MSc. Chemistry Eshita Pasreja and Dishika Garg 2023

# PINEAPPLE RESIDUES: A TRANSITION FROM REMNANTS TO THE REALM OF A BASKET OF CHEMICALS AND VALUE-ADDED PRODUCTS

A PROJECT REPORT
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE
OF
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IN
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Submitted by

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## **CANDIDATE'S DECLARATION**

We, Eshita Pasreja (2k21/MSCCHE/18) and Dishika Garg (2k21/MSCCHE/14) of M.Sc. Chemistry, hereby declare that the project titled "Pineapple residues: a transition from remnants to the realm of a basket of chemicals and value-added products" which is submitted by us to the Department of Applied Chemistry, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Science, Chemistry is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi

Date:

**ESHITA PASREJA**

**DISHIKA GARG**

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# **CERTIFICATE**

I hereby certify that the Project titled "Pineapple residues: a transition from remnants to the realm of a basket of chemicals and value-added products" which is submitted by Eshita Pasreja, 2k21/MSCCHE/18 and Dishika Garg, 2k21/MSCCHE/14 of Department of Applied Chemistry, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Science, Chemistry, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Date:

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**ABSTRACT**

The major part of food waste in our surroundings is produced due to the processing of fruits and vegetables. To recycle this waste, a considerable amount of money is required and as a result these pollutants are either dumped in open spaces or else burned which tends to intensify the pollution problems. This project report provides the information regarding the potential of pineapple waste including the left-over peels, core, stem and crown portions to generate value-added compounds and the techniques that can be used to extract these compounds from the by-products have also been assembled from literature. Further, the applications of these compounds in numerous fields were extensively explored. The highly nutritious profile of pineapple waste including its high carbohydrate content makes it a suitable substrate for manufacture of important chemicals such as organic acids, essential oils, nanocellulose, xylooligosaccharides, polyphenols, bromelain and others that may find use in the food industry, production of aerogels, fibers, biofuels, animal feed, production of nanoparticles, heavy metal intoxication, bioadsorbent and a variety of clinical application. Such utilisation of waste would be immensely helpful in the reduction of environmental issues and would also provide an innovative way to manufacture useful compounds out of waste.

**ACKNOWLEDGEMENT**

With immense gratitude, first and foremost we owe a deep sense of regard to our institutional guide Dr. Ram Singh (Professor, Department of Applied Chemistry, Delhi Technological University) for his continuous motivation and healthy scrutiny without which this feat would not have been possible.

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**ESHITA PASREJA**

**DISHIKA GARG**

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# CHAPTER - 1

# INTRODUCTION

## 1.1 General aspects of *Ananas cosmosus*

The waste generated from fruits and vegetables which is also known as agricultural wastes (or agri-waste) are the source of numerous chemicals. The lack of proper harvesting method, logistical management, storage facilities and improper transportation results in the production of huge amount of agri-waste (Roda and Lambri, 2019). Out of the many types of agri-waste, the waste generated from fruits and fruit processing industries constitutes noticeable amount.

The tropical fruit *Ananas comosus*, commonly referred as pineapple, belongs to the Bromeliaceae family. The pineapple plant is herbaceous, monocotyledonous and constitutes the stem, leaves, peduncle, crown, shoots and adventitious roots as its basic morphological components (Hossain, 2016). The initial leaf sprout is tender and the leaves gradually become stiffer and acquires a sword-shaped structure that wraps around the fruit (Fouda Mbanga and Tywabi Ngeva, 2022). Acidic loams, sandy loams and clay loams all support the growth of high-quality pineapples in warm, humid climates with sunny days and chilly nights, with the ideal soil pH range between 4.5 and 6.5 (Hossain, 2016). According to the data from Food and Agriculture Organization (FAO), 28 million tonnes of pineapple have been produced globally in 2020 and the Philippines, Costa Rica, Brazil, Indonesia, and mainland China make up the top five nations that produce pineapples (Figure 1.1) (“FAOSTAT,” 2020). The five groups of commercial pineapple cultivars are Cayenne, Queen, Spanish, Pernambuco, and Mordilona. Despite considerable variability among the types within each class, the diverse pineapple cultivars are divided into four major classes for international trade: "Smooth Cayenne", "Red Spanish", "Queen" and "Abacaxi". Smooth Cayenne has a distinctively smooth exterior and is the most grown cultivar for fresh fruit and canning. Abacaxi has distinctive fruits that are long, white, translucent and delicious. Although it is the most exquisite type of pineapple, due to its fragility, it cannot be canned. Queen has a dwarf plant with short, extremely spiky, dark purplish-green leaves that have high sugar content. Its fruit is conical, deep yellow and has deep eyes; a thick cut is needed to entirely remove the peel; when mature, it has a wonderful fragrance and flavor. Red Spanish fruit has deep eyes and is often rounded with an orange-red exterior. When fully grown, the fruit is robust and readily and neatly snaps off at the base during harvest. In addition to these, it is known that there are numerous hybrid pineapple cultivars (Banerjee et al., 2018; ITFNet, 2016).

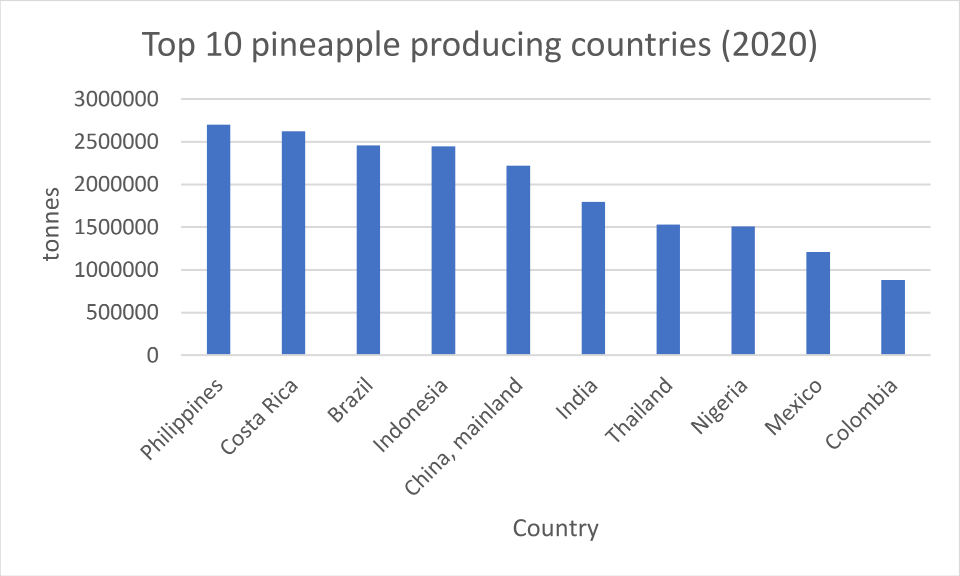


Figure 2.1: Leading countries in pineapple production ("FAOSTAT," 2020)

## 1.2 WASTE GENERATION FROM PINEAPPLES

Waste from pineapples have been categorized as pineapple processing waste (PPW) and pineapple on-farm waste (POFW). After pineapples have been harvested, POFW contains the leftover leaves, stems and roots in the fields. Then the pineapples are processed which includes slicing, pulping and juicing (Banerjee et al., 2018). Waste produced by the industries that process pineapples includes leftover skin, peel, pulps, stems and leaves (Rabiu et al., 2018). The removal of the crown is the initial processing stage, which is followed by the simultaneous removal of the peels and core and the waste produced at this stage is PPW (Banerjee et al., 2018). The main reason pineapples are grown is for their fruit, which is eaten either fresh or in canned fruit and juice form. Besides this, huge quantities of by-products are produced during the processing of pineapple, with peels accounting for 29–42% (w/w), core accounting for 9–20% (w/w), crown accounting for 2.7-5.9% (w/w) and stem accounting for 2.4-6.8 % (w/w). All these by-products contain cellulose, hemicellulose and lignin (Figure 1.2) (Rico et al., 2020; Sukruansuwan and Napathorn, 2018). There is significant interest in leftover pineapple peels, crown and other by-products to convert it into value-added products. By-products such as peels, leaves, seeds and leftover flesh account for up to 50% by weight of the overall pineapple crop. The primary components of pineapple waste include the remaining pulp, the peels, the stems and the leaves. During industrial processing, pineapple fruits produced 55% of leftovers, which included peel (40%), bagasse (23%) and stem and crown portions (14%) (Rajapaksha et al., 2019). The increase in the amount of processed pineapple leads to enormous waste generation (Upadhyay et al., 2010). Unrefined pineapple industry effluent contains higher concentrations of carbohydrates like sucrose, glucose and fructose, which may lead to environment pollution when released into the rivers. The pineapple industry's wastewater discharge results in high level of suspended solids (SS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD). High COD concentrations in wastewater is harmful to biological life and have an impact on the aquatic environment. Nearly every step of the production process in the pineapple refining industry requires a significant amount of water as due to which a lot of solid and liquid waste is produced which accounts for serious environmental issues (Fouda Mbanga and Tywabi Ngeva, 2022).

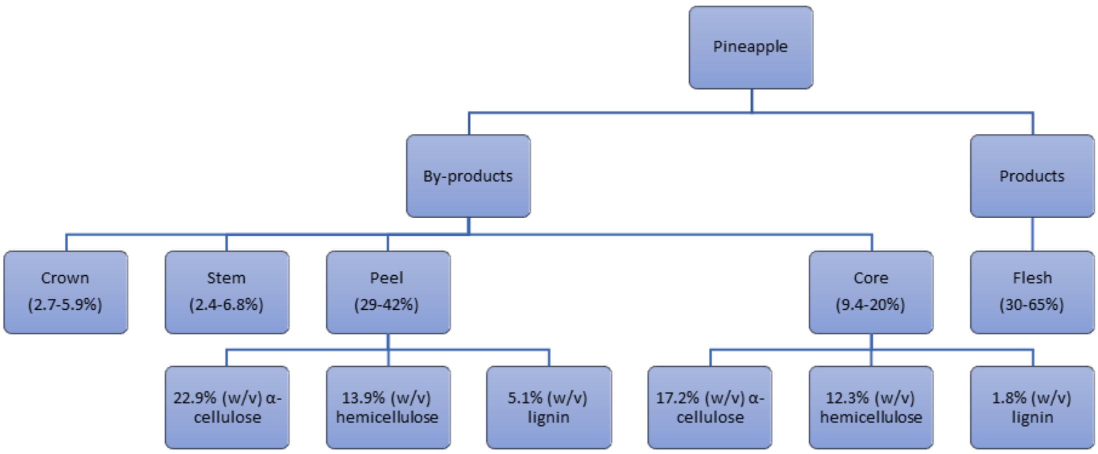


Figure 1.2: Fruit processing (Rico et al., 2020; Sukruansuwan and Napathorn, 2018)

A number of articles have been published on utilisation of pineapple waste (Figure 1.3) (“Dimensions,” 2022).

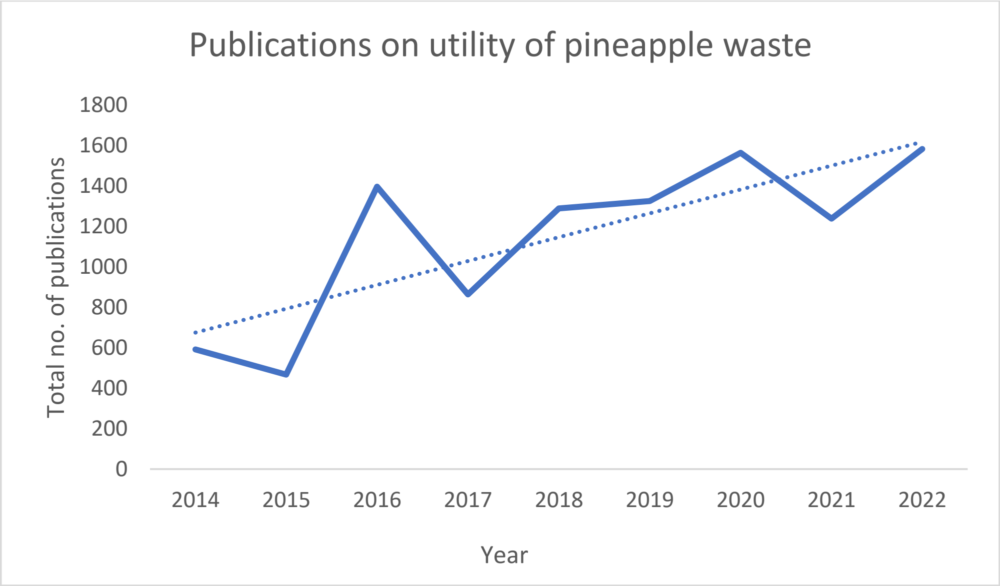


Figure 1.3: Publications on utility of pineapple waste ("Dimensions," 2022)

# CHAPTER - 2

# PINEAPPLE WASTE UTILISATION

## 2.1 MOLECULES EXTRACTED FROM PINEAPPLE WASTE

The pineapple waste is a valuable substrate with significant potential if appropriate processes and technologies are applied to transform its various components into value-added products (Roda and Lambri, 2019). Due to high sugar content, antioxidants, bioactive compounds and bromelain enzyme, pineapple by-products have a significant potential for use in the production of organic acids, polyphenols, bromelain, adsorbent as well as biofuels and biogas (Aili Hamzah et al., 2021). Pineapple pulp has the greatest values in terms of protein, ash, and fibre content (Pardo et al., 2014). Pineapple waste served as both, a carbon source for acid fermentation and a beneficial nutrient for bacterial growth (Abdullah and Mat, 2008). The PW's non-reducing sugars, carbohydrates and protein are used as a nutritional medium for the growth of microorganisms and yeast fermentation, which can further produce ethanol and single cell protein (Hemalatha and Anbuselvi, 2013). The prebiotic effects of pineapple peel flour can promote the development of probiotic bacteria in the gut. Vinegar and vanillin were produced from pineapple waste (Cheok et al., 2018; Roda et al., 2017).

### *2.1.1 Organic acids*

Pineapple waste can be utilized to produce organic acids namely citric acid, succinic acid, lactic acid, acetic acid, and oxalic acid by the process of fermentation employing different microorganisms for its production (Figure 2.1, Table 2.1).

#### Citric acid

Citric acid, having molecular formula $C_6H_8O_7$ is a weak organic acid that contains three carboxyl (R-COOH) groups (Berovic and Legisa, 2007). The citric acid is produced by solid state fermentation (SSF) of glucose or sucrose. The process of microbial fermentation is more cost-effective than the chemical methods used for its production. Solid pineapple waste has been utilized as a substrate for the production of citric acid using *Yarrowia lipolytica* through SSF (Imandi et al., 2008). *Aspergillus niger* was also used to produce citric acid from agri-waste and used less expensive raw materials, high product yield and lack of unfavourable reactions (Majumder et al., 2010; El-Holi and Al Delaimy, 2003).

**Succinic acid**

Succinic acid, 1,4-dicarboxylic acid, having molecular formula $C_4H_6O_4$ and the IUPAC name butanedioic acid is one of the potential compounds that are produced from pineapple waste (Jusoh et al., 2014). High levels of sugar and other macro- and micronutrients are present in liquid pineapple waste, which have been employed as a substrate for the production of succinic acid (Jusoh et al., 2014). Solid pineapple waste, notably the peel portion, was used as a carbon source and fermentation with *Actinobacillus succinogenes* resulted in bio-based succinic acid production (Pathanibul and Hongkulsup, 2021). The liquid pineapple waste was fermented with *Escherichia coli* under aerobic conditions to produce succinic acid (Jusoh et al., 2014). *Aspergillus niger* and *Rhizopus oryzae* produced fermentable sugars by biological hydrolysis of pineapple waste. Then, *Actinobacillus succinogenes* was used to carry out the biotransformation of the solid waste hydrolysate to produce succinic acid (Dessie et al., 2018).

**Lactic acid**

Lactic acid, hydroxycarboxylic acid having chemical formula $CH_3CH(OH)COOH$ and the IUPAC name 2-hydroxypropionic acid can be produced from pineapple syrup, a by-product of the pineapple processing industry. Pineapple syrup was employed as an inexpensive substrate and through fermentation process using *Lactobacillus lactis* and the enzyme invertase, lactic acid has been produced (Ueno et al., 2003). Pineapple waste streams were utilised as a production medium for lactic acid using microorganisms, *Rhizopus arrhizus* and *R.oryzae* and fungal biomass by single stage simultaneous saccharification and fermentation process (Jin et al., 2005). Liquid pineapple waste was employed as the substrate which was then subjected to a 72-hour fermentation to convert it into lactic acid using *Lactobacillus delbrueckii*. Calcium alginate was employed as the immobilisation matrix by varying temperature and pH conditions (Idris and Suzana, 2006).

**Acetic acid**

Acetic acid (ethanoic acid) is a carboxylic acid having the molecular formula $CH_3COOH$. Pineapple waste contains high sugar content which was exploited to produce acetic acid. PW was saccharified using physical and enzymatic processes and the resulting substrate was fermented with *Saccharomyces cerevisiae* for 7–10 days at 25°C in aerobic conditions. *Acetobacter aceti* was employed as the inoculum and the alcoholic medium was used as a seed broth for the fermentation process and it took roughly 30 days at 32°C to produce acetic acid (Roda et al., 2017). In particular, the fermentation of vinegar involves two steps: first, anaerobic fermentation of fermentable carbohydrates into ethanol by yeasts typically of the *Saccharomyces* genus and then aerobic oxidation of ethanol to acetic acid by bacteria generally of *Acetobacter* genus. High rates of aeration during the process can result in better yield of acetic acid (Umaru et al., 2015).

**Table 2.1**: Organic acids from *Ananas cosmosus*

| Organic Acid | Method of Production | Microorganism | Reference |
|---|---|---|---|
| Citric acid | Fermentation | *Yarrowia lipolytica*<br>*Aspergillus niger* | Ayeni et al., 2019; Papagianni, 2007 |
| Succinic acid | Fermentation | *Actinobacillus succinogenes*<br>*Escherichia coli* | Jusoh et al., 2014; Pathanibul and Hongkulsup, 2021; Dessie et al., 2018 |
| Lactic acid | Fermentation | *Lactobacillus lactis*<br>*Lactobacillus delbrueckii*<br>*Rhizopus arrhizus*<br>*R. oryzae* | Datta and Tsai, 1997; Idris and Suzana, 2006; Jin et al., 2005; Ueno et al., 2003 |
| Acetic acid | Fermentation | *Saccharomyces cerevisiae*<br>*Acetobacter aceti* | Umaru, 2015; Roda et al., 2017 |
| Oxalic acid | Fermentation | *Aspergillus niger* | Amenaghawon and Kazeem, 2020 |

**Oxalic acid**

Oxalic acid (OA), also known as ethanedioic acid is the simplest aliphatic dicarboxylic acid having the chemical formula $C_2H_2O_4$ (Amenaghawon and Kazeem, 2020). Pineapple juice serves as a carbon source and fermenting it with a filamentous fungus *Aspergillus niger*, oxalic acid has been produced (Amenaghawon and Kazeem, 2020).

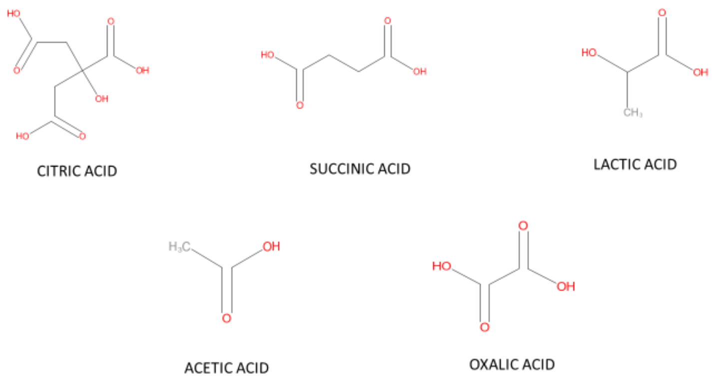


Figure 2.1: Structure of organic acids derived from pineapple waste

### *2.1.2 Essential oils*

Essential oils have been extracted from the peel and fibre portions of pineapple waste. Of the 35 compounds found in the oil, esters (37%), alcohols (29%), aldehydes (9%), ketones (9%), and acids (6%) were the most prevalent compounds in pineapple waste (Barretto et al., 2013). Essential oils were extracted from pineapple waste using three distinct techniques namely hydro-distillation (HD), hydro-distillation with enzyme-assisted pre-treatment (HDEA) and supercritical fluid extraction (SFE) (Mohamad et al., 2019).

**Hydro-distillation (HD)**

Essential oils from pineapple waste were extracted using hydro-distillation process where pineapple peels and distilled water were added to a round bottom flask connected to the clevenger-type apparatus and once the process was completed, essential oils were collected in the trap (Mohamad et al., 2019).

**Hydro-distillation with enzyme-assisted pre-treatment (HDEA)**:

Hydro-distillation with enzyme-assisted pre-treatment method can be used for the extraction of essential oils from dried pineapple peels by mixing the peels with acetate buffer followed by addition of acremonium cellulase solution at different enzyme loadings prior to hydro-distillation procedure (Mohamad et al., 2019).

**Supercritical fluid extraction (SFE)**

SFE was used for the extraction of essential oils from the pineapple peels. The ground-dried pineapple peels were placed in the SC–$CO_2$ extraction apparatus (Kamali et al., 2015). Then, the compressed $CO_2$ was pumped into the extractor at the pressure of 180 bar and a temperature of 50 °C and a static period was used to allow contact between the sample and $CO_2$ solvent followed by dynamic extraction (Kamali et al., 2015). After the extraction, the extracted oil, wax and solid residue were collected, with the release of $CO_2$ into the air (Mohamad et al., 2019). Distillation using SFE gave the highest oil (0.17%) as compared to distillation using HD and HDEA methods which produced hydrosol instead of essential oils (Barretto et al., 2013). Propanoic acid ethyl ester (40.25%), lactic acid ethyl ester (19.35%), 2-heptanol (15.02%), propanol (8.18%), 3-hexanone (2.60%), and butanoic acid ethyl ester (1.58%) were the main components of the essential oil produced from pineapple peels by the SFE process (Barretto et al., 2013).

### *2.1.3 Carbohydrates*

Xylan-rich lignocellulosic waste from pineapple was used for the production of xylooligosaccharides (Banerjee et al., 2018). Pineapple peel waste was used as a substrate to produce hemicellulose using hydrothermal-assisted alkali extraction technique. The peels were incubated at various alkali concentrations with temperatures varying from 35 °C to a maximum of 65 °C for a time period of 16 hours to extract the hemicellulose. Then, the extracted hemicellulose was enzymatically hydrolysed using endo-1, 4-β-xylanase M1 to produce XOS (Banerjee et al., 2019). Fermentable sugars were produced from sugarcane baggase by enzymatic hydrolysis using a mixture of Cellic CTec2 and Cellic HTec2 and using autohydrolysis technique for pre-treatment followed by mechanical refining technique (Batalha et al., 2015). The fermentable sugars were produced by using pineapple leaf waste that are rich in polymers such as cellulose and hemicellulose. Reducing sugars were produced through enzymatic means through delignification of pineapple leaf waste using laccase and saccharification employing cellulase-xylanase concoction (Banerjee et al., 2017).

**Pectin**

Pectin was extracted from pineapple waste using conventional and distinctive methodology (Marić et al., 2018). The ultrasound-assisted extraction (UAE) technique was used to extract pectin from pineapple peel (PP) waste (Shivamathi et al., 2022). Pectin was also extracted using acid extraction and ethanol precipitation (Sarangi et al., 2020). Dried pineapple waste was taken in a beaker and distilled water and sulphuric acid was added to it. The mixture was then stirred continuously with simultaneous heating. It was followed by the filtration process; ethanol was added for the coagulation of filtrate. Pectin was obtained after filtration and was washed with varying concentrations of ethanol (Sarangi et al., 2020). Pectin was also extracted using microwave heating (ME) (Zakaria et al., 2021). The solvent used was sulphuric acid with concentration, 0.5 N $H_2SO_4$, pH 1.83 and 1:30 (w/v) solid-to-solvent ratio.

**Starch**

Starch have been extracted from the remnants of pineapple, particularly stem by mechanical extraction using water. Pineapple stem was taken and grounded with distilled water with a weight ratio of 1:1 using a grinder and a paste with crude fibrous material was obtained. Fibrous materials were then filtered out with a cloth. Then, the starch was separated from the extracted compounds using the process of centrifugation. The process was then repeated multiple times until the liquid fraction became clear and was dried in oven and sieved through a mesh screen to obtain starch (Nakthong et al., 2017).

**Glucose**

Pineapple waste rich in cellulose has been utilized to produce glucose by the process of enzymatic hydrolysis utilising cellulase from *Trichoderma reesei*. The enzyme substrate was incubated at pH 5.5, 50 °C, 120 rpm and 72 h with 10% (w/v) solid loadings of substrate for the production of glucose. The enzyme was inactivated by heating it at 95 °C, followed by centrifugation for the enzyme to settle down and the supernatant was filtered to determine the glucose concentration using HPLC (Banerjee et al., 2022).

### *2.1.4 Polyphenols*

Pineapple skin contains significant amount of phenolic chemicals (Yahya et al., 2019). Salicylic acid, caffeic acid, myricetin, syringic acid, sinapic acid, ferulic acid etc. were some of the phenolics identified in pineapple (Figure 2.2). Their extraction methods included soxhlet extraction (Madhumeena et al., 2021; Salve and Ray, 2020), supercritical fluid extraction (Salve and Ray, 2020), pressurised solvent extraction (Kaufmann and Christen, 2002), ultrasound assisted extraction (Kumar et al., 2021; Salve and Ray, 2020), microwave assisted extraction (Alias and Abbas, 2017; Salve and Ray, 2020; Vargas-Serna et al., 2022) and autohydrolysis (Batalha et al., 2015; Sepúlveda et al., 2018) (Table 2.1).

**Soxhlet extraction**

The sample containing pineapple waste was put in the thimble, which was then placed in a distillation flask filled with solvent (Salve and Ray, 2020). Methanol, ethyl acetate, gasoline and their aqueous solvents were found to be the most commonly used solvents for the production of polyphenols from plant sources. Aqueous methanol was identified as a most popular choice due to its high boiling point and its economic availability (Madhumeena et al., 2021).

**Supercritical fluid extraction**

The polyphenols present in pineapple waste can be extracted using SFE technique. The $CO_2$ is regarded as an optimal solvent for SFE as its critical temperature is close to room temperature and it has low critical pressure. Dichloromethane ($CH_2Cl_2$) can be employed as a chemical modifier and aid in the extraction procedure of polyphenols (Salve and Ray, 2020).

**Pressurised solvent extraction**

The solid or semi-solid sample of pineapple waste is placed in the extraction cell and is filled with the solvent and heated in an oven. It uses diethyl ether and other organic solvents at high pressures and temperatures that helps to improve the effectiveness of the extraction process. Pressure in the extraction cell is produced by solvent expansion during the heating process (Kaufmann and Christen, 2002).

**Ultrasound assisted extraction**

The process of ultrasound assisted extraction (UAE) is used to extract polyphenols from pineapple peel (Salve and Ray, 2020). In the cellular structure of the pineapple plant, collapsing cavitation bubble and the sound waves may cause one or a combination of factors that includes localised erosion, pore formation, enhanced absorption, shear force, fragmentation, and swelling index. Shockwaves are produced by collapsing cavitation bubbles and the fragmentation of cellular structure is brought on by accelerated inter-particle collision. The bioactive components become solubilized in the solvent as a result of the rapid fragmentation. Ultrasound causes damage to the plant known as erosion, which is the explosion of cavitation bubble on the surface of the plant. The release of polyphenols is caused by the development of pores during cavitation, a process known as sonoporation. Additionally, the formation and disintegration of cavitation bubbles cause turbulence and shear force, which causes the breaking of cell walls and aids in the release of polyphenols (Kumar et al., 2021).

Microwave assisted extraction: Microwave assisted extraction is a technique that involves heating the solvent in the vicinity of sample containing pineapple waste and employing microwave energy to extract polyphenols (Salve and Ray, 2020). The principle behind the extraction process is to use a microwave to generate heat, concisely electromagnetic energy is transformed into heat, accompanied by ionic conduction and molecular dipole rotation. Three successive processes involve the MAE mechanism: 1. solute separation from the sample matrix's active sites under increasing pressure and temperature; 2. solvent diffusion over the sample matrix; and 3. solute release from sample matrix to solvent (Salve and Ray, 2020). DESs (choline chloride-glycerol and choline chloride-malic acid), environmentally friendly solvents due to their low toxicity and high capacity for the extraction of polyphenols were used for the microwave assisted extraction of phenolic compounds from pineapple peels (Vargas-Serna et al., 2022).

**Autohydrolysis**

The polyphenols can be extracted from pineapple waste using autohydrolysis method which is a green method that utilises water as a solvent. Pineapple waste and distilled water were combined at different mass-to-volume ratios in steel cylinders immersed in a temperature-controlled oil bath. At the completion of the reaction period, the cylinders were immersed in an ice bath to cool down. Following, solid and liquid fractions were separated through filtration to produce hydrolysates. UHPLC was used to determine the amount of polyphenols present in the hydrolysates from the autohydrolysis experiment (Sepúlveda et al., 2018). Pineapple peel contains ferulic acid (FA), a phenolic antioxidant (Tilay et al., 2008) that also acts as a precursor for the production of vanillic acid and vanillin (Lun et al., 2014). Ferulic acid can be extracted from pineapple core waste through fermentation (Li et al., 2014). Vanillic acid and vanillin were produced by *Aspergillus niger* and *Pycnoporus cinnabarinus* using pineapple cannery waste as a substrate (Lun et al., 2014). The biotransformation of ferulic acid to vanillin occurs in a two-step process, the first step involved the production of vanilic acid from ferulic acid through the process of metabolism by the ascomycete, *Aspergillus niger* and then vanillin was obtained from vanillic acid by the basidiomycete, *Pycnoporus cinnabarinus* (Lesage-Meessen et al., 1996). This is a simple extraction method as compared to enzymatic (Faulds and Williamson, 1993) and alkaline extraction (Liu et al., 2006) methods which were cumbersome and expensive. In order to extract FA by alkali extraction, first the pineapple waste was crushed to powder and then a simple extraction method was employed. Resulting sample was taken into an Erlenmeyer flask and was saponified with NaOH followed by the addition of sodium hydrogen sulfite. Further, the mixture was centrifuged, and the supernatant was acidified with dilute HCl and the phenolic acids were extracted using ethyl acetate (Tilay et al., 2008).

### *2.1.5 Lipids*

Pineapple pulp has been employed as a cheap and efficient carbon source for growth and lipid production by *Rhodotorula glutinis*. The sugars in the pineapple pulp were converted into lipids by *R. glutinis*. Liquid-liquid extraction utilizing chloroform and methanol as the extracting solvent was used as the standard procedure (Tinoi and

Rakariyatham, 2016). The primary components were discovered to be C-16 and C-18 fatty acids, which included linoleic acid, oleic acid, stearic acid, and palmitic acid (Figure 2.3) (Tinoi and Rakariyatham, 2016).

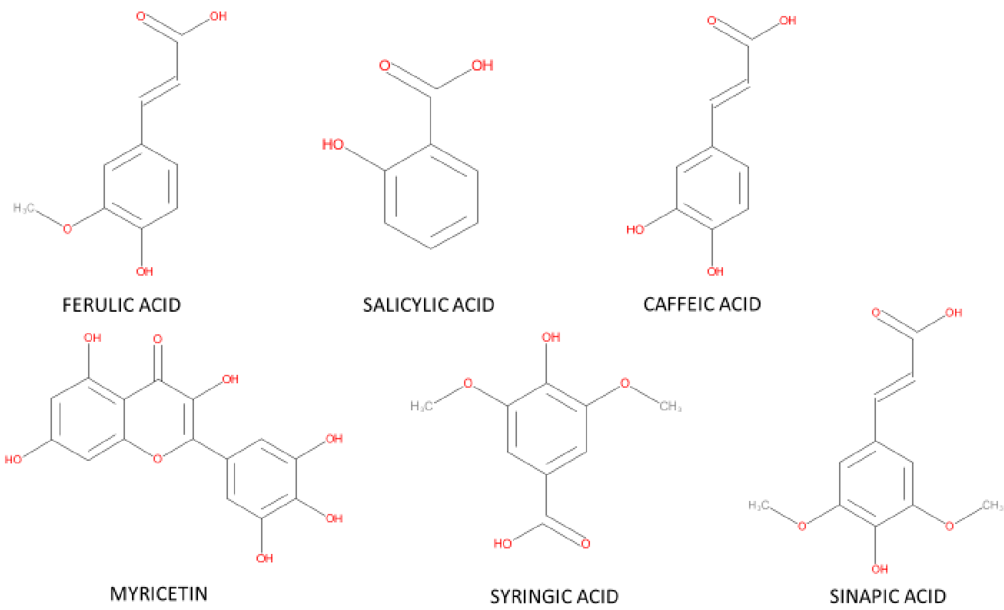


Figure 2.2: Structure of polyphenols derived from pineapple waste

### *2.1.6 Bromelain*

The enzyme bromelain (Figure 2.4) and other cysteine proteases are found in various parts (Ketnawa et al., 2010; Rolle, 1998; Schieber et al., 2001) of pineapple waste (Nor et al., 2016). Reverse micellar system, aqueous two-phase extraction, cation exchange chromatography, and ammonium sulphate precipitation are common methods used for the extraction of bromelain from crude pineapple extract (Nadzirah et al., 2013). Bromelain was precipitated from pineapple fruit juice by adding ammonium sulphate [$(NH_4)_2SO_4$] gradually with continuous stirring at a temperature of 4 °C (Devakate et al., 2009). Extraction of bromelain was done from pineapple peel by using the reverse micelles method (Wan et al., 2016). The reverse micelle was prepared in known proportions of n-hexane, 1-hexanol, surfactant and water with 1-hexanol and n-hexane taken in volume ratio of 1:9.

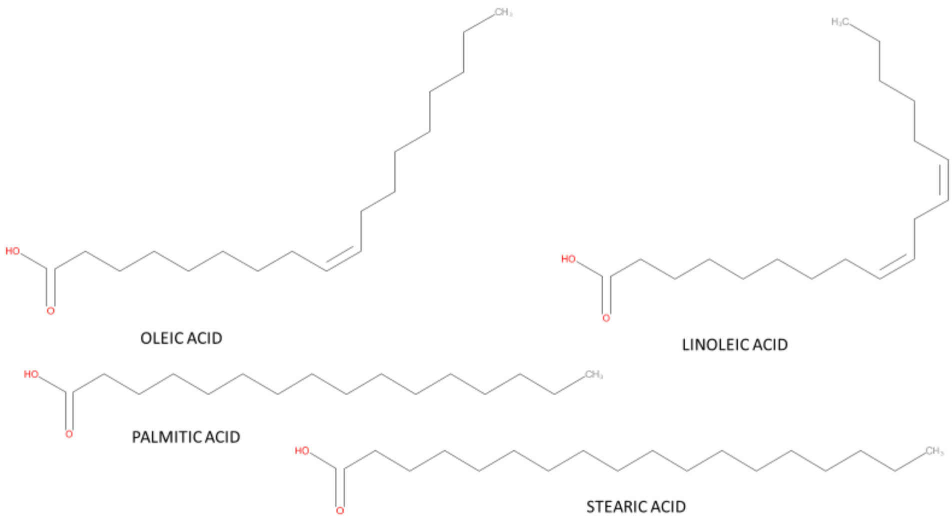


Figure 2.3: Structure of lipids derived from pineapple waste

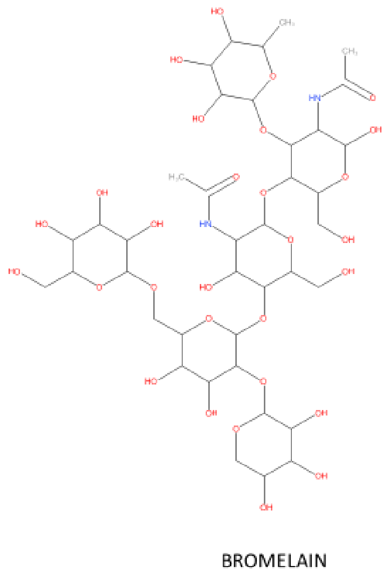


Figure 2.4: Structure of bromelain derived from pineapple waste

Phase separation was achieved by centrifuging for 30 to 50 minutes at 14,000 rpm. The aqueous phase was examined for bromelain activity after the reverse extraction (Wan et al., 2016). Aqueous two-phase system (ATPS) was employed for the extraction of bromelain from pineapple peels (Ketnawa et al., 2011). Bromelain was primarily partitioned to the phase that was high in polyethylene glycol (Ketnawa et al., 2011). Purified bromelain extracts were produced using consecutive batch membrane processing techniques that included microfiltration, ultrafiltration, and ultracentrifugation (Doko et al., 1991).

### *2.1.7 Aromatic compounds*

Pineapple crown leaves were subjected to pyrolysis that yielded oxygenated chemicals which were then transformed into aromatic compounds using the HZSM-5 catalyst at 600 °C. Fast pyrolysis, a high-temperature process was used that involved heating of PCL without oxygen to produce vapours, which were then instantly cooled to generate pyrolysis/bio-oil and which when passed over zeolites was changed into aromatic compounds (Peacocke and Bridgwater, 2000; Maneffa et al., 2016). The process began with the formation of anhydrous sugars from cellulose or hemicellulose molecules, which were then dehydrated to form furans and further reactions occurred on acid zeolite to give aromatic compounds (Barbosa et al., 2019; Maneffa et al., 2016). Through the process of fast catalytic pyrolysis, lignocellulosic biomass is converted into aromatic compounds of industrial interest like benzene, toluene, ethylbenzene, and xylene (Barbosa et al., 2019; Maneffa et al., 2016)

**Table 1.2:** Molecules and method of extraction

| S. No. | Molecules extracted | Method of extraction and a brief description | Extraction time | Solvent | Advantages | Disadvantages | Reference |
|---|---|---|---|---|---|---|---|
| 1. | Citric acid | Solid state fermentation (SSF) of glucose or sucrose by *Aspergillus niger*. | 24 h | Methanol | Low cost, higher product stability | Growth rate of microbes on solid substratum is relatively slow, production of excessive heat in the medium | Ayeni et al., 2019; Papagianni, 2007 |
| 2. | Succinic acid | Fermentation of pineapple hydrosylate using *Actinobacillus succinogenes*, *Escherichia coli* | 3-4 days | Sulfuric acid | Simple process, higher product stability | Time consuming, high cost | Jusoh et al., 2014; Pathanibul and Hongkulsup, 2021 Dessie et al., 2018 |
| 3. | Lactic acid | Fermentation using *Lactobacillus lactis* and the enzyme invertase to hydrolyze sucrose into glucose and fructose | 72 h | Calcium alginate | Simple technology, higher yield, low cost | Difficult to scale up and maintain parameters like pH, moisture and temperature | Datta and Tsai, 1997; Idris and Suzana, 2006; Jin et al., 2005; Ueno et al., 2003 |
| 4. | Acetic acid | Fermentation using *Saccharomyces cerevisiae, Acetobacter aceti* | 10-30 days | Ethanol | Simple process, higher product stability | Time consuming, high cost | Umaru, 2015; Roda et al., 2017 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5. | Oxalic acid | Fermentation using *Aspergillus niger* | 9 days | $KH_2PO_4$, $MgSO_4$ and $NaNO_3$ | Simple technology, higher yield, low cost | Time consuming | Amenaghawon and Kazeem, 2020 |
| 6. | Essential oils | Hydro-distillation (HD) in which aqueous solution of pineapple peels was first added to a round bottom flask and then connected to clevenger-type apparatus | 3 h | water | Simple instrumentation, low cost, free from organic solvents | Thermal degradation of products, high consumption of energy | Mohamad et al., 2019 |
| | | Hydro-distillation with enzyme-assisted pre-treatment (HDEA) in which pineapple peels were mixed with acetate buffer and acremonium cellulase solution for different enzyme loadings followed by HD procedure. | 90 mins | acetate buffer | High efficiency, requires mild conditions | Only produced hydrosols instead of essential oil, expensive | Mohamad et al., 2019 |
| | | Supercritical fluid extraction (SFE) in which pineapple peels were placed in the SC–$CO_2$ extraction apparatus | 3 h | $CO_2$ | Solvent $CO_2$ is inexpensive, solvent recycling can be done | Loss of desired compounds with improper solvent selection, specialized instrument required | Mohamad et al., 2019; Kamali et al., 2015 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | followed by dynamic extraction | | | | | |
| 7. | Carbohydrates | Enzymatic hydrolysis of hemicellulose to produce XOS | 16 h | Acetate buffer | Able to produce phases which aren't stable at higher temperatures safely | Higher incubation temperatures can lead to disintegration of the hemicellulose | Banerjee et al., 2019 |
| 8. | Pectin | Acid extraction and ethanol precipitation in which dried PW was taken in a beaker followed by the addition of distilled water and sulphuric acid, then ethanol was added for the coagulation of filtrate | 65 mins | Ethanol | Simple and requires manual work | High consumption of energy and material | Sarangi et al., 2020 |
| | | Ultrasound assisted extraction (UAE) which induced the collapse of cavitation bubbles near cell walls which causes cell disruption, thus causing stronger and enhanced solvent entrance into the cells and amplification of the mass transfer | 15-30 mins | Acidified water | High yield, requires less solvent, green method | Requires optimisation | Shivamathi et al., 2022 |

| | | | | | | | |
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| | | Microwave heating in which there is absorption of strong microwave energy to heat the solvent in order to permit the partitioning of analytes in the sample matrix into the solvent | 1-20 minute | 0.5 N $H_2SO_4$ with pH 1.83 and 1:30 (w/v) solid-to-solvent ratio | Rapid, high yield with enhanced purity | High maintenance cost | Zakaria et al., 2021 |
| 9. | Starch | Mechanical extraction, a simple process of wet grinding and washing | 48-50 h | Distilled water | Cost effective, takes less time | Choice of sample can be difficult | Nakthong et al., 2017 |
| 10. | Glucose | Enzymatic hydrolysis using cellulase | 72 h | Sodium citrate buffer | Low toxicity | Time consuming | Banerjee et al., 2022; Mund et al., 2021 |
| 11. | Poly-phenols | Soxhlet extraction/solid-liquid extraction technique for polyphenols using soxhlet apparatus | 6-8 h | Aqueous methanol | A very simple process that involves limited preparation | Time consuming, large volume of solvent required | Madhumeena et al., 2021; Salve and Ray, 2020 |
| | | Supercritical fluid extraction (SFE), a green technology due to use of supercritical $CO_2$ | 10-60 mins | $CO_2$ | Takes less time and is eco safe, recycling of supercritical fluid is feasible. | Many parameters to optimize, $CO_2$ is unsuitable for polar materials | Salve and Ray, 2020 |

| | | | | | | | |
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| | | Pressurised solvent extraction in which analyte extraction from the sample is done under elevated temperature and pressure conditions. | 5-10 mins | Organic solvents such as diethyl ether | Less extraction time, and less solvent required. | Cost of equipment and thermal degradation | Kaufmann and Christen, 2002 |
| | | Ultrasonic-assisted extraction method to extract polyphenols whose main principle involved acoustic cavitation | 10–90 mins | Ethanol | Less solvent required and less extraction time, cost-effective | Requires optimisation, possible negative pressure cavitation | Carreira-Casais et al., 2021; Kumar et al., 2021; Salve and Ray, 2020 |
| | | Microwave assisted extraction in which electromagnetic energy is transformed into heat, accompanied by ionic conduction and molecular dipole rotation | 30-60 sec | Ethanol, methanol, DESs | Decreased thermal gradients, equipment size reduced, rapid | Extraction solvent must absorb microwave energy | Alias and Abbas, 2017; Salve and Ray, 2020; Vargas-Serna et al., 2022 |
| | | Autohydrolysis, a green method that utilises only water as a solvent system | 30 mins | Water | Absence of chemical solvent, no corrosion problems, simple to operate, cost-effective and economical | Less recovery of polyphenols | Batalha et al., 2015; Sepúlveda et al., 2018 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 12. | Ferulic acid | Enzymatic that includes microbial fermentation by feruloyl esterase | 3 h | Dry methanol | Highly efficient | Lengthy, cumbersome, and uneconomical | Faulds and Williamson, 1993 |
| | | Alkaline, a simple extraction method was employed using alkaline hydrolysate | 24 h | NaOH | Facile instrumentation | Not an environment friendly technique | Liu et al., 2006 |
| 13. | Lipids | Liquid-liquid extraction in which the sugars in pineapple pulp were converted into lipids by *R. glutinis* | 4-5 hour | Chloroform, methanol | Useful to separate single component from multi-component mixture | Large amounts of solvents may be consumed | Tinoi and Rakariyatham, 2016 |
| 14. | Bromelain | Ammonium sulphate precipitation in which bromelain was precipitated from clarified pineapple extract by adding [$(NH_4)_2SO_4$] | 15 min | – | Allows for the rapid, bulk precipitation of cellular proteins. | Bromelain produced is not as pure as expected causing another purification process to take place. | Devakate et al., 2009 |
| | | Reverse micellar system in which phase separation followed by reverse extraction; the aqueous phase was examined for bromelain. | 60-90 min | 1- hexanol to n-hexane in 1:9 volume ratio | Highly purified bromelain can be extracted. | Drop-in activity due to alteration in structures of proteins, slow rate of reverse extraction | Wan et al., 2016 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Aqueous two-phase extraction that was performed in 50-mL centrifuge tubes and the effect of PEG on the partitioning of bromelain was done | 20-25min | 17% $MgSO_4$ | simple, fast, and relatively cheap | Predicting the partitioning of biomolecules in ATPS can be difficult. | Ketnawa et al., 2011 |
| 15. | Aromatic compounds | Catalytic fast pyrolysis, a high-temperature process that involves rapid heating without oxygen | 2-10 sec | Zeolite catalysts | Simple, inexpensive | Energy intensive, produces undesirable by-products | Barbosa et al., 2019; Peacocke and Bridgwater, 2000; Maneffa et al., 2016 |

## 2.2 VALUE-ADDITION TO PINEAPPLE WASTE

### *2.2.1 Aerogels*

Pineapple fibres from pineapple leaves were explored as a viable source for cellulose-based aerogel development due to their biodegradability, low cost, high cellulose content, and exceptional mechanical properties. A highly porous cellulose aerogel with a high adsorption capacity can be produced by combining natural fibres from agricultural waste such as pineapple fibres with an adhesive reagent. Using deionized water as a solvent and polyvinyl alcohol (PVA) as an adhesive, flexible cellulose aerogel from raw pineapple-leaf fibres (PALF) have been produced (Do et al., 2020).

### *2.2.2 Pineapple waste assisted nanoparticles synthesis*

Pineapple remnants including pericarp, fibres, leaves etc. contains high phenolic content, different kinds of phytochemicals and a high concentration of cellulose, hemicellulose, and lignin. All these properties of pineapple waste can be utilised in the production of nanoparticles including ZnO nanoparticles, carbon nanosheets, silver nanoparticles and nanocellulose.

**ZnO nanoparticles**

Pineapple plant extracts are rich in phytochemicals such as polyphenols, terpenoids, flavonoid alkaloids and sugars that function either as reducing agent or as capping or stabilising agent in the synthesis of nanoparticles. In the production of ZnO nanoparticles, pineapple peel extract was used as the capping agent and KOH solution and wood ash lye were utilised as reducing agents (Klinbumrung et al., 2022). The discarded pineapple pericarp can also be used to produce nanoparticles using sonication. Pineapple rind is a waste product that can be used as coating and stabilising agents in the production of nanoparticles (Mirgane et al., 2021).

**Carbon nanosheets**

Pineapple leaves, a novel sustainable source, were effectively used to prepare activated carbon in the form of extremely porous, open-channel carbon nanosheets (Sodtipinta et al., 2017). The process starts with the raw material being transformed into pineapple leaf fibre (PALF) which is then used to produce activated carbon using hydrothermal process, chemical activation, and heat treatment in an argon atmosphere (Sodtipinta et al., 2017).

**Silver nanoparticles (AgNPs)**

Pineapple leaf was utilised to produce silver nanoparticles (Emeka et al., 2014). The pineapple peel extract acts as the reducing agent to produce silver nanoparticles by a cost-effective and ecologically friendly method of biosynthesis with size ranging from 20 nm to 30 nm (Syed Omar and Mustapa, 2018; Poadang et al., 2017). Pineapple leaf extract was used to produce AgNPs at a temperature of 70 °C. The smallest AgNPs particle size was 30 nm, which was attained in a solution of 1 mM AgNO3 after 24 hours of stirring at 70 °C. The stability of the colloidal AgNPs lasted up to 7 days (Hamdiani and Shih, 2021). Without the use of any reducing or stabilising agents, an aqueous extract of pineapple peel waste was successfully used to synthesise ultra-small (average size 14–20 nm) AgNPs. Two key variables, namely the concentration ratio of peel extract to silver ion precursor and the synthesis pH, were discovered to be important for producing monodispersed and stable AgNPs (Agnihotri et al., 2018). Colloidal silver nanoparticles (AgNPs) were synthesised using pineapple peel extract as a reductant and stabiliser. The synthesised AgNPs had diameters ranging from 10 to 55 nm and were virtually spherical in shape. Phytochemical in pineapple peel extract were found responsible for the reduction and stabilisation of the biogenic AgNPs (Poadang et al., 2017).

**Cellulose nanocrystals**

There are three methods namely acid hydrolysis, enzymatic hydrolysis, and mechanical method for the extraction of nanocellulose (Nguyen et al., 2021). The pineapple crown is a rich source of cellulose and cellulose nanocrystals can be extracted from it by mercerization, bleaching and acid hydrolysis with $H_2SO_4$ (Prado and Spinacé, 2019). With the help of sulfuric acid hydrolysis, bleaching and alkali treatments, needle-like nanocellulose (PPNc) were extracted from pineapple peels (Dai et al., 2018). Pineapple peel residual juice contains sugar and nitrogen components that were helpful for the production of bacterial cellulose by

*Gluconacetobacter xylinus*, which upon sulfuric acid hydrolysis gave cellulose nanocrystals (CNC) (Anwar et al., 2015). The effective extraction of cellulose nanofibrils from pineapple leaf fibres using mechanical methods involves steam explosion method. In order to depolymerize and defibrillate pineapple leaf fibres and make nanofibrils, steam-coupled acid treatment is useful (Cherian et al., 2010). The steam explosion is characterised by high-pressure steaming and quick decompression. The material is saturated with steam at high pressure and temperature and following the pressure is suddenly released causing the water to flash evaporate and create a thermomechanical force that causes the material to rupture (Cherian et al., 2010). The pre-treatment method of steam explosion can be utilised to lower the amount of non-cellulosic components followed by acid treatment to give the nanocellulose (Cherian et al., 2010). Chemo-mechanical approach to extract nanocellulose from PALF (pineapple leaf fibres) involves chemical processing, sonication and milling. The pre-treatment aims to get rid of components like lignin and hemicellulose and further acid hydrolysis is used to obtain nanocellulose (Gadzama et al., 2020) (Table 2.2).

**Table 2.3**: Extraction techniques of cellulose nanocrystals

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Cellulose nano-crystals | Acid hydrolysis | The needle-like nano cellulose (PPNc), isolated using sulfuric acid hydrolysis | 15 h | Sulfuric acid | Simple waste processing and low raw material costs. | Long reaction time and high concentrations of acid results in corrosion | Anwar et al., 2015; Dai et al., 2018; Prado and Spinacé, 2019 |
| | Enzymatic hydrolysis | Production of nanocellulose by enzymes of various activity | 72 h | Sodium-citrate buffer | Does not release toxic residues and can be conducted under room temperature and pressure for energy-saving purposes | Less effective than acid hydrolysis | de Campos et al., 2013 |
| | Steam explosion method | Extraction of cellulose nanofibrils from pineapple leaf fibres by steam coupled acid treatment | 6-7 h | Oxalic acid | Environmentally friendly and requires low capital investment | Some changes occur in the arrangement of macromolecular chains and degradation of cellulose, hemi-celluloses and lignin is difficult to control. | Cherian et al., 2010 |
| | Chemo-mechanical | Extraction using pre-treatment employing bleaching, acid hydrolysis followed by sonication and milling. | 5-6 h | NaOH | Reduced need for extensive chemical pre-treatment, minimized the use of expensive and potentially environmentally damaging chemicals | Time consuming | Gadzama et al., 2020 |

### *2.2.3 Fibres and polymer matrix composites*

One of the widely accessible waste materials from pineapple plant is pineapple leaf fibre (PALF). Ash (1.1%), lignin (5–12%), and holocellulose (70–82%) make up the chemical composition of PALF (Arib et al., 2004; Asim et al., 2015). PALF have been used as raw materials for the industries rather than the costly and non-renewable synthetic fibre. Natural fibre's only disadvantage is its tendency to absorb moisture which can be overcomed by adding chemicals to alter its surface property (Asim et al., 2015). Manual or hand scraping, mechanical decortication, and retting are some of the conventional techniques for extracting PALF. These techniques produce PALF in the form of lengthy fibre bundles. PALF can be further processed using sodium hydroxide and the mechanical forces of a high-speed mixer to create pineapple leaf microfiber (PALMF). Both PALF and PALMF have a strong potential as reinforcement for polymer matrix composites due to their good mechanical capabilities (Kengkhetkit et al., 2018). Low-density polyethylene (LDPE) composites (George et al., 1998), biodegradable plastic composites (Asim et al., 2015), and reinforced polymer composites (Mishra et al., 2001; Pavithran et al., 1987) using pineapple (PALF) showed excellent mechanical qualities.

### *2.2.4 Anti-dyeing agent*

The waste from pineapple such as the peel, core and crown has also been used to remove dyes as pineapple adsorbent is inexpensive and can reduce disposal costs (Subki, 2017). The magnetized activated carbon from pineapple crown leaves was prepared to be used as an adsorbent for removing methyl violet, an organic dye that is commonly used in the paint and textile industries (Astuti et al., 2019), mesoporous activated carbons were produced from PCL to remove caffeine (Beltrame et al., 2018) and titanium dioxide nano bio-adsorbent ($TiO_2L$) was also synthesised to remove Victoria blue dye (Fakhar et al., 2020). Pineapple stem was employed as an adsorbent to remove the cationic dye (Hameed et al., 2009) and safranin-O from water (Mohammed et al., 2014) and to extract methylene blue from an aqueous solution. Biochar and activated carbon were produced from pineapple waste biomass (PWB) for the purpose of immobilizing lipase and RBBR (remazol brilliant blue R) dye adsorption (Veeramalai et al., 2022). Pineapple Peels were used for the biosorption of an anionic dye, Eosin Yellow (Ugbe et al., 2018).

### *2.2.5 For heavy metal intoxication*

Pineapple waste have attracted attention as sorbents for hazardous metals. Heavy metals and chemical oxygen demand (COD) in wastewater are reduced by activated carbon made from pineapple waste (Subki, 2017). Pineapple fruit peel biomass that has undergone chemical oxidation has been employed as a biosorbent to remove Cd(II) and Pb(II) from aqueous solutions (Ahmad et al., 2016). The pineapple crown leaf was employed as a bioadsorbent of Cr(VI) and Cr(III) in the aqueous phase, an affordable approach for the treatment of wastewater (Gogoi et al., 2018; Ponou et al., 2011). In order to remove heavy metals (cadmium, lead, and zinc) from contaminated soils, pineapple waste is also employed as a soil remediation agent (Feng et al., 2018). The stem of the pineapple plant is employed as an adsorbent to lower the concentration of Pb (II) in aqueous solutions (Ayob et al., 2020; Ting et al., 2019). Cell-EDTA and Cell-CM, produced either by the modification of cellulose fibre obtained from pineapple leaves with ethylenediaminetetraacetic acid (EDTA) and carboxymethyl (CM) groups respectively were used as heavy metal ion adsorbents of Pb(II) and Cd(II) (Daochalermwong et al., 2020) or by the reaction with succinic anhydride in pyridine and dimethyl sulfoxide solvent or by chemical modification, i.e., the introduction of carboxylic groups were used as heavy metal ion adsorbents of Cu(II), Cd(II), and Pb(II) (Hu and Huang, 2010). The adsorption of cadmium and lead ions is more effective on adsorbents made from pineapple waste after treatment with sodium hydroxide (Mopoung and Kengkhetkit, 2016). For removing Fe(III) from aqueous solutions, $KMnO_4$ modified carbon was prepared from the pineapple leaf fibre (Mopoung and Bunterm, 2016). For the elimination of Cr(VI) from the aqueous solution, pineapple leaf fibre was surface-modified by alkali solution (APF), followed by polyethyleneimine-grafting utilising carbamate-linkage reaction (APF-PEI) (Tangtubtim and Saikrasun, 2019).

### *2.2.6 Pineapple waste as carbon source*

**Bioenergy**

Pineapple waste has been utilised as a fuel and using zinc and copper electrodes, this produced bioelectricity using single-chamber microbial fuel cells (Rojas-Flores et al., 2022). Waste from pineapples including peel, core, leaf and crown have been utilised to produce biofuels like biohydrogen, bioethanol, biodiesel, biobutanol, biogas and biohythane which are environmentally beneficial fuels and are the energy carriers to meet future needs.

**Production of biohydrogen**

Waste from pineapples (peel, core, and leaf) has been utilised in the production of biohydrogen (Cahyari et al., 2018). Biohydrogen is the preferred energy carrier to meet future needs due to its better properties such as lower emissions of greenhouse gases, high energy density, high energy conversion rate using a fuel cell (Cahyari et al., 2018) and use of less energy (Reungsang and Sreela-or, 2013). Pineapple waste were fermented in dark, mesophilic environment to produce biohydrogen (Cahyari et al., 2018). The fermentation process has a significant potential for commercialization energy production in future because it can be carried out at standard pressure and temperature conditions (Abd Jalil et al., 2018). Anaerobic microorganisms were used in fermentation due to their ability to utilise carbon substrates and to release hydrogen (Sivagurunathan et al., 2017). The well-known bacteria Clostridium sp. was found to be ideal for higher yields of biohydrogen (Bru et al., 2012). Co-culture approach for biohydrogen production was found to be the ideal choice as it resulted in enhancement of cell activity and culturing in order to increase production in a short period of fermentation (Goers et al., 2014; Kao et al., 2014).

**Production of bioethanol**

The high levels of sugar and lignocellulose found in the peel and crown of PW proved to be a valuable source for fermentation in the production of bioethanol (Casabar et al., 2019; Tropea et al., 2014). Three different methods were used for the extraction of bioethanol from PW: simultaneous saccharification and fermentation

(SSF), separate hydrolysis and fermentation (SHF), and direct fermentation (DF) (Casabar et al., 2019). Pineapple waste can be utilised in the production of cellulase using *Trichoderma reesei* where the cellulase produced was used in the production of bioethanol (Saravanan et al., 2013).

**Production of biodiesel**

Pineapple leaves were converted into biodiesel through the process of transesterification and calcination. The calcined pineapple leaves (CPL) exhibited a high catalytic efficiency and conversions greater than 98% were measured. CPL were found to reduce biowaste while acting as a highly effective biodiesel catalyst (Barros et al., 2020). Pineapple waste was used as a carbon substrate for the production of lipids using *Candida tropicalis* as the microorganism through the process of fermentation. Extracted lipids were then converted into fatty acids methyl esters (FAME) called the biodiesel through the transesterification reaction (Kanakdande et al., 2020). Pineapple peels were used to produce lipase by anaerobic fermentation and were found to be a prospective choice because of non-toxicity, tolerance to organic solvents, reusability, and insensitivity to free fatty acids. Partially purified lipase (PPL) could be an efficient and effective biocatalyst for biodiesel production as the lipase generated was found to exhibit greater catalytic efficiency for the conversion of palm oil into biodiesel (Selvakumar and Sivashanmugam, 2017).

**Production of biobutanol**

ABE fermentation, also known as acetone-butanol-ethanol synthesis is the method used to produce biobutanol from pineapple waste. *Clostridium* sp. converts sugars present in pineapple waste to butanol by employing acid hydrolysis and detoxification with activated carbon (Huzir et al., 2018; Khedkar et al., 2017). *C. beijerinckii* (Sanguanchaipaiwong and Leksawasdi, 2018) and *C. acetobutylicum* (Khedkar et al., 2017) are the two most commonly used solventogenic species for the synthesis of butanol.

**Production of biogas**

Pineapple peels were found to be a potential source for the production of biogas due to their high cellulose, hemicellulose, and other carbohydrate content. Mixed fruit wastes containing pineapple waste was used for biogas production (Lane, 1984; Viswanath et al., 1992). Under varied conditions, pineapple peels produced biogas that ranged from 0.41 to 0.67 mg/kg in volatile solids with a methane content of 41 to 65 % (Rani and Nand, 2004). By adopting semicontinuous anaerobic digestion, pineapple waste was used to produce methane, with a maximum methane concentration of 51% and a maximum daily biogas production rate of up to 1682 mL/day (Bardiya et al., 1996). Using municipal sewage sludge as the $H_2$ producer, pineapple waste was used as the carbon source (Wang et al., 2006). Volatile fatty acids and methane both were produced using solid pineapple waste. Along with methane, acetic, propionic, butyric, ibutyric, and valeric acids were also produced (Babel et al., 2004). The nutritional requirement for economically viable biohythane synthesis was obtained by co-digestion of fruit pineapple waste (Dareioti and Kornaros, 2015; Sen et al., 2016).

**Single cell protein (SCP)**

Single cell protein refers to the dried, dead microbial cells or total amount of protein that can be isolated from pure microbial cultures of filamentous fungi, algae, bacteria, unicellular algae, and cyanobacteria. These microbial cultures are grown on diverse carbon sources such as pineapple waste and utilized as a protein supplement (Mensah and Twumasi, 2017). Pineapple waste served as the carbon source for the fermentation media on which the two strains of yeast, *Saccharomyces cerevisiae* and *Candida tropicalis* were cultivated. Using conventional methods, PW and other food wastes were used as the growing medium for *A. niger* (Oshoma and Eguakun-Owie, 2018). The biomass yield and protein synthesis within yeast cells were improved by using pineapple waste as a substrate (Dharumadurai et al., 2011).

**Enzyme production**

β-Glucosidase enzyme was produced from pineapple waste by P. miczynskii (Beitel and Knob, 2013). Esterases, a significant class of hydrolytic enzymes was also produced from pineapple waste enriched soil using esterase producing bacteria, Bacillus subtilis E9 and Bacillus sp. E46 (Soumya and Kochupurackal, 2020). PW was employed as nutrient substance in culture broth and cellulase production. It was used as the substrate for optimisation of cellulase production utilising statistical methods based on experimental designs using Trichoderma reesei. Fermentation process was carried out in Erlenmeyer flasks with pineapple waste powder. Flask was then covered with cotton, and it was autoclaved for 20 min. The flasks were then kept at room temperature for 48 hours post cooling. Cellulase production was determined to be at its highest on the sixth day of fermentation (Saravanan et al., 2013).

### *2.2.7 Therapeutic applications*

Pineapple peel has the potential for medical usage, including source for the synthesis of antibiotics (Lubaina et al., 2019). Pineapple peel extract of the fermented fruit can prove to be an emerging potential in therapeutic approaches for cancer (Rashad et al., 2015). Transcinnamic acid and ferulic acid work together to give the plant its antibacterial, anticancer, and antioxidant effects (Jayashree et al., 2017) and gallic acid also contributes to a variety of characteristic properties that includes antibacterial, antifungal, and anticancer effects (Polanía et al., 2022). Pineapple waste contains polyphenols in its skin, pulp, and juice (Yahya et al., 2019). Polyphenols are known to exhibit biological and antioxidant activity (Segovia Gómez and Almajano Pablos, 2016). The two main types of polyphenols in pineapples found responsible for its antioxidant activity were flavonoids and phenolic acids (da Silva et al., 2013). For the recovery of polyphenols from dried PS, a more environmentally friendly ultrasound-assisted extraction (UAE) approach that requires less solvent and reduced extraction time (Zardo et al., 2019) was used (Yahya et al., 2019). A flavonoid known as myricetin is linked to antioxidant activity and is also involved in cellular processes that inhibit the growth of tumor cells (Johnson, 2004). Three phenolic acids found in pineapples-caffeic acid, p-coumaric acid, and ferulic acid were found to exhibit antioxidant, anticancer, and antibacterial activity (Heleno et al., 2015). The total phenolic content and antioxidant activities of methanolic extracts of pineapple residues (pulp, seeds, and peels) were determined, utilising DPPH and superoxide anion scavenging activity (de Oliveira et al., 2009; Li et al., 2014). Catechin, epicatechin, gallic acid, and ferulic acid were discovered to be the main polyphenolic components present in pineapple peels and these components were responsible for its antioxidant activity (Li et al., 2014). Raw pineapple extracts are rich in nutrients and bioactive substances like proteins, minerals, lipids, vitamin C, phenolic compounds, flavonoids, and carotenes and thus offers a variety of therapeutic benefits (Romelle et al., 2016; Niramol et al., 2018; Sah et al., 2016). Bioactive components from *Ananas comosus* reduced the release of inflammatory cytokines and decreased T-cell proliferation (Kumar et al., 2022). Consequently, *Ananas comosus* nanoemulsion (NE) can be utilised for the treatment of cancer (Kumar et al., 2022). PW waste has the potential to be used as a nutraceutical for the treatment of diabetes (Riya et al., 2014). The extraction is usually done by traditional methods such as macerating, hydro-distillation, and solid-liquid extraction utilising organic solvents (Giacometti et al., 2018; Wang and Weller, 2006).

The potential of pineapple peel in growth medium for the *Lactobacillus* species was also explored. Pineapple waste was used as the source of carbon for the fermentation media to support the growth of three probiotic strains of *Lactobacillus* sp. (Pyar et al., 2014). Pineapple peel was found to be an essential prebiotic component in the production of yogurt with higher nutrient content and functionality (Sah et al., 2015). Pineapple peel flour contains around 60% of fibre and 20% of the total amount of soluble carbohydrates which makes the pineapple peel a rich carbon source for the growth of lactic acid bacteria. Pineapple peel's fermentable properties, high level of total dietary fibre, and antioxidant characteristics makes it a functional ingredient (Diaz-Vela et al., 2013). PW has a high reducing sugar content (30.5 mg/100g) as well as a high ash level (1.8 mg/100 g). It also showed high concentrations of crude fibre, non-reducing sugars, carbohydrates, and proteins, all of which can act as substrate for the growth of probiotics and yeast fermentation which results in the production of ethanol and single-cell protein (Hemalatha and Anbuselvi, 2013). Additionally, pineapple peel and stem extracts were taken in account for their prebiotic action in the development of a new functional ingredient. Six different probiotic strains from the two unique genera *Lactobacillus* sp. and *Bifidobacterium* sp. were used for the initial screening. With the exception of Lactobacillus acidophilus, all other bacteria showed favourable growth in response to pineapple extracts (Campos, 2018).

**Hydrogels**

Hydrogels can be produced from the cellulose present in pineapple peels. To obtain CMC, carboxymethylation was carried out by the reaction of pineapple cellulose with chloroacetic acid (Tuyet Phan et al., 2021). Carboxymethyl cellulose (CMC) was obtained from pineapple leaf waste through the process of etherification by treating pineapple leaf powder with a solution of NaOH followed by $HNO_3$. The hydrogel was prepared by graft copolymerization of acrylic acid and acrylamide with the synthesised CMC (Tuyet Phan et al., 2021). N,N′-methylenebisacrylamide (MBA) acted as the crosslinking agent and ammonium persulfate (APS) as the initiator during the reaction (Tuyet Phan et al., 2021). By grafting acrylic acid and carrying out homogenous acetylation of cellulose in ionic liquid 1-butyl-3-methylimidazolium chloride, pineapple peel-based hydrogels and sepia ink were produced (Dai and Huang, 2016). First, pineapple pulp was filtered through etamine and the leftover material was dried before being pulverised through a mesh screen. Dried pineapple peel powder was incubated with distilled water for two hours to extract the cellulose. Sodium chlorite was combined with the insoluble residue to remove lignin after the filtration. The residue was then shaken with potassium hydroxide solution at the room temperature. PPC was obtained after the solution was cleaned and dried with water and ethanol. Superabsorbent hydrogels were synthesised by grafting acrylic acid and acrylamide onto carboxymethyl cellulose from pineapple peels (Dai and Huang, 2017). Carclazyte was additionally added to the hydrogels to enhance their pH sensitivity and swelling capacity.

### *2.2.8 Reformation of retrieved compounds into valuable products for use in food and drinks*

The production of rock buns, a snack diet enhanced with pineapple pomace contains larger amounts of fibre and vitamin C which boosts the nutritional content, fosters dietary diversity and ensures food sustainability (Badjona et al., 2019).

**Production of biopolymers**

Pineapple waste, particularly the stem contains holocellulose and hemicellulose which makes it a suitable substrate for the production of biopolymers

(Chen, 2014). A natural polymer cellulose is obtained by refluxing the pineapple by-products (Xu et al., 2009). Carboxymethylcellulose (CMC), a biopolymer can be obtained from pineapple peel through cellulose by the process of etherification (Ramadhan and Handayani, 2020). Tapioca-based bioplastic resin (TBR) can be prepared from pineapple leaf fiber (PALF) (Mathivanan et al., 2016). *B.drentensis* strain BP17 is a bacteria used for PHB production using pineapple peel as a low-cost alternative carbon source (Penkhrue et al., 2020). For extracting biopolymers, the pineapple peels were fermented with ammonium sulphate or dipotassium phosphate, followed by hydrolysis with $H_2SO_4$ at a rate of 4000 rpm (Maraveas, 2020). Waste from the agro-industrial sector like pineapple peel residues can also be used to make biopolymers like polyhydroxyalkanoates (PHA) through fermentation using *Ralsthonia eutropha* ATCC 17697 strain.

### *2.2.9 Animal Feed and organic fertilizers*

Pineapple waste has also been utilised to produce high quality animal feed because of its palatability and presence of anti-nutrient factors like phytic acid and tannic acid (Bakri et al., 2020; Sruamsiri, 2007). The animal feed containing pineapple waste proved to boost the protein intake of animals and also increased the animal weight and digestibility (Costa et al., 2007). Pineapple liquid waste can be utilised as organic fertilizers (Sutanto, 2016) by using the process known as vermicomposting in which PLW acts as a substrate for the growth of bacteria. It decomposes very rapidly due to its high moisture content and presence of soluble carbohydrates (Sruamsiri, 2007). The nutritional content of pineapple waste combined with rice straw can be preserved by the process of ensiling (Jitramano, 2005). Dried and ensiled pineapple waste can be used as extra roughage which can replace 50% of the roughage in the total mixed ration for dairy cattle without having an impact on animal productivity (Sruamsiri, 2007). The growth performance of *Nile tilapia* (an aquatic organism) was enhanced by feed formulation using waste from pineapples (Sukri et al., 2022). Ruminant feed made from the leaves and the outer peel of the pineapples can be used in canning (Tran, 2006). Pineapple pulp can be also utilised for human consumption (Cabrera et al., 2000). However, the high fiber content and low protein content of the by-product of the pineapple processing sector makes it unattractive as animal feed (Correia et al., 2004).

**Table 2.4**: Summary of applications of pineapple waste

| S. No. | Production | Part of pineapple used | Benefit of production | Reference |
|---|---|---|---|---|
| 1. | Aerogels | Pineapple fibres | Ethylene gas adsorption and nickel (II) ion removal, Oil/water separation, Dye removal, Energy storage as supercapacitor electrode, Cr (VI) removal. | Do et al., 2022; Feng et al., 2015; Hao et al., 2014; Lim et al., 2020; Tan et al., 2023 |
| 2. | ZnO nanoparticles | Pineapple peel, pericarp | Antibacterial properties and capacity for wound healing, use in cotton textiles for ultraviolet light protection, wastewater treatment and photocatalytic activity. | Belay et al., 2020; Kaushik et al., 2019; Khalafi et al., 2019; Mirgane et al., 2021 |
| 3. | Carbon nanosheets | Pineapple leaves | High-performance energy storage devices like supercapacitors | Sodtipinta et al., 2017 |
| 4. | Silver nanoparticles | Pineapple leaves | Medicinal, cosmetic and environmental applications including the ability to eradicate harmful bacterial strains | Agnihotri et al., 2018 |
| 5. | Cellulose nanocrystals | Pineapple peel | Simple waste processing, and low raw material costs. | Dai et al., 2018 |
| 6. | Fibres | Pineapple leaf fiber (PALF) | Low-density polyethylene (LDPE) composites, biodegradable plastic composites and reinforced polymer composites | Asim et al., 2015; George et al., 1998; Mishra et al., 2001; Pavithran et al., 1987 |
| 7. | Anti-dyeing agent | Pineapple peel, core and crown | Paint and textile industries | Astuti et al., 2019 |

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|---|---|---|---|---|
| 8. | Heavy metal intoxication | Pineapple fruit peel, crown leaf | Soil remediation, wastewater treatment | Feng et al., 2018 |
| 9. | Biohydrogen | Pineapple peel, core, and leaf | Energy carrier to meet future needs | Reungsang and Sreela-or, 2013 |
| 10. | Bioethanol | Pineapple peel, crown | Sustainable bioethanol production | Tropea et al., 2014 |
| 11. | Biodiesel | Pineapple leaves | Environmentally beneficial fuel | Barros et al., 2020 |
| 12. | Biobutanol | Pineapple peel | Sustainable biobutanol production | Huzir et al., 2018 |
| 13. | Biogas | Pineapple peel | Environmentally beneficial fuel | Rani and Nand, 2004 |
| 14. | Single cell protein | Pineapple skin waste, peels, mesocarp | Address the world's protein deficit | Dharumadurai et al., 2011 |
| 15. | Enzyme production | Pineapple pulp and peels | Food industries, biomass hydrolysis for bioethanol production and enhancing the flavor of wine, tea and fruit juice | Beitel and Knob, 2013 |
| 16. | Antioxidants | Skin, pulp, and juice | Exhibits antioxidant, anticancer, and antibacterial activity | Heleno et al., 2015 |
| 17. | Medicinal properties | Pineapple peel | Antibacterial, anticancer, and antioxidant properties | Jayashree et al., 2017 |
| 18. | Probiotics | Pineapple peel | Production of ethanol and single-cell protein | Hemalatha and Anbuselvi, 2013 |
| 19. | Hydrogels | Pineapple peel | Water-manageable materials, slowrelease fertiliser and controlled drug release, contact lenses, personal care items, and wound dressings | Caló and Khutoryanskiy, 2015; Dai and Huang, 2017 |
| 20. | Biopolymers | Pineapple peel | Biomedical applications, including heart valves, tissue regeneration scaffolds, vascular grafts, stents, dental | Zinn et al., 2001 |

| | | | | |
|---|---|---|---|---|
| | | | and maxillofacial procedures, orthopedics, urology and wound management supplies (sutures and dressings). | |
| 21. | Animal feed | Crown, core, peel, leaves, and leftover flesh trimmings | Animal feed and fertiliser | Sukri et al., 2022 |

# CHAPTER - 3

# CONCLUSION

The pineapple industry involves huge quantity of by-products (stems, roots, and leaves) that possesses high economic potential. Collaborative efforts were made to recover and utilise pineapple waste in production of important chemicals such as organic acids, essential oils, nanocellulose, along with their application in pharmaceuticals, cosmetic, and textile sectors.

This article covered the processing of pineapple waste into useful molecules and highlights its utility in various sectors of the community. Pineapple by-products have a great potential in the production of organic acids, polyphenols, bromelain, pectin, and holds applications in generation of bioenergy. Pineapple waste was utilised as fermentable substrate which served as both, a carbon source for acid fermentation and as medium for bacterial growth. Thus, it can be utilised to produce organic acids namely citric acid, succinic acid, lactic acid, acetic acid and oxalic acid through the process of fermentation by employing different microorganisms. Essential oil can also be extracted from the peel and fibre of pineapple waste. Furthermore, xylan-rich lignocellulosic waste from pineapples can be used to produce XOS. Pineapple skin contained enough amount of phenolic chemicals that can be utilised in the pharmaceutical and cosmetics sectors. Salicylic acid, caffeic acid, myricetin, syringic acid, sinapic acid, ferulic acid etc. were the identified phenolics in pineapple, that were responsible for its antioxidant activity. Pineapple peel exhibited strong potential as a natural plasticizer and a source of pectin. Bromelain, a proteolytic enzyme was extracted from pineapple waste that can be utilised in pharmaceutical industries. Additionally, dietary fibres and phenolic antioxidants could be employed as a future source of nutraceuticals, providing low-income areas with a significant low-cost nutritional dietary supplement. Pineapple remnants such as pericarp, fibres, leaves etc. contained high phenolic content, various phytochemicals and a high concentration of cellulose, hemicellulose, and lignin which lead to the production of nanoparticles like ZnO nanoparticles, carbon nanosheets, and silver nanoparticles. The pineapple plant's stems and leaves were a great source for white, creamy, silk-like fibre. Pineapple leaf fibre (PALF) can replace the costly and non-renewable synthetic fibre and thus can act as a new source of raw materials for the industries. Further the usage of PALF as the source for cellulose-based aerogel development can prove effective due to their biodegradability, low cost, exceptional mechanical properties and high cellulose content. The peel, core, and crown, can also be used to remove dyes due to economic reasons and can also be utilised to produce biofuels like biohydrogen, bioethanol, biodiesel, biobutanol, biogas, biohythane which are environment friendly energy carriers to satisfy future needs. Pineapple waste have recently gained attention as sorbents for hazardous metals, due to their ability to adsorb toxic metals from aqueous systems. Pineapple peel was utilised as the source for the synthesis of antibiotics and also have the potential to be used as a nutraceutical in treatment of diabetes. Peels of pineapple can also be employed in making bioplastics (or biopolymers) by refluxing it with acid or alkaline solutions. Other such uses included utilising pineapple waste as fuel, in production of rock buns, and in making paper. Therefore, in conclusion, the waste from pineapples can be turned into valuable products if innovative scientific techniques are used.

# CHAPTER - 4

# REFERENCES

Abd Jalil, N.K., Asli, U.A., Hashim, H., Abd Jalil, A., Ahmad, A. and Khamis, A.K., 2018. Biohydrogen production from pineapple biomass residue using immobilized co-culture of Clostridium sporogenes and Enterobacter aerogenes. Journal of Energy and Safety Technology (JEST), 1(1).

Abdullah, A. and Mat, H., 2008. Characterisation of solid and liquid pineapple waste. Reaktor, 12(1), pp.48-52.

Agnihotri, S., Sillu, D., Sharma, G. and Arya, R.K., 2018. Photocatalytic and antibacterial potential of silver nanoparticles derived from pineapple waste: process optimization and modeling kinetics for dye removal. Applied Nanoscience, 8, pp.2077-2092.

Ahmad, A., Khatoon, A., Mohd-Setapar, S.H., Kumar, R. and Rafatullah, M., 2016. Chemically oxidized pineapple fruit peel for the biosorption of heavy metals from aqueous solutions. Desalination and Water Treatment, 57(14), pp.6432-6442.

Aili Hamzah, A.F., Hamzah, M.H., Che Man, H., Jamali, N.S., Siajam, S.I. and Ismail, M.H., 2021. Recent updates on the conversion of pineapple waste (Ananas comosus) to value-added products, future perspectives and challenges. Agronomy, 11(11), p.2221.

Alias, N.H. and Abbas, Z., 2017. Microwave-assisted extraction of phenolic compound from pineapple skins: The optimum operating condition and comparison with soxhlet extraction. Malaysian Journal of Analytical Sciences, 21(3), pp.690-699.

Amenaghawon, N.A. and Kazeem, J.O., 2020. Evaluation of response surface methodology, artificial neural network and adaptive neurons fuzzy inference system for modelling and optimizing oxalic acid production from pineapple waste. FUW Trends in Science & Technology Journal, 5(1), pp.255-263.

Anwar, B., Bundjali, B. and Arcana, I.M., 2015. Isolation of cellulose nanocrystals from bacterial cellulose produced from pineapple peel waste juice as culture medium. Procedia Chemistry, 16, pp.279-284.

Arib, R.M.N., Sapuan, S.M., Hamdan, M.A.M.M., Paridah, M.T. and Zaman, H.M.D.K., 2004. A literature review of pineapple fibre reinforced polymer composites. Polymers and Polymer Composites, 12(4), pp.341-348.

Asim, M., Abdan, K., Jawaid, M., Nasir, M., Dashtizadeh, Z., Ishak, M.R. and Hoque, M.E., 2015. A review on pineapple leaves fibre and its composites. International Journal of Polymer Science, 2015.

Astuti, W., Sulistyaningsih, T., Kusumastuti, E., Thomas, G.Y.R.S. and Kusnadi, R.Y., 2019. Thermal conversion of pineapple crown leaf waste to magnetized activated carbon for dye removal. Bioresource Technology, 287, p.121426.

Ayeni, A., Daramola, M.O., Taiwo, O., Olanrewaju, O.I., Oyekunle, D.T., Sekoai, P.T. and Elehinafe, F.B., 2019. Production of citric acid from the fermentation of pineapple waste by Aspergillus niger. The Open Chemical Engineering Journal, 13(1).

Ayob, A., Zamre, N.M., Izzati, N., Ariffin, M., Hidayu, N., Rani, A. and Mohamad, F., 2020. Pineapple waste as an adsorbent to remove lead from synthetic wastewater. International Journal of Latest Research in Engineering and Management, 4, pp.1-8.

Babel, S., Fukushi, K. and Sitanrassamee, B., 2004. Effect of acid speciation on solid waste liquefaction in an anaerobic acid digester. Water Research, 38(9), pp.2417-2423.

Badjona, A., Adubofuor, J., Amoah, I. and Diako, C., 2019. Valorisation of carrot and pineapple pomaces for rock buns development. Scientific African, 6, p.e00160.

Bakri, N.F.M., Ishak, Z., Jusoh, A.Z. and Hadijah, H., 2020. Quantification of nutritional composition and some antinutrient factors of banana peels and pineapple skins. Asian Food Science Journal, pp.1-10.

Banerjee, R., Chintagunta, A.D. and Ray, S., 2017. A cleaner and eco-friendly bioprocess for enhancing reducing sugar production from pineapple leaf waste. Journal of Cleaner Production, 149, pp.387-395.

Banerjee, S., Patti, A.F., Ranganathan, V. and Arora, A., 2019. Hemicellulose based biorefinery from pineapple peel waste: Xylan extraction and its conversion into xylooligosaccharides. Food and Bioproducts Processing, 117, pp.38-50.

Banerjee, S., Ranganathan, V., Patti, A. and Arora, A., 2018. Valorisation of pineapple wastes for food and therapeutic applications. Trends in Food Science & Technology, 82, pp.60-70.

Banerjee, S., Vijayaraghavan, R., Patti, A.F. and Arora, A., 2022. Integrated biorefinery strategy for valorization of pineapple processing waste into high-value products. Waste and Biomass Valorization, 13(1), pp.631-643.

Barbosa, A.S., Siqueira, L.A., Medeiros, R.L., Melo, D.M., Melo, M.A., Freitas, J.C. and Braga, R.M., 2019. Renewable aromatics through catalytic flash pyrolysis of pineapple crown leaves using HZSM-5 synthesized with RHA and diatomite. Waste Management, 88, pp.347-355.

Bardiya, N., Somayaji, D. and Khanna, S., 1996. Biomethanation of banana peel and pineapple waste. Bioresource Technology, *58*(1), pp.73-76.

Barretto, L.C.D.O., Moreira, J.D.J.D.S., Santos, J.A.B.D., Narendra, N. and Santos, R.A.R.D., 2013. Characterization and extraction of volatile compounds from pineapple (Ananas comosus L. Merril) processing residues. Food Science and Technology, 33, pp.638-645.

Barros, S.D.S., Junior, W.A.P., Sá, I.S., Takeno, M.L., Nobre, F.X., Pinheiro, W., Manzato, L., Iglauer, S. and de Freitas, F.A., 2020. Pineapple (Ananás comosus) leaves ash as a solid base catalyst for biodiesel synthesis. Bioresource Technology, 312, p.123569.

Batalha, L.A.R., Han, Q., Jameel, H., Chang, H.M., Colodette, J.L. and Gomes, F.J.B., 2015. Production of fermentable sugars from sugarcane bagasse by enzymatic hydrolysis after autohydrolysis and mechanical refining. Bioresource Technology, 180, pp.97-105.

Beitel, S.M. and Knob, A., 2013. Penicillium miczynskii β-glucosidase: a glucose-tolerant enzyme produced using pineapple peel as substrate. Industrial Biotechnology, 9(5), pp.293-300.

Belay, A., Mekuria, M. and Adam, G., 2020. Incorporation of zinc oxide nanoparticles in cotton textiles for ultraviolet light protection and antibacterial activities. Nanomaterials and Nanotechnology, 10, p.1847980420970052.

Beltrame, K.K., Cazetta, A.L., de Souza, P.S., Spessato, L., Silva, T.L. and Almeida, V.C., 2018. Adsorption of caffeine on mesoporous activated carbon fibers prepared from pineapple plant leaves. Ecotoxicology and Environmental Safety, 147, pp.64-71.

Berovic, M. and Legisa, M., 2007. Citric acid production. Biotechnology Annual Review, 13, pp.303-343.

Bru, K., Blazy, V., Joulian, C., Trably, E., Latrille, E., Quéméneur, M. and Dictor, M.C., 2012. Innovative CO2 pretreatment for enhancing biohydrogen production from the organic fraction of municipal solid waste (OFMSW). International Journal of Hydrogen Energy, 37(19), pp.14062-14071.

Cabrera, H.A.P., Menezes, H.C., Oliveira, J.V. and Batista, R.F.S., 2000. Evaluation of residual levels of benomyl, methyl parathion, diuron, and vamidothion in pineapple pulp and bagasse (Smooth cayenne). Journal of Agricultural and Food Chemistry, 48(11), pp.5750-5753.

Cahyari, K., Putri, A.M., Oktaviani, E.D., Hidayat, M.A. and Norajsha, J.D., 2018, May. Biohydrogen production from pineapple waste: effect of substrate concentration and acid pretreatment. In IOP Conference Series: Materials Science and Engineering (Vol. 358, No. 1, p. 012001). IOP Publishing.

Caló, E. and Khutoryanskiy, V.V., 2015. Biomedical applications of hydrogels: A review of patents and commercial products. European Polymer Journal, 65, pp.252-267.

Campos, D., Ribeiro, T., Teixeira, J., Pastrana, L. and Pintado, M.E., 2018. Assessment of potential prebiotic activity of pineapple by-products (peels and stems) extracts and maintenance of bioavailability through in vitro gastrointestinal tract system. In International Symposium of the International Scientific Association of Probiotics and Prebiotics.

Carreira-Casais, A., Otero, P., Garcia-Perez, P., Garcia-Oliveira, P., Pereira, A.G., Carpena, M., Soria-Lopez, A., Simal-Gandara, J. and Prieto, M.A., 2021. Benefits and drawbacks of ultrasound-assisted extraction for the recovery of bioactive compounds from marine algae. International Journal of Environmental Research and Public Health, 18(17), p.9153.

Casabar, J.T., Unpaprom, Y. and Ramaraj, R., 2019. Fermentation of pineapple fruit peel wastes for bioethanol production. Biomass Conversion and Biorefinery, 9, pp.761-765.

Chen, H., 2014. Applications of lignocellulose biotechnology in bioenergy. Biotechnology of Lignocellulose: Theory and Practice, pp.213-245.

Cheok, C.Y., Mohd Adzahan, N., Abdul Rahman, R., Zainal Abedin, N.H., Hussain, N., Sulaiman, R. and Chong, G.H., 2018. Current trends of tropical fruit waste utilization. Critical Reviews in Food Science and Nutrition, 58(3), pp.335-361.

Cherian, B.M., Leão, A.L., De Souza, S.F., Thomas, S., Pothan, L.A. and Kottaisamy, M., 2010. Isolation of nanocellulose from pineapple leaf fibres by steam explosion. Carbohydrate Polymers, 81(3), pp.720-725.

Correia, R.T., McCue, P., Magalhães, M.M., Macêdo, G.R. and Shetty, K., 2004. Production of phenolic antioxidants by the solid-state bioconversion of pineapple waste mixed with soy flour using Rhizopus oligosporus. Process Biochemistry, 39(12), pp.2167-2172.

Costa, R.G., Correia, M.X.C., Da Silva, J.H.V., De Medeiros, A.N. and De Carvalho, F.F.R., 2007. Effect of different levels of dehydrated pineapple by-products on intake, digestibility and performance of growing goats. Small Ruminant Research, 71(1-3), pp.138-143.

da Silva, D.I., Nogueira, G.D., Duzzioni, A.G. and Barrozo, M.A., 2013. Changes of antioxidant constituents in pineapple (Ananas comosus) residue during drying process. Industrial Crops and Products, 50, pp.557-562.

Dai, H. and Huang, H., 2016. Modified pineapple peel cellulose hydrogels embedded with sepia ink for effective removal of methylene blue. Carbohydrate Polymers, 148, pp.1-10.

Dai, H. and Huang, H., 2017. Enhanced swelling and responsive properties of pineapple peel carboxymethyl cellulose-g-poly (acrylic acid-co-acrylamide) superabsorbent hydrogel by the introduction of carclazyte. Journal of Agricultural and Food Chemistry, 65(3), pp.565-574.

Dai, H., Ou, S., Huang, Y. and Huang, H., 2018. Utilization of pineapple peel for production of nanocellulose and film application. Cellulose, 25, pp.1743-1756. .

Daochalermwong, A., Chanka, N., Songsrirote, K., Dittanet, P., Niamnuy, C. and Seubsai, A., 2020. Removal of heavy metal ions using modified celluloses prepared from pineapple leaf fiber. Acs Omega, 5(10), pp.5285-5296.

Dareioti, M.A. and Kornaros, M., 2015. Anaerobic mesophilic co-digestion of ensiled sorghum, cheese whey and liquid cow manure in a two-stage CSTR system: Effect of hydraulic retention time. Bioresource Technology, 175, pp.553-562.

Datta, R. and Tsai, S.P., 1997. Lactic acid production and potential uses: A technology and economics assessment. Fuels and Chemicals from Biomass, Chapter 12, pp.224-

236. De Campos, A., Correa, A.C., Cannella, D., de M Teixeira, E., Marconcini, J.M., Dufresne, A., Mattoso, L.H., Cassland, P. and Sanadi, A.R., 2013. Obtaining nanofibers from curauá and sugarcane bagasse fibers using enzymatic hydrolysis followed by sonication. Cellulose, 20, pp.1491-1500.

de Oliveira, A.C., Valentim, I.B., Silva, C.A., Bechara, E.J.H., de Barros, M.P., Mano, C.M. and Goulart, M.O.F., 2009. Total phenolic content and free radical scavenging activities of methanolic extract powders of tropical fruit residues. Food Chemistry, 115(2), pp.469-475.

Dessie, W., Zhang, W., Xin, F., Dong, W., Zhang, M., Ma, J. and Jiang, M., 2018. Succinic acid production from fruit and vegetable wastes hydrolyzed by on-site enzyme mixtures through solid state fermentation. Bioresource Technology, 247, pp.1177-1180.

Devakate, R.V., Patil, V.V., Waje, S.S. and Thorat, B.N., 2009. Purification and drying of bromelain. Separation and Purification Technology, 64(3), pp.259-264.

Dharumadurai, D., Subramaniyan, L., Subhasish, S., Nooruddin, T. and Annamalai, P., 2011. Production of single cell protein from pineapple waste using yeast. Innovative Romanian Food Biotechnology, (8), pp.26-32.

Diaz-Vela, J., Totosaus, A., Cruz-Guerrero, A.E. and de Lourdes Pérez-Chabela, M., 2013. In vitro evaluation of the fermentation of added-value agroindustrial by-products: cactus pear (O puntia ficus-indica L.) peel and pineapple (A nanas comosus) peel as functional ingredients. International Journal of Food science & Technology, 48(7), pp.1460-1467.

Dimensions (2022). Available at: https://app.dimensions.ai/discover/publication (Accessed: March 6, 2023).

Do, N.H., Luu, T.P., Thai, Q.B., Le, D.K., Chau, N.D.Q., Nguyen, S.T., Le, P.K., Phan-Thien, N. and Duong, H.M., 2020. Advanced fabrication and application of pineapple aerogels from agricultural waste. Materials Technology, 35(11-12), pp.807-814.

Do, N.H., Truong, B.Y., Nguyen, P.T., Le, K.A., Duong, H.M. and Le, P.K., 2022. Composite aerogels of TEMPO-oxidized pineapple leaf pulp and chitosan for dyes removal. Separation and Purification Technology, 283, p.120200.

Doko, M.B., Bassani, V., Casadebaig, J., Cavailles, L. and Jacob, M., 1991. Preparation of proteolytic enzyme extracts from Ananas comosus L., Merr. fruit juice using semipermeable membrane, ammonium sulfate extraction, centrifugation and freeze-drying processes. International Journal of Pharmaceutics, 76(3), pp.199-206.

El-Holi, M.A. and Al-Delaimy, S., 2003. Citric acid production from whey with sugars and additives by Aspergillus niger. African Journal of Biotechnology, *2*(10), pp.356-359.

Emeka, E.E., Ojiefoh, O.C., Aleruchi, C., Hassan, L.A., Christiana, O.M., Rebecca, M., Dare, E.O. and Temitope, A.E., 2014. Evaluation of antibacterial activities of silver nanoparticles green-synthesized using pineapple leaf (Ananas comosus). Micron, 57, pp.1-5.

Fakhar, N., Siddiqi, W.A., Khan, T.A. and Siddiqui, M.F., 2020. Fabrication of Ananas comosus leaf extract modified titanium dioxide nano bio adsorbent for the sequestration of basic dye from aqueous phase: equilibrium and kinetic studies. Materials Research Express, 7(1), p.015077.

FAOSTAT (2020). Available at: https://www.fao.org/faostat/en/#home (Accessed: March 6, 2023).

Faulds, C.B. and Williamson, G., 1993. Release of ferulic acid from plant polysaccharides by ferulic acid esterase from Streptomyces olivochromogenes. Carbohydrate Polymers, 21(2-3), pp.153-155.

Feng, C., Zhang, S., Li, L., Wang, G., Xu, X., Li, T. and Zhong, Q., 2018. Feasibility of four wastes to remove heavy metals from contaminated soils. Journal of Environmental Management, 212, pp.258-265.

Feng, J., Nguyen, S.T., Fan, Z. and Duong, H.M., 2015. Advanced fabrication and oil absorption properties of super-hydrophobic recycled cellulose aerogels. Chemical Engineering Journal, 270, pp.168-175.

Fouda-Mbanga, B.G. and Tywabi-Ngeva, Z., 2022. Application of pineapple waste to the removal of toxic contaminants: A review. Toxics, 10(10), p.561.

Gadzama, S.W., Sunmonu, O.K., Isiaku, U.S. and Danladi, A., 2020. Isolation and characterization of nanocellulose from pineapple leaf fibres via chemo-mechanical method. Science World Journal, 15(2), pp.100-105.

George, J., Bhagawan, S.S. and Thomas, S., 1998. Effects of environment on the properties of low-density polyethylene composites reinforced with pineapple-leaf fibre. Composites Science and Technology, 58(9), pp.1471-1485.

Giacometti, J., Kovačević, D.B., Putnik, P., Gabrić, D., Bilušić, T., Krešić, G., Stulić, V., Barba, F.J., Chemat, F., Barbosa-Cánovas, G. and Jambrak, A.R., 2018. Extraction of bioactive compounds and essential oils from mediterranean herbs by conventional and green innovative techniques: A review. Food Research International, 113, pp.245-262.

Goers, L., Freemont, P. and Polizzi, K.M., 2014. Co-culture systems and technologies: taking synthetic biology to the next level. Journal of The Royal Society Interface, 11(96), p.20140065.

Gogoi, S., Chakraborty, S. and Saikia, M.D., 2018. Surface modified pineapple crown leaf for adsorption of Cr (VI) and Cr (III) ions from aqueous solution. Journal of Environmental Chemical Engineering, 6(2), pp.2492-2501.

Hamdiani, S. and Shih, Y.F., 2021. A green method for synthesis of silver-nanoparticles-diatomite (AgNPs-D) composite from pineapple (Ananas comosus) leaf extract. Indonesian Journal of Chemistry, 21(3), pp.740-752.

Hameed, 5.8.B., Krishni, R.R. and Sata, S.A., 2009. A novel agricultural waste adsorbent for the removal of cationic dye from aqueous solutions. Journal of Hazardous Materials, 162(1), pp.305-311.

Hao, P., Zhao, Z., Tian, J., Li, H., Sang, Y., Yu, G., Cai, H., Liu, H., Wong, C.P. and Umar, A., 2014. Hierarchical porous carbon aerogel derived from bagasse for high performance supercapacitor electrode. Nanoscale, 6(20), pp.12120-12129.

Hassan, A., Othman, Z. and Siriphanich, J., 2011. Pineapple (Ananas comosus L. Merr.). In postharvest biology and technology of tropical and subtropical fruits (pp. 194-218e). Woodhead Publishing.

Heleno, S.A., Martins, A., Queiroz, M.J.R. and Ferreira, I.C., 2015. Bioactivity of phenolic acids: Metabolites versus parent compounds: A review. Food Chemistry, 173, pp.501-513.

Hemalatha, R. and Anbuselvi, S., 2013. Physicohemical constituents of pineapple pulp and waste. Journal of Chemical and Pharmaceutical Research, 5(2), pp.240-242.

Hossain, M.F., 2016. World pineapple production: An overview. African Journal of Food, Agriculture, Nutrition and Development, 16(4), pp.11443-11456.

Hu, X., Zhao, M. and Huang, H., 2010. Modification of pineapple peel fiber as metal ion adsorbent through reaction with succinic anhydride in pyridine and dimethyl sulfoxide solvents. Water Environment Research, 82(8), pp.733-741.

Huzir, N.M., Aziz, M.M.A., Ismail, S.B., Abdullah, B., Mahmood, N.A.N., Umor, N.A. and Muhammad, S.A.F.A.S., 2018. Agro-industrial waste to biobutanol production: Eco-friendly biofuels for next generation. Renewable and Sustainable Energy Reviews, 94, pp.476-485.

Idris, A. and Suzana, W., 2006. Effect of sodium alginate concentration, bead diameter, initial pH and temperature on lactic acid production from pineapple waste using immobilized Lactobacillus delbrueckii. Process Biochemistry, 41(5), pp.1117-1123.

Imandi, S.B., Bandaru, V.V.R., Somalanka, S.R., Bandaru, S.R. and Garapati, H.R., 2008. Application of statistical experimental designs for the optimization of medium constituents for the production of citric acid from pineapple waste. Bioresource Technology, 99(10), pp.4445-4450. Jayashree, J., Priya, D., Karthikeyan, S. and Ramesh Babu, N.G., 2017. Production and characterization of ferulic acid from pineapple waste and its anticancer activity using HeLa cell line. International Journal of Innovative Research in Science, Engineering and Technology, 6, pp.1-6.

Jin, B., Yin, P., Ma, Y. and Zhao, L., 2005. Production of lactic acid and fungal biomass by rhizopus fungi from food processing waste streams. Journal of Industrial Microbiology and Biotechnology, 32(11-12), pp.678-686.

Jitramano, P., 2005. The use of pineapple waste as cattle feed: physical characteristic and nutritive value of ensiled pineapple waste with rice straw. In The 6th Annual Conference, Maejo University, Chiang Mai, 2005.

Johnson, I.T., 2004. New approaches to the role of diet in the prevention of cancers of the alimentary tract. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis, 551(1-2), pp.9-28.

Jusoh, N., Othman, N., Idris, A. and Nasruddin, A., 2014. Characterization of liquid pineapple waste as carbon source for production of succinic acid. Jurnal Teknologi (Sciences & Engineering), 69(4).

Kamali, H., Aminimoghadamfarouj, N., Golmakani, E. and Nematollahi, A., 2015. The optimization of essential oils supercritical CO2 extraction from Lavandula hybrida through static-dynamic steps procedure and semi-continuous technique using response surface method. Pharmacognosy Research, 7(1), p.57.

Kanakdande, A., Agrwal, D. and Khobragade, C., 2020. Pineapple waste and wastewater: route for biodiesel production from Candida tropicalis (MF510172). Brazilian Archives of Biology and Technology, 62.

Kao, P.M., Hsu, B.M., Huang, K.H., Tao, C.W., Chang, C.M. and Ji, W.T., 2014. Biohydrogen production by immobilized co-culture of Clostridium butyricum and Rhodopseudomonas palustris. Energy Procedia, 61, pp.834-837.

Kaufmann, B. and Christen, P., 2002. Recent extraction techniques for natural products: microwave-assisted extraction and pressurised solvent extraction. Phytochemical Analysis: An International Journal of Plant Chemical and Biochemical Techniques, 13(2), pp.105-113.

Kaushik, M., Niranjan, R., Thangam, R., Madhan, B., Pandiyarasan, V., Ramachandran, C., Oh, D.H. and Venkatasubbu, G.D., 2019. Investigations on the antimicrobial activity and wound healing potential of ZnO nanoparticles. Applied Surface Science, 479, pp.1169-1177. Kengkhetkit, N., Wongpreedee, T. and Amornsakchai, T., 2018. Pineapple leaf fiber: from waste to high-performance green reinforcement for plastics and rubbers. Lignocellulosic Composite Materials, pp.271-291.

Ketnawa, S., Chaiwut, P. and Rawdkuen, S., 2011. Aqueous two-phase extraction of bromelain from pineapple peels (‘Phu Lae’cultv.) and its biochemical properties. Food Science and Biotechnology, 20, pp.1219-1226.

Ketnawa, S., Rawdkuen, S. and Chaiwut, P., 2010. Two phase partitioning and collagen hydrolysis of bromelain from pineapple peel Nang Lae cultivar. Biochemical Engineering Journal, 52(2-3), pp.205-211.

Khalafi, T., Buazar, F. and Ghanemi, K., 2019. Phycosynthesis and enhanced photocatalytic activity of zinc oxide nanoparticles toward organosulfur pollutants. Scientific Reports, 9(1), pp.1-10.

Khedkar, M.A., Nimbalkar, P.R., Gaikwad, S.G., Chavan, P.V. and Bankar, S.B., 2017. Sustainable biobutanol production from pineapple waste by using Clostridium acetobutylicum B 527: drying kinetics study. Bioresource Technology, 225, pp.359-366.

Klinbumrung, A., Panya, R., Pung-Ngama, A., Nasomjai, P., Saowalakmeka, J. and Sirirak, R., 2022. Green synthesis of ZnO nanoparticles by pineapple peel extract from various alkali sources. Journal of Asian Ceramic Societies, 10(4), pp.755-765.

Kumar, K., Srivastav, S. and Sharanagat, V.S., 2021. Ultrasound assisted extraction (UAE) of bioactive compounds from fruit and vegetable processing by-products: A review. Ultrasonics Sonochemistry, 70, p.105325.

Kumar, V., Garg, V. and Dureja, H., 2022. Ananas comosus loaded nanoemulsion a promising therapeutic approach for cancer. Medical Theory and Hypothesis, 5(3), p.13.

Lane, A.G., 1984. Laboratory scale anaerobic digestion of fruit and vegetable solid waste. Biomass, *5*(4), pp.245-259. Lesage-Meessen, L., Delattre, M., Haon, M., Thibault, J.F., Ceccaldi, B.C., Brunerie, P. and Asther, M., 1996. A two-step bioconversion process for vanillin production from ferulic acid combining *Aspergillus niger* and *Pycnoporus cinnabarinus*. Journal of Biotechnology, 50(2-3), pp.107-113.

Li, T., Shen, P., Liu, W., Liu, C., Liang, R., Yan, N. and Chen, J., 2014. Major polyphenolics in pineapple peels and their antioxidant interactions. International Journal of Food Properties, 17(8), pp.1805-1817.

Lim, Z.E., Thai, Q.B., Le, D.K., Luu, T.P., Nguyen, P.T., Do, N.H., Le, P.K., Phan-Thien, N., Goh, X.Y. and Duong, H.M., 2020. Functionalized pineapple aerogels for ethylene gas adsorption and nickel (II) ion removal applications. Journal of Environmental Chemical Engineering, 8(6), p.104524.

Liu, Z., Wang, J., Shen, P., Wang, C. and Shen, Y., 2006. Microwave-assisted extraction and high-speed counter-current chromatography purification of ferulic acid from Radix Angelicae sinensis. Separation and Purification Technology, 52(1), pp.18-21.

Lubaina, A.S., Renjith, P.R. and Kumar, P., 2019. Antibacterial potential of different extracts of pineapple peel against gram-positive and gram-negative bacterial strains. Asian Journal of Pharmacy and Pharmacology, 5(S1), pp.66-70.

Lun, O.K., Wai, T.B. and Ling, L.S., 2014. Pineapple cannery waste as a potential substrate for microbial biotranformation to produce vanillic acid and vanillin. International Food Research Journal, 21(3), p.953.

Madhumeena, S., Preetha, R. and Prasad, S., 2021, August. Effective utilization of pineapple waste. In Journal of Physics: Conference Series (Vol. 1979, No. 1, p. 012001). IOP Publishing.

Majumder, L., Khalil, I., Munshi, M.K., Alam, K., Rashid, H.O., Begum, R. and Alam, N., 2010. Citric acid production by *Aspergillus niger* using molasses and pumpkin as substrates. European Journal of Biological Sciences, 2(1), pp.01-08.

Maneffa, A., Priecel, P. and Lopez-Sanchez, J.A., 2016. Biomass-derived renewable aromatics: selective routes and outlook for p-xylene commercialisation. ChemSusChem, 9(19), pp.2736-2748.

Maraveas, C., 2020. Production of sustainable and biodegradable polymers from agricultural waste. Polymers, 12(5), p.1127.

Marić, M., Grassino, A.N., Zhu, Z., Barba, F.J., Brnčić, M. and Brnčić, S.R., 2018. An overview of the traditional and innovative approaches for pectin extraction from plant food wastes and by-products: Ultrasound-, microwaves-, and enzyme-assisted extraction. Trends in Food Science & Technology, 76, pp.28-37.

Mathivanan, D., Norfazilah, H., Siregar, J.P., Rejab, M.R.M., Bachtiar, D. and Cionita, T., 2016. The study of mechanical properties of pineapple leaf fibre reinforced tapioca based bioplastic resin composite. In MATEC Web of Conferences (Vol. 74).

Mensah, J.K. and Twumasi, P., 2017. Use of pineapple waste for single cell protein (SCP) production and the effect of substrate concentration on the yield. Journal of Food Process Engineering, 40(3), p.e12478.

Mirgane, N.A., Shivankar, V.S., Kotwal, S.B., Wadhawa, G.C. and Sonawale, M.C., 2021. Waste pericarp of Ananas comosus in green synthesis zinc oxide nanoparticles and their application in waste water treatment. Materials Today: Proceedings, 37, pp.886-889.

Mishra, S., Misra, M., Tripathy, S.S., Nayak, S.K. and Mohanty, A.K., 2001. Potentiality of pineapple leaf fibre as reinforcement in PALF-polyester composite: Surface modification and mechanical performance. Journal of Reinforced Plastics and Composites, 20(4), pp.321-334.

Mohamad, N., Ramli, N., Abd-Aziz, S. and Ibrahim, M.F., 2019. Comparison of hydro-distillation, hydro-distillation with enzyme-assisted and supercritical fluid for the extraction of essential oil from pineapple peels. 3 Biotech, 9, pp.1-9.

Mohammed, M.A., Ibrahim, A. and Shitu, A., 2014. Batch removal of hazardous safranin-O in wastewater using pineapple peels as an agricultural waste based adsorbent. International Journal of Environmental Monitoring and Analysis, 2(3), pp.128-133.

Mopoung, R. and Kengkhetkit, N., 2016. Lead and cadmium removal efficiency from aqueous solution by NaOH treated pineapple waste. International Journal of Applied Chemistry, *12*(1), pp.23-35.

Mopoung, S. and Bunterm, T., 2016. KMnO4 modified carbon prepared from waste of pineapple leaf fiber production processing for removal of ferric ion from aqueous solution. American Journal of Applied Sciences, 13, pp.814-826. Mund, N.K., Dash, D., Mishra, P. and Nayak, N.R., 2021. Cellulose solvent–based pretreatment and enzymatic hydrolysis of pineapple leaf waste biomass for efficient release of glucose towards biofuel production. Biomass Conversion and Biorefinery, pp.1-10.

Nadzirah, K.Z., Zainal, S., Noriham, A. and Normah, I., 2013. Efficacy of selected purification techniques for bromelain. International Food Research Journal, 20(1), p.43.

Nakthong, N., Wongsagonsup, R. and Amornsakchai, T., 2017. Characteristics and potential utilizations of starch from pineapple stem waste. Industrial Crops and Products, 105, pp.74-82.

Nguyen, C.T.X., Bui, K.H., Truong, B.Y., Do, N.H.N. and Le, P.T.K., 2021. Nanocellulose from pineapple leaf and its applications towards high-value engineering materials. Chemical Engineering Transactions, 89, pp.19-24.

Niramol, P., Katemanee, S. and Wanwisa, S., 2018. Antimicrobial activity of pineapple peel extract. In Proceedings of the Innovation of Functional Foods in Asia Conference, Mae Ka, Thailand (pp. 22-24).

Nor, M.Z.M., Ramchandran, L., Duke, M. and Vasiljevic, T., 2016. Separation of bromelain from crude pineapple waste mixture by a two stage ceramic ultrafiltration process. Food and Bioproducts Processing, 98, pp.142-150.

Oshoma, C.E. and Eguakun-Owie, S.O., 2018. Conversion of food waste to single cell protein using *Aspergillus niger*. Journal of Applied Sciences and Environmental Management, 22(3), pp.350-355.

Papagianni, M., 2007. Advances in citric acid fermentation by *Aspergillus niger*: biochemical aspects, membrane transport and modeling. Biotechnology Advances, 25(3), pp.244-263.

Pardo, M.E.S., Cassellis, M.E.R., Escobedo, R.M. and García, E.J., 2014. Chemical characterisation of the industrial residues of the pineapple (*Ananas comosus*). Journal of Agricultural Chemistry and Environment, 3(2), pp.53-56.

Pathanibul, P. and Hongkulsup, C., 2021. Production of succinic acid from pineapple peel waste. Research Square.

Pavithran, C., Mukherjee, P.S., Brahmakumar, M. and Damodaran, A.D., 1987. Impact properties of natural fibre composites. Journal of Materials Science Letters, 6, pp.882-884.

Peacocke, G.V.C. and Bridgwater, A.V., 2000. Fast pyrolysis processes for biomass. Renewable and Sustainable Energy Reviews, 4(1), pp.1-73.

Penkhrue, W., Jendrossek, D., Khanongnuch, C., Pathom-Aree, W., Aizawa, T., Behrens, R.L. and Lumyong, S., 2020. Response surface method for polyhydroxybutyrate (PHB) bioplastic accumulation in *Bacillus drentensis* BP17 using pineapple peel. PloS One, 15(3), p.e0230443. Poadang, S., Yongvanich, N. and Phongtongpasuk, S., 2017. Synthesis, characterization, and antibacterial properties of silver nanoparticles prepared from aqueous peel extract of pineapple, ananas comosus. Chiang Mai University Journal of Natural Sciences, 16(2), pp.123-33.

Polanía, A.M., Londoño, L., Ramírez, C., Bolivar, G. and Aguilar, C.N., 2022. Valorization of pineapple waste as novel source of nutraceuticals and biofunctional compounds. Biomass Conversion and Biorefinery, pp.1-26.

Ponou, J., Kim, J., Wang, L.P., Dodbiba, G. and Fujita, T., 2011. Sorption of Cr (VI) anions in aqueous solution using carbonized or dried pineapple leaves. Chemical Engineering Journal, 172(2-3), pp.906-913.Prado, K.S. and Spinacé, M.A., 2019. Isolation and characterization of cellulose nanocrystals from pineapple crown waste and their potential uses. International Journal of Biological Macromolecules, 122, pp.410-416.

Pyar, H., Liong, M.T. and Peh, K.K., 2014. Potentials of pineapple waste as growth medium for Lactobacillus species. International Journal of Pharmacy and Pharmaceutical Sciences, 6(1), pp.142-145.

Rabiu, Z., Maigari, F.U., Lawan, U. and Mukhtar, Z.G., 2018. Pineapple waste utilization as a sustainable means of waste management. Sustainable Technologies for the Management of Agricultural Wastes, pp.143-154.

Rajapaksha, R.A.D., Adassooriya, N.M., Sandarani, M.D.J.C. and Jayasinghe, C.V.L.,2019. Pineapple (*Ananas comosus* L.) peel waste based cellulose fibers as probiotic encapsulant: characterization. Proceedings of the 8th YSF Symposium.

Ramadhan, M.O. and Handayani, M.N., 2020, December. The potential of food waste as bioplastic material to promote environmental sustainability: A review. In IOP Conference Series: Materials Science and Engineering (Vol. 980, No. 1, p. 012082). IOP Publishing.

Rani, D.S. and Nand, K., 2004. Ensilage of pineapple processing waste for methane generation. Waste Management, 24(5), pp.523-528.

Rashad, M.M., Mahmoud, A.E., Ali, M.M., Nooman, M.U. and Al-Kashef, A.S., 2015. Antioxidant and anticancer agents produced from pineapple waste by solid state fermentation. International Journal of Toxicological and Pharmacological Research 7(6), pp.287-296.

Reungsang, A. and Sreela-or, C., 2013. Bio-hydrogen production from pineapple waste extract by anaerobic mixed cultures. Energies, 6(4), pp.2175-2190.

Rico, X., Gullón, B., Alonso, J.L. and Yáñez, R., 2020. Recovery of high value-added compounds from pineapple, melon, watermelon and pumpkin processing by-products: An overview. Food Research International, 132, p.109086.

Riya, M.P., Antu, K.A., Vinu, T., Chandrakanth, K.C., Anilkumar, K.S. and Raghu, K.G., 2014. An in vitro study reveals nutraceutical properties of Ananas comosus (L.) Merr. var. Mauritius fruit residue

Roda, A. and Lambri, M., 2019. Food uses of pineapple waste and by products: a review. International Journal of Food Science & Technology, 54(4), pp.1009-1017.

Roda, A., Lucini, L., Torchio, F., Dordoni, R., De Faveri, D.M. and Lambri, M., 2017. Metabolite profiling and volatiles of pineapple wine and vinegar obtained from pineapple waste. Food Chemistry, 229, pp.734-742.

Rojas-Flores, S., Nazario-Naveda, R., Benites, S.M., Gallozzo-Cardenas, M., Delfín-Narciso, D. and Díaz, F., 2022. Use of pineapple waste as fuel in microbial fuel cell for the generation of bioelectricity. Molecules, 27(21), p.7389. Rolle, R.S., 1998. Enzyme applications for agro-processing in developing countries: an inventory of current and potential applications. World Journal of Microbiology and Biotechnology, 14, pp.611-619. Romelle, F.D., Rani, A. and Manohar, R.S., 2016. Chemical composition of some selected fruit peels. European Journal of Food Science and Technology, 4(4), pp.12-21.

Sah, B.N.P., Vasiljevic, T., McKechnie, S. and Donkor, O.N., 2015. Effect of refrigerated storage on probiotic viability and the production and stability of antimutagenic and antioxidant peptides in yogurt supplemented with pineapple peel. Journal of Dairy Science, 98(9), pp.5905-5916.

Sah, B.N.P., Vasiljevic, T., McKechnie, S. and Donkor, O.N., 2016. Effect of pineapple waste powder on probiotic growth, antioxidant and antimutagenic activities of yogurt. Journal of Food Science and Technology, 53, pp.1698-1708.

Salve, R.R. and Ray, S., 2020. Comprehensive study of different extraction methods of extracting bioactive compounds from pineapple waste—A review. The Pharma Innovation International Journal, 9, pp.327-340.

Sanguanchaipaiwong, V. and Leksawasdi, N., 2018. Butanol production by *Clostridium beijerinckii* from pineapple waste juice. Energy Procedia, 153, pp.231-

236. Sarangi, P.K., Singh, J.N. and Singh, T.A., 2020. Pectin from pineapple waste: isolation and process optimization. International Journal of Current Microbiology and Applied Sciences, 9(5), pp.143-148.

Saravanan, P., Muthuvelayudham, R. and Viruthagiri, T., 2013. Enhanced production of cellulase from pineapple waste by response surface methodology. Journal of Engineering, 2013.

Schieber, A., Stintzing, F.C. and Carle, R., 2001. By-products of plant food processing as a source of functional compounds—recent developments. Trends in Food Science & Technology, 12(11), pp.401-413.

Segovia Gómez, F. and Almajano Pablos, M.P., 2016. Pineapple waste extract for preventing oxidation in model food systems. Journal of Food Science, 81(7), pp.C1622-C1628.

Selvakumar, P. and Sivashanmugam, P., 2017. Optimization of lipase production from organic solid waste by anaerobic digestion and its application in biodiesel production. Fuel Processing Technology, 165, pp.1-8. Sen, B., Aravind, J., Kanmani, P. and Lay, C.H., 2016. State of the art and future concept of food waste fermentation to bioenergy. Renewable and Sustainable Energy Reviews, 53, pp.547-557.

Sepúlveda, L., Romaní, A., Aguilar, C.N. and Teixeira, J., 2018. Valorization of pineapple waste for the extraction of bioactive compounds and glycosides using autohydrolysis. Innovative Food Science & Emerging Technologies, 47, pp.38-45.

Shivamathi, C.S., Gunaseelan, S., Soosai, M.R., Vignesh, N.S., Varalakshmi, P., Kumar, R.S., Karthikumar, S., Kumar, R.V., Baskar, R., Rigby, S.P. and Syed, A., 2022. Process optimization and characterization of pectin derived from underexploited pineapple peel biowaste as a value-added product. Food Hydrocolloids, 123, p.107141.

Sivagurunathan, P., Anburajan, P., Park, J.H., Kumar, G., Park, H.D. and Kim, S.H., 2017. Mesophilic biogenic H2 production using galactose in a fixed bed reactor. International Journal of Hydrogen Energy, 42(6), pp.3658-3666.

Sodtipinta, J., Ieosakulrat, C., Poonyayant, N., Kidkhunthod, P., Chanlek, N., Amornsakchai, T. and Pakawatpanurut, P., 2017. Interconnected open-channel carbon nanosheets derived from pineapple leaf fiber as a sustainable active material for supercapacitors. Industrial Crops and Products, 104, pp.13-20.

Soumya, P. and Kochupurackal, J., 2020. Pineapple peel extract as an effective substrate for esterase production from Bacillus subtilis E9. Current Microbiology, 77(10), pp.3024-3034.

Sruamsiri, S., 2007. Agricultural wastes as dairy feed in Chiang Mai. Animal Science Journal, 78(4), pp.335-341.

Subki, N.S., 2017. Environmental contamination by batik wastewater and the potential application of activated carbon from pineapple waste for wastewater treatment. Doctor of Philosophy), Universiti Sains Malaysia.

Sukri, S.A.M., Andu, Y., Harith, Z.T., Sarijan, S., Pauzi, M.N.F., Wei, L.S., Dawood, M.A. and Kari, Z.A., 2022. Effect of feeding pineapple waste on growth performance, texture quality and flesh colour of nile tilapia (Oreochromis niloticus) fingerlings. Saudi Journal of Biological Sciences, 29(4), pp.2514-2519.

Sukruansuwan, V. and Napathorn, S.C., 2018. Use of agro-industrial residue from the canned pineapple industry for polyhydroxybutyrate production by Cupriavidus necator strain A-04. Biotechnology for Biofuels, 11(1), pp.1-15. Sutanto, A., Zen, S., Noor, R. and Siddiq, B.R., 2016. Fertilizer application of pineapple liquid waste (plw) weight of pineapple (*Ananas comosus*, L. Merr). International Advisory Board, p.339.

Syed Omar, S.M.Z. and Mustapa, A.N., 2018. Silver nanoparticle synthesis using pineapple waste. Malaysian Journal of Chemical Engineering and Technology (MJCET), 1, pp.68-74.

Tan, L.N., Nguyen, N.C.T., Trinh, A.M.H., Do, N.H., Le, K.A. and Le, P.K., 2023. Eco-friendly synthesis of durable aerogel composites from chitosan and pineapple leaf-based cellulose for Cr (VI) removal. Separation and Purification Technology, 304, p.122415.

Tangtubtim, S. and Saikrasun, S., 2019. Adsorption behavior of polyethyleneimine-carbamate linked pineapple leaf fiber for Cr (VI) removal. Applied Surface Science, 467, pp.596-607.

TFNet - International Tropical Fruits Network (2016) TFNet International Tropical Fruits Network.

Tilay, A., Bule, M., Kishenkumar, J. and Annapure, U., 2008. Preparation of ferulic acid from agricultural wastes: its improved extraction and purification. Journal of Agricultural and Food Chemistry, 56(17), pp.7644-7648.

Ting, V.L.Z., Ping, T.Y. and Abdullah, A.H., 2019. Removal of Pb (II) from aqueous solution by pineapple plant stem. Malaysian Journal of Analytical Sciences, 23(2), pp.219-228.

Tinoi, J. and Rakariyatham, N., 2016. Optimization of pineapple pulp residue hydrolysis for lipid production by *Rhodotorula glutinis* TISTR5159 using as biodiesel feedstock. Bioscience, Biotechnology, and Biochemistry, 80(8), pp.1641-1649.

Tropea, A., Wilson, D., La Torre, L.G., Curto, R.B.L., Saugman, P., Troy-Davies, P., Dugo, G. and Waldron, K.W., 2014. Bioethanol production from pineapple wastes. Journal of Food Research, 3(4), p.60.

Tuyet Phan, M.T., Pham, L.N., Nguyen, L.H. and To, L.P., 2021. Investigation on synthesis of hydrogel starting from Vietnamese pineapple leaf waste-derived carboxymethylcellulose. Journal of Analytical Methods in Chemistry, 2021, pp.1-12.

Ueno, T., Ozawa, Y., Ishikawa, M., Nakanishi, K. and Kimura, T., 2003. Lactic acid production using two food processing wastes, canned pineapple syrup and grape invertase, as substrate and enzyme. Biotechnology Letters, 25, pp.573-577.

Ugbe, F.A., Anebi, P.O. and Ikudayisi, V.A., 2018. Biosorption of an anionic dye, eosin yellow onto pineapple peels: isotherm and thermodynamic study. International Annals of Science, 4(1), pp.14-19.

Umaru, F.F., Esedafe, W.K., Obidah, J.S., Akinwotu, O. and Danba, E., 2015. Production of vinegar from pineapple peel wine using Acetobacter species. In Proceedings of the 3rd International Conference on Biological, Chemical & Environmental Sciences (BCES-2015), Kuala Lumpur, Malaysia (pp. 21-22).

Upadhyay, A., Lama, J.P. and Tawata, S., 2010. Utilization of pineapple waste: a review. Journal of Food Science and Technology Nepal, 6, pp.10-18.

Van Tran, A., 2006. Chemical analysis and pulping study of pineapple crown leaves. Industrial Crops and Products, 24(1), pp.66-74.

Vargas-Serna, C.L., Ochoa-Martínez, C.I. and Vélez-Pasos, C., 2022. Microwave-assisted extraction of phenolic compounds from pineapple peel using deep eutectic solvents. Horticulturae, 8(9), p.791. Veeramalai, S., Ramlee, N.N., Mahdi, H.I., Manas, N.H.A., Ramli, A.N.M., Illias, R.M. and Azelee, N.I.W., 2022. Development of organic porous material from pineapple waste as a support for enzyme and dye adsorption. Industrial Crops and Products, 181, p.114823. Viswanath, P., Devi, S.S. and Nand, K., 1992. Anaerobic digestion of fruit and vegetable processing wastes for biogas production. Bioresource Technology, 40(1), pp.43-48.

Wan, J., Guo, J., Miao, Z. and Guo, X., 2016. Reverse micellar extraction of bromelain from pineapple peel–effect of surfactant structure. Food Chemistry, 197, pp.450-456.

Wang, C.H., Lin, P.J. and Chang, J.S., 2006. Fermentative conversion of sucrose and pineapple waste into hydrogen gas in phosphate-buffered culture seeded with municipal sewage sludge. Process Biochemistry, 41(6), pp.1353-1358.

Wang, L. and Weller, C.L., 2006. Recent advances in extraction of nutraceuticals from plants. Trends in Food Science & Technology, 17(6), pp.300-312.

Xu, W., Reddy, N. and Yang, Y., 2009. Extraction, characterization and potential applications of cellulose in corn kernels and Distillers' dried grains with solubles (DDGS). Carbohydrate Polymers, 76(4), pp.521-527.

Yahya, N.A., Wahab, R.A., Xine, T.L.S. and Hamid, M.A., 2019, September. Ultrasound-assisted extraction of polyphenols from pineapple skin. In AIP Conference Proceedings (Vol. 2155, No. 1, p. 020002). AIP Publishing LLC.

Zakaria, N.A., Rahman, R.A., Zaidel, D.N.A., Dailin, D.J. and Jusoh, M., 2021. Microwave-assisted extraction of pectin from pineapple peel. Malaysian Journal of Fundamental and Applied Sciences, 17(1), pp.33 38.

Zardo, I., de Espíndola Sobczyk, A., Marczak, L.D.F. and Sarkis, J., 2019. Optimization of ultrasound assisted extraction of phenolic compounds from sunflower seed cake using response surface methodology. Waste and Biomass Valorization, 10, pp.33-44.

Zinn, M., Witholt, B. and Egli, T., 2001. Occurrence, synthesis and medical application of bacterial polyhydroxyalkanoate. Advanced Drug Delivery Reviews, 53(1), pp.5-21.

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