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Review

Unraveling the Valorization Potential of Pineapple Waste to Obtain Value-Added Products towards a Sustainable Circular Bioeconomy

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Abstract: The pineapple (*Ananas comosus*) is one of the most commercialized tropical fruits worldwide. Its high processing and consumption generate huge quantities of organic waste and severe economic and environmental issues. Embracing the circular bioeconomy concept, this fruit waste can be applied as a bioresource (raw material) for the obtention of a wide range of high-valued biocompounds by applying innovative and ecofriendly technologies. In this paper, we critically describe pineapple-derived waste, from their chemical composition to their functional and biological properties, as well as the latest advances on valorization technologies, particular solid and submerged fermentations. Notably, this article highlights the possibility of using pineapple waste to obtain bioactive compounds such as bromelain, phenolic compounds, and dietary fiber, which have important biological properties such as antioxidant, anticancer, antimicrobial, and prebiotic capacities. Indeed, pineapple wastes can become valued materials by using green and biotechnological technologies that allow us to maximize their potential and might avoid wastage and environmental issues. Nevertheless, it is necessary to further investigate the biomolecules present in the waste derived from different pineapple varieties and their health beneficial effects as well as emerging technologies in order to obtain a full spectrum of natural value-added compounds that industries and society demand today.

Keywords: bioactive compounds; bromelain enzyme; phenolic compounds; fiber; biological properties; nutritional value; solid and submerged fermentation

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1. Introduction

The pineapple (*Ananas comosus*) belongs to the Bromeliaceae family. It is a monocotyledonous plant with 46 genera and 2000 species, approximately. Its fruit is considered an infructescence and ends in a set of leaves; it is fleshy, fibrous, and yellow; its hue depends on the variety [1].

The pineapple is one of the most important tropical fruits globally, and the main producing areas are South and Central America and Southeast Asia. Indonesia is the largest pineapple producer in the world among more than 80 countries that produce this fruit, with a production of 3,203,775.15 tons in 2022, followed by the Philippines and Costa Rica [2].

Much of the pineapple produced in these countries is exported to the United States and the European Union.

The agricultural production and processing of pineapple generate a lot of waste. In developing countries, the biowastes are taken to incinerators or landfills, mostly located in vulnerable areas, generating health problems [3]. Additionally, the biowastes generate bacterial decomposition, volatilization, and chemical reactions, causing high rates of methane and carbon dioxide; also, strong odors are produced due to the formation of esters, hydrogen sulfide, organosulfides, alkylbenzenes, limonene, and other hydrocarbons. As well as affecting people's health, these gases contribute to global warming [4].

In this sense, the integral management of biowastes contributes to the development of sustainable businesses and the environment [5]. In recent years, the European Union has implemented strategies to promulgate the circular bioeconomy in the energy security [6] Pineapple wastes are made up of important nutritional and functional components, among which carbohydrates, insoluble dietary fiber (cellulose and hemicellulose), and soluble dietary fiber (pectin, gums, and oligosaccharides) stand out [7]. Due to their chemical composition, food loss and by-products can be used in the food and pharmaceutical industry in the production of high-added-value compounds such as phenolic compounds [8], strong and inexpensive fibers [9], and enzymes [5]. Also, these biowaste can be used in biotechnology in the synthesis of organic acids [10] and polyhydroxyalkanoates (PHA) [11], the energetic industry [12], and the environmental industry (bioremediation) [13]. The increase in the interest of different industries in polyphenols suggests there will be an increase in their price from 2021 to 2026 of 6.47%.

Pineapple waste also has a high biological activity; phenolic compounds and specific proteases extracted from this biological material have been used as antioxidant, antimicrobial [14], anticancer [15], antidiabetic [16], and anti-inflammatory agents [17].

Laftah & Wan Abdul Rahman [18], Dungani et al. [19], Asim et al. [20], Silva et al. [21], Campelo et al. [22], Verma et al. [23] and Verma [24] only highlight the different uses of the fiber obtained from the leaves of pineapple plantations. Aditiya et al. [25] theoretically show the amount of biofuel that can be made using pineapple peel, and Kringel et al. [26], Roda & Lambri [27], Moreno-González & Ottens [28], Ong et al. [29], Campos et al. [30], Campos et al. [31], Rico et al. [7] and Banerjee et al. [32] reported some applications and extraction methods of added-value compounds using pineapple by-products as the raw material. Kumar et al. [33] and Chaudhary & Singh [34] published a complete review on the conversion of pineapple waste to bioethanol, biobutanol, biohydrogen, and biomethane along with animal feed and vermicompost. However, recent information on the chemical composition, biological activity, and biotechnological applications of pineapple food loss and by-products of the various varieties cultivated in the world is still lacking [35]. Hamzah et al. [36] provide a comprehensive overview of the pineapple's commercial use and waste production, with an emphasis on biofuel production. Recently, Sarangi et al. [37] described the technologies developed to achieve zero waste in pineapple wastes in the different productive sectors and Dhar et al. [38] critically described the current and future perspectives and challenges associated with using pineapple. However, no review articles currently exist that delineate the potential for pineapple waste valorization within the context of the "circular bioeconomy". The objective of this review is to present a detailed description of pineapple wastes and their chemical and functional potential for the sustainable production of value-added products, embracing the concept of the "circular bioeconomy".

2. Pineapple Waste

From field harvesting and post-harvest activities to household consumption, large amounts of waste are found in pineapples [39].

In the plantations, after the harvest of the fruits, the first food losses are produced. The pineapple plant must be renewed every two years due to its low profitability, but some farmers recommend replanting the pineapple after the first fruit due to its growth cycle. This process depends on cultural and agricultural practices [40]. At this point, the food losses are stem and leaves, which together form a gold honey pineapple plant, also known as MD2, which is approximately 3.2 kg [41]. In Costa Rica, pineapple cultivation produces about four million tons of residual biomass every two years, mainly leaves [40]. The food losses produced are eliminated to prepare the soil for the new planting; the most common disposal practice corresponds to drying in the sun and then burning [42].

In the post-harvest stages, the fruits are marketed fresh or taken to industries for further transformation. Fresh-marketed fruits must meet certain quality standards, depending on the country where the fruits are marketed. If these fruits do not meet these standards, they add to the percentage of food losses. Many pathogenic organisms can attack pineapple crops and prevent the fruits from being consumed; for example, *Phytophthora* [43], nematodes *Meloidogyne javanica* and *Meloidogyne incógnita* [44], insect *Mealybug* [45], the *Strymon basilides*, the *Elaphria nucicolora*, and the *Metamasius dimidiatipennis* [46].

In pineapple agro-industrialization, the by-products generated in processing depend on the pineapple variety and the final product. During processing, the crown is removed first, followed by the shell, and finally, the core [39]. These by-products represent between approximately 50 and 60% of the total fruit, mostly made up of the peel (29–42%) and core (9.4–20%), and in smaller quantities per crown (2.7–5.9%) [7] (Figure 1).

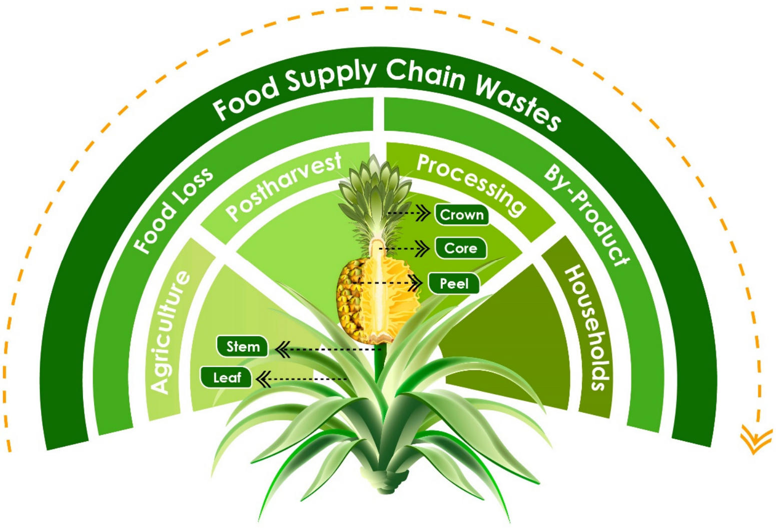

Figure 1. By-product generation chain (crown, core, and shell) and food loss (stem and leaves) of pineapple.

There are no individual data on food waste in the last part of the food supply chain, household consumption. However, FAO [47] published global data on food waste, comparing developed and developing countries; in Europe and the United States, per capita food waste is between 95 and 115 kg/year, and in sub-Saharan Africa and South and Southeast Asia, it is only 6–11 kg/year.

All the waste from the food supply chain for the pineapple is shown in Figure 1, with the terms used in this review. Food loss is waste in the field, by-products are waste from industries, and households are waste from houses.

3. Nutritional Composition of Pineapple Waste

Pineapple waste contains 10% dry matter, of which 96% is organic matter, and the remaining 4% is inorganic matter [48]. These wastes are enriched raw material for many extraction processes of nutritional and functional compounds because they contain insoluble fibers, pectins, proteins, vitamins, minerals, phenolic compounds, and simple sugars and complex carbohydrates such as cellulose and hemicellulose that are potentially hydrolyzable into fermentable sugars [49].

Tables 1 and 2 show that the main by-products of pineapple, peel and core, have high amounts of dietary fiber, cellulose, hemicellulose, and lignin, and a low amount of proteins, and that the fiber from the leaves of the pineapple crop contains mostly cellulose. However, the nutritional content of food losses and by-products depends mainly on the variables of the growing area and genetic factors [50].

Table 1. Proximal composition of the waste from different varieties of pineapple (dry basis).

Source	Protein (%)	Lipids (%)	Total Carbohydrates (%)	Ashes (%)	References
			Peel		
Colombia (Gold MD2)	0.80		6.65		[51]
Colombia (Gold MD2)	0.63	0.21	27.08		[11]
India	3.13			3.88	[52]
India			35.00	10.60	[53]
India (Indian Kew)	3.90			5.90	[39]
India (Smooth Cayenne)	5.11	5.31	55.52	4.39	[54]
Nigeria (Smooth Cayenne)	2.85		74.08	6.80	[55]
Sri lanka (Mauritius)	5.04	2.78	43.95		[56]
Brazil	8.80	1.10		1.50	[57]
Mexico	0.75	2.00		1.50	[58]
			Core		
Colombia (Gold MD2)	0.40		7.21		[51]
Sri lanka (Mauritius)	3.67	2.35	83.03		[56]
Mexico	0.85	3.17		1.30	[58]
			Crown		
Mexico	0.70	3.50		7.37	[58]
Brazil				5.20	[9]
			Pomace		
Costa Rica (Gold MD2)	4.71	0.61	43.46	2.24	[59]
			Leaf		
Costa Rica	6.90	3.00		6.10	[40]
Malaysia				2.00	[60]
India				0.90	[61]

Table 2. Lignocellulosic content and its constituents of pineapple waste.

Source	Total Fiber (%)	Lignin (%)	Hemicellulos (%)	Cellulose (%)	Pectin (%)	References
			Peel			
India		11.52	7.00	11.20	6.70	[52]
India			11.70	19.80		[53]
India (Indian Kew)		10.4	31.80	20.90		[32]
India (Smooth Cayenne)	14.80					[54]
Nigeria (Smooth Cayenne)	13.96					[55]
Sri lanka (Mauritius)	42.02					[56]
Brazil	16.30					[57]
Mexico	65.00	10.01	28.69	40.55	2.49	[58]
			Core			
Sri lanka (Mauritius)	9.14					[56]
Mexico	47.60	5.78	28.53	24.53	1.58	[58]

Table 2. *Cont.*

Source	Total Fiber (%)	Lignin (%)	Hemicellulos (%)	Cellulose (%)	Pectin (%)	References
			Crown			
Mexico	62.50	13.88	21.88	43.53	2.32	[58]
Brazil		24.30	19.10	17.40		[9]
India (Giant Kew)			21.00	41.10		[62]
			Leaf			
Costa Rica		7.30	26.10	22.60		[40]
Malaysia		10.50		73.40		[60]
India		6.04		68.50	1.10	[61]

3.1. Protein

The protein content fluctuates between 0.63 and 6.9 w/w %. This variation depends on the variety, the part of the fruit, and the conditions of the growing area (Table 1). The protein content of the by-products in pineapple is low; for this reason, mechanisms have been used to increase this nutritional value. Pineapple by-products have been widely used as a low-cost protein supplement for animal feed [55].

3.2. Lipids

In pineapple by-products, the lipid content is between 0.21 and 3.50 w/w % (Table 1). According to Morais et al. [57], pineapple by-products contain significant amounts of saturated fatty acids such as palmitic acid (174.4 $\pm$ 17.5 mg/100 g) and stearic (29.9 $\pm$ 3.4 mg/100 g), monounsaturated fatty acids like omega-9 or oleic acid (85.3 $\pm$ 14.8 mg/100 g), polyunsaturated fatty acids like omega-6 or linoleic acid (159.6 $\pm$ 14.5 mg/100 g), and omega-3 or linolenic acid (130.8 $\pm$ 25 mg/100 g).

3.3. Carbohydrates

The total carbohydrate content is between 6.65 and 83.03 w/w % (Table 1). This percentage is high concerning the content of proteins and lipids. Fresh pineapple waste is an important source of fermentable sugars. Zain et al. [10] and Abdullah & Mat [63] reported a glucose, fructose, and sucrose content of 8.24–11.74%, 9.70–12.17%, and 2.05%, respectively. In addition, these wastes have long chains of hydrolyzable monomers.

Nakthong et al. [64] reported 9% starch in pineapple stems on a wet basis. This polysaccharide contains 34.4% amylose. The characteristics of this polysaccharide make the pineapple stem a good source of resistant thermoplastic starch for food and non-food applications. Starch is a naturally occurring carbohydrate in granular form, composed of two polysaccharides: amylose and amylopectin. The granular diameters of starch vary from less than 1 µm to more than 100 µm, and the shapes vary. The different morphologies, compositions, and molecular structures allow for the different physical and functional properties of starch [64].

3.4. Minerals

As can be seen in Table 1, the ash content fluctuates between 0.9 and 10.60 w/w %. Among the main minerals in the peel, core, and pineapple leaf are the macro minerals such as calcium (57.00 mg/kg) and phosphorus (49.00 mg/kg) [51], and among the main microminerals are potassium (26.09 mg/kg) and zinc (298.18 mg/kg) [11]. Calcium is essential for the bones and teeth, and phosphorus works in energy production, while potassium and zinc regulate various organ systems and work as a cofactor, respectively [65]. However, the amount of minerals in pineapple residues and by-products fluctuates depending on the variety and part of the fruit. According to El-Demerdash et al. [66], the amount of minerals is also influenced by the state of maturity and the agronomic condition.

4. Value-Added Product of Pineapple Waste

4.1. Fibers

Table 2 shows the lignocellulosic content of each of the by-products of pineapple and the leaves of the pineapple plant, and it is observed that these organic materials have high potential as a source of fiber. Martínez et al. [67] reported in MD2 pineapple peel and core a fiber content of 75.8% on a dry basis, corresponding to insoluble (75.2%) and soluble (0.6%) fiber, with a water retention capacity of 14.6 ± 0.25 g/g, higher than that reported for mango, passion fruit, and guava residues, and an oil retention capacity of 0.7 ± 0.08 g/g.

Uses of Fibers

The fibers of pineapple leaves serve as a reinforcement for thermoplastic materials such as low-density polyethylene (LDPE) [68], polypropylene (PP), and starch/poly (lactic acid) (PLA) [33,69]. Pineapple leaves grown in Malaysia and in India (Queen variety) are used for the manufacture of Kraft paper [70], high-quality yarn (90 tex) [71], and films for agricultural applications [72].

Gnanasekaran et al. [73] and Fernandes Pereira et al. [9] used fiber from the leaves of the pineapple crop for the extraction and isolation of cellulose with high resistance and rigidity, and Putra et al. [74] used fiber from pineapple leaves to develop acoustic insulation.

Anindya et al. [75] isolated xylan from the stem of the pineapple plant to use it in conjugation with mesalamine and test its efficacy as an anti-inflammatory agent. The xylan is the most abundant hemicellulose in these structures. It is useful as a biofilm and packaging; it can act as a barrier for fats and oils and has properties such as high light transmittance, low oxygen permeability, and aroma permeability [76].

The hemicellulose content (Table 2) of pineapple peels is higher than the other by-products, such as rice straw, wheat [77], and sugarcane bagasse [78]. Banerjee et al. [32] used the high hemicellulose content of pineapple peels to extract xylooligosaccharides and xylose. This last product can be converted into xylitol, which is widely used in the food industry due to its low caloric content and sweetening power.

4.2. Phenolic Compounds

Steingass et al. [79] identified many of the phenolic compounds found in the by-products of MD2 pineapple grown in Ghana using the technology HPLC-DAD-ESI-MS (Table 3). The authors of this study coincide with the results of the analysis carried out by Brito et al. [80] with a gas chromatograph with a flame ionization detector (GC-FID). The two studies detected that the pineapple crown is characterized by containing isomeric esters of p-cumaric or ferulic acid with aldaric acids. Regarding the phenolic compounds detected in the peel, the study carried out by Steingass et al. [79] coincides with that reported by Li et al. [81]. The peel contains mainly gallic acid, catechin, epicatechin, and ferulic acid.

The type and quantity of phenolic compounds depend on different factors; variety, part of the fruit (Table 3), maturity of fruit, environmental factors such as soil type and climate, genetic factors, and processing and extraction methods. The extraction and recovery of phenols in pineapple residues is influenced by the affinity with the solvent used for this process [82]. Hossain & Rahman [83] used three different solvents for phenol extraction and found that the solvent with the best yield was methanol (21.50%), followed by ethyl acetate (4.90%) and extraction with water (4.30%).

Phenolic compounds are a group of secondary metabolites and are one of the most important biologically active phytochemicals. They have been widely studied for their biological properties, such as antioxidant activity. In recent years, their extraction from agro-industrial waste has been studied [84]. Phenolic compounds have other important biological properties, such as anti-allergenic, antiatherogenic, anti-inflammatory, antimicrobial, antithrombotic, cardioprotective, and vasodilator properties [33]. These compounds are in plants in two forms: free or linked by covalent bonds to constituents of plant cells [85].

Table 3. Phenolic compounds and other metabolites isolated from MD2 pineapple by-products (*Ananas comosus* [L.] Merr.) [a] identified with the HPLC-DAD-ESI-MS technique.

Rt (min)	N [b] (m/z)	Compounds	Parts of the Fruit	
			Peel	Crown
8.1	472	Glutathione derivative	•	
13.0	371	Caffeoyl aldarate	•	•
11.4	355	p-Coumaroyl aldaratec	•	•
12.2	289	4-Hydroxy-2,5-dimethyl-3(2H)-furanone-hexoside	•	
14.6	385	Feruloyl aldarate	•	•
15.5	360	1-(1H-Pyrrole-2-carboxyl)-glucuronosylglycerol	•	•
16.1	341	Caffeoyl hexoside	•	
20.7	331	Galloyl hexoside	•	
22.5	353	5-Caffeoylquinic acid (chlorogenic acid)		•
23.1	355	Feruloyl hexoside	•	•
24.5	385	Sinapoyl hexoside	•	
24.6	253	Caffeoylglycerol	•	
26.0	660	S-Sinapylglutathione derivative	•	
29.4	438	S-p-Coumarylglutathione	•	
32.5	337	p-Coumaroylisocitrate or quinic acid	•	•
33.1	411	N-L-γ-Glutamyl-S-coniferyl-L-cysteine	•	
33.9	441	N-L-γ-Glutamyl-S-sinapyl-L-cysteine	•	
34.0	367	Feruloylisocitrate or quinic acid	•	•
36.6	625	Quercetin dihexoside		•
37.6	579	Syringaresinol hexoside	•	
40.0	463	Quercetin hexoside		•
43.8	623	Isorhametin rhamosyl-hexoside	•	
44.8	415	Dicaffeoylglycerol	•	•
47.2	399	p-Coumaroyl-caffeoylglycerol	•	
47.4	429	Feruloyl-caffeoylglycerol	•	•
49.4	413	p-Coumaroyl-feruloylglycerol	•	•

[a] Taken from Steingass et al. [72]. [b] m/z of $[M\text{-}H]^-$.

4.3. Enzymes

Different parts of pineapple waste have been used for enzyme extraction. Coelho Silvestre et al. [86] evaluated the Perola variety pineapple peel extract as a source of proteolytic enzymes. The authors found a content of 5.76 U/mg of protein and optimal activity of these enzymes between pH 6–7 and 70 °C. Rojas et al. [5] evaluated the enzymatic content of pineapple core and crown and reported amounts of 2233.50 ± 78.86 U/mg and 36.111 ± 1.62, respectively. Although many authors agree with these data, Ketnawa et al. [87] recommend the extraction of enzymes from pineapple peel because it is the largest by-product of pineapple processing.

Bromelain is the predominant enzyme in pineapple residues. Enzymes have been reported in the stem, such as stem bromelain (EC 3.4.22.32), ananain (EC 3.4.22.31), and comosain, and in the fruit juice, bromelain from fruit (EC 3.4.22.33). Similar proteases are also present in pineapple rind, core, crown, and leaves, with the highest proteolytic activity and protein content detected in pineapple crown extract. This enzyme has many properties and has been used for various purposes; due to this wide range of applications, bromelain has a high commercial value (2400 USD/kg) [87].

5. Biological Properties of Value-Added Products

5.1. Antioxidant Capacity

As observed in Table 4, the number of phenolic compounds in pineapple by-products can fluctuate between 1.12 and 120.90 mg of gallic acid/g. More antioxidant activity studies have been carried out on pineapple peel and core than on crown; these studies show that the quantification of antioxidants present in the shell and heart are higher than those found in the crown. However, all the research authors agree that pineapple fruit processing residues are an important source of antioxidant compounds.

Table 4. Antioxidants and phenolic compounds in pineapple by-products.

By-Products	Total Phenols [a]	DPPH·	ABTS·+	References
Pulp, peel, core, and crown	1.12	86.00 [b]		[8]
Peel and crown	120.90	4.80 [c]	7.70 [c]	[67]
Pulp, peel, core, and crown	3.00	86.90 [b]		[82]
Crown	5.80	0.05 [c]	0.10 [c]	[80]
Peel	4.30			[88]
Peel and Core		27.40 [b]	57.10 [b]	[89]
Peel	3.00	209.60 [d]		[31]
Core	1.57	93.40 [d]		
Peel			69.00 [b]	[90]
Peel	68.30	78.10 [b]		[91]

[a] Expressed as mg of gallic acid/g dry substrate. [b] Expressed as inhibitory percentage. [c] Expressed as μM Trolox/g. [d] Expressed as mg ascorbic acid equivalent/100 g. All the results are presented on a dry basis.

In the measurement of antioxidant activity, the DPPH· method allows us to understand whether the extract enriched with antioxidants can block the oxidation initiation phase due to neutralizing or inhibiting the formation of reactive oxygen species (ROS). In contrast, the ABTS·+ method is based on the ability of antioxidants to scavenge long-lasting radical cation ABTS·+ [92]. The DPPH· and ABTS·+ radical scavenging activity is highly varied. This could be due to differences in the phenolic combinations since the DPPH· radical scavenging activity depends on its phenolic structure and the number and location of hydroxyl groups [93] (Table 4).

Through the consumption of oxygen, the human body produces ROS, such as the superoxide anion radical, the hydroxyl radical, and hydrogen peroxide. In small proportions, these ROS can be beneficial to health. However, during oxidative stress, large amounts of ROS are produced, causing diseases like mutagenesis, and coronary cardiopathy, among other cardiovascular and neurodegenerative diseases [94]. The body needs antioxidant agents capable of balancing ROS. Recent research has been based on the search for natural antioxidants to replace synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT), which could be carcinogenic and even toxic [95]. According to Sepúlveda et al. [89], the polyphenolic compounds extracted from pineapple by-products have a powerful antioxidant activity compared to commercial antioxidants.

5.2. Antimicrobial Activity

Pineapple waste is a potential source of antimicrobial compounds [96]. Some authors have reported the antimicrobial capacity of phenolic compounds extracted from pineapple waste. Upadhyay et al. [97] reported the antimicrobial capacity of ferulic acid and syringic acid. Brito et al. [80] found antimicrobial capacity in linalool, α-terpineol, and furfural, extracted from the essential oil of pineapple crown, against *Escherichia coli*, *Listeria monocytogenes*, and *Staphylococcus aureus*.

Pineapple plant and fruit proteases have also been extensively studied as antimicrobial agents. [98]. Bromelain has an effect on *Pseudomonas aeruginosa*, *Pseudomonas* sp., *E. coli*, and *S. aureus*, among many other pathogenic microorganisms [99]. Abbas et al. [100] demonstrated the effectiveness of bromelain, extracted from the heart, peel, crown, and stem, against acne due to its inhibitory capacity against *Propionibacterium acnés*. Furthermore, Dutta & Bhattacharyya [101] demonstrated that pineapple crown extract can be used for tissue repair, wound healing, and can possibly prevent secondary infections from microbial organisms due to the action of specific proteases in this part of the plant.

In the identification of compounds of the different parts of the pineapple fruit, hydrazones have also been found [82], compounds recognized for their antimicrobial capacity [102].

5.3. Anticancer Activity

Cancer is one of the medical problems that cause the most deaths in the world. In recent years, research has been carried out to seek alternatives for the treatment of this disease that do not bring contraindications [103]. For this reason, Pauzi et al. [103] investigated in vitro the action of bromelain independently and in synergistic action with cisplatin against MDA-MB-231 human breast cancer cells, finding that the synergistic action of these two compounds has an apoptosis effect on MDA-MB-231 cells and Beuth & Braun [104] evaluated the effect of bromelain on metastasis in L-1 sarcoma cells, and found favorable results.

The effect of polyphenolic compounds in pineapple waste as an anticancer agent has also been evaluated. Rashad et al. [8] demonstrated in vitro the positive effect of extracts rich in phenolic compounds from pineapple waste against HepG2, MCF-7, A549, HL-60, and HCT116 cancer cell lines. Chen et al. [15] demonstrated the use of pineapple leaf extracts as a UV ray protector and ROS scavenger, thus confirming its possible effectiveness against skin cancer.

5.4. Antidiabetic Activity

Not only have pineapple leaves been used for the regulation of blood sugar [105] and the significant improvement of exogenous insulin sensitivity [106], but also their positive effect as an antidislipidemic has been demonstrated [16], making them a promising option for the treatment of diabetic dyslipidemia and diabetes.

Type 2 diabetes is a chronic metabolic disorder that affects more than 5% of the world's population. However, current oral treatments have serious adverse effects [16]. Mismanagement of diabetes can trigger other medical problems, such as cardiovascular disease and damage to vital organs. Dyslipidemia is a metabolic abnormality associated with diabetes, characterized by quantitative and qualitative changes in lipids and lipoproteins [107].

5.5. Anti-Inflammatory Activity

Pineapple waste extracts have been used to treat conditions such as rheumatoid arthritis, severe burns to the tongue and esophagus [17], inflammation of the colon, chronic pain, and asthma due to their anti-inflammatory potential [108]. Mondal et al. [109] evaluated methanolic extracts of pineapple leaves to reduce inflammation caused by edema in rats, finding a percentage of inhibition of inflammation of 84.93. Secor et al. [110] demonstrated the positive result of the use of bromelain in the inflammation of the respiratory tract caused by allergies.

Inflammations can be caused by different factors and occur in other parts of the body, as the accumulation and activation of inflammatory cells mediated by cytokines and chemokines can cause intestinal inflammation [108], burns of the tongue and esophagus [17] and soft tissue injuries [109].

6. Bioeconomy

Currently, in much of the planet, the linear economy predominates, based on producing, using, and throwing away; only 12% of waste is recycled. These practices generate large monetary losses throughout the world; it is estimated that agroindustry waste represents an economic loss of 800,000 million euros [111]. This is why the circular economy is proposed, in which waste is recycled and reused, minimizing production material and generating less waste [112], and the term "bioeconomy" is introduced, which refers to a promising economic strategy to reduce the environmental impact caused by agroindustry. In countries with an agricultural economic base, such as Colombia, the goal for 2030 is for the bioeconomy to contribute 10% of the gross domestic product by developing more than 500 records of new bioproducts to strengthen value chains [113]. In Europe, it is estimated that the current bioeconomy is worth around 2 trillion euros; while in the UK, the entire bioeconomy, including all activities for the sustainable conversion of biomass into bioproducts, injected a total of €220 billion and supported 5.2 million jobs in 2014. An estimated increase in growth of €440 billion is expected by 2030 in the UK [114].

Within the pineapple bioeconomy is the biorefinery that allows for the manufacturing of various value-added products. These products are a source of income for current industries and respond to emerging environmental challenges. Chemistry plays an important role in environmental safety with the manufacturing of green chemicals within a circular economy [115]. Fossil fuels dominate the world's primary energy supply, meeting 80% of current global demand, which is projected to increase by 40% by 2035. The economic viability of such biorefineries is evaluated by integrating the fuel/energy production pathways along with those of biochemical and value-added products.

In recent years, different technologies have been used to modify pineapple waste. These wastes are currently used in different industries. Among the most notable products are products for bioremediation, biofuels, and products from pineapple waste fermentation.

6.1. Bioremediation

Different treatments in pineapple waste allow for the elimination of toxic chemical compounds from wastewater from industries. Astuti et al. [13] transformed pineapple crowns into magnetized activated carbon capable of removing the methyl violet dye from contaminated water. Dai et al. [116] made improved hydrogels based on cellulose from pineapple peel for the adsorption of methylene blue. Veeramalai et al. [117] showed the effectiveness of activated carbon from pineapple waste for the elimination of dyes and the immobilization of lipases by adsorption. Paudyal et al. [118] used the core of the pineapple as a biosorbent for the elimination of Fe(II), and Zhuang et al. [42] used pineapple cellulose modified with potassium permanganate as the copper ion absorber. Currently, this area of research is working on improving the adsorption capacity. Research seeks to improve efficiency through new technologies [119].

6.2. Biofuels

Biogas and bioethanol have been made from the highly biodegradable polysaccharide structures of pineapple waste. Recent research has demonstrated the potential of the leaves of the pineapple crop of different varieties, such as Queen, Kew, and Simanchal, for obtaining second-generation fuels using chemical and enzymatic treatments to increase fermentable sugars [12]. Namsree et al. [120] produced biogas through the use of pineapple pulp and peel, with a yield of 0.43 m^3/kg chemical oxygen demand. Chen et al. [40] produced 2.1 tons of bioethanol with 125 tons of fresh weight of pineapple leaves, enough to replace 8.51% of the consumption of fossil fuels for transportation in Costa Rica, and Casabar et al. [121] produced bioethanol from pineapple peels with a yield of 5.98 ± 1.01 g/L.

6.3. Products of Solid and Submerged Fermentation

6.3.1. Solid Fermentation

The use of pineapple by-products as support in solid-state fermentation has been studied to synthesize and break covalent bonds to release compounds of high commercial value from the biological matrix (Figure 2). Solid-state fermentation (FES) is a biotechnological process in which organisms grow on non-soluble solid substrates, in the absence or near absence of water. Table 5 shows that with this biotechnological method, the recovery of phenolic compounds and crude protein has been increased, and PHA and organic acids have been synthesized.

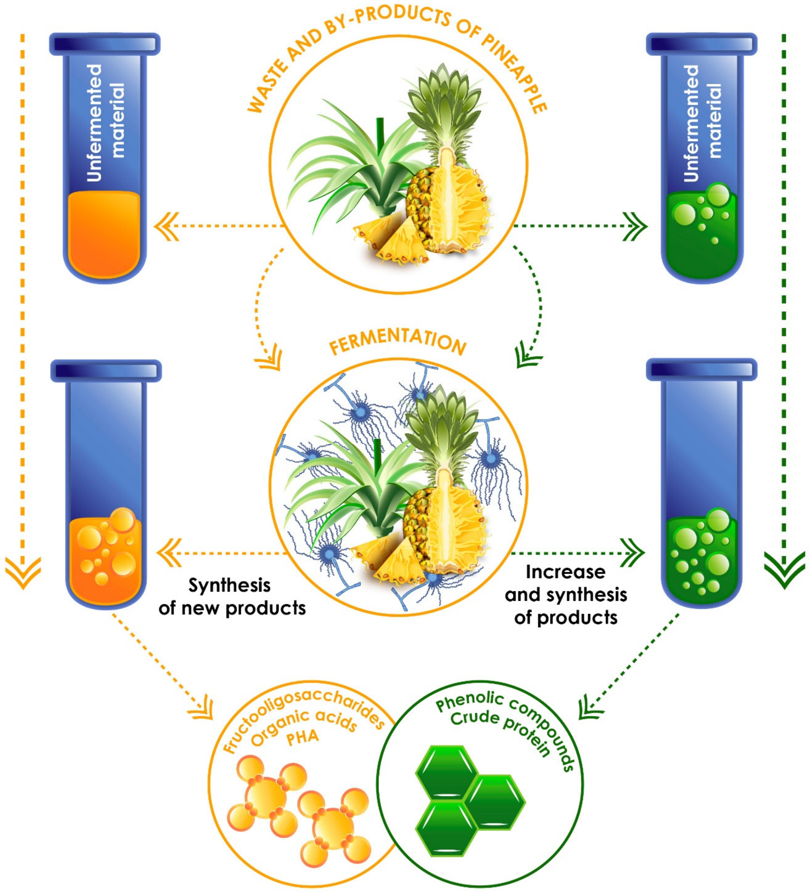

Figure 2. Pineapple by-product fermentation process.

Table 5. Products of submerged fermentation of pineapple by-products.

Waste	Microorganism	Product	Unfermented Material	Fermented Material	References
Solid Fermentation					
Pulp, peel, core, and crown	*Kluyveromyces marxianus*	Phenolic compounds (mg GAE/g)	1.12	1.20	[8]
Pulp, peel, core, and crown	*Rhizopus oligosporus*	Phenolic compounds (mg GAE/g)	3.00	5.20	[82]
Peel	*Trichoderma viride ATCC 36316*	Crude protein (%)	4.53	14.89	[55]
Peel	*Ralsthonia eutropha*	Polyhydroxyalkanoates (mg/100 g)		44	[11]
Pulp, peel, core, and crown	*Rhizopus oryzae NRRL 395*	Lactic acid (mg/g)		103.69	[10]
Peel	*Aspergillus oryzae*	Fructooligosaccharides (g/L)		4.15	[122]
Submerged Fermentation					
Stem	*Bacillus subtilis BKDS1*	Pectinase (U/mL)		1508.50	[1]
Leaf	*Saccharomyces cerevisiae (SA-1)*	Bioethanol (g/L)		15.24	[123]
Peel	*Saccharomyces cerevisiae*	Bioetanol (g/L)		30.77	[121]
Peel	*Lactobacillus rhamnosus GG* *Pediococcus pentosaceus UAM22*	Lactic acid (g/L) Acetic acid (g/L) Propionic acid (g/L)		2.63 0.49 0.15	[90]
Pulp, peel, core, and crown	*Lactobacillus delbrueckii* subsp. *delbrueckii ATCC 9649*	Lactic acid (g/L)		13.10	[48]
Pulp, peel, core, and crown	*Chromobacterium violaceum*	Violacein (mg/L)		5790	[124]
Peel and core	*Cupriavidus necator cepa A-04*	Polyhydroxybutyrate (g/L)		57.20	[125]

6.3.2. Submerged Fermentation

The use of pineapple by-products as a source of nutrients for the growth of microorganisms in submerged fermentation has been a widely used practice in biotechnology to produce enzymes, biofuels, acids, and organic dyes (Table 5).

In submerged fermentation, a lot of water is used for the fermentation process and, therefore, there are some disadvantages concerning solid-state fermentation. However, it has enormous potential for the production of enzymes by filamentous fungi. Solid-state fermentation allows for a better homogeneous culture system, and its raw fermented product can be used directly as enzymatic cocktails for other industries [126].

During the fermentation process of pineapple, important enzymes are produced, such as pectinolytic enzymes, responsible for hydrolyzing proteins, the main polysaccharide present in the cell wall of plants [1]. Enzymes are essential in fermentation processes; they are responsible for allowing fermentation to break bonds in the fermentation support, leaving fermentable material available to the microorganism that was not previously available. Moreover, this same mechanism of action allows for the recovery of compounds with high biological activity, such as phenolic compounds.

Other products obtained from the fermentation of pineapple by-products are pigments, bacterial cellulose, and 2,5-furandicarboxylic acid. Fungal pigments [127] and bacterial pigments (violacein) [124] are produced from pineapple waste, widely used in the industry as a sustainable and environmentally friendly alternative. Bacterial cellulose is a cellulose produced during acetic fermentation with superior properties to plant cellulose [128]. The 2,5-furandicarboxylic acid is the basis for the production of plastic; according to Omana et al. [129], this is produced through fermentation by Aspergillus flavus of pineapple waste, mitigating the pollution caused by conventional production.

The amount of acetic acid produced from the fermentation of pineapple by-products is similar to that obtained from the fermentation of glucose [130]. Acetic acid has applications in the food industry as a seasoning or preservative and is useful in rural areas of developing countries to preserve food.

Citric acid and lactic acid can be produced by fermentation from pineapple by-products. Subramaniyan et al. [131] and Abdullah [48] showed that pineapple by-products are a good support for synthesizing citric acid and lactic acid, respectively. Citric acid is one of the most widely used fermented products in the world; it is estimated that about 10,000 tons are produced annually to supply the demand for it, mainly in the food and pharmaceutical industries [132]. Lactic acid is widely used in the food industry as a flavor enhancer, pH regulator, preservative or buffering agent, and in the chemical industry it is used as a solvent, pH regulator, and as a raw material for biodegradable polymers [133].

Polyhydroxybutyrate (PHB) is a PHA that has been synthesized using pineapple by-products as a carbon source. Sukruansuwan & Napathorn [125] hydrolyzed pineapple by-products with phosphoric acid and synthesized PHB by fermenting pineapple core and peel, extracting up to 57.2 ± 1.0 g/L and 28.6 ± 0.6, respectively. Vega-Castro et al. [11] produced PHA from pineapple peel and obtained a combination of 40% PHB and 60% Polyhydroxyvalerate (PHV), and Sangkharak et al. [134] purified PHA from bromelain.

Polyhydroxyalkanoates (PHAs) are microbial polyesters that are synthesized and accumulated in a wide variety of microorganisms as an internal storage energy source. The biggest drawback is its high cost of production and purification [134].

7. Technological Perspective

From pineapple, essential molecules can be obtained for the optimal functioning of the human body and functional compounds for the food and pharmaceutical industries [10]. Fermentation in the solid and liquid state [122], the use of hydrostatic pressure [135], ultrasound [136], microwave-assisted [137] and heat treatments [5] are environmentally friendly methodologies, which provide the opportunity to take advantage of a large part of these biocomposites found in organic waste such as pineapple waste. At the end of the fermentation, using pineapple by-products as support material, compounds of high biological value, such as phenolic compounds and organic acids, are obtained [8].

Pineapple waste is also a good source of strong and inexpensive fibers; it can be used in food as a functional ingredient and for biodegradable packaging and edible films [138]. The latest studies for the recovery of fibers from pineapple affirm that chemical treatments with organic compounds are highly effective in obtaining fiber of high economic value and producing a low amount of polluting residues [9]. In the same way, recent studies show that the addition of pineapple waste to the diet of animals improves various characteristics of these animals [139].

8. Conclusions

Pineapple residues are an important source of phenolic compounds, organic acids, fibers, and enzymes. Their high content of phenolic compounds and bromelain gives them biological properties such as antioxidant, anticancer, and antimicrobial capacities. Since recent studies focus mainly on proteins and phenols present in pineapple residues and by-products, the reason why to continue researching and disseminating the prop-erties of the other compounds in these biological materials.

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References

1. Kavuthodi, B.; Sebastian, D. Biotechnological valorization of pineapple stem for pectinase production by *Bacillus subtilis* BKDS1: Media formulation and statistical optimization for submerged fermentation. *Biocatal. Agric. Biotechnol.* **2018**, *16*, 715–722. [CrossRef]
2. FAOSTAT. Cultivos. 2022. FAO Statistics, Food and Agriculture Organization of the United Nations. Available online: http://www.fao.org/faostat/en/#data/QC/visualize (accessed on 13 February 2022).
3. Castañeda Torres, S.; Rodriguez Miranda, J.P. Modelo de aprovechamiento sustentable de residuos sólidos orgánicos en Cundinamarca, Colombia. *Univ. Salud* **2017**, *19*, 116. [CrossRef]
4. Ferronato, N.; Moresco, L.; Guisbert Lizarazu, G.E.; Gorritty Portillo, M.A.; Conti, F.; Torretta, V. Sensitivity analysis and improvements of the recycling rate in municipal solid waste life cycle assessment: Focus on a Latin American developing context. *Waste Manag.* **2021**, *128*, 1–15. [CrossRef] [PubMed]
5. Rojas, L.F.; Cortés, C.F.; Zapata, P.; Jiménez, C. Extraction and identification of endopeptidases in convection dried papaya and pineapple residues: A methodological approach for application to higher scale. *Waste Manag.* **2018**, *78*, 58–68. [CrossRef] [PubMed]
6. Ding, Z.; Hamann, K.T.; Grundmann, P. Enhancing circular bioeconomy in Europe: Sustainable valorization of residual grassland biomass for emerging bio-based value chains. *Sustain. Prod. Consum.* **2024**, *45*, 265–280. [CrossRef]
7. Rico, X.; Gullón, B.; Alonso, J.L.; Yáñez, R. Recovery of high value-added compounds from pineapple, melon, watermelon and pumpkin processing by-products: An overview. *Food Res. Int.* **2020**, *132*, 109086. [CrossRef]
8. Rashad, M.M.; Mahmoud, A.E.; Ali, M.M.; Nooman, M.U.; Al-Kashef, A.S. Antioxidant and anticancer agents produced from pineapple waste by solid state fermentation. *Int. J. Toxicol. Pharmacol. Res.* **2015**, *7*, 287–296.
9. Pereira, P.H.F.; Ornaghi, H.L.; Arantes, V.; Cioffi, M.O.H. Effect of chemical treatment of pineapple crown fiber in the production, chemical composition, crystalline structure, thermal stability and thermal degradation kinetic properties of cellulosic materials. *Carbohydr. Res.* **2021**, *499*, 108227. [CrossRef]
10. Zain, N.A.M.; Aziman, S.N.; Suhaimi, M.S.; Idris, A. Optimization of L(+) Lactic Acid Production from Solid Pineapple Waste (SPW) by Rhizopus oryzae NRRL 395. *J. Polym. Environ.* **2020**, *29*, 230–249. [CrossRef]
11. Vega-Castro, O.; Contreras-Calderon, J.; León, E.; Segura, A.; Arias, M.; Pérez, L.; Sobral, P.J. Characterization of a polyhydroxyalkanoate obtained from pineapple peel waste using *Ralsthonia eutropha*. *J. Biotechnol.* **2016**, *231*, 232–238. [CrossRef]
12. Ochieng, E.; Kiplimo, R.; Mutwiwa, U. Heliyon Optimization of anaerobic digestion parameters for biogas production from pineapple wastes co-digested with livestock wastes. *Heliyon* **2023**, *9*, e14041. [CrossRef]
13. Astuti, W.; Sulistyaningsih, T.; Kusumastuti, E.; Thomas, G.Y.R.S.; Kusnadi, R.Y. Thermal conversion of pineapple crown leaf waste to magnetized activated carbon for dye removal. *Bioresour. Technol.* **2019**, *287*, 121426. [CrossRef] [PubMed]

14. Paz-Arteaga, S.L.; Ascacio-Valdes, J.A.; Aguilar, C.N.; Cadena-Chamorro, E.; Serna-Cock, L.; Aguilar-Gonzalez, M.A.; Ramirez-Guzman, N.; Torres-Leon, C. Bioprocessing of pineapple waste for sustainable production of bioactive compounds using solid-state fermentation. *Innov. Food Sci. Emerg. Technol.* **2023**, *85*, 103313. [CrossRef]
15. Chen, Y.-H.; Chen, Y.-J.; Chou, C.-Y.; Wen, C.-C.; Cheng, C.-C. UV-protective activities of pineapple leaf extract in zebrafish embryos. *Res. Chem. Intermed.* **2019**, *45*, 65–75. [CrossRef]
16. Hu, J.; Lin, H.; Shen, J.; Lan, J.; Ma, C.; Zhao, Y.; Lei, F.; Xing, D.; Du, L. Developmental toxicity of orally administered pineapple leaf extract in rats. *Food Chem. Toxicol.* **2011**, *49*, 1455–1463. [CrossRef] [PubMed]
17. Şehirli, A.Ö.; Sayiner, S.; Savtekin, G.; Velioğlu-Öğünç, A. Protective effect of bromelain on corrosive burn in rats. *Burns* **2020**, *47*, 6–12. [CrossRef]
18. Laftah, W.A.; Wan Abdul Rahman, W.A. Pulping Process and the Potential of Using Non-Wood Pineapple Leaves Fiber for Pulp and Paper Production: A Review. *J. Nat. Fibers* **2016**, *13*, 85–102. [CrossRef]
19. Dungani, R.; Karina, M.; Subyakto; Sulaeman, A.; Hermawan, D.; Hadiyane, A. Agricultural waste fibers towards sustainability and advanced utilization: A review. *Asian J. Plant Sci.* **2016**, *15*, 42–55. [CrossRef]
20. Asim, M.; Abdan, K.; Jawaid, M.; Nasir, M.; Dashtizadeh, Z.; Ishak, M.R.; Hoque, M.E.; Deng, Y. A review on pineapple leaves fibre and its composites. *Int. J. Polym. Sci.* **2015**, *2015*, 950567. [CrossRef]
21. Silva, G.; Kim, S.; Aguilar, R.; Nakamatsu, J. Natural fibers as reinforcement additives for geopolymers—A review of potential eco-friendly applications to the construction industry. *Sustain. Mater. Technol.* **2020**, *23*, e00132. [CrossRef]
22. Campelo, P.H.; Ana, A.S.S.; Teresa, M.; Silva, P. ScienceDirect Starch nanoparticles: Production methods, structure, and properties for food applications. *Curr. Opin. Food Sci.* **2020**, *33*, 136–140. [CrossRef]
23. Verma, D. *Bagasse Fiber Composites: A Review Bagasse Fiber Composites—A Review*; Springer: Berlin/Heidelberg, Germany, 2015.
24. Verma, M.; Kaur Brar, S.; Sarma, S.J.; Ajila, C.M.; Antzak, C.; Gassara, F. La quitina y el quitosano como floculantes naturales para la clarificación de la cerveza. *J. Food Eng.* **2015**, *166*, 80–85.
25. Aditiya, H.B.; Chong, W.T.; Mahlia, T.M.I.; Sebayang, A.H.; Berawi, M.A.; Nur, H. Second generation bioethanol potential from selected Malaysia's biodiversity biomasses: A review. *Waste Manag.* **2016**, *47*, 46–61. [CrossRef] [PubMed]
26. Kringel, D.H.; Dias, A.R.G.; Zavareze, E.D.R.; Gandra, E.A. Fruit Wastes as Promising Sources of Starch: Extraction, Properties, and Applications. *Starch-Staerke* **2020**, *72*, 1900200. [CrossRef]
27. Roda, A.; Lambri, M. Food uses of pineapple waste and by-products: A review. *Int. J. Food Sci. Technol.* **2019**, *54*, 1009–1017. [CrossRef]
28. Moreno-González, M.; Ottens, M. A Structured Approach to Recover Valuable Compounds from Agri-food Side Streams. *Food Bioprocess Technol.* **2021**, *14*, 1387–1406. [CrossRef]
29. Ong, K.L.; Kaur, G.; Pensupa, N.; Uisan, K.; Lin, C.S.K. Trends in food waste valorization for the production of chemicals, materials and fuels: Case study South and Southeast Asia. *Bioresour. Technol.* **2018**, *248*, 100–112. [CrossRef]
30. Campos, D.A.; Gómez-García, R.; Vilas-Boas, A.A.; Madureira, A.R.; Pintado, M.M. Management of fruit industrial by-products—A case study on circular economy approach. *Molecules* **2020**, *25*, 320. [CrossRef]
31. Campos, D.A.; Ribeiro, T.B.; Teixeira, J.A.; Pastrana, L.; Pintado, M.M. Integral valorization of pineapple (*Ananas comosus* L.) By-products through a green chemistry approach towards Added Value Ingredients. *Foods* **2020**, *9*, 60. [CrossRef]
32. Banerjee, S.; Patti, A.F.; Ranganathan, V.; Arora, A. Hemicellulose based biorefinery from pineapple peel waste: Xylan extraction and its conversion into xylooligosaccharides. *Food Bioprod. Process.* **2019**, *117*, 38–50. [CrossRef]
33. Singh, Y.; Kumar, J.; Pramod Naik, T.; Pabla, B.S.; Singh, I. Processing and characterization of pineapple fiber reinforced recycled polyethylene composites. *Mater. Today Proc.* **2021**, *44*, 2153–2157. [CrossRef]
34. Chaudhary, S.; Singh, B. Pineapple by-products utilization: Progress towards the circular economy. *Food Humanit.* **2024**, *2*, 100243. [CrossRef]
35. Paz-Arteaga, S.L.; Cadena-Chamorro, E.; Serna-Cock, L.; Torres-Castañeda, H.; Pab, O.V.; Agudelo-Morales, C.E.; Ram, N.; Ascacio-Vald, J.A.; Aguilar, N.; Torres-Le, C. Dual Emerging Applications of Solid-State Fermentation (SSF) with *Aspergillus niger* and Ultrasonic-Assisted Extraction (UAE) for the Obtention of Antimicrobial Polyphenols from Pineapple Waste. *Fermentation* **2023**, *9*, 706. [CrossRef]
36. Hamzah, A.F.A.; Hamzah, M.H.; Man, H.C.; Jamali, N.S.; Siajam, S.I.; Ismail, M.H. Recent Updates on the Conversion of Pineapple Waste (*Ananas comosus*) to Value-Added Products, Future Perspectives and Challenges. *Agronomy* **2021**, *11*, 2221. [CrossRef]
37. Sarangi, P.K.; Singh, A.K.; Srivastava, R.K.; Gupta, V.K. Recent Progress and Future Perspectives for Zero Agriculture Waste Technologies: Pineapple Waste as a Case Study. *Sustainability* **2023**, *15*, 3575. [CrossRef]
38. Dhar, P.; Nickhil, C.; Pandiselvam, R.; Deka, S.C. Pineapple waste-based-biorefinery for sustainable generation of value-added products. *Biomass Convers. Biorefin.* **2023**, *3*, 1–22. [CrossRef]
39. Banerjee, S.; Ranganathan, V.; Patti, A.; Arora, A. Valorisation of pineapple wastes for food and therapeutic applications. *Trends Food Sci. Technol.* **2018**, *82*, 60–70. [CrossRef]
40. Chen, A.; Guan, Y.J.; Bustamante, M.; Uribe, L.; Uribe-Loríо, L.; Roos, M.M.; Liu, Y. Production of renewable fuel and value-added bioproducts using pineapple leaves in Costa Rica. *Biomass Bioenerg.* **2020**, *141*, 105675. [CrossRef]
41. Rodríguez, R.; Becquer, R.; Pino, Y.; López, D.; Rodríguez, R.C.; González, G.Y.L.; Izquierdo, R.E. Fruits production of pineapple (*Ananas comosus* (L.) Merr.) MD-2 from vitroplants. *Cultiv. Trop.* **2016**, *37*, 40–49. [CrossRef]

42. Zhuang, Y.; Liu, J.; Chen, J.; Fei, P. Modified pineapple bran cellulose by potassium permanganate as a copper ion adsorbent and its adsorption kinetic and adsorption thermodynamic. *Food Bioprod. Process.* **2020**, *122*, 82–88. [CrossRef]
43. Oculi, J.; Bua, B.; Ocwa, A. Reactions of pineapple cultivars to pineapple heart rot disease in central Uganda. *Crop Prot.* **2020**, *135*, 105213. [CrossRef]
44. Kiriga, A.W.; Haukeland, S.; Kariuki, G.M.; Coyne, D.L.; Beek, N.V. Effect of Trichoderma spp. and Purpureocillium lilacinum on Meloidogyne javanica in commercial pineapple production in Kenya. *Biol. Control* **2018**, *119*, 27–32. [CrossRef]
45. Hernandez-Rodriguez, L.; Ramos-Gonzalez, P.L.; Garcia-Garcia, G.; Zamora, V.; Peralta-Martin, A.M.; Peña, I.; Perez, J.M.; Ferriol, X. Geographic distribution of mealybug wilt disease of pineapple and genetic diversity of viruses infecting pineapple in Cuba. *Crop Prot.* **2014**, *65*, 43–50. [CrossRef]
46. Monge, M. *Guía para la Identificación de las Principales plagas y Enfermedades en el Cultivo de Piña*; Instituto Nacional de Innovación y Transferencia de Tecnología: Apodaca, NL, Mexico, 2018; pp. 1–46.
47. FAO. *Food Loss and Food Waste: Causes and Solutions*; Food and Agriculture Organization: Rome, Italy, 2011; ISBN 9781788975391.
48. Abdullah, A. Solid and Liquid Pineapple Waste Utilization for Lactic Acid Fermentation. *Reaktor* **2007**, *11*, 50–52. [CrossRef]
49. Seguí, L.; Fito Maupoey, P. An integrated approach for pineapple waste valorisation. Bioethanol production and bromelain extraction from pineapple residues. *J. Clean. Prod.* **2018**, *172*, 1224–1231. [CrossRef]
50. Burton-Freeman, B. Dietary composition and obesity: Do we need to look beyond dietary fat? *J. Nutr.* **2000**, *130* (Suppl. 2), 272–275. [CrossRef]
51. Micanquer-Carlosama, A.; Cortés-Rodríguez, M.; Serna-Cock, L. Formulation of a fermentation substrate from pineapple and sacha inchi wastes to grow *Weissella cibaria*. *Heliyon* **2020**, *6*, e03790. [CrossRef]
52. Rani, D.S.; Nand, K. Ensilage of pineapple processing waste for methane generation. *Waste Manag.* **2004**, *24*, 523–528. [CrossRef]
53. Bardiya, N.; Somayaji, D.; Khanna, S. Biomethanation of banana peel and pineapple waste. *Bioresour. Technol.* **1996**, *58*, 73–76. [CrossRef]
54. Dibanda Romelle, F.; Ashwini, R.P.; Manohar, R.S. Chemical composition of some selected fruit peels. *Eur. J. Food Sci. Technol.* **2016**, *4*, 12–21.
55. Aruna, T.E. Production of value-added product from pineapple peels using solid state fermentation. *Innov. Food Sci. Emerg. Technol.* **2019**, *57*, 102193. [CrossRef]
56. Kodagoda, K.; Marapana, R. Development of non-alcoholic wines from the wastes of Mauritius pineapple variety and its physicochemical properties KHGK Kodagoda and RAUJ Marapana. *J. Pharmacogn. Phytochem.* **2017**, *6*, 492–497.
57. Morais, D.R.; Rotta, E.M.; Sargi, S.C.; Bonafe, E.G.; Suzuki, R.M.; Souza, N.E.; Matsushita, M.; Visentainer, J.V. Proximate composition, mineral contents and fatty acid composition of the different parts and dried peels of tropical fruits cultivated in Brazil. *J. Braz. Chem. Soc.* **2017**, *28*, 308–318. [CrossRef]
58. Sánchez Pardo, M.E.; Ramos Cassellis, M.E.; Mora Escobedo, R.; Jiménez García, E. Chemical Characterisation of the Industrial Residues of the Pineapple (*Ananas comosus*). *J. Agric. Chem. Environ.* **2014**, *3*, 53–56. [CrossRef]
59. Mabel, M.; Guidolin, S.; Brazaca, C.; Tadeu, C.; Ratnayake, W.S.; Flores, R.A.; Bianchini, A. Characterisation and potential application of pineapple pomace in an extruded product for fibre enhancement. *Food Chem.* **2014**, *163*, 23–30. [CrossRef]
60. Khalil, H.P.S.A.; Alwani, M.S.; Omar, A.K.M. Chemical composition, anatomy, lignin distribution, and cell wall structure of Malaysian plant waste fibers. *BioResources* **2006**, *1*, 220–232. [CrossRef]
61. Saha, S.C.; Das, B.K.; Ray, P.K.; Pandey, S.N.; Goswami, K. SEM Studies of the Surface and Fracture Morphology of Pineapple Leaf Fibers. *Text. Res. J.* **1990**, *60*, 726–731. [CrossRef]
62. Banerjee, R.; Chintagunta, A.D.; Ray, S. A cleaner and eco-friendly bioprocess for enhancing reducing sugar production from pineapple leaf waste. *J. Clean. Prod.* **2017**, *149*, 387–395. [CrossRef]
63. Abdullah, A.; Mat, H. Characterisation of Solid and Liquid Pineapple Waste. *Reaktor* **2008**, *12*, 48. [CrossRef]
64. Nakthong, N.; Wongsagonsup, R.; Amornsakchai, T. Industrial Crops & Products Characteristics and potential utilizations of starch from pineapple stem waste. *Ind. Crops Prod.* **2017**, *105*, 74–82. [CrossRef]
65. Gharibzahedi, S.M.T.; Jafari, S.M. The importance of minerals in human nutrition: Bioavailability, food fortification, processing effects and nanoencapsulation. *Trends Food Sci. Technol.* **2017**, *62*, 119–132. [CrossRef]
66. El-Demerdash, F.M.; Baghdadi, H.H.; Ghanem, N.F.; Mhanna, A.B.A. Nephroprotective role of bromelain against oxidative injury induced by aluminium in rats. *Environ. Toxicol. Pharmacol.* **2020**, *80*, 103509. [CrossRef] [PubMed]
67. Martínez, R.; Torres, P.; Meneses, M.A.; Figueroa, J.G.; Pérez-Álvarez, J.A.; Viuda-Martos, M. Chemical, technological and in vitro antioxidant properties of mango, guava, pineapple and passion fruit dietary fibre concentrate. *Food Chem.* **2012**, *135*, 1520–1526. [CrossRef] [PubMed]
68. Aurelio, R.H.; Mextlisol, C.V.S.; Páramo-Calderón, D.E.; Acevedo-Gómez, R.; Gerardo, G.G.; Nolasco-Hipolito, C.; Eduardo, B.G.J.; Carlos, C.A.J.; Alejandro, A.S. Functionality and characterization of modified starch films with pineapple leaf fibers. *Int J. Biol. Macromol.* **2023**, *246*, 125611. [CrossRef]
69. Jaramillo, N.; Hoyos, D.; Santa, J.F. Composites with pineapple-leaf fibers manufactured by layered compression molding. *Ing. Compet.* **2016**, *18*, 151–162.
70. Laftah, W.A.; Abdul Rahaman, W.A.W. Chemical pulping of waste pineapple leaves fiber for kraft paper production. *J. Mater. Res. Technol.* **2015**, *4*, 254–261. [CrossRef]

71. Hazarika, D.; Gogoi, N.; Jose, S.; Das, R.; Basu, G. Exploration of future prospects of Indian pineapple leaf, an agro waste for textile application. *J. Clean. Prod.* **2017**, *141*, 580–586. [CrossRef]
72. Justice, M.; Puseletso, J.; Mpho, M.; Mngomezulu, M.; Tywabi-ngeva, Z. Heliyon Chemical, thermal and morphological properties of polybutylene succinate-waste pineapple leaf fibres composites. *Heliyon* **2023**, *9*, e21238. [CrossRef]
73. Gnanasekaran, S.; Nordin, N.I.A.A.; Jamari, S.S.; Shariffuddin, J.H. Effect of Steam-Alkaline coupled treatment on N36 cultivar pineapple leave fibre for isolation of cellulose. *Mater. Today Proc.* **2021**, *48*, 753–760. [CrossRef]
74. Putra, A.; Or, K.H.; Selamat, M.Z.; Nor, M.J.M.; Hassan, M.H.; Prasetiyo, I. Sound absorption of extracted pineapple-leaf fibres. *Appl. Acoust.* **2018**, *136*, 9–15. [CrossRef]
75. Anindya, A.L.; Oktaviani, R.D.; Praevina, B.R.; Damayanti, S.; Kurniati, N.F.; Riani, C.; Rachmawati, H. Xylan from Pineapple Stem Waste: A Potential Biopolymer for Colonic Targeting of Anti-inflammatory Agent Mesalamine. *AAPS PharmSciTech* **2019**, *20*, 112. [CrossRef] [PubMed]
76. Stevanic, J.S.; Joly, C.; Mikkonen, K.S.; Pirkkalainen, K.; Serimaa, R.; Rémond, C.; Toriz, G.; Gatenholm, P.; Tenkanen, M.; Salmén, L. Bacterial Nanocellulose-Reinforced Arabinoxylan Films. *J. Appl. Polym. Sci.* **2011**, *122*, 1030–1039. [CrossRef]
77. Prasad, S.; Singh, A.; Joshi, H.C. Ethanol as an alternative fuel from agricultural, industrial and urban residues. *Resour. Conserv. Recycl.* **2007**, *50*, 1–39. [CrossRef]
78. Kim, M.; Day, D.F. Composition of sugar cane, energy cane, and sweet sorghum suitable for ethanol production at Louisiana sugar mills. *J. Ind. Microbiol. Biotechnol.* **2011**, *38*, 803–807. [CrossRef]
79. Steingass, C.B.; Glock, M.P.; Schweiggert, R.M.; Carle, R. Studies into the phenolic patterns of different tissues of pineapple (*Ananas comosus* [L.] Merr.) infructescence by HPLC-DAD-ESI-MSn and GC-MS analysis. *Anal. Bioanal. Chem.* **2015**, *407*, 6463–6479. [CrossRef]
80. Brito, T.; Lima, L.R.; Santos, M.B.; Moreira, R.A.; Cameron, L.; Fai, A.C.; Ferreira, M.S. Antimicrobial, antioxidant, volatile and phenolic profiles of cabbage-stalk and pineapple-crown flour revealed by GC-MS and UPLC-MSE. *Food Chem.* **2021**, *339*, 127882. [CrossRef]
81. Li, T.; Shen, P.; Liu, W.; Liu, C.; Liang, R.; Yan, N.; Chen, J. Major polyphenolics in pineapple peels and their antioxidant interactions. *Int. J. Food Prop.* **2014**, *17*, 1805–1817. [CrossRef]
82. Correia, R.T.P.; McCue, P.; Magalhães, M.M.A.; Macêdo, G.R.; Shetty, K. Production of phenolic antioxidants by the solid-state bioconversion of pineapple waste mixed with soy flour using *Rhizopus oligosporus*. *Process Biochem.* **2004**, *39*, 2167–2172. [CrossRef]
83. Hossain, M.A.; Rahman, S.M.M. Total phenolics, flavonoids and antioxidant activity of tropical fruit pineapple. *Food Res. Int.* **2011**, *44*, 672–676. [CrossRef]
84. Lizardi-Jiménez, M.A.; Hernández-Martínez, R. Solid state fermentation (SSF): Diversity of applications to valorize waste and biomass. *3 Biotech* **2017**, *7*, 44. [CrossRef]
85. Zhang, B.; Zhang, Y.; Li, H.; Deng, Z.; Tsao, R. A review on insoluble-bound phenolics in plant-based food matrix and their contribution to human health with future perspectives. *Trends Food Sci. Technol.* **2020**, *105*, 347–362. [CrossRef]
86. Coelho Silvestre, M.P.; Linhares Carreira, R.; Ramalho Silva, M.; Campos Corgosinho, F.; Pereira Monteiro, M.R.; Aley Morais, H. Effect of pH and Temperature on the Activity of Enzymatic Extracts from Pineapple Peel. *Food Bioprocess Technol.* **2012**, *5*, 1824–1831. [CrossRef]
87. Ketnawa, S.; Chaiwut, P.; Rawdkuen, S. Pineapple wastes: A potential source for bromelain extraction. *Food Bioprod. Process.* **2012**, *90*, 385–391. [CrossRef]
88. Morais, D.R.; Rotta, E.M.; Sargi, S.C.; Schmidt, E.M.; Bonafe, E.G.; Eberlin, M.N.; Sawaya, A.C.H.F.; Visentainer, J.V. Antioxidant activity, phenolics and UPLC-ESI(-)-MS of extracts from different tropical fruits parts and processed peels. *Food Res. Int.* **2015**, *77*, 392–399. [CrossRef]
89. Sepúlveda, L.; Romaní, A.; Aguilar, C.N.; Teixeira, J. Valorization of pineapple waste for the extraction of bioactive compounds and glycosides using autohydrolysis. *Innov. Food Sci. Emerg. Technol.* **2018**, *47*, 38–45. [CrossRef]
90. Diaz-Vela, J.; Totosaus, A.; Cruz-Guerrero, A.E.; De Lourdes Pérez-Chabela, M. In vitro evaluation of the fermentation of added-value agroindustrial by-products: Cactus pear (*Opuntia ficus-indica* L.) peel and pineapple (*Ananas comosus*) peel as functional ingredients. *Int. J. Food Sci. Technol.* **2013**, *48*, 1460–1467. [CrossRef]
91. Kuppusamy, S.; Venkateswarlu, K.; Megharaj, M. Examining the polyphenol content, antioxidant activity and fatty acid composition of twenty-one different wastes of fruits, vegetables, oilseeds and beverages. *SN Appl. Sci.* **2020**, *2*, 673. [CrossRef]
92. Shahidi, F.; Zhong, Y. Measurement of antioxidant activity. *J. Funct. Foods* **2015**, *18*, 757–781. [CrossRef]
93. Staszowska-Karkut, M.; Materska, M. Phenolic composition, mineral content, and beneficial bioactivities of leaf extracts from black currant (*Ribes nigrum* L.), raspberry (*Rubus idaeus*), and aronia (*Aronia melanocarpa*). *Nutrients* **2020**, *12*, 463. [CrossRef]
94. Poprac, P.; Jomova, K.; Simunkova, M.; Kollar, V.; Rhodes, C.J.; Valko, M. Targeting Free Radicals in Oxidative Stress-Related Human Diseases. *Trends Pharmacol. Sci.* **2017**, *38*, 592–607. [CrossRef]
95. Moure, A.; Cruz, J.M.; Franco, D.; Manuel Domínguez, J.; Sineiro, J.; Domínguez, H.; Núñez, M.J.; Carlos Parajó, J. Natural antioxidants from residual sources. *Food Chem.* **2001**, *72*, 145–171. [CrossRef]
96. Gnanasaraswathi, M.; Lakshmipraba, S.; Rajadurai, R.P.; Abhinayashree, M.; Fathima, B.; Lakshmipriya, A.; Kamatchi, S. Potent anti-oxidant behaviour of citrus fruit peels and their bactericidal activity against multi drug resistant organism *Pseudomonas aeruginosa*. *J. Chem. Pharm. Sci.* **2014**, *2*, 139–144.
97. Upadhyay, A.; Lama, J.P.; Tawata, S. Utilization of Pineapple Waste: A Review. *J. Food Sci. Technol. Nepal* **2010**, *6*, 10–18. [CrossRef]

98. Bhattacharyya, B.K. Bromelain: An overview. *Indian J. Nat. Prod. Resour.* **2008**, *7*, 359–363.
99. Ghanbari, R.; Ebrahimpour, A. Separation and identification of bromelain-generated antibacterial peptides from *Actinopyga lecanora*. *Food Sci. Biotechnol.* **2018**, *27*, 591–598. [CrossRef] [PubMed]
100. Abbas, S.; Shanbhag, T.; Kothare, A. Applications of bromelain from pineapple waste towards acne. *Saudi J. Biol. Sci.* **2021**, *28*, 1001–1009. [CrossRef]
101. Dutta, S.; Bhattacharyya, D. Enzymatic, antimicrobial and toxicity studies of the aqueous extract of *Ananas comosus* (pineapple) crown leaf. *J. Ethnopharmacol.* **2013**, *150*, 451–457. [CrossRef]
102. Rollas, S.; Küçükgüzel, Ş.G. Biological activities of hydrazone derivatives. *Molecules* **2007**, *12*, 1910–1939. [CrossRef]
103. Pauzi, A.Z.M.; Yeap, S.K.; Abu, N.; Lim, K.L.; Omar, A.R.; Aziz, S.A.; Chow, A.L.T.; Subramani, T.; Tan, S.G.; Alitheen, N.B. Combination of cisplatin and bromelain exerts synergistic cytotoxic effects against breast cancer cell line MDA-MB-231 in vitro. *Chin. Med.* **2016**, *11*, 46. [CrossRef]
104. Beuth, J.; Braun, J.M. Modulation of murine tumor growth and colonization by bromelaine, an extract of the pineapple plant (*Ananas comosum* L.). *In Vivo* **2005**, *19*, 483–486.
105. Xie, W.; Wang, W.; Su, H.; Xing, D.; Pan, Y.; Du, L. Effect of ethanolic extracts of *Ananas comosus* L. leaves on insulin sensitivity in rats and HepG2. *Comp. Biochem. Physiol. C Toxicol. Pharmacol.* **2006**, *143*, 429–435. [CrossRef] [PubMed]
106. Xie, W.; Xing, D.; Sun, H.; Wang, W.; Ding, Y.; Du, L. The effects of *Ananas comosus* L. leaves on diabetic-dyslipidemic rats induced by alloxan and a high-fat/high-cholesterol diet. *Am. J. Chin. Med.* **2005**, *33*, 95–105. [CrossRef]
107. Wu, L.; Parhofer, K.G. Diabetic dyslipidemia. *Metabolism* **2014**, *63*, 1469–1479. [CrossRef] [PubMed]
108. Hale, L.P.; Greer, P.K.; Trinh, C.T.; Gottfried, M.R. Treatment with oral bromelain decreases colonic inflammation in the IL-10-deficient murine model of inflammatory bowel disease. *Clin. Immunol.* **2005**, *116*, 135–142. [CrossRef] [PubMed]
109. Mondal, S.; Bhattacharya, S.; Pandey, J.; Biswas, M. Evaluation of acute anti-inflammatory effect of ananas comosus leaf extracts in rats. *Pharmacologyonline* **2011**, *1315*, 1312–1315.
110. Secor, E.R.; Carson IV, W.F.; Cloutier, M.M.; Guernsey, L.A.; Schramm, C.M.; Wu, C.A.; Thrall, R.S. Bromelain exerts anti-inflammatory effects in an ovalbumin-induced murine model of allergic airway disease. *Cell. Immunol.* **2005**, *237*, 68–75. [CrossRef]
111. Yafetto, L.; Odamtten, G.T.; Wiafe-Kwagyan, M. Valorization of agro-industrial wastes into animal feed through microbial fermentation: A review of the global and Ghanaian case. *Heliyon* **2023**, *9*, e14814. [CrossRef]
112. Mir-Cerdà, A.; Nuñez, O.; Granados, M.; Sentellas, S.; Saurina, J. An overview of the extraction and characterization of bioactive phenolic compounds from agri-food waste within the framework of circular bioeconomy. *TrAC—Trends Anal. Chem.* **2023**, *161*, 116994. [CrossRef]
113. Grilli, G.; Cantillo, T.; Turner, K.; Erazo, J.; Murcia López, M.A.; Valle Parra, J.S.; Cardona, F.G.; Ferrini, S. A decision support procedure for the bioeconomy transition: A Colombian case study. *J. Environ. Manag.* **2024**, *352*, 120042. [CrossRef]
114. Ajayi, V.A.; Lateef, A. Biotechnological valorization of agrowastes for circular bioeconomy: Melon seed shell, groundnut shell and groundnut peel. *Clean. Circ. Bioecon.* **2023**, *4*, 100039. [CrossRef]
115. Mishra, K.; Siwal, S.S.; Nayaka, S.C.; Guan, Z.; Thakur, V.K. Waste-to-chemicals: Green solutions for bioeconomy markets. *Sci. Total Environ.* **2023**, *887*, 164006. [CrossRef]
116. Dai, H.; Huang, Y.; Zhang, Y.; Zhang, H.; Huang, H. Green and facile fabrication of pineapple peel cellulose/magnetic diatomite hydrogels in ionic liquid for methylene blue adsorption. *Cellulose* **2019**, *26*, 3825–3844. [CrossRef]
117. Veeramalai, S.; Nasya, N.; Ibnu, H. Industrial Crops & Products Development of organic porous material from pineapple waste as a support for enzyme and dye adsorption. *Ind. Crops Prod.* **2022**, *181*, 114823. [CrossRef]
118. Paudyal, H.; Adhikari, S.; Nath, K.; Gyawali, D. Results in Chemistry Synthesis, characterization and cation exchange performance of chemically modified pineapple waste biomass for the removal of Fe (II) from water. *Results Chem.* **2022**, *4*, 100608. [CrossRef]
119. Van Tran, T.; Nguyen, D.T.C.; Nguyen, T.T.T.; Nguyen, D.H.; Alhassan, M.; Jalil, A.A.; Nabgan, W.; Lee, T. A critical review on pineapple (*Ananas comosus*) wastes for water treatment, challenges and future prospects towards circular economy. *Sci. Total Environ.* **2023**, *856*, 158817. [CrossRef]
120. Namsree, P.; Suvajittanont, W.; Puttanlek, C.; Uttapap, D.; Rungsardthong, V. Anaerobic digestion of pineapple pulp and peel in a plug-flow reactor. *J. Environ. Manag.* **2012**, *110*, 40–47. [CrossRef]
121. Casabar, J.T.; Unpaprom, Y.; Ramaraj, R. Fermentation of pineapple fruit peel wastes for bioethanol production. *Biomass Convers. Biorefin.* **2019**, *9*, 761–765. [CrossRef]
122. de la Rosa, O.; Múñiz-Marquez, D.B.; Contreras-Esquivel, J.C.; Wong-Paz, J.E.; Rodríguez-Herrera, R.; Aguilar, C.N. Improving the fructooligosaccharides production by solid-state fermentation. *Biocatal. Agric. Biotechnol.* **2020**, *27*, 101704. [CrossRef]
123. da Silva, C.N.; Bronzato, G.R.F.; Cesarino, I.; Leão, A.L. Second-generation ethanol from pineapple leaf fibers. *J. Nat. Fibers* **2020**, *17*, 113–121. [CrossRef]
124. Ahmad, W.A.; Venil, C.K.; Aruldass, C.A. Production of Violacein by *Chromobacterium violaceum* Grown in Liquid Pineapple Waste: Current Scenario. In *Beneficial Microorganisms in Agriculture, Aquaculture and Other Areas*; Springer: Cham, Switzerland, 2015; pp. 45–58. [CrossRef]
125. Sukruansuwan, V.; Napathorn, S.C. Use of agro-industrial residue from the canned pineapple industry for polyhydroxybutyrate production by *Cupriavidus necator* strain A-04. *Biotechnol. Biofuels* **2018**, *11*, 202. [CrossRef]

126. Cano y Postigo, L.O.; Jacobo-Velázquez, D.A.; Guajardo-Flores, D.; Garcia Amezquita, L.E.; García-Cayuela, T. Solid-state fermentation for enhancing the nutraceutical content of agrifood by-products: Recent advances and its industrial feasibility. *Food Biosci.* **2021**, *41*, 100926. [CrossRef]
127. Umesh, M.; Suresh, S.; Santosh, A.S.; Prasad, S.; Chinnathambi, A.; Al Obaid, S.; Jhanani, G.; Shanmugam, S. Valorization of pineapple peel waste for fungal pigment production using *Talaromyces albobiverticillius*: Insights into antibacterial, antioxidant and textile dyeing properties. *Environ. Res.* **2023**, *229*, 115973. [CrossRef]
128. Mardawati, E.; Maulida, D.; Rachmadona, N.; Satoto, R.; Karina, M. Heliyon Pineapple core from the canning industrial waste for bacterial cellulose production by *Komagataeibacter xylinus*. *Heliyon* **2023**, *9*, e22010. [CrossRef]
129. Omana, R.; Sreevidya, N.; Akhila, S.; Krishnan, T.; Dileep, N.R.; Júlio, C.; Porto, L.; Vandenberghe, D.S.; Ricardo, C.; Sindhu, R.; et al. Bioresource Technology Whole-cell synthesis of 2,5-furandicarboxylic acid from pineapple waste under various fermentation strategies. *Bioresour. Technol.* **2023**, *386*, 129545. [CrossRef]
130. Roda, A.; De Faveri, D.M.; Dordoni, R.; Lambri, M. Vinegar production from pineapple wastes-preliminary saccharification trials. *Chem. Eng. Trans.* **2014**, *37*, 607–612. [CrossRef]
131. Subramaniyan, S.; Paramasivam, S.; Kannaiyan, M.; Chinnaiyan, U. Utilization of Fruit Waste f or the Production of Citric Acid by using. *J. Drug Deliv. Ther.* **2019**, *9*, 9–14.
132. Jianlong, W. Production of citric acid by immobilized *Aspergillus niger* using a rotating biological contactor (RBC). *Bioresour. Technol.* **2000**, *75*, 245–247. [CrossRef]
133. Rattu, G.; Krishna, M. Enzyme-free colorimetric nanosensor for the rapid detection of lactic acid in food quality analysis. *J. Agric. Food Res.* **2022**, *7*, 100268. [CrossRef]
134. Sangkharak, K.; Wangsirikul, P.; Pichid, N.; Yunu, T.; Prasertsan, P. Partitioning of bromelain from pineapple stem (*Smooth cayenne*) by aqueous two phase system and its application for recovery and purification of polyhydroxyalkanoate. *Chiang Mai J. Sci.* **2016**, *43*, 794–807.
135. Santos, D.I.; Martins, C.F.; Amaral, R.A.; Saraiva, J.A.; Vicente, A.; Mold, M. Pineapple (*Ananas comosus* L.) By-Products Valorization: Novel Bio Ingredients for Functional Foods. *Molecules* **2021**, *26*, 3216. [CrossRef]
136. Rathnakumar, K.; Anal, A.; Lakshmi, K. Optimization of Ultrasonic Assisted Extraction of Bioactive components from different Parts of Pineapple WasteOptimization of Ultrasonic Assisted Extraction of Bioactive components from different Parts of Pineapple WasteOptimization of Ultrasonic Assisted. *Int. J. Agric. Environ. Biotechnol.* **2017**, *10*, 553. [CrossRef]
137. Nor, S.; Anis, S.; Ching, W.; Mohd, A.; Idayu, I.; Hui, S.; Zahran, A. Microwave-assisted green synthesis of silver nanoparticles using pineapple leaves waste. *Clean. Eng. Technol.* **2023**, *15*, 100660. [CrossRef]
138. Elleuch, M.; Bedigian, D.; Roiseux, O.; Besbes, S.; Blecker, C.; Attia, H. Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chem.* **2011**, *124*, 411–421. [CrossRef]
139. Anis, S.; Sukri, M.; Andu, Y.; Tuan, Z.; Sarijan, S.; Naim, M.; Pauzi, F.; Seong, L.; Dawood, M.A.O.; Abdul, Z. Saudi Journal of Biological Sciences Effect of feeding pineapple waste on growth performance, texture quality and flesh colour of nile tilapia (*Oreochromis niloticus*) fingerlings. *Saudi J. Biol. Sci.* **2022**, *29*, 2514–2519. [CrossRef]