

# Pineapple (*Ananas comosus* L. Merr.), Waste Streams, Characterisation and Valorisation: An Overview

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## Abstract

Processing pineapple industry produces huge amounts of waste thus contributing to worsen the global environmental problem. Valorising pineapple waste through further processing until it is transformed into valuable products using environmentally friendly techniques is both, a challenge, and an opportunity. The aim of this review is to characterize and highlight the phytochemical constituents of pineapple peel, their biological activity, and to evaluate the current state-of-art for the utilization of pineapple waste from the processing industry for obtaining pharmaceuticals, food, and beverages, biocombustibles, biodegradable fibers, and other different usage. Pineapple residues are rich in many bioactive compounds such as ferulic acid, vitamin A and C as antioxidant, and containing alkaloids, flavonoids, saponins, tannins, cardiac glycoside, steroids, triterpenoids and phytosterols may provide a good source of several beneficial properties, as well as bromelain that showed significant anticancer activity. Also, pineapple processing residues contain important volatile compounds used as aroma enhancing products and have high potential to produce value-added natural essences. Pineapple peels can be used as non-

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pharmacological therapeutical in the form of processed food and instant drinks; its potent natural antimicrobial properties may be applied for food conservation and as potential leads to discover new drugs to control some infectious microbial. Pineapple waste is a promising source of metabolites for therapeutics, functional foods, and cosmeceutical applications.

## Keywords

Pineapple Peel, *Ananas comosus*, Phytochemical Constituents, Antioxidant Activity, Anticancer, Antimicrobial Activities

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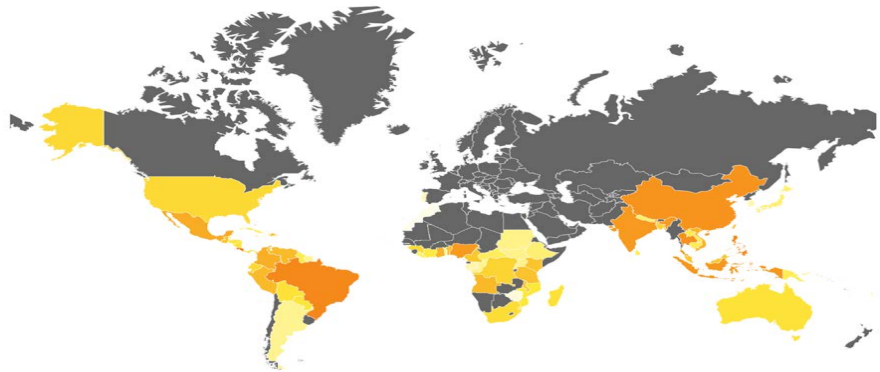
## 1. Introduction

Pineapple (*Ananas comosus* L. Merr.) is a tropical fruit belonging to the family of Bromeliaceae [1], having a short stem and slender hard leaves that grow to medium to large-sized fruit. It is the third most important tropical fruit produced globally after bananas and mangos. It is native to South America in Brazil and Paraguay, and often referred to as pineapple. The fruit was spread from native to South and Central America, when the Guarani Indians took *A. comosus* on sea voyages as provisions and to prevent scurvy. When Columbus found the fruit in 1493 called it pina, because he thought it looked like a pin cone. The hybrids known today first appear, when the Dutch improved the fruit by cross-breeding, around 1700. The cuttings of the plants were sold to English, who grew them as pot-house plants [2] [3].

Pineapple is a medium tall (1 - 1.5 m) herbaceous perennial plant with 30 or more trough-shaped and pointed leaves 30 - 100 cm long, surrounding a thick stem. *A. comosus* is an example of a multiple fruit: multiple, spirally arranged flowers along the axis each produce a fresh fruit that becomes pressed against the fruits of adjacent flowers, forming what appears to be a single fleshy fruit. The fruit lets of *A. comosus* are arranged in two interlocking spirals, eight spirals direction, thirteen in the other; each being a Fibonacci number. Pollination is required for seed formation; the presence of seeds negatively affects the quality of the fruit [2] [3]. Pineapple is not a single fruit but a composite of many, originated from flowers whose individual fruit fuse together around a central core. Each fruit let can be identified by the rough spiny marking on the *A. comosus* surface. Pineapple has a wide cylindrical shape, a scaly green, brown, or yellow skin and a regal crown of spiny, blue-green leaves. The fibrous flesh of *A. comosus* is yellow in colour and has a vibrant tropical flavour that balances the testes of sweet and tart. The area closer to the base of the fruit has more sugar content and therefore a sweeter taste and more tender texture [2] [3]. **Table 1** and **Figure 1** show the pineapple production worldwide in 2019.

The pineapple has a world production of 25.4 million metric tonnes. The consumption of the pineapple is wide due to its sweet and acidic flavour and varies as it is consumed fresh, cooked, juiced, or preserved. The tropical fruit is an ex-

cellent source of vitamins, minerals, and nutrients and is rich in antioxidants. Pineapples are made up of a cluster of multiple berries that grow within the second year of cultivation and are harvested one year later. Pineapples best grow in subtropical and tropical areas where the weather is warm, but cool at night [1] [4].



**Figure 1.** Pineapple producing countries.

**Table 1.** Countries in pineapple production worldwide in 2019 [FAO, 2021].

Country	Value (Tonnes)
Angola	870,257
Antigua and Barbuda	494
Argentina	3278
Australia	86,201
Bangladesh	217,439
Belize	3585
Benin	355,854
Bolivia	87,658
Brazil	2,426,526
Brunei Darussalam	1207
Cambodia	25,797
Cameroon	348,340
Central African Republic	17,225
China	2,158,691
China, mainland	1,727,607
China, Taiwan Province	431,084
Colombia	1,008,687
Congo	3412
Cook Islands	25
Costa Rica	3,328,100
Côte d'Ivoire	41,151

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Cuba	40,301
Democratic Republic of the Congo	193,367
Dominica	133
Dominican Republic	461,025
Ecuador	46,348
El Salvador	1136
Eswatini	2043
Ethiopia	1164
Fiji	7158
French Polynesia	4079
Gabon	1473
Ghana	743,098
Grenada	382
Guatemala	358,560
Guinea	139,027
Guinea-Bissau	469
Guyana	29,944
Haiti	8289
Honduras	69,943
India	1,711,000
Indonesia	2,196,456
Israel	282
Jamaica	33,938
Japan	6297
Kenya	278,179
Lao People's Democratic Republic	43,466
Liberia	9241
Madagascar	104,603
Malawi	300,000
Malaysia	299,912
Mauritius	8459
Mexico	1,041,161
Mozambique	65,569
Nepal	13,846
Nicaragua	70,253
Nigeria	1,671,440
Panama	111,070
Papua New Guinea	23,368

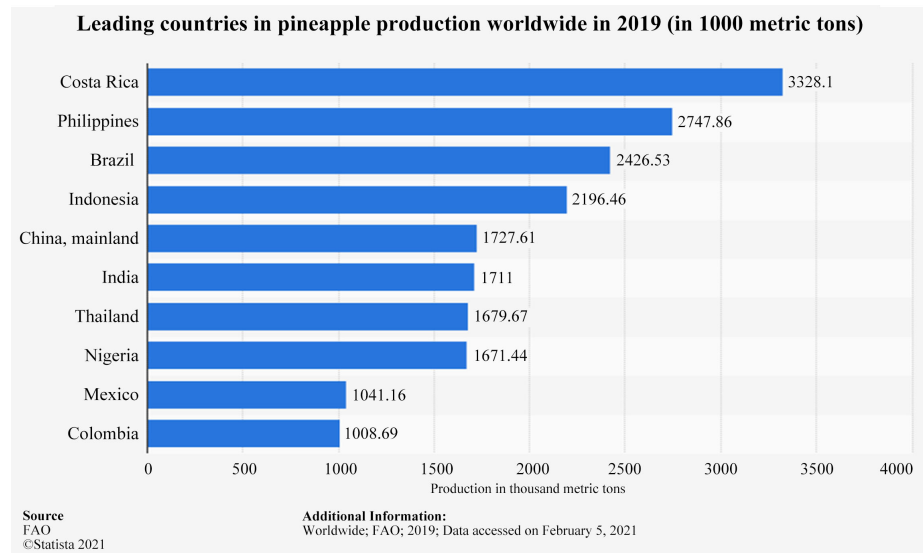
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Paraguay	85,216
Peru	568,907
Philippines	2,747,856
Puerto Rico	3871
Republic of Korea	976
Rwanda	36,372
Saint Lucia	55
Samoa	4435
Seychelles	20
South Africa	115,106
South Sudan	6500
Sri Lanka	43,001
Sudan	1500
Suriname	3899
Thailand	1,679,668
Timor-Leste	103
Togo	2061
Trinidad and Tobago	2795
Uganda	4072
United Republic of Tanzania	454,008
United States of America	144,569
Venezuela	485,964
Viet Nam	707,880
Zimbabwe	144

The pineapple has a world production of 25.4 million metric tonnes. The consumption of the pineapple is wide due to its sweet and acidic flavour and varies as it is consumed fresh, cooked, juiced, or preserved. The tropical fruit is an excellent source of vitamins, minerals, and nutrients and is rich in antioxidants. Pineapples are made up of a cluster of multiple berries that grow within the second year of cultivation and are harvested one year later. Pineapples best grow in subtropical and tropical areas where the weather is warm, but cool at night [1] [4].

There are four varieties of Pineapple available worldwide: Smooth Cayenne, Red Spanish, Queen, and Abacaxi [5] [6]. Pineapples are cultivated on more than a million hectares of soil, resulting in US\$ 9 billion to the global economy annually [7] [8]. The main pineapple varieties for commercial use are Smooth Cayenne, Singapore Spanish, Red Spanish and Selangor Green [9]. In Brazil, the most popular varieties are Perola and Smooth Cayenne [10]. Costa Rica, India, Thailand, Philippines, Brazil, China, Nigeria, Mexico, Indonesia, Columbia are the leading producers (Figure 2).



**Figure 2.** Top 10 countries in pineapple production (2019) [FAO, 2021].

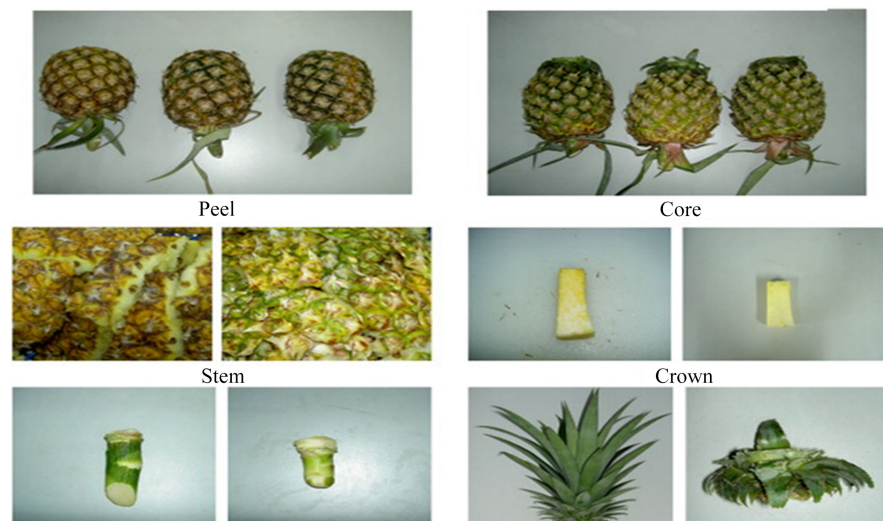
Approximately, 60% of the pineapple fruits are edible, thus processing residuals range between 45% to 65% [11]. The crown and stem of the pineapple are cut off before peeling and the centre is eliminated during processing. All these wastes like core, peel, stem, crown, and leaves account for about 50% (w/w) of general pineapple weight. Two types of waste may be labelled from pineapple production: POFW (pineapple on farm waste) and PPW (pineapple peel waste). POFW normally involves leaves, roots, and stem leftovers at the farm. Pineapple is processed in many methods inside the pineapple product zone, together with slicing, pulping, and juicing. Before the pineapple product changed into processed, exclusive steps were taken to get rid of the crown, then put off the peels and core. A one-of-a-kind volume of PPW is generated through every step. Researchers located that 9.12% of middle, 13.48% of peels, 14.4% of pulp, 14.87% of the top, and 48.04% of completed products have been produced by using pineapple. Therefore, with increasing pineapple production, pineapple waste increases proportionally. Waste disposal is a growing issue because it is usually prone to microbial spoilage and causes serious environmental problems. It directly represents the enormous challenge of pineapple waste disposal, which will further lead to environmental pollution if not successfully used [11].

Due to their pleasant aroma and its attractive sweet flavour, pineapple is widely consumed fresh, canned, in processed juices, and as an ingredient in exotic foods [12], and its derived products are popular. Besides its sweet flavour, pineapple is very wealthy in essential nutrients consisting of potassium, calcium, phosphorus and iron, vitamin C, copper, folate, glycans, fibers, and different crucial factors. All these substances make pineapple an excellent candidate for part of a balanced dietary weight-reduction plan. One of the most favourable aspects of its composition is that it consists of a minimum amount of fat and sodium, but incorporates high quantities of carbohydrates [13] [14].

Pineapple canning industries produce large quantity of solid waste. The dry matter content of pineapple waste is around 10%, composed of about 96% organic matter and 4% inorganic matter [15]. According to Conesa *et al.* [16], in the elaboration of pineapple-based food products, this value can be 50%. Other authors reported a waste production from pineapples processing in the range of 25% - 35% of the weight of the fruit [17]. This discrepancy can be due to pineapple variety and the type of processing used. Worldwide, agricultural industries generate large amounts of bio-mass residues which can cause environmental and pollution concerns [18]. Wastes derived from food processing are identified as major resources for the bio-based processes development [19] [20] and a sustainable use of these food by-products to produce value-added products (as chemicals, materials, and fuels) could contribute to reduce environmental concerns and improvement of economic growth. Taking this in consideration, strategies are needed to recover other added value compounds available in pineapple wastes. **Figure 3** shows pineapple wastes.

## 2. Bioactive Components in Pineapple Waste

Pineapple waste is a rich source of bioactive components. Pineapple primarily has its waste in the form of crown, peel, stem, and core. There is a different bioactive compound present in each portion. For example, citric acid in pineapple leaves, bromelain in the leaves, stem, and peel, ferulic acid in the leaves, ascorbic acid in the core [4]. Moreover, phenolic compounds also found in pineapple residues are of great interest in the pharmaceutical and food industry due to their biological properties with application on human health, examples as myricetin, salicylic acid, tannic acid, trans-cinnamic acid and p-coumaric acid identified in a high dietary fiber powder from pineapple shell which is a part of waste and these compounds were reported as potent antioxidants [21]. On the other hand, it has been shown that the polyphenols found from pineapple wastes such as



**Figure 3.** Pineapple wastes.

ferulic acid and syringic acid, are responsible for antioxidant and antimicrobial activity [22]. Also, glycosides obtained from these residues have various applications as food additives, prebiotics, and bio preservatives [23]. Also, pineapple waste is an enriched raw material, as insoluble fibers, pectins, sugars, protein, vitamins, minerals and phenolic compounds [24] [25] [26] [27], and bromelain, a group of proteases with different applications in the food, textile, cosmetics and others [28].

Pineapple fruit is rich in vitamins A and C, flavonoids, tannins, and other polyphenolic compounds, organic acids, and soluble monosaccharides and disaccharides (up to 15%). Carotenoids are the source of characteristic fruit colour, while the flavour comes from a very complex mix of substances where oxygenated aliphatic compounds have the main role. Stem and full-grown fruit contain proteolytic enzyme that breaks down protein, bromelain, which belongs to the group of endopeptidases [11] [29]. Pineapple fruit is also low in sodium and rich in potassium [2] [3]. Pineapple residue contains high concentrations of vitamins, sugars, fibers, and other constituents which can be used for human consumption [30]. Previous scientific studies have reported the use of pineapple processing residue for citric acid extraction [31], phenolic compounds production [31], bromelain from stem and rind [31], hydrogel from peel cellulose [31], nanocellulose from leaf fibres [32].

The canning industry is producing large quantities of solid and liquid wastes, could be a potential source for the extraction of beneficial bioactive compounds including bromelain [33] [34], fibers, protein, carotenoid, mineral composition, total polyphenol content [35] [36]. Gallic acid (31.76 mg/100g dry extracts), catechin (58.51 mg/100g), epicatechin (50.00 mg/100 g), and ferulic acid (19.50 mg/100g) were found to be the main polyphenolics in pineapple peels [37], vitamin C, carotenoid, phenolic compounds, flavonoids [38] [39] [40] [41]. Arsyada *et al.* [42], reported that pineapple peel extract contains chemical compounds namely: flavonoids, saponins, tannins, and enzymes bromelain and flavonoids were the highest concentration of chemical compounds in pineapple peel extract. Also, pineapple is a rich source of manganese, which helps build and maintain bone strength and it also has plenty of vitamin C. It also contains bromelain, that can reduce swelling, bruising, healing time and pain associated with injury and surgical intervention [43]. The phytochemical analysis of the pineapple peel showed that, alkaloids, flavonoids and saponin had the highest abundance of the phytochemical properties; and phenolic, tannins and terpenoids were present as moderately as well as glycoside and steroids as trace amount [44]. Chlorogenic acid and ferulic acid in aqueous pineapple extract is considered having an important role as reducing agent or antioxidant [45].

The aroma volatile compounds are important properties of fruits and are vital factors to determine the attributes of fresh and processed fruit [31]. Many volatiles have been identified in the pineapple fruit and its derivatives [31] [46] [47] [48] [49]. Barretto *et al.* [50], identified volatile compounds from pineapple residues, using two techniques: simple hydrodistillation and hydrodistillation by passing ni-



trogen gas. Among the identified components were esters (37%), alcohols (29%), aldehydes (9%), ketones (9%), acids (6%), and other compounds (11%). The main volatile compounds identified in the distillate of pineapple processing residue obtained by simple hydrodistillation were (Z)-3-hexen-1-ol (35.58%), methyl octanoate (26.11%), 2-phenyl-1-ethanol (13.51%), 2-methyl-3-buten-2-ol (8.69%), and 1-hexanol (3.84%). By hydrodistillation by passing nitrogen gas, Pineapple processing residue was composed mainly of esters (35%), followed by ketones (26%), alcohols (18%), aldehydes (9%), acids (3%), and other compounds (9%). The major volatile compounds obtained by hydrodistillation by passing nitrogen gas were 1-hexanol (60.19%), ethyl phenyl-acetate (14.54%), 2-methyl-3-buten-2-ol (9.33%),  $\gamma$ -butyrolactone (2.08%), 2-phenyl ethyl-acetate (1.72%), and ethyl octanoate (1.19%). This suggests that the use of an inert gas and lower temperatures helped maintain higher amounts of flavor compounds. These data indicate that pineapple processing residue contained important volatile compounds which can be extracted and used as aroma enhancing products and have high potential to produce value-added natural essences [50].

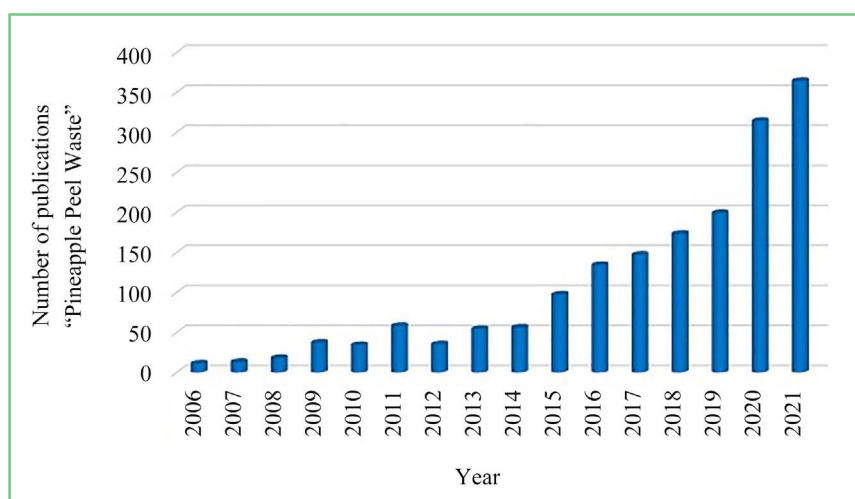
Wei *et al.* [51] identified 44 volatile compounds from pineapple pulp and core. Some of them were methyl hexanoate, ethyl hexanoate, methyl 3-(methylthio) propanoate, methyl octanoate, ethyl decanoate,  $\alpha$ -terpineol, nonanal, and decanal. However, the ones with the highest odor activity values were ethyl hexanoate, nonanal, and decanal. Morais and Silva [46] emphasized that ethyl hexanoate is one of the most important compounds related to the pineapple flavor. Also, they found ethyl hexanoate is an important pineapple aroma volatile compound with decanal, ethyl octanoate, acetic acid, 1-hexanol, and many ketones such as  $\gamma$  hexalactone,  $\gamma$ -octalactone,  $\delta$ -octalactone,  $\gamma$ -decalactone and  $\gamma$ -dodecalactone. According to Facundo [47], the compound ethyl hexanoate is related to the aroma note described as “pineapple”. This compound was also identified in the pineapple processing residue distillate obtained by simple hydrodistillation technique, beside Ethyl octanoate, 2-heptanone, and  $\gamma$ -hexalactone [47]. Tokitomo *et al.* [52] detected 29 odor-active compounds, some of them were  $\gamma$ -octalactone,  $\delta$ -octalactone,  $\gamma$ -decalactone, and  $\gamma$ -dodecalactone. Also, Elss *et al.* [48] reported the presence of the following volatile compounds of fresh pineapple juice and its water phase extracts: 2-methyl-3-buten-2-ol, methyl pentanoate, butyl acetate, hexanal, 2-pentanol, 1-butanol, ethyl hexanoate, limonene,  $\alpha$ -ocimene, linalool, furfural, acetic acid,  $\alpha$ -terpineol, geraniol, and  $\gamma$ -octalactone. As well as, Spanier *et al.* [49] analyzed volatile components present in fresh-cut pineapple and the effect of its storage such as acetic acid, 1-hexanol, and nonanal. Zhang *et al.* [53], reported that 57 volatile compounds were detected of pineapple peel oil including 25 esters, 9 alcohols, 8 acids, 7 phenolic compounds, 6 aldehydes and ketones, 1 terpene and 1 lactone. The content of alcohols is the largest. Phenethyl alcohol (22.18%), 3-methyl-1-butano (6.91%), 2-methyl-1-butano (4.75%), 2,3-butanediol (8.35%), 2-methoxy-4-vinylphenol (5.66%) and octanoic acid (4.29%) were the major constituents.

The number of publications for the term, Pineapple peel waste on ScienceDirect clearly shows that scientists started intensive research only 6 years ago, but it has been particularly pronounced in the last two years. **Figure 4** shows the graphical number of reported publications in the last sixteen years.

### 3. The Advantages (Benefits) of Pineapple Waste

#### 3.1. Antioxidant Capacity of Pineapple Peels

de Oliveira *et al.* [54] have concentrated on the antioxidant capacity of pineapples. They studied the total phenolic content and antioxidant activities of methanolic extracts of pineapple residues (including pulp, seeds, and peels from a local juice factory) using DPPH and superoxide anion scavenging activity. Hossain *et al.* [37] extracted total polyphenols of pineapple with different solvents, and the results showed that the polyphenolic contents of the extracts were found to be highest in methanol corresponding to the highest antioxidant properties. Gallic acid, catechin, epicatechin, and ferulic acid were found to be the main polyphenolics in pineapple peels. Results of polyphenolics' interactions indicated no synergistic effects. In the combinations of ferulic acid-epicatechin and ferulic acid-gallic acid, additive effects were found using both antioxidant activity assays [55]. However, some researchers have reported that pineapple peel is a potential source of bioactive compounds, such as vitamin C, carotenoid, phenolic compounds, flavonoids [38] [39] [40] [41], and these compounds have been reported to have antioxidant activity and various biological activities [21] [56] [57]. However, these bioactive compounds are varied depending on many factors, including cultivar, pre-and postharvest treatment and particularly method for raw material and extract preparation [58] [59] [60] [61] [62]. Also, some studies confirmed the antioxidant activity of pineapple peel extract [31] [63] [64] [65]. Chlorogenic acid and ferulic acid in aqueous pineapple extract is considered having an important role as reducing agent or antioxidant [44].



**Figure 4.** The graphical number of publications on ScienceDirect in the last sixteen years for pineapple peel waste.

### 3.2. Anticancer Activity

Ferulic acid is a hydroxycinnamic acid, a type of organic compound. It is an abundant phenolic photochemical found in extracted from pineapple peel. It is related to trans-cinnamic acid and contributes to the antibacterial, anticancer activity and antioxidant properties of the plant [66]. The antioxidant potential for extracted and standard ferulic acid was calculated by DPPH assay of 87.3% and 81.92% respectively and the total antioxidant capacity was calculated by FRAP assay which is expressed as 2315  $\mu\text{M}$  and 3985  $\mu\text{M}$ . The anticancer activity of extracted ferulic acid was evaluated based on viability of cells using MTT assay. The optimum cell viability was 48.04% at a concentration 125  $\mu\text{g}/\text{ml}$  and the maximum cell viability was 91.63% obtained at the concentration of 7.8  $\mu\text{g}/\text{ml}$  using MTT assay. So, pineapple is a potent source of ferulic acid that can be extracted and used as anticancer and antioxidant [66]. Bromelain also showed significant anticancer activity against breast cancer cells, melanoma cells, human epidermoid carcinoma cells, malignant peritoneal mesothelioma cells and mammary carcinoma cells. The major anticancer mechanism of bromelain is by inhibiting cancer cell proliferation and inducing differentiation of leukemic cells [31].

### 3.3. Antibacterial Activity

Recycling pineapple wastes by using pineapple waste as potential lead to discover new drugs to control some food poisoning and other infectious bacteria is a promising aim. Lubaina *et al.* [67] showed that the antibacterial potential exhibited by ethyl acetate extract of pineapple peel was effective against gram-positive and gram-negative bacterial strains such as *Staphylococcus aureus* (ATCC 29213), *Escherichia coli* (ATCC 25922), *Pseudomonas aeruginosa* (ATCC 27853), *Vibrio cholera* (MCV09) and *Klebsiella pneumoniae* (ATCC 700603). From the results it can be concluded that pineapple peel could be a useful source for antibiotic production and has the potential of medicinal and industrial application. Antimicrobial properties of various extracts from pineapple peel have recently been of great interest because of their possible use as natural additives emerged from a growing tendency to replace synthetic antimicrobials with natural ones [67]. Das *et al.* [68] reported antioxidant, antibacterial, antidiabetic, and cytotoxicity of pineapple peel.

The antibacterial activity revealed by the pineapple extracts might be due to presence of polyphenols, flavonoids, saponins and other secondary metabolites present in the extract. Flavonoids and polyphenols are more potent in inhibiting gram-positive bacteria. Both are phenolic compounds which have polar properties mostly work in the peptidoglycan layer in gram-positive bacteria rather than the non-polar lipid layer. Most plant phenolic compounds are non-toxic for human consumption therefore they could be used to prevent growth of many food-borne and food spoilage microorganisms. These phenols have the ability to denatures the protein and its lipophilic nature helps them to attract the lipid mole-

cules contained in the cell membranes and damage the bacterial cell membrane [69]. Both bromelain and saponins act on bacterial cell wall and membranes. The active compound working against gram-negative bacteria is mainly bromelain. Bromelain is a proteolytic enzyme play a role in the breakdown of proteins, one of the essential components in bacterial membrane causing injury and cell death. It also disintegrates protein in surface membrane which eventually weakens the cell wall, leads to cell leakage and damages the cell. The numbers of amino acids in the bacterial cell wall are thought to determine the antibacterial activity of proteolytic enzymes. Saponins increases the permeability of the bacterial cell membrane, causing alteration in the structure and function of the membrane thereby disrupting the surface tension of the cell wall and allowing antibacterial substances to easily enter the cells and interfere the cell metabolism which in turn leads to the lysis of membrane. Saponins selectively interact with cholesterol on cell membrane leaving a hole in the membrane [70]. Phenols alter the permeability of the membrane that could result in the uncoupling of oxidative phosphorylation, inhibition of active transport, and loss of metabolites due to membrane damage. Polyphenols inhibit bacterial DNA gyrase by binding to the ATP binding site [71]. Gallic acid has proven antifungal and antibacterial properties [72]. Similarly, tannins exert antimicrobial activities by iron deprivation, hydrogen binding or specific interactions with vital proteins, such as enzymes in microbial cells, bind to adhesions, complex with cell wall, other membranes and metal ion complexes. Flavonoids are also possessing antimicrobial potential by link to adhesions or complexes with the cell wall, inactivation of enzymes and inhibition of HIV reverse transcriptase [73].

Bromelain is an extract isolated from pineapple mainly containing proteinase. It is a crude, aqueous extract showed significant antibacterial activity against gram negative and gram-positive bacteria such as *Bacillus subtilis*, *Streptococcus pyogenes*, *Corynebacterium* spp, *Streptococcus sanguis* (10556 ATCC), *Enterococcus faecalis*, *Escherichia coli*, *Proteus* spp and *Pseudomonas aeruginosa*. The anti-bacterial mechanism of bromelain is not well known but, it may inhibit the growth of bacteria through hydrolysis of some peptide bonds present in the bacterial cell wall [31]. Bromelain was extracted from all parts of pineapple. Bromelain was tested for antibacterial activity against bacterial pathogens. Among them, Pulp bromelain had maximum inhibition effect on *Bacillus subtilis*, *Klebsiella pneumonia* and Core bromelain had maximum inhibitory effect on *Bacillus subtilis*, *Proteus vulgaris*, *Schigella flexneri* and *Escherichia coli* and there was no inhibitory activity for the other tested pathogens [74]. Das *et al.* [68] investigated the antimicrobial activity of pineapple peel (PP) extract (PPE) to observe possibility of using it as a natural antimicrobial agent in food. The antimicrobial activity of the PPE was performed against some food pathogens (*Bacillus cereus*, *Staphylococcus aureus*, *Salmonella typhimurium* and *Escherichia coli*). In addition, the gram-positive bacteria tended to be more susceptible to the PPE than the gram negative one. *B. cereus* exhibited the most sensitive strain with mini-

imum inhibition concentration (MIC) of 0.0675 g/mL, followed by *S. aureus* and *E. coli* (0.1349 g/mL) and *S. typhimurium* (0.2699 g/mL), respectively. In addition, the minimum bactericidal concentration (MBC) against all the tested bacteria in broth dilution assay was 0.0675 g/mL, except *B. cereus*, in which the lethally effect was not detected. The results suggested that the pineapple peel extract is a potent natural antimicrobial agent for food application. IUPAC name for Bromelain is N-[(2S,3R,4R,5S,6R) 2-[(2R,3S,4R,5R)-5-acetamido-6-hydroxy-2-(hydroxymethyl)-4-[(2S,3S,4R,5S,6S) 3,4,5trihydroxy-6-methyloxan-2-yl]oxyoxan-3-yl]oxy-5-[(2S,3S,4S,5S,6R)-4,5-dihydroxy 6[[[(2S,3S,4S,5S,6R)-3,4,5-trihydroxy-6-(hydroxymethyl)oxan-2-yl]oxymethyl]-3 [(2S,3R,4S,5R)-3,4,5-trihydroxyoxan-2-yl]oxyoxan-2-yl]oxy-4-hydroxy-6 (hydroxymethyl)oxan-3-yl]acetamide. The chemical structure has been drawn by ChemDraw Professional software (Figure 5).

Pineapple peel extract demonstrates antibacterial properties because it contains chemical compounds. In addition to flavonoids as the highest concentration of chemical compounds in pineapple peel extract, there are other active compounds, namely: saponins, tannins, and enzymes bromelain. Each of these chemical compounds has a specific role in inhibiting the growth of *Enterococcus faecalis* [42] [75]. Flavonoid compounds have the ability to form complex bonds with extracellular protein through hydrogen bonding. Hydrogen bonds with extracellular proteins cause bacterial cell membrane structures containing proteins to become unstable. Consequently, the permeability of bacterial cell wall will be disrupted, resulting in bacterial cell death [76]. Tannin compounds can damage bacterial cell membranes and result in reduced permeability, so the growth and activities at bacterial cells is inhibited [77]. In other chemical compounds, saponin, as an antibacterial agent, can reduce the surface tension leading to the increasing

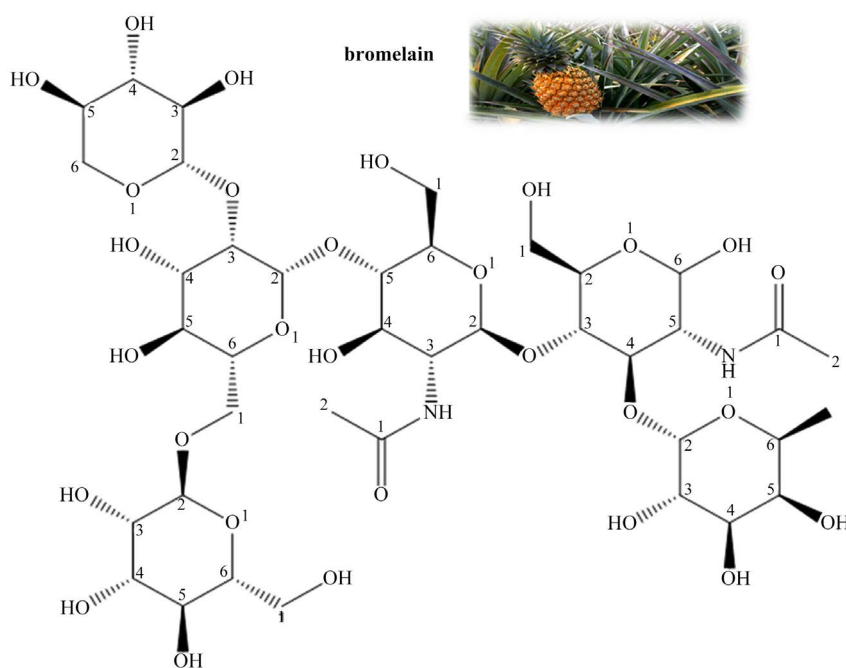


Figure 5. Chemical structure of bromelain.

permeability of cell membranes. Changes in cell membrane permeability cause release of intracellular compounds from the cell that leads to bacterial lysis [77]. The action mechanism of the bromelain enzyme as an antimicrobial lies in altering or damaging the wall structure of bacteria-containing protein. The bromelain enzyme will break down and denature the protein constituent of bacterial cell walls. As the cell weakens it can allow small molecule to leak out [70]. Okoh *et al.* [44] performed the antibacterial activity of the peel extract and showed a greater inhibition for *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Salmonella typhi*. The data obtained show that the pineapple peel contains potential antimicrobial component that may be of great use for the development of pharmaceutical based therapies against various diseases. Drinking the juice or its peel eating can help to hydrate the body and restore the immune system.

### 3.4. Antifungal Activity

Olakunle *et al.* [78] investigated the antifungal activity and phytochemical analysis of selected fruit peels (orange, pineapple cashew and banana fruits). Extracts were prepared from each powder using water and ethanol as solvents. The antimicrobial activity of each of the aqueous extracts (100 mg/ml) against *Aspergillus niger* and *Alternaria alternata*. Results obtained showed that *Aspergillus niger* had its respective inhibition zones with orange, cashew, pineapple, and banana peel extracts as  $0.33 \pm 0.33$ ,  $0.40 \pm 0.30$ ,  $0.60 \pm 0.20$  and  $0.87 \pm 0.33$  cm while inhibition zones of *Alternaria alternata* with the peels in the same order were  $0.50 \pm 0.50$ ,  $0.60 \pm 0.35$ ,  $0.87 \pm 0.43$  and  $1.37 \pm 0.67$  cm. Hence, the order of antifungal activity of the peel extracts against *Aspergillus niger* and *Alternaria alternata* was banana > pineapple > cashew > orange. The antifungal activity of these peel extracts could be due to different classes of compounds such as alkaloid, flavonoid, tannin, cardiac glycoside, saponin and phlobatannin found in them. The phytochemical constituents of ethanolic extracts of pineapple peels were alkaloid, tannin and cardiac glycoside [78]. Antimicrobial properties of plants extracts had been attributed to the presence of alkaloids and flavonoids [79] [80] [81]. Phytochemicals with bitter taste such as alkaloids and flavonoids have been found to possess microbial properties and the presence of cardiac glycosides, flavonoids and alkaloids suggest that the possible antimicrobial activity was due to the presence of these phytochemicals in the peels. These bioactive groups of natural products have been reported for their inhibition roles against pathogens in ethnobotany, drug application and plant health management [82] [83]. These results have opened up the possibility of the use of peels in the treatment of fruits against spoilage microorganisms. The peels are novel, natural and economic sources of antimicrobics, which can be used in the control of post-harvest diseases [78].

### 3.5. Other Uses

Along the pineapple processing chain, waste products such as peels, crowns, stems

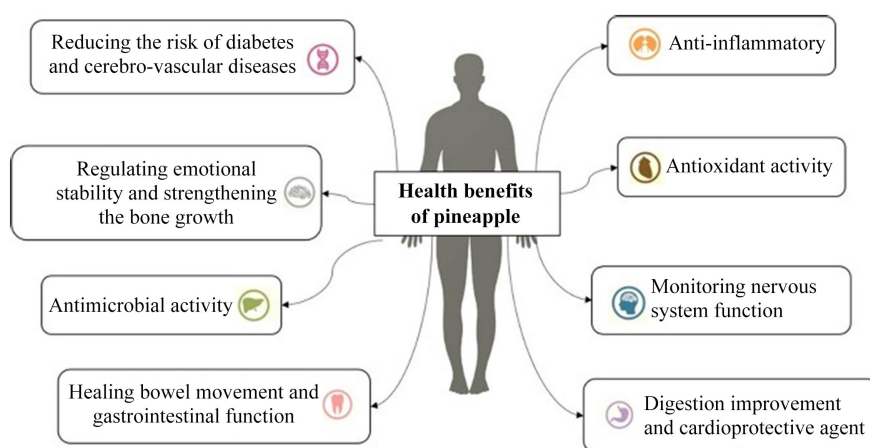
and cores result, and these parts are usually containing significant amounts of the enzyme bromelain [84] [85]. Bromelain, a protease found in pineapples, is of high demand in the pharmaceutical, cosmetic and in the food industries, which use as a meat tenderiser, anti-browning agent and in the production of infant formulas [86]. As a protease, it hydrolyses proteins in these formulas, thus making amino acids more readily available to infants. Cosmetic and pharmaceutical usage of bromelain, as well as usage in the textile industry, has also been reported [87] [88] [89] [90].

Pineapple peel has the potential to being used as a nonpharmacological treatment in the form of processed food and instant drinks. One of the causes of hypertension is reduction of intracellular potassium concentrations in the body. Increased potassium intake could be done by consuming pineapple, because it is one of the superior fruits which have a high content of potassium [91]. Safriani *et al.* [91] showed that potassium levels in pineapple peel were 938.48 mg/kg. The potassium content is greater than flesh and core which are 485.28 mg/kg and 12.98 mg/kg, respectively. From the result, it was appeared that, the peel contains more potassium than flesh and core. Also, producing vinegar from fermented pineapple by-products (peels). The vinegar was produced after fermenting the peels of pineapple using three selected strains of acetic acid bacteria. such as propionic bacterium *acidipropionici*, *panteo agglomerans*, and *pantea dispersa*. The results of Chalchisa *et al.* [92] work have revealed that it is possible to produce vinegar from pineapple peels. This was done via the use of yeast (*Saccharomyces cerevisiae*) as an aerobic degradation of sugar to ethanol and *Acetobacter aceti* oxidizers ethanol to acetic acid (vinegar) by using different strain of acetic acid bacterias. The study also revealed that while cleaning the environment, an added value can be achieved through recycle or conversion of supposed wastes into useful products [93]. In addition to pineapples consumption as fresh, cooked, juiced, and preserved and are found in a wide array of cuisines., the pineapple leaves are used to produce the textile fibre pina employed as a component of wallpaper and furnishings, among other uses. Pineapple peel, is normally used as animal feed [94], development of new products such as cereal bars [95] [96], cakes [97] and jellies [31] [98], citric acid extraction [31], phenolic compounds production [31], bromelain from stem and rind [31], hydrogel from peel cellulose [31], nanocellulose from leaf fibres [32].

Generally, Pineapple peel waste (PPW) has been used for animal feed or land fertilizer [99], and substrate for production of bio-ethanol [41]. Antioxidant or reducing agent plays an important role both in health sector and chemical industry. Therefore, explored PPW as a potential of natural antioxidant is one of interesting pineapple applications as reducing agent is in biosynthesis of metal nanoparticles. It is found that biosynthesis of metal nanoparticles can be carried out by aqueous pineapple extract [45], and had successfully produced silver and cooper nanoparticles. Although fruit is the most used part of plant, other parts (root, rhizome, leaf, cortex, and stem) also have various nutritional and medici-

nal properties. Leaves, stem, and pineapple fruit have an important role in traditional medicine as good antioxidants, antidiabetics, vermicides, emmenagogues, and hypolipemic agents. They are also used in different stadiums of wound healing and as an anti-edematous and anti-inflammatory agents in healing of soft tissue injuries, as well as in the treatment of arthritis, hematoma, and necrotic tissue [100] [101] [102] [103] [104]. The root and fruit are either eaten or applied topically as an anti-inflammatory and as a proteolytic agent. It is traditionally used as an anti-helminthic agent in the Philippine. A root decoction is used to treat diarrhea [2] [3]; however, this fruit also has anti-inflammatory and digestive properties. The fruit can also be used to aid in digestion. It can clear bronchial passages in those suffering with pneumonia and bronchitis [2] [3].

Pineapple has been used as a medicinal plant in numerous cultures, both La-wal [105] and Dabesor *et al.* [106] reported that the solvent extracts of the various parts of *A. comosus* exhibit antibacterial, antiviral, antifungal, antiparasitic and anti-inflammatory properties. Moreover, pineapple juice, can be taken to alleviate sore throat and seasickness. The functional bioactivity of a plant extract, in general, depends upon the presence of compounds such as polyphenols, carotenoids and chlorophyll [14] [107], due to the antioxidant activity of polyphenolic compounds [108]. Flavonoids, mainly present as colouring pigments in plants also function as potent antioxidants at various levels. Some studies showed that flavonoids could protect membrane lipids from oxidation [109]. The anti-inflammatory properties in the fruit help reduce the symptoms of arthritis, and help reduce pain after surgery and sport injuries. *A. comosus* juice is taken as a diuretic and to expediate labour, also as a gargle in cases of sore throat and as an antidote for sea sickness, also to expel intestinal worms; and as a drastic treatment for venereal diseases. In Africa the dried, powdered root is a remedy for edema. The crushed rind is applied on fractures and the rind decoction with rosemary is applied on hemorrhoids. Indians in Panama use the leaf juice as a purgative, emmenagogue and vermifuge [2] [3]. **Figure 6** shows the health benefits of pineapple waste (Ali *et al.*, 2020) [110].



**Figure 6.** Health benefits of pineapple waste.



## 4. Conclusion

Waste generated from pineapple fruit is an important concern in the context of effective waste management. Therefore, it is useful to exploit of such waste with a view to the optimal exploitation of the waste. By appropriate extraction technologies to extract important nutritional and bioactive components is an important concern in the waste. This study reviews pineapple peel as becomes a profitable by-product, given its unique aroma, abundant volatile compounds, and nutritional values and the processing of waste into food and other application. In pineapple waste, many reusable substances with a high final value are found. There are significant amounts of high-value bioactive compounds in various waste generated from pineapple, such as a crown, peel or skin, core, etc. The results obtained in this study showed that pineapple peel has varying degrees of antimicrobial activity, anticancer and antioxidant activities. The results also revealed the presence of medicinally important constituents in peel. Many evidences gathered in earlier studies have confirmed the identified phytochemicals to be bioactive. Therefore, pineapple peel could be used as a good source of nonpharmacological treatment in the form of processed food and instant drinks and a promising source of metabolites for therapeutics, functional foods, and cosmeceutical applications.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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