 2018 Roda et al., 2017a Roda et al., 2017b
Pineapple peel	Essential oil - Butanoic acid ethyl ester - 1-Pentanol - 2-Ethyl butyric acid - 2,3-Dihydro 5-methyl-2-furanone	Supercritical fluid extraction	0.17-0.53	Ali et al., 2020 Mahmud et al., 2020
	Concrete		0.64-0.78	Roda et al., 2017a Roda et al., 2017b

1.7.3 Dietary fiber (soluble & insoluble)

The food industry places a high value on dietary fiber with favorable nutritional and physicochemical properties, replacing the fibre-rich portion of agricultural waste as a substitute for supplements in functional foods. This waste fibre matrix performs various functional properties, such as swelling capacity, water-holding activity, gel-forming capacity, and cation exchange capacities. In this approach, (casaba et al., 2020) supported the claim that pineapple waste contains fibre-rich fractions (insoluble and soluble) with larger potential and uses in the creation of low-calorie and dietary fiber-rich foods. Pineapple waste contains antioxidants such as vitamin C and beta-carotene, which can be extracted and used as a natural antioxidant source in food products. This would provide a natural way to preserve food products and promote their shelf life. Finally, the fiber-rich fractions in pineapple waste could be used as a functional ingredient in food products such as sauces, dressings, and meat products to improve texture, water retention, and other properties

Due to inter-molecular and intra-molecular hydrogen bonding, microfiber and nanofibre from pineapple leaves exhibit notable mechanical properties as a function of cellulose. One potential application for these fibers is in the development of biocomposite materials. The fibers could be incorporated into a matrix material, such as a natural or synthetic polymer, to enhance its mechanical properties.

The potential uses of pineapple leaf fibers in the food industry are limited, their mechanical properties and natural characteristics make them an attractive option for certain applications such as edible films and coatings, natural food coloring, and prebiotic fibers. The natural fibre from pineapple and its waste has various characteristics, including texture, length, water-holding capacity, dye-holding capacity, brightness, whiteness, resistance to salt, and tension strength. These dietary fiber components extracted from pineapple waste have been shown to have a variety of uses as prebiotics, food additives, and bio-preservatives. Auto hydrolysis, improving technology for the waste valorization process of pineapple, effectively extracts the accessible glycosides (Seguí and Maupoey, 2018). As a source of protein, minerals, and dietary fiber in addition to fiber, pineapple peel powder has been shown in several studies to accelerate the growth of Lactobacilli (Masebinu et al., 2018).

The study (Leong and Chang, 2022) showed that adding pineapple segments with immobilized Lactococcuslactis to yogurt increased the probiotic vitality during storage for almost a month. This way, peel powder could affect and change the physicochemical, textural, rheological, and microstructural characteristics of yogurt and its established functional activity for probiotic organisms and consumers. (Ventura et al., 2021) findings showed that pineapple peels bioactive fibre and antioxidant components might promote the growth of thermotolerant beneficial microorganisms. In order to encourage the creation of an alternative and valuable cooked meat product, flour from pineapple peel was added to cooked pork sausage that had been injected with thermotolerant bacteria (lactic acid bacteria).

Due to the addition of fibre, the final beef sausage displayed greater water retention; however, oxidative rancidity significantly decreased. Additionally, adding certain kinds of flour to the infected sausages enhanced the growth of thermotolerant bacteria, leading to changes in textural characteristics after storage (Duan et al., 2022). In addition, pineapple peel flour may be an excellent substitute for other raw materials used to make cereal bars since it contains significant amounts of crude fibre, which enhances the nutritional value of the finished product.

Various types of fruit peel flour have been found to possess functional properties that are crucial for food preparation, such as water and oil holding capacity, swelling capacity, pH, and rheological behavior (D'Silva et al., 2023). The use of fruit peel flour in food products serves two primary objectives: improving texture and providing health benefits, such as reducing the glycemic index and preventing obesity. Several studies have examined the antioxidant potential, phenolic content, and other phytochemical profiles of agro-waste flour (Hemalatha et al., 2021). Mango peel flour (MPF) can serve as a viable substitute for ordinary flour. When MPF is used to replace wheat flour in biscuits at levels ranging from 5-20%, dough stability, and expandability decrease due to the increased rate of water-holding capacity caused by MPF's high dietary fiber content (D'Silva et al., 2023). Other studies have reported similar outcomes when adding mango peel flour (Saha et al., 2018). For instance, a sponge cake containing 30% MPF had a lower anticipated glycemic index since starch was digested slowly, and the density of the cake increased due to the high fiber content of MPF.

1.7.4 Bioactive compounds

Due to the biological attributes and future uses, bioactive polyphenolic chemicals are significant factors in the pharmaceutical and dietary supplement industries. Pineapple waste is comprised of some of these antioxidants, including myricetin, salicylic, tannic, trans-cinnamic, and p-coumaric acid (Altendorf 2017). Seguí et al., 2018, noticed a considerable extraction of primary bioactive compounds, such as phenolic acid, following the treatment at the time-temperature combination of 30 min at 200°C with 1/10 (w/v). Additionally, pineapple waste has antibacterial action due to ferulic acid and syringic acids, which outperformed commercial antioxidant extracts in terms of effectiveness (Seguí et al., 2018). According to other researchers (Chaudhary et al., 2021), impoverished communities may benefit most from these nutraceutical extracts since they will be able to include affordable nutritional dietary supplements in their daily intake.

1.7.5 Organic acid

The free sugars present in fruits are normally transformed into various organic acids by a fermentation process. The substantial amount of sugar present in pineapple waste makes it an ideal substrate for the synthesis of organic acids, which are in high demand in the food and healthcare industries (Soltan et al., 2019). In the search for low-cost substrates, research on the synthesis of organic acids from fruit waste gained interest. Particularly, numerous organic acids such as citric, lactic, and ferulic acid, have been produced using fermentation technology from pineapple wastes (Table 1.6). The pineapple waste generated by industrial processes primarily comprises sucrose, glucose, fructose, and other nutrients (Siow and Lee 2017). Untreated discharge of these wastes into the environment could result in major environmental issues. In many circumstances, the waste can be recycled to get raw materials or transformed into valuable products with higher value-added, such as organic acid (Saha et al., 2018). This is in addition to their potential for pollution and hazards. The pharmaceutical, chemical, cosmetic, and food industries have long used organic acid (Asaithambi et al., 2021). Lactic acid has recently been regarded as a crucial raw element for the manufacture of biodegradable lactide polymer (Rahma et al., 2019)

1.7.5.1 Citric acid

This economically viable substance is frequently used as a substrate to acidify and enhance flavor in the food, pharmaceutical, and beverage sectors. Citric acid is produced by A. niger using pineapple juice extractor waste as a substrate under solid-state fermentation conditions has been studied by (Duguma 2020). Additionally, it was discovered that methanol had an impact on solid-state fermentation, increasing the yield of citric acid from 37.8% to 54.2%. The pineapple contains the substrate for Yarrowialipolytica's solid-state fermentation experiments to produce citric acid (George et al., 2021). They improved the growing conditions, and 202.35 g/kg of dried pineapple waste of citric acid was produced. In many other experiments produced citric acid using pineapple waste as a substrate (Cetecioglu et al., 2022). It was discovered that Aspergillus foetidus ACM 3996 produced more citric acid during solid-state fermentation than other waste sources such as apple pomace, rice, or wheat brans. Another study compared the generation of citric acid during solid-state fermentation using four different Aspergillus species. While pineapple waste can be a potential source of citric acid, it is not the primary source of citric acid production. The majority of citric acid production worldwide is obtained through microbial fermentation using Aspergillus niger, a filamentous fungus that produces citric acid in large quantities (Hikal et al., 2021).

Table 1.6: Organic acid from pineapple waste

Organic acid	Organism	Yield g/100g substrate	Reference
Citric acid	Aspergillusniger	11.3 g/100g	Aili Hamzah et al.,
	A. niger	7.9 g/100g	2021
	Aspergillusniger	15.51 g/ L	Ayeni et al., 2019
	A. niger	60.61 g/kg	Abdullah et al., 2020
	Yarrowialipolytica	20.24 g/100g	
	A. niger ACM 4993	16.4 g/100g	
	A. niger ACM 4992	19.4 g/100g	
	A. foetidus	16 g/100g	
	A. foetidus ACM 3996A	16.1 g/100g	
Lactic acid	Lactococcuslactis	92 g/ L	AiliHamzah et al.,
	Lactobacillus delbrueckii	0.78-0.82 g/g	2021
	Lactobacillus delbrueckii	glucose	Ayeni et al., 2019
	Rhizopusarrhizus	54.97 g/L	Abdullah et al., 2020
	R. oryzae	19.3 g/ L	
	R. oryzae	14.7 g/ L	
	R. oryzae	103.69 mg/ g	
		0.0236 g/ g	
Ferulic acid	Alkali extraction;	0.018 – 0.02 %	Tang et al., 2020
(esterified)	Chromatographic		
Succinic acid	E.Coli	6.26 – 7.21 g /L	Rabiu et al., 2018

However, compared to other agro-products that are potential sources of citric acid production, pineapple waste contains relatively lower concentrations of citric acid. For example, sugarcane molasses and citrus fruits such as oranges and lemons contain higher concentrations of citric acid. Despite this, the production of citric acid from pineapple waste and other agro products is dependent on several factors such as the availability of raw materials, the cost of production, and the market demand for citric acid (Ismail et al., 2018). Therefore, the choice of raw material for citric acid production depends on several factors such as availability, cost, and the specific needs of the production process.

1.7.5.2 Lactic acid

Due to its use in food and non-food industries, lactic acid holds a significant position in the family of carboxylic acids. In the food industry, it serves as an acidulant and preservative. However, because of the raw ingredients utilized, commercial manufacturing of lactic acid is expensive (exploitation of biological waste). As a food processing byproduct, pineapple syrup has been employed by some researchers as a cheap substrate for the manufacture of lactic acid by Lactobacillus lactis, which hydrolyzes sucrose in the form of glucose and fructose. The yield from 20 and 100 g of total sugars/L was reported to be 20 and 92 g/L. (Rahma et al., 2019), employed liquid waste of pineapple as the substrate for a 72-hour anaerobic fermentation to produce lactic acid using L.bacillusdelbrueckii. Under various temperature and pH conditions, they produced the highest output of 0.78 to 0.83 g lactic acid/g glucose using calcium alginate as the immobilization matrix. With Rhizopusarrhizus and R. oryzae, lactic acid synthesis by fungi from pineapple waste produced 19.3 and 14.7g/L of the acid, respectively (Cheok et al., 2018).

1.7.5.3 Ferulic acid

Ferulic acid is a prevalent hydroxycinnamic acid found in plant cell walls, including pineapple peel. It is a phenolic antioxidant that finds application in the food and cosmetic industries. Extraction of ferulic acid from pineapple peel has been achieved using an alkali process, and the results are comparable to those obtained from other crops. For instance, rice bran and wheat bran are also sources of ferulic acid that have been extracted using an alkali process (Hikal et al., 2021). In the food industry, ferulic acid is used as a food preservative and flavor enhancer due to its antioxidant properties. It can also be added to food products such as bread, cereal, and snacks to increase their nutritional value. Ferulic acid is also used in the development of biodegradable materials such as films, coatings, and packaging. Its antioxidant properties can help to prolong the shelf life of food products, while its biodegradability makes it a sustainable alternative to synthetic antioxidants. In the pharmaceutical industry, ferulic acid is being studied for its potential as a therapeutic agent. It has been found to have anti-inflammatory, anti-cancer, and neuroprotective properties, making it a promising candidate for the development of drugs to treat various diseases (Ismail et al., 2018). Overall, ferulic acid is a versatile compound with numerous applications in various industries such as food, cosmetics, and pharmaceuticals. Its extraction from pineapple peel and other crops using an alkali process provides a sustainable source of this valuable compound.

1.7.6 Enzyme

Bromelain, a well-known proteolytic enzyme found in practically all portions of pineapple is a source of other enzymatic compounds (Masebinu et al., 2018). It is used for various things, including manufacturing protein hydrolysates, brewing, baking, and tenderizing meat. Even in traditional medicine, bromelain enzyme was used to treat wounds, reduce inflammation, stop diarrhea, and aid digestion (Banerjee et al., 2017). Ismail et al., 2018 reported an improvement in the production of both bromelain enzyme and ethanol from pineapple waste in their recent study using a novel and integrated technique. In this method, they extracted a concentrated solution of bromelain enzymes from pineapple waste by using a liquid phase extraction through centrifugation, membrane separation, microfiltration, and ultrafiltration. The inclusion of water or solvent was avoided during the extraction process (Priyadarshani et al., 2019). After lyophilization, the enzyme sample exhibited similar proteolytic activity to several commercial preparations. The results suggested that sugar breakdown and the production of inhibitory chemicals like furfural and hydroxymethylfurfural may be avoided. To boost the saccharification of the lignocellulosic matrix, the microwave was used to treat the solid pineapple waste after it had been removed from the liquid.

1.7.7 Phenolic compounds

Over the past few years, there has been significant growth in the pursuit of new natural antioxidants. Agro-industrial waste is being used in this instance for a thorough investigation of this waste. One of the factors may be the low expense of these wastes, which would else be disposed of as environmental by-product. The primary bioactive compounds are believed to be phytochemicals, particularly phenolic, found in fruits and vegetables having health-beneficial effects. These substances are by-products of the plant's metabolic pathways (Nakthong et al., 2017). The chemistry of phenolic compounds has been described by their antioxidant activity, presence in different foods, bioavailability, and metabolism.

Phenolic compounds were determined to be 40.4 mg/100g as gallic acid equivalent with the highest ethyl acetate bound phenolic (Priyandarshani et al., 2019), around 2.58 as chlorogenic acid equivalent (Nakthong et al., 2017), and 358 mg/L as gallic acid equivalent in pineapple juice (Zhang et al., 2020). In contrast to (Lasekan and Hussein, 2018) study which explains the extraction of fruit in 80% acetone, immediately following base digestion and extraction with ethyl acetate, (Zhang et al., 2020) centrifuged the whole extract before calculating the total phenolic content. Aqueous methanol/ethanol or acetone extraction of crude polyphenols is highly popular and regularly carried out (Ismail et al., 2018). The amount of phenolic compound removed is also influenced by the solvent concentrations employed. The most effective solvents for phenolic compound extraction are a mixture of 50% acetone and 70% ethanol (Tan et al., 2022). In some circumstances, hexane extraction, followed by ethyl acetate extraction, is used to concentrate highly polar compound.

The yield of methanolic extraction of pineapple waste including peel, seeds, pulp, and total phenolic contents in the same was found 30.2% and 10 mg/g GAE, respectively (Siow and Lee 2017). Syringic and ferulic phenolic acids, as well as others, may be amenable to the antioxidant properties of the H2O extract, according to prior research with waste products from the bromelain manufacturing process (Lasekan and Hussein 2018). Additionally, the cytochrome P4502C9 isozyme may convert phenolic antioxidants from pineapple waste to more powerful molecules in vitro (Mahmud et al., 2020).

Table 1.7: Phenolic antioxidants from pineapple fruits and wastes

Source	Amount	Reference
Fruit	40.4 mg/ 100g GAE	Mazzucotelli et al., 2018
	2.58mg/ 100g CAE	Gupta et al., 2017
Juice	358mg/ L GAE	Hayat et al., 2019
Residue	1.3mg/g GAE	Zampar, et al., 2022
Shell	22.7 mg/ g dry matter	Brito et al., 2021;
Peel	2.01mmol FRAP/ 100g wet weight	Lubaina et al., 2020
	111.1 mg/g dry matter GAE	Tallei et al., 2023
Pomace	269.8 mg/ 100g GAE	Kumar, 2021

Utilizing certain bioprocesses, phenolic compounds from pineapple waste have been improved (De Conno et al., 2022). When the fungus Rhizopusoligosporus was incubated for 12 days in a 1:1 mixture of pineapple and soybean flour, the amount of total phenolics increased by two times. The results of a different bioprocess using R. oligosporus and mixtures of pineapple waste and soy flour (9:1 and 5:5) showed that the extracts obtained after two days with the 9:1 treatment displayed strong alpha-amylase inhibition, while the extract obtained after ten days with the 5:5 treatment displayed Helicobacter pylori inhibition (Awasthi et al., 2022).

According to other studies, pineapple leaves were extracted by ethanolic extracts that contain significant amounts of phytochemicals such as p-coumaric acid, 1-o-pcoumaroylglycerol, caffeic acid, and 1-o-caffeoylglycerol (Roda et al., 2017). They concluded that the pineapple leaves extract prevented the onset of insulin resistance in diabetic rats given a high-fat diet and treated with low doses of streptozotozin. Additionally, the extract prevented HepG2 cells from developing insulin resistance. In mice fed fructose, the ethanolic extract of pineapple leaves with high phenolic content dramatically reduced the rise in blood triglycerides by 40% (Roda et al., 2017). The extract helps in the selective activation of the activity of coenzyme-A reductase on lipoprotein lipase by 20–49% *in vitro* suggesting that it has a hypolipidemic impact. Ismail et al., 2018, described the phenolic involved in these actions found eight phenylpropane di-glycerides, three hydroxy cinnamoyl quinic acids, two hydroxycinnamic acids, four phenylpropane mono-glycerides, three flavones, and six phenylpropanoid glycosides.

1.7.8 Residual sugar recovery

The pineapple waste is a great resource of sugar, it may be the best substrate for fermentation, with the potential for pineapple fruit to produce alcohol and acetic acid to produce vinegar (Tanamool et al., 2020). Using fruit waste as a starting point, a whole process was put into place to produce both pineapple wine and pineapple vinegar from pineapple waste (Al-Maqtari et al., 2019). Three steps of fermentation were used to make pineapple vinegar, starting with the saccharification of the cellulose fraction (Jalgaonkar et al., 2018). Different pre-treatments were used to increase fermentable sugar yield; enzymes were given to break down polysaccharides. The optimal time and temperature parameters for hydrolysis using enzymes were assessed. Invertase, pectinase, cellulose, and hemicellulose were applied for an optimal time-temperature combination of residual sugar from pineapple waste. According to the findings, high pressure using an autoclave was the best treatment for enzymatic hydrolysis. After that, the alcoholic fermentation of pineapple waste requires using three different strains of Saccharomyces cerevisiae, and more temperature testing should be applied. During 96 hours of fermentation, more than 7% volume-to-volume of ethanol was produced (Jalgaonkar et al., 2018). This caused the major sugars in pineapple must, primarily glucose, to decline.

1.7.9 Hydrogels and cellulose nanofiber production

Pineapple waste has a higher biological and chemical oxygen requirement, and disposing of it poses a major environmental risk (Chen et al., 2019). For this reason, pineapple waste fiber provides a different supply of natural fiber that can be used in composites in place of traditional mechanical materials. Despite being infrequently used, pineapple fiber is abundant, renewable, and biodegradable (Ali et al., 2020). The right use of pineapple fiber could help with waste disposal because the fiber from pineapple is burned along with other waste. The fiber from various pineapple species is to assess the fiber properties and inherent variabilities for engineering applications. It was discovered that the mechanical properties of composite materials were impacted by the degree of crystallinity high in pineapple leaf fibre-extracted cellulose.

Additionally, pineapple waste fiber has been frequently used as biomass and energy sources. Pineapple waste fiber has a smooth surface as compared to other natural fiber. It is white, making it perfect for use in biocomposites to limit the waste of renewable resources. Polysaccharides, lignin, wax, pectin, uronic acid, pentosane, and inorganic compounds, are only a few of the chemical components found in pineapple fiber (Nirmal et al., 2023). Due to its high specific strength and flexural rigidity, it can also take the place of raw materials in composite matrix reinforcements. To further optimize the use of pineapple leaf fiber, more recent applications have increased for a variety of functions, including textile, automotive, mechanical equipment, sporting goods, insulators, and more (Nirmal et al., 2023). Additional uses for pineapple leaf fiber include biopolymer coatings, cosmetics, and pharmaceuticals. Considering the high cellulose content found in pineapple waste, it can be utilized to make furniture and building construction products (Khanvilkar and Nagarjee, 2021). To offer the most vitality, pineapple leaf fibre develops early into a silky-white, robust fibre. It has been used to weave coarse textiles or fabric as part of an effort to create processed goods based on pineapple leaf fibre.

Table 1.8: Various dyes from pineapple waste

Absorbent	Dye	Removal efficiency (%)	Adsorption capacity (mg/g)	Reference
Hydrogen from pineapple peel cellulose	Methylene blue	-	138.25	Yuliusman et al., 2018
Activated carbon from pineapple waste	Methylene blue	38.6	-	Yuliusman et al., 2018
Activated carbon from pineapple waste	Malachite green	18.7	-	Yuliusman et al., 2018
Activated carbon from pineapple waste	Methylene blue	-	288.34	Jawad et al., 2018
Activated carbon from pineapple leaves	Reactive black 5	-	50	Abd Latif et al., 2021
Pineaaple leaf fiber adsorbents	Congo red	>95	-	Mahmud et al., 2021
Activated carbon from pineapple waste	Methylene blue	96	-	Patel et al., 2021
Hydrogen from pineapple peel cellulose	Methylene blue	-	153.85	Dai et al., 2017
Hydrogen from pineapple peel cellulose	Methylene blue	-	101.94	Dai et al., 2019
Hydrogen from pineapple peels	Congo red	-	138.89	
Silver nanoparticles from pineapple peel waste	Methylene blue	98.04	-	Dai et al., 2020
Pineapple peels	Safranin-O	-	21.7	Agnihotri et al., 2018

Additionally, pineapple fibre has been converted into a casting net and used to wrap cigars in large quantities. In West Africa, pineapple fibre makes hats for tribal chiefs and a string for jewellery. The composition for biocomposite applications was revealed by a study reported by (Mayo-mayo et al., 2020), which was extracted from pineapple leaf fibres. Table 1.8 shows different use of absorbent from pineapple waste to extract dyes. The matrix polymer is compatible with the elemental composition of the fibre surface, which includes potassium, oxygen and carbon in a range of 3, 43, and 53%, respectively. On the other side, using available microorganisms, pineapple peel can be converted into methane gas.

1.7.10 Methane production

Methane gas production has the potential to be used for pineapple waste treatment to provide alternatives to green energy that will safeguard the environment from pollution. Additionally, the pineapple waste, such as the peel, leaf, and core, is being potentially used as animal feed. For instance, as dairy feed, dairy animals were fed fermented pineapple waste that was more acidic than fresh waste. The pineapple waste that had been dried and ensiled was adequate as supplementary roughage can be used in the dairy industry (Duque-Acevedo et al., 2022). Another significant source of cellulose for replacing leaf waste with chemical treatments is the pineapple crown. Nirmal et al., 2023 investigated the viability of using pineapple crowns to bleach out non-cellulose chemicals. Like other pineapple sections, the pineapple fruit stem is a starch-based pharmacological excipient. Drying to separate the starch from the pineapple stem was done by spray drying to enhance the physical characteristics of pineapple waste (Ali et al., 2020). It is envisaged that discarded pineapple waste material can be treated for other commercial uses, such as fermentation and the extraction of bioactive compounds. Table 1.9 shows methane production from pineapple waste with their pre-treatment and operating conditions.

Table 1.9: Methane production from pineapple waste

Pineapple waste part	Pre-treatment	Operating conditions	Methane content (%)	Reference
Pineapple peels	Hydrogen peroxide and sulfuric acid	T= 37°C; STD=VDI 4630	70	Dahunsi et al., 2019
Pineapple peels		T= 37° C; pH= 7; Agitation=150 rpm	66.10	Chu et al., 2020
Pineapple waste		T= 35-45° C; pH=7-7.5; C/N=30	57.40	Chu et al., 2020
Pineapple waste		T= 37° C; Ph=7; Agitation= continuous	65	Nguyen et al., 2021
Pineapple waste		T= 55.2° C; SIR=1:2; HRT=8 days TS=6.25%	71.10	Aworanti et al., 2017
Pineapple waste		T=60° C; SIR=1:3 and 3:1; Agitation=30rpm	58	Aworanti et al., 2017
Pineapple waste		T=ambient; SIR=1:2.4; VS≤ 8%; HRT=92, 73 and 67 days	70.50	Azouma et al., 2018
Pineapple leaf residue		T= 35° C; pH=7; TS=20%; C/N=25	63.20	Ali et al., 2020
Pineapple peels and leaves		T=37° C; pH=7	56.61	Kumar et al., 2017

T= Temperature; TS=total solid; C/N= carbon to nitrogen ratio; SIR= substrate to inoculum ratio; HRT= hydraulic retention time; STD= standard, VS= volatile solid; VDI= vereindeutscheringenieure standard

1.8 Health benefits

It is widely acknowledged that consuming enough nutrients is crucial for human well-being. It has long been known that pineapples have valuable bioactive secondary metabolites for use in medicine. The fruit works effectively as a diuretic or contraceptive to eliminate intestinal worms (Altendorf 2017). Additionally, pineapple is frequently used to stimulate fat excretion for proper exfoliation and promote hunger for dietary nutriment. In place of a proteolytic enzyme, pineapple is used as a source of bromelain to treat soft tissue inflammation (Meena et al., 2018). The anti-inflammatory potential of pineapple leaf extract was effectively explored by Sepúlveda et al., 2018 in order to pinpoint the phytochemical elements that caused acute inflammatory disorders. The pineapple leaf extract found proteins, flavonoids, tannins, phenols, glycosides, carbohydrates, and other substances in that investigation.

Additionally, pineapple is a good source of micronutrients that should be consumed regularly. Illustrations of pineapple's potential health advantages are shown in Fig 1.3. According to a study report by Chaudhary, a ripe pineapple contained around 16% of the recommended daily intake (RDI) of vitamin C or the equivalent weight of 28 mg of vitamin C in a glass and a half of pineapple juice. In particular, vitamin C is recognized as an effective antioxidant that protects cells from free radicals and delays osteoblast aging while also observing the growth of diabetes. The thiamine content of pineapple is crucial for regulating nervous system activity. Thiamine is essential for synthesizing red blood cells and for minimizing the metabolic alterations brought on by diabetes and high glucose levels, especially in people with nervous system disorders (Zdrojewicz et al., 2018). Pineapple is a good source of insoluble dietary fiber and can help constipation, bowel movements, and gastrointestinal health (Roda et al., 2019).

The presence of dietary fiber in pineapple is vital for lowering the risk of cardiovascular illnesses, diabetes, and colon cancer and easing the symptoms of diarrhea. The malic acid in pineapple is also known to help preserve oral health, boost immunity, and reduce the development of bacterial plaque in dental health (Duque-Acevedo et al., 2022). Manganese is the most significant trace micronutrient in pineapple providing 73% of the recommended daily consumption, which is essential for generating energy (Altendorf 2017). Manganese has been linked to improvements in Type 2 diabetes, insulin resistance, blood glucose regulation, and skeletal abnormalities (Roda et al., 2019). The micronutrients enable the action of oxidizing enzymes like ligases and transferases, which is important against free radicals for the breakdown of cholesterol. According to (Duque-Acevedo et al., 2022), these positive benefits are critical for controlling emotional stability and supporting adult bone growth. Considering the nutrition, one of the most powerful antioxidants found in pineapple is called bromelain. Complex bioactive substances promote digestion, function as antioxidants, and act as cardioprotective agents (Campos et al., 2020). Studies show that bromelain is effective against bacterial infections, bronchitis, pneumonia, sinusitis, and parasitic gastrointestinal illnesses in addition to intestinal worms such as tapeworms and nematodes.

According to (Khanvilkar and Nagarjee, 2021), the digestive enzyme bromelain was, when combined with other analgesics, frequently used to control the sternness of myocardial infarction and treat patients with acute thrombophlebitis and treat skin infections, oedema, and inflammation. In addition to the abundance of nutrients, the many ways bromelain can be used to highlight the beneficial health effects and functional composition of pineapple, which can help develop a wide range of functional pineapple waste-based products aimed at advancing future functionalities and commercial applications. Table 1.8 shows use of different part of pineapple waste for food-based products.

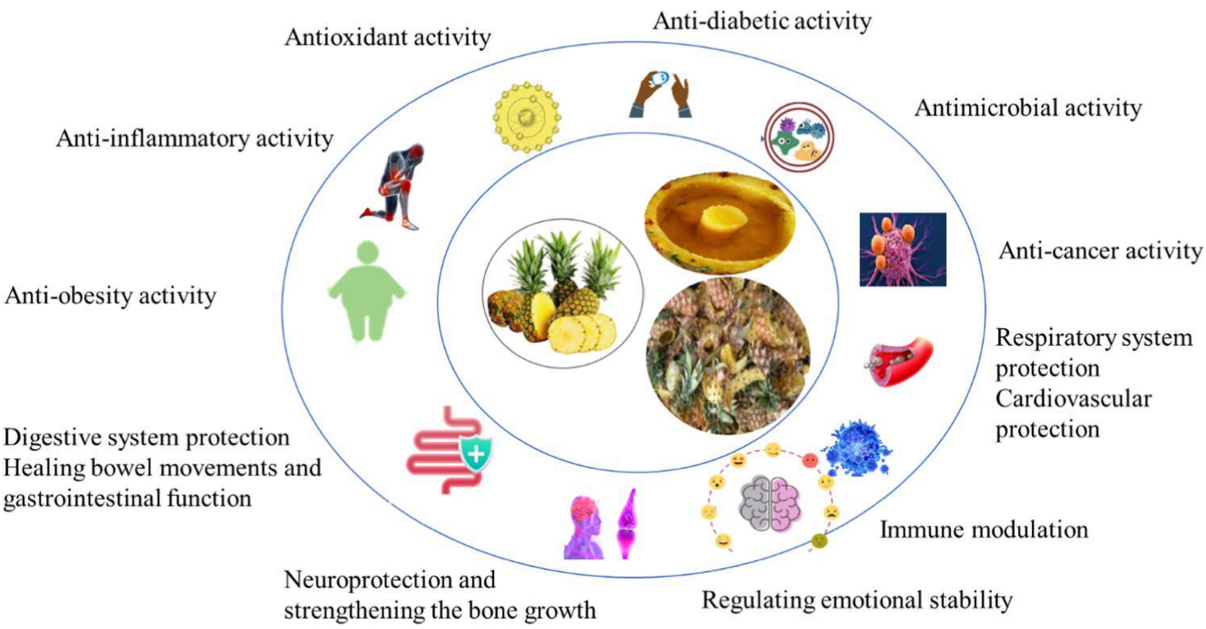

Fig. 1.3 Potential health benefits of pineapple

1.9 Dietary fiber as a functional component

In recent years, functional food has received high market demand due to consumer concern about health-beneficial effects. Product development is required to obtain health health-beneficial effects of functional food (Helkar et al., 2016). Dietary fiber (DF) addition can change a the texture, rheological behavior, consistency, and sensory qualities of food. In applications with lower fat content, it can also be utilized as a water binding agent and bulking agent. Due to its gel-forming, anticlumping, antistick, fat-mimetic, thickening, and water-holding properties, dietary fiber can extend the shelf life of food products (Guo et al., 2018). Citrus fiber, fractions of grains and multifruits, beetroot fiber, oat bran, potato peel fiber, legume fiber, defatted rice bran, and date fiber are among the food products that use various forms of DF (Hossain et al., 2015). The nutritional quality, total, insoluble, and soluble fiber contents, calorie content, antioxidant capacity, fermentability, and water retention capacity all play a role in the selection of a fiber source (Yangilar, 2013).

Pineapple waste has been used to enhance the dietary fibre content of the final product. The waste had low fat and high dietary fibre, which enriched the fibre content into the product, such as some extruded snacks, bakery products, etc. Some Results also showed the addition of dietary fiber to the food model with low microbiological counts, water activity, and pH indicating good microbiological quality and low risk of physicochemical deterioration (Kurek et al., 2018).

1.10 Extraction of dietary fiber

Dietary fiber has outstanding health promotion functions. Soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) are two different fractions of dietary fiber. Fibers are classified as SDF; are partially soluble in water but cannot be digested or absorbed by human systems and IDF; is a kind of fiber that is insoluble in water and cannot be absorbed or digested by human systems. The physicochemical, functional characteristics, and total dietary fiber content of dietary fibers derived from various sources varies (Daou and Zhang, 2014). Extraction of SDF and IDF from various sources was investigated and its functional properties were studied. The extraction method of dietary fiber depends on the composition, chemical nature, degree of polymerization, and the presence of polysaccharide. Dry, wet, chemical, gravimetric, enzymatic, physical, microbial, and a mix of these processes can all be used in extraction. The structure of dietary fiber is affected differently by different treatment techniques. In order to increase the overall yield and preserve or improve its functionality, recent research has concentrated on the extraction process using developing technologies (ultrasound, microwave, and high-pressure processing). These techniques may decrease processing durations, lower processing temperatures, and minimize solvent use (Li et al., 2014).

1.11 Modification of dietary fiber

Food components that cannot be digested by the human digestive system represent the majority of DF. Additionally, DF types are grouped based on physiological effects, fermentability, and solubility. In terms of solubility, dietary fibers are divided into two groups: (i) water-soluble (also known as soluble dietary fibers, or SDF) which includes pectin, gums, and mucilage, and (ii) water-insoluble (also known as insoluble dietary fibers, or IDF) which includes cellulose, hemicellulose, and lignin (Bianchini et al., 2016). While SDF are distinguished by their ability to promote viscosity, IDF are porous, metabolically inert, and function to increase fecal volume and decrease intestinal transit (Macagnan et al., 2016). In addition to having better functional qualities than IDF, SDF is also more able to create gels, boost viscosity, and function as an emulsifier. Furthermore, compared to IDF, SDF typically offers superior texture and flavor, making it easier to include in food formulations (Martinez et al., 2012). The potential development of a wide range of fiber-enriched meals, such as bakery goods, snacks, sauces, beverages, cereals, biscuits, dairy products, and meat products, depends on the nutritional value and technological qualities of dietary fibers (Morais et al., 2015). However, because of their large molecular weight and limited solubility, fibers can alter food products' texture in ways that are not desirable, therefore their inclusion in meals should generally not be excessive (Mudgil et al., 2013). Therefore, a variety of techniques have been employed to alter fibers in order to increase their amount in food compositions. According to Garcia-Amezquita et al. (2018), these procedures include chemical, physical, or enzymatic treatment, or even a mix of them. Enzymatic alterations present an intriguing alternative in this context due to their environmentally friendly nature. These actions are taken to enhance the functional characteristics of the fiber, such as its ability to absorb more or less water or oil, improve solubility, and raise or decrease viscosity. An additional factor under consideration in the field of fiber modification is the growing demand to guarantee the use of agro-industrial byproducts to reduce the environmental effect.

IDF is modified to become SDF to improve its physicochemical and functional characteristics (Padayachee et al., 2013). Thermal, mechanical, chemical, enzymatic, and microbiological fermentation processes are examples of modification techniques. In general, a combination technique may work better than a single one. Examples of modification techniques given are chemical-enzymatic, ultrasound-enzymatic, and microwave-enzymatic. Because of the compounds that are bound to IDF, some researchers have demonstrated the nutritional significance of it; nevertheless, the nutritional effect is diminished because of its limited bioavailability. To increase these molecules' bioaccessibility and optimize the potential health advantages of DF linked to phenolic compounds, it is recommended to convert IDF into SDF. Various methods can be used to accomplish this aim. Chemical treatments are the least expensive and most straightforward to apply, but they are frequently inappropriate for food products since they change the sensory qualities of the finished product and make consumers feel that it is not naturally occurring (Quirós-Sauceda et al., 2014). Food's sensory and nutritional qualities can be preserved and enhanced by enzymatic processes, but mechanical methods have poor conversion efficacy (Rabiu et al., 2018).

1.12 Antidiabetic study:

Diabetes mellitus (DM) is a persistent endocrine metabolic disorder marked by high blood sugar levels and disrupted lipid and protein metabolism (Ramli et al., 2017). DM primarily arises from reduced insulin secretion and varying levels of peripheral insulin resistance. Complications related to diabetes are linked to obesity, oxidative damage, and organ dysfunction and failure. In the intestinal lumen and the brush border membrane, α-glucosidase enzymes are crucial for carbohydrate digestion, breaking down starch and oligosaccharides into monosaccharides for absorption (Ribas-Agustí et al., 2017). According to the Liu et al. (2020), inhibiting the activity of these digestive enzymes would postpone the breakdown of starch and oligosaccharides. This, in turn, would reduce the amount of glucose absorbed and, as a result, the rising of blood glucose levels after meals. Carbohydrate digestion and absorption are slowed down by α-glucosidase inhibitor. According to Saikia et al. (2016), diabetes mellitus (DM) is closely linked to oxidative stress, which can result from heightened production of free radicals, weakened antioxidant defenses, or both. Patients with diabetes mellitus may have multiple types of tissue damage and pancreatic β-cell malfunction due to oxidative stress brought on by hyperglycemia. Pineapple is widely used to increase appetite for dietary nutrients and to encourage fat excretion for appropriate exfoliation. Consuming dietary fibre on a daily basis helps avoid a number of nutritional problems, including those like diabetes that are marked by persistent hyperglycemia. To treat muscle inflammation, pineapple is employed as a source of bromelain enzyme instead of a proteolytic enzyme. Pineapple contains dietary fiber, which is essential for reducing the risk of diabetes, colon cancer, and cardiovascular diseases as well as for relieving the symptoms of diarrhea. Pineapple can benefit gastrointestinal health, constipation, and bowel motions. It is a good source of insoluble dietary fiber. Dietary fiber

(DF) consumption helps prevent diabetes because it lowers postprandial blood glucose levels through a number of methods.

1.13 Development of functional food:

Food ingredients must be appealing, natural, and nutrient-rich. People are finding it more difficult to obtain natural, healthful food due to a number of factors, including the world's population growth occurring at a rapid rate, environmental degradation caused by our unrelenting technological advancement, lack of access to knowledge, and the effects of poor nutrition. According to scientific findings, an adequate and balanced intake of key nutrients, including proteins, carbs, fats, vitamins, and minerals, is a hallmark of sound nutrition. This guarantees the body's cells operate effectively, fostering general health and vigor. For consumers, however, the presence of fat in the composition of certain dietary products presents a challenge. Dietary fiber, which is not only useful but also enhances the texture and sensory aspects of products, can be employed as a solution to this issue. Thus, peels, cores, and pomace—byproducts of fruit processing—might be viewed as a substitute source of bioactive compounds. Therefore, to increase the value-adding of these by-products, more study in this area would be required. This would be a helpful tactic for enhancing their functional and nutritional qualities as well as their physical attributes, aiding in the avoidance of illnesses including diabetes, cancer, constipation, and high cholesterol (Saloni et al., 2017). Food processing waste can be used, such as, pineapple waste can be used more extensively, and by-products high in dietary fiber and bioactive substances can be fully utilized as multipurpose food ingredients. Fibers possess technological properties such as solubility index, water holding capacity, and oil binding capacity. These properties can be helpful in hydrating products, preventing syneresis, increasing yield, stabilizing high-fat food products and emulsions, and adjusting texture and viscosity, which have been shown to have positive effects on bakery products. The value-added production of high-value goods from pineapple waste has intrigued the curiosity of researchers. Research has indicated that pineapple waste contain bioactive elements like proteins, lipids, fiber, and antioxidants. This has prompted in-depth investigation into the possible uses of these processing waste in a range of sectors, such as food, medicine, and cosmetics. Modern studies have concentrated on creating novel methods for the extraction and application of bioactive components from pineapple waste with the goal of optimizing its economic significance and ecological sustainability.

The edible portions of plants or comparable carbohydrates that are resistant to absorption and digestion in the human small intestine and either full or partial fermentation in the large intestine are referred to as dietary fiber (DF). The sources of DF in the human diet are plant-based foods such fruits, vegetables, cereals, and other grains. Cereals account for half (50%) of the daily consumption of DF, followed by fruits (16%), vegetables (30–40%), and other sources (3%). Dietary fiber (DF) is mostly composed of non-starch polysaccharides, which are categorized as either soluble (SDF) or insoluble (IDF) based on how soluble they are in water. Cellulose, hemicellulose, and chitin are included in IDF, while non-starch polysaccharides like pectin, β-glucans, gums, mucilage, oligosaccharides, and inulin are included in SDF. Additionally, other indigestible substances such waxes, saponins, phytates, phytosterols, resistant protein, and phenolic compounds are directly linked to DF (Sciarini et al., 2017).

1.14 Hypothesis

Functional food development from queen pineapple waste of northeast India exhibiting bioactive functional properties and anti-diabetic properties.

1.15 Gap of research

1. The optimal extraction methods for obtaining the highest yield of bioactive compounds from queen pineapple waste are not well-established.
2. The bioactivity profiles of queen pineapple waste, including antidiabetic properties, have not been extensively studied.
3. There are limited studies on the incorporation of queen pineapple waste extracts into the development of functional food and their effects on food quality.

1.16 Objectives

1. To study different extraction methods on dietary fiber from queen pineapple waste of Northeast India and its process optimization.
    I. To study the effect of conventional and ultrasound-assisted extraction and its process optimization
    II. To study the physicochemical, thermal, functional, and structural properties of extracted dietary fiber.
2. To evaluate the effect of enzymatic modification of extracted dietary fiber and its characterization.
3. To study the *in vitro* antidiabetic activity of modified dietary fiber.
4. To develop a fiber-rich functional food and its quality evaluation.

Objective 1: To study different extraction methods on dietary fiber from queen pineapple waste of Northeast India and its process optimization.

Locally collected ripened fruits (Queen pineapple) from the Northeast (Tripura) were used as samples for the present investigation. The fruit waste was collected, wasted, and then dried. Finally, the dried waste was ground to powder for further investigation. Physicochemical properties were analyzed of the prepared sample.

The extraction of dietary fibre (DF) from the queen pineapple waste was performed by using different extraction methods (Ultrasound-assisted extraction and Conventional extraction). The process parameters were optimized based on the total yield of extracted DF. The best-found DF was taken for further analysis of physicochemical (Water holding, oil holding, swelling capacity, etc.), thermal (TGA), functional (FT-IR, XRD), and structural properties (SEM). The extracted dietary fiber was separated based on their solubilities such as insoluble dietary fibre (IDF) and soluble dietary fibre (SDF).

Objective 2: To evaluate the effect of enzymatic modification of extracted dietary fiber and its characterization.

This objective aims to evaluate the modification of optimized extracted DF. Enzymatic modification methods were performed and its functional properties like water holding capacity (WHC) and oil holding capacity (OHC), swelling capacity (SC), structural properties (SEM), FT-IR, and thermal properties (TGA) were characterized. The enzyme-modified DF was taken forward for the next objective.

Objective 3: To study the *in vitro* anti-diabetic activity of extracted dietary fiber

The enzyme-modified DF was used to check the *in vitro* anti-diabetic activity at different concentrations based on their enzyme inhibition properties for α-amylase, α-glucosidase, and DPP-IV. For further investigation, two human cell lines were taken (Caco2 and Hep G2). The cytotoxicity effect was investigated in both cell lines. Glucose uptake analysis was done on both the cell lines and RNA extraction and Differential expression genes were also analyzed.

Objective 4: To develop a fiber-rich functional food and its quality evaluation.

In the end, the extracted modified DF was incorporated at different concentration levels into a food model, and its sensory acceptability was evaluated. The final test of the product was done by the determination of sensory attributes. It was done following a triangular test and rating of its hedonic impressions, in terms of color, aroma, flavor, mouthfeel, and overall aspect, on 9-point hedonic scales ranging from 1 (“dislike extremely”) to 9 (“like extremely”). *In vitro* digestibility of the formulated functional food, and predicted glycemic index was analyzed.

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