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Ananas comosus peel waste, a novel substrate of therapeutic potential: Evidences and prospects

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Ananas comosus (Pineapple) is one of the most important edible fruit in the world. Around 75-80% of the pineapple gets discarded as by products, which are produced from crown; core and peel. Whereas 30-35% alone accounts to peel. This agricultural waste is thrown causing environmental damage. However, the *A. comosus* peel constitutes a number of natural bioactive compounds such as flavonoids, phenols, terpenoids, saponin, carotenoids, lignin, coumarins, ascorbic acid, gallic acid, catechin, epicatechin, myricetin, salicylic acid, ferulic acid etc. That is responsible for possessing enormous medicinal and therapeutic values like antimicrobial, antioxidative, anti-inflammatory, hypoglycaemic, hypocholestrolemic, anticarcinogenic, antihypertensive, along with excellent pre-biotic potential. Its major applications is noted at the industrial level for the formulation of nutritionally enriched wine, vinegar, biscuits, gummy candies, nanoparticles, and many other products.

Keywords: *Ananas comosus*, Antioxidants, Polyphenols, Prebiotic potential, Therapeutic applications.

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Introduction

India is a country of diverse climatic conditions from the point of varied agricultural productions consisting of fruits, vegetables, ornamental plants, spices, medicinal herbs, tubers, roots, aromatic plants and plantation crops. During farming, handing out, harvesting and consumption of agricultural products, a large amount of lignocellulosic bio wastes are produced every year. For different applications, this biomass can be utilized for the production of less expensive biosorbent, biochemical and biofuels, different enzymes and metabolites along with the production of functional foods for the eradication of these wastes from the environment and for evading solid-waste[1]. Nearly 90% of horticultural production in India accounts to fruits and vegetables from which 31.2% share is from fruits[2].

Ananas comosus (Pineapple) is from *Bromeliaceae* family and one of the leading members of the most important edible fruits in the world. Major producer countries are Brazil, Thailand, Philippines, Costa Rica, China, and India with a total cultivation area of 909.84 thousands ha and 19412.91 thousand tons production per annum in the world[3,4]. From the total production, 7% share is of India with a total production of 1,415.00 thousand tons which was cultivated in 89 thousand ha area and is most abundantly grown in Karnataka, West Bengal, Bihar, Kerala, Goa, Maharashtra and other states. Approximately 75-85% of the production is discarded as crown, peel, and core; while out of the total waste, peel alone contributes about 30-35%[5]. *A. comosus* is a short plant with a height of 75-150 cm with an extension of 90-120 cm, having fibrous, tapered, and spiny leaves with corpulent stump. A succulent conical shaped fleshy fruit accompanied with crown at the top develops from this plant[6]. Due to its outstanding flavour and taste, it ranks third in World's most important tropical fruits[7]. A fresh pineapple contains about 80-85% of moisture content and around 60% of edible portion. It contains 0.6% acid, 0.5% ash, 12-15% sugars, 0.4% protein, 0.1% fat, the remaining part consists of fibre, vitamin A, C and antioxidants, mainly flavonoids. It also contains a proteolytic enzyme named bromelain[8] which is beneficial for the breakdown of protein molecules into amino acids along with helping in digestion[3,9]. *A. comosus* plant is classified under the kingdom *Plantae*; phylum *Tracheophyta*; division *Spermatophyte*; sub-division *Angiospermae*; class *Lilopsida*, sub-class *Magnoliales*; order *Bromeliales*; family *Bromeliaceae*; genus *Ananas* and; species *A. comosus*[10].

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In 1493 Europeans first explored *A. comosus* in the Caribbean island after which it was named as Guadalupe. Even though it is known to have originated in South America. Then, it was brought back to Europe by Columbus and other discoverers and revealed that this fruit needs a tropical climate for cultivating sweet and high quality fruit but was unable to grow due to environmental conditions. *A. comosus* was introduced by Portuguese and Spanish explorers, into many other countries of south pacific, African and Asian colonies by the end of 16th century and still, it is grown in those areas. In 18th century, it began to be cultivated in Hawaii, which is the lone state in the U.S. where it is still cultivated. Commercially, this plant is also cultivated in Mexico, Thailand, Philippines, Brazil and China[11].

Large amount of *A. comosus* production is used for extracting out juice in the world, at industrial level which produces enormous amounts of waste including peel and other parts. This waste leads to produce odour, soil pollution, harbourage for insects, and other serious environmental pollution[12]. Previous studies showed that about 40-80% of pineapple is not edible and remains as waste. From one pineapple, 34.7% is peel, 48.04% is pulp, and remaining 17.26% consists of other parts like crown, core etc. It contains higher amounts of vitamin A, C, B-complex, calcium, iron, potassium, and fiber (mainly insoluble fiber which is beneficial for relieving constipation and enhances satiety level by interfering in the metabolism of carbohydrate and lipids). Thus, it is well-known as functional food[13-15].

A. comosus peel consists of some natural antioxidants like as flavonoids, phenolic compounds and ascorbic acid. The main polyphenols found in the pineapple peel are gallic acid, ferulic acid, catechin, and epicatechin[16,17]. Ferulic acid is a precursor for vanillic acid, which generates vanillin (4-hydroxy-3 -methoxybenzaldehyde), the most important component of vanilla[18]. In a study, Gunwuntrao *et al.*, reported that peels of *A. comosus* show good antimicrobial activity because it consists of many phytochemicals like as vitamins, terpenoids, carotenoids, saponin coumarins, lignin, flavonoids, and plant sterol[12]. The main compound responsible for the antimicrobial activity is polyphenols which inhibits the growth of the pathogenic microorganisms responsible for deteriorating the food quality. It also possesses good potential in medicinal and industrial applications; therefore it can be utilized for manufacturing antibiotics. It exhibits good antimutagenic and antioxidative property[19]. Upadhyay *et al.*, reported that proteolytic enzyme bromelain can be obtained from a crude extract of *A. comosus* peel and it was strongly related to proteinases with wide applications such as antiedematous, anti-inflammatory, antithrombotic, anticancer, and fibrinolytic properties[6]. According to the toxicological studies, peels of *A. comosus* also show carcinogenic, teratogenic or mutagenic effects due to the presence of secondary metabolites and no allergic reactions were observed after consumption of these peels[20-22]. As this fruit consists of 34.7% of peel, this biomass can be utilized instead of disposing or feeding it to the livestock[13,15]. Figuerola *et al.*, reported that the peel has an excellent physico-chemical property[23]. This fibre rich by-product ingredient can be added to many foods to develop a better product as it increases the volume of food by reducing water loss[13]. The major core area of this article is to review literature and to abridge the metabolism, nutritional composition, phytochemistry, and therapeutic applications of the major bioactive compounds existing in the peels of *A. comosus.*

Metabolism

A. comosus peel consists mainly of phenolic antioxidants. The important polyphenols present are ferulic acid, gallic acid, catechin, and epicatechin. Many studies revealed that phenols obtained from high dietary fibre of pineapple peel powder contain *p*-coumaric acid, myricetin, *trans*-cinnamic acid, tannic acid and salicyclic acid[16,17,19].

Quir´os-Sauceda *et al.*, reported that in the upper part of gastrointestinal tract, phenolic compounds are unconfined from the food matrix either by directly solubilising in intestinal fluid at 37 ºC and 1-7.5 pH or by enzymatic activity as the enzymes hydrolyse protein, carbohydrate, and lipids and in return releases phenolics from food matrix. After that, to some extent, low molecular weight accessible phenolics are absorbed by the mucosa of the small intestine. Other remaining parts that are inaccessible pass through the upper intestine. Undissolved and unaltered phenolics with food matrix consisting of dietary fibre, changes the effectiveness of physical, enzymatic and chemical digestion processes[24].

Saura-Calixto stated that dietary fibre and antioxidants could be studied together in nutrition and health because approximately 50% of dietary antioxidants (mainly polyphenols) conjugated with dietary fibre travels to the small intestine. After reaching the small intestine they release fibre matrix in the colon through bacterial action which produces metabolites and an antioxidative environment. Hence, it was concluded that dietary antioxidants are transported in the digestive tract with dietary fibre[25]. Ferulic acid when taken with diet gets absorbed in combination of facilitated transport and passive transcellular diffusion mechanism by the colonic epithelium. On the serosal side, these mechanisms produce free ferulic acid with less quantity of conjugated forms. It is accessible to the body after crossing the intestinal barrier mainly in the free form and a small amount is present in conjugated form as feruloyl-glucuronide, the main metabolite followed by sulphate and dihydroferulic acid. Further in the liver both of these forms can be metabolized. In contrast, its availability in the blood for further uptake by the tissues depends on its source, form and amount ingested[26]. Fig. 1 shows the health benefits of the consumption of dietary fibre together with phenolic compounds.

Nutritional composition

Earlier studies revealed that *A. comosus* peel mainly consists of insoluble dietary fiber, polyphenols, phytates, oxalates, flavonoids, tannins, glucosinolates, pectin, melanin, antioxidant potentials, and protease activity etc[12,27,28,38]. The nutritional compositions of the *A. comosus* peel are shown in Tables 1 to 5.

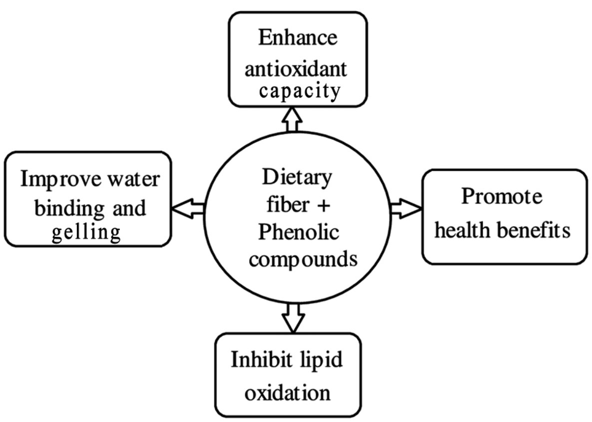

Fig. 1 — Health benefits of the consumption of dietary fiber together with phenolic compounds.

Phytochemistry

A. comosus peels have had higher ethnomedicinal uses since ancient times due to its good nutritional and anti-nutritional potential. The major biologically active constituents present in the peels of *A. comosus* are shown in Table 6 with their chemical structure in Fig. 2. Kaur *et al.*, assessed higher antioxidative capacity (15.93±0.04 mg AAE/g) of pineapple peel in the form of ascorbic acid, flavonoids, phenols, carotene, and additional bioactive components like gallic acid, ferulic acid, catechin, and epicatechin which is accountable for the synergistic and antagonistic effect of the antioxidant activity[40]. Koffi and Han grew *Saccharomyces cerevisiae* and *Zymomonas* mobiles in pineapple waste for the synthesis of alcohol. It was assessed that pineapple peel contains high dietary fibre as lignin, cellulose, hemicelluloses, and cell soluble matters as 19, 22, 5, and 53% respectively. But the relatively low concentration of soluble sugars likes sucrose, glucose, and fructose as 5.2, 3.1, and 3.4% respectively[41]. Sah *et al.*, assessed high dietary fibre content (44.90-58.48 g/100g of dry matter) and low concentration of crude protein, fat, and total ash content in the pineapple peel. Highest level of potassium (5967.28–10,144.32 mg/kg of dry matter), followed by calcium (893.03-2206.75 mg/kg of dry matter) and sodium (610.69–1033.57 mg/kg of dry matter) were assessed as minerals content. Very low concentrations of cobalt, zinc, and copper along with other trace elements were also analysed[19]. Novaes *et al.*, reported the presence of bromelain in smaller amounts in *A. comosus* peel in comparison to stem[42]. From an environmental and commercial point of view, withdrawal of bromelain

Table 2 — Mineral composition of dried *A. comosus* peel (mg/100 g dry peel)

	Romelle *et al.*,[28]
Calcium	8.30±0.54
Zinc	6.46±0.43
Iron	25.52±3.38
Manganese	5.32±0.49

Table 1 — Proximate composition of dried *A. comosus* peel (g/100 g dry peel)

	Romelle *et al.*, [28]	Damasceno *et al.*,[13]	Diaz-vela[29]	Romo-Zamarron *et al.*,[30]	Huang *et al.*,[31]	Pardo *et al.*,[32]	Roda *et al.*,[33]
Crude protein	5.11±0.02	6.93±0.39	0.32±0.05	ND	9.13±0.25	0.75±0.01	ND
Lipids	5.31±0.74	1.17±0.08	ND	ND	1.57±0.13	2.0±0.01	ND
Ash	4.39±0.14	4.57±0.04	2.81±1.52	ND	4.81±0.03	1.5±0.00	10.60
Crude fiber	14.80±0.01	4.92±0.5	62.54±3.21	38.99±0.04–45.67±0.47	42.2±0.89	65±0.0	ND
Carbohydrate	55.52±0.92	75.63±2.33	22.59±1.99	ND	42.3	ND	ND
Moisture	ND	6.78±0.5	11.57±2.54	4.19±0.28-5.44±0.05	ND	ND	92.2

(ND: not documented)

Table 3 — Phytochemicals screening of *A. comosus* peel in different extracts

	Gunwantrao *et al.*,[12]		Wijayati *et al.*,[34]	Dias *et al.*,[35]		Olakunle *et al.*,[36]		Sharma *et al.*,[37]					
	E.E.	M.E.	E.E.	W.E.	M.E.	E.E.	W.E.	E.E.	M.E.	A.E.	n-hex. E.	C.E.	Ea.E.
Protein	+	+	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Carbohydrate	-	-	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Alkaloids	+	+	ND	ND	ND	+	+	+	+	+	+	+	+
Tannins	+	-	+	-	-	-	-	+	-	-	-	-	-
Flavonoids	-	+	+	ND	ND	+	-	+	+	+	+	-	-
Steroids	+	+	ND	-	-	ND	ND	ND	ND	ND	ND	ND	ND
Saponin	+	-	+	ND	ND	-	-	-	-	-	-	-	-
Terpenoids	-	+	ND	ND	ND	ND	ND	+	+	-	-	-	-
Cardiac glycosides	ND	ND	ND	+	+	+	+	+	-	+	-	-	-
Phlobatannin	ND	ND	ND	ND	ND	-	-	ND	ND	ND	ND	ND	ND
Phenols	ND	ND	ND	ND	ND	ND	ND	+	+	+	+	+	+
Napthoquinone	ND	ND	ND	ND	ND	ND	ND	-	-	-	-	-	-
Inulin	ND	ND	ND	ND	ND	ND	ND	+	-	-	-	+	+

ND= not documented; E.E.= ethanolic extract; M.E.= methanolic extract; W.E.= water extract; A.E.= aqueous extract; n-hex. E.= n-hexane extract; Ea.E.= ethyl acetate extract; C.E.= dichloromethane extract.

Table 4 — Anti-nutritional composition of *A. comosus* peel extracts (% concentration)

	Romelle *et al.*,[28]	Dabesor[38]	
	Ethanolic extract	Aqueous extract	Ethanolic extract
Oxalates	129.06±15.95	5.46±0.06	5.31±0.02
Hydrogen cyanide	71.50±0.02	ND	ND
Alkaloid	16.19±3.28	11.1±0.03	12.24±0.02
Phytates	1.99±0.01	0.63±0.06	0.52±0.01
Tannins	ND	3.16±0.014	2.11±0.03
Glycosides	ND	1.25±0.0	1.16±0.01

(ND: not documented)

Table 5 — Polyphenolic compounds in dried *A. comosus* peel (mg/100 g dry peel)

	Li *et al.*,[39]
Gallic acid	31.76±2.28
Catechin	58.51±3.59
Epicatechin	50.00±4.39
Ferulic acid	19.50±1.93

from pineapple waste is fascinating as it contains many phenolic compounds such as salicylic acid, myricetin, tannic acid, *p*-coumaric acid, trans-cinnamic acid along with high dietary fibre[6].

Therapeutic applications

A. comosus peel contains many functional compounds such as minerals, vitamins, and polyphenolic components (ferulic acid, epicatechin, catechin, gallic acid, and carotenoids). These natural antioxidants are responsible for lowering the risk of chronic and non-chronic diseases like cardiovascular disease, high blood pressure, diabetes, obesity, neurodegenerative, gastrointestinal disorders, and cancer[39].

Antioxidative

The substances that are present in small concentration when compared to oxidizable substrate that prevents or inhibits substrate oxidation are known as antioxidant. There are several mechanisms of action through which it shows activity that includes O_2 removal by inhibiting the formation of reactive oxygen or nitrogen species (ROS/RNS) or scavenging ROS/RNS, it also binds the metal ions that are necessary for the catalysis of ROS generation and regulates the endogenous antioxidant defences[50,51]. Sah *et al.*, investigated the activity and viability of *Lactobacillus paracasei* ssp. *Paracasei* (ATCC BAA52), *Lactobacillus casei* (ATCC 393) and *Lactobacillus acidophilus* (ATCC 4356) in yogurts supplemented with pineapple peel powder during the storage for 28 days at 4 °C. Significantly, in symbiotic yogurt a higher degree of proteolysis was observed than non-supplemented yogurt. Addition of pineapple waste powder in yogurt results in greater anti-mutagenic and antioxidant activities when compared with non-supplemented yogurts[19].

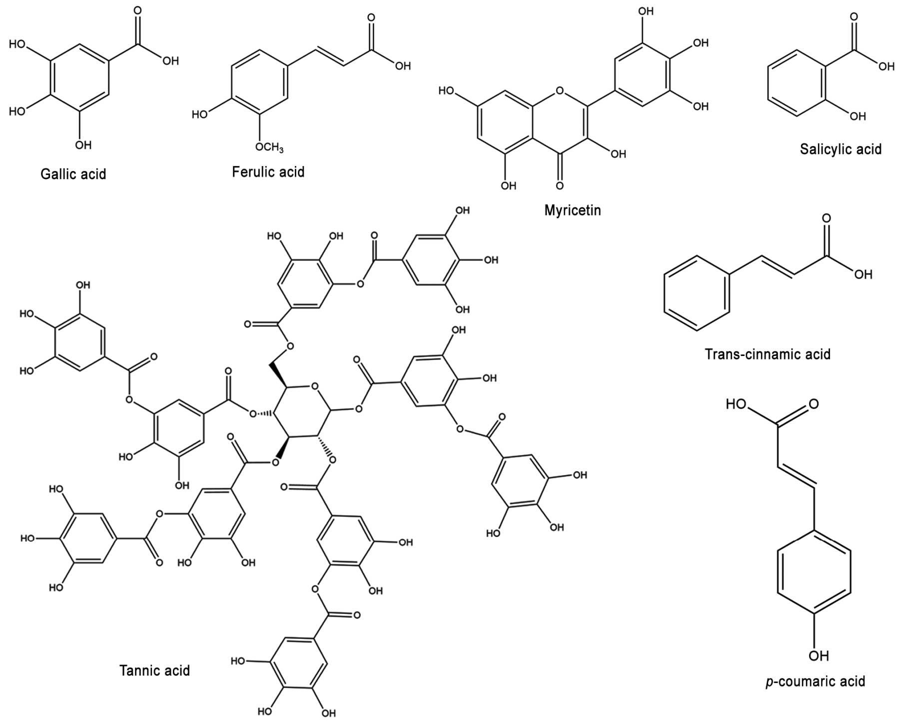

Fig. 2 — Chemical structure of biologically active constituents present in *Ananas comosus* peel.

Table 6 — The chemical identity of biologically active constituents present in *A. comosus* peel

Bioactive compounds	Description	Chemical formula	Formula weight
Gallic acid	It contains three hydroxyl groups at positions 3, 4 and 5 of the benzene ring, so basically it is a trihydroxybenzoic acid. It may function as a mordant, an inhibitor of cyclooxygenase 2, metabolite of plant, an antioxidant, an antineoplastic agent, a metabolite of human xenobiotic and inducer of apoptosis. It is a conjugate acid of a gallate[43].	$(HO)_3C_6H_2CO_2H$	170.12
Ferulic acid	It is composed of trans-cinnamic acid containing methoxy and hydroxy groups at 3 and 4 positions respectively on phenyl rings. It may function as an antioxidant, a matrix material of MALDI, a metabolite of plant, anti-inflammatory agent, an inhibitor of apoptosis and an agent for cardio protection. It is a conjugate acid of a ferulate[44].	$C_{10}H_{10}O_4$	194.18
Myricetin	It is composed of hexahydroxyflavone which is flavones containing hydroxy groups at 3, 3', 4', 5, 5' and 7 positions. It may function as an inhibitor of cyclooxygenase 1, an antineoplastic agent, as an antioxidant, a metabolite of plant, a component of food and an anti-hyperglycemic agent. It is a conjugate acid of a myricetin (1-)[45].	$C_{15}H_{10}O_8$	318.24
Salicylic acid	It is composed of monohydroxybenzoic acid which is benzoic acid containing hydroxy groups at ortho positions. It may function as an curing agent for infection, antifungal agent, a keratolytic drug, an inhibitor of EC 1.11.1.11 (L-ascorbate peroxidise), a metabolite and hormone of plant. It is a conjugate acid of a salicylate[46].	$2^{-}(HO)C_6H_4CO_2H$	138.12
Tannic acid	A polymer of glucose and gallic acid molecules is tannic acid. It will be broken down into gallic or ellagic acid and glucose units after hydrolyzation. It is a fragrance-free but very astringent taste compound. In pure form it is a light yellowish colour and shapeless powder[47].	$C_{76}H_{52}O_{46}$	1701.20
Trans-cinnamic acid	It is composed of monocarboxylic acid which is acrylic acid containing a phenyl substituent at the 3-position. It can be get from *Cinnamomum cassia*. It is a metabolite of plant. It is a constituent of styrenes and an element of cinnamic acids. It is a conjugate acid of a cinnamate[48].	C_6H_5CH= CHCOOH	148.16
p-coumaric acid	It cinnamic is derived from the hydroxy acid which is present in many edible plants. It may function as an antioxidant, anti-inflammatory and antimicrobial agent. It has been showed appreciable suppression in the growth of tumor by blocking the angiogenesis *in vivo*[49].	HOC_6H_4CH= $CHCO_2H$	164.16

Uchoi *et al.*, studied the antioxidative potential of *A. comosus* peel extracts of Indian mackerel stored in a refrigerator. The total phenol and total flavonoid content were determined to analyse the antioxidative potential. Measurement of lipid changes during refrigerated storage revealed that pineapple peel treated samples produce more protective effect against lipid peroxidation than control samples. Overall, pineapple peel exhibited a significant level of antioxidant compounds that can be used as a basis of natural antioxidants after extraction[16]. Putri *et al.*, evaluated the antioxidative activity of *A. comosus* peel extract using ABTS and DPPH method. Results revealed the maximum ABTS activity with IC_{50} value of 46.69 µg/mL in the methanol extract and maximum DPPH activity with IC_{50} value of 266.02 µg/mL in aqueous extract. Thus, *A. comosus* peel shows good antioxidant potential[52].

Erukainure *et al.*, studied the effect of alcohol-induced oxidative stress in male albino rats' spleen tissues to understand the antioxidative effect of the pineapple peel extracts. The test group of rats were fasted overnight and through cervical dislocation, were sacrificed after the oral administration of ethanol (5 mL/kg) for 28 days. Reduced glutathione (GSH), superoxide dismutase (SOD), protein concentration, lipid peroxidation, and catalase were assessed by using homogenates of splenic tissue. In GSH level there was considerable fall especially in the alcohol fed group and increase in GSH activities was observed in pineapple peel extract treated group. There was no significant difference between SOD levels of the negative control whereas the test group was only fed with pineapple peel extract. An increased catalase activity was noticed in the negative control group but significant reduction of catalase was observed after feeding with pineapple peel extract. Significant reduction in malondialdehyde (MDA) and increased protein concentration was also observed in alcohol-fed groups after treating with pineapple peel extract. Finally, results indicated the defending role of pineapple peel extract on alcohol-induced oxidative stress[53].

Saraswaty *et al.*, studied the pineapple peel waste as an impending source of antioxidant compound by using water and ethanol extract with a range of concentrations from 15 to 95% (v/v) at room temperature for a day. The chemical properties like total sugar content, antioxidant activity, total phenolic content (gallic acid equivalent/GAE) were assessed. Antioxidant activity was evaluated in terms of range of inhibition concentration (IC_{50}) value and the resulted range was 0.8±0.05 to 1.3±0.09 and 0.25±0.01 to 0.59±0.01 mg/mL for dried and fresh pineapple peel waste extract, respectively. The water extract showed the highest antioxidant value with the highest phenolic content of 0.9 mg/g GAE[54].

Larrauri *et al.*, assessed and compared some properties of high dietary fibre pineapple shell powder with several fibres of commercial fruit. Similarly, total dietary fibre content (70.6%) was assessed in several commercial fruits like citrus fruits and apple from which 99% accounted for insoluble dietary fibre. Xylose (36%) was a major neutral sugar in soluble dietary fibre while glucose (43%) was a major sugar in insoluble dietary fibre. Total uronic acid (5.1%) and lignin (11.2%) were also analyzed. Higher antioxidative activity (86.7%) of pineapple peel fibre was recorded than fibre of orange peel (34.6%) at a concentration of 0.5 g of powdered sample/100 mL of mixture. The major polyphenol identified for the antioxidant activity was myricetin[55].

Li *et al.*, evaluated the pineapple peel for the presence of major polyphenolic compounds. By using DPPH scavenging activity and phosphomolybdenum method, antioxidant capacities of major polyphenolic compounds present in peel extract were assessed. Major polyphenols identified were gallic acid, catechin, epicatecin, and ferulic acid in different concentrations 31.76, 58.51, 50 and 19.5 mg/100g dry extract, respectively. The DPPH scavenging assay showed 1.13 mg/mL of an IC_{50} value and 0.037 g ascorbic acid equivalents/g of total antioxidant capacity. No synergistic effect was indicated by polyphenolic interactions. Additive effects were observed by means of both antioxidant activity methods in combinations of ferulic acid-gallic acid and ferulic acid-epicatechin[39].

Kalaiselvi *et al.*, assessed *in vitro* ethanolic extract of pineapple peel for its antioxidant capacity by using DPPH, ABTS, FRAP, colour decolourization test, hydroxyl radical (OH), hydrogen peroxide, nitric oxide radical inhibition activity (NO), superoxide radical, total antioxidant capacity assay and lipid peroxidation inhibition activity. High antiradical activity against these mentioned radicals were observed. When the antioxidant capacity was compared with standard BHT and vitamin C, pineapple peel showed stronger antioxidant capacity against reactive oxygen species[56] and it can be proposed as having good pharmacological properties as shown in Table 7.

Table 7 — Total phenolic, total flavonoid, and antioxidant activity of *A. comosus* peel

	Poadang *et al.*,[57]	Romelle *et al.*,[28]
Total phenolic content (mg GAE/g sample)	4.21±0.036	1.42±0.09
Total flavanoid content (mg RE/g sample)	1.35±0.113	ND
Antioxidant activity FRAP method (mg $FeSO_4$/g sample)	32.63±0.019	ND
(ND: not documented)		

Antimicrobial

Putri *et al.*, used broth dilution method to assess the antibacterial activity of pineapple peel extract and analyzed the antibacterial activity of n-hexane extract and aqueous extract with an inhibition value of 5.03 and 11.65% against *Pseudomonas aeruginosa* and *Bacillus subtilis*. Thus, signifying good antibacterial and antioxidant potential of the *A. comosus* peel[52].

Gunwantrao *et al.*, analyzed antimicrobial activity of *A. comosus* peel against some pathogenic bacterial strains namely *Klebsiella pneumonia* K2044, *Pseudomonas aeruginosa* MTCC4676, *Bacillus subtillis* Py79 and *Xanthomonas axonopodis pv. malvacearum* LMG859 and observed the highest inhibition zone in ethanol extract sample and the minimum zone of inhibition in methanol extract sample of *A. comosus* peel against all test pathogens. Results conclude that *A. comosus* peel extract shows effective antimicrobial activity against tested pathogenic bacteria[12].

Dabesor *et al.*, investigated the antimicrobial activities and phytochemical constituents of ethanolic and aqueous extracts of *A. comosus* peel. Analysis of antimicrobial activities was done against food borne pathogens, namely *Escherichia coli*, *Bacillus cereus, Staphylococcus aureus*, and *Klebsiella pneumonia* by agar well diffusion method. Ethanolic extract exhibited maximum zone of inhibition against *B. cereus* (15.0±0.6 mm), *S. aureus* (14.0±0.22 mm) followed by *E. coli* (12.3.0±0.12 mm), whereas the aqueous extract appeared to have maximum zone of inhibition against *B. cereus,* (14.0±0.5 mm), *S. aureus* (14.0±0.11 mm), and *K. pneumonia* (14.0±0.10 mm). Hence, *A. comosus* peel can be considered an antimicrobial agent[38].

Lawal *et al.*, reviewed that at a concentration of 50 mg/mL methanolic extract of *A. comosus* peel was inactive against *E. coli* and *B. subtilis* whereas at a concentration of 100 mg/mL extract it was active against *S. typhi*. The chloroform extract of peel was active against *Staphlococcus aureus* ATCC 29737, *Corynebacterium rubrum* ATCC14898, *Klebsiella pneumonia* NCIM2719 and S. *typhimurium* ATCC23564 with an inhibition zone of 11, 9, 12.7, and 9.3 mm, respectively while it was inactive against *S. subflava* NCIM2178, *Enterobacter aerogenes* ATCC1304 and *Proteus mirabilis* NCIM2241. Extract prepared with acetone showed significant activity against *S. aureus*, *S. subflava*, *E. aerogenes*, *K. pneumoniea, P. Mirabilis*, and *S. typhimurium* with an inhibition zone of 11, 10, 9, 10, 9, and 9 mm, respectively. *A. comosus* peel methanolic extract exhibited activity against *S. aureus* and *K. pneumoniea* with an inhibition zone of 12 and 9 mm, respectively whereas it was inactive against *E. aerogenes, S. subflava, S. Typhimurium*, and *P. mirabilis*. *A. comosus* peel hexane extract was active against *S. subflava*, *S. typhimurium* but inactive against *S. aureus, E. aerogene, K. pneumoniea* and *P. mirabilis*. *A. comosus* peel ethanolic extract exhibited activity against *S. typhi* at 100 mg/cm^3 with an inhibition zone of 15 mm diameter. The authors also reported the antibacterial activity of *A. comosus* peel ethanolic extract against *Salmonella* species and *A. hydrophila*[11].

Poadang *et al.*, used *A. comosus* peel extract as a reductant as well as stabilizer for the synthesis of colloidal silver nanoparticles (AgNPs) followed with investigation of antibacterial activities by means of disc diffusion assay in case of selected pathogenic bacteria which resulted in effective inhibition of the growth of *Pseudomonas aeruginosa* and *Staphylococcus aureus*[52]. The antibacterial activity in different extracts of *A. comosus* peel with their relative percentage of inhibition zone in mm is given in Table 8.

Prebiotic potential

Prebiotic is a term used for defining the non-digestible food ingredients which selectively enhance the growth of several bacteria in the colon and benefit the host. Possible health-related beneficial effects of prebiotics are constipation relief, diarrhoea suppression and decline in the risk of osteoporosis, atherosclerosis, insulin resistance, type II diabetes, and obesity whereas, probiotics are microbial dietary supplement which shows a positive effect on the intestinal tract of the host. Numerous health-related effects in humans can be seen with the consumption

Table 8 — Antibacterial activity in different extracts of *A. comosus* peel

Microorganisms	Zone of inhibition (mm)							
	Putri *et al.*[52]				Gunwantrao *et al.*[12]		Dabesor *et al.*[38]	
	n-hex. E. (10 mg/mL)	Ea. E. (10mg/mL)	M.E. (10mg/mL)	W.E. (10mg/mL)	M.E. (50 mg/mL)	E.E. (50 mg/mL)	W.E. (50 mg/mL)	E.E. (50 mg/mL)
Pseudomonas aeruginosa	5.03±0.006	ND	ND	ND	20±0.47	19±0.43	ND	ND
Bacillus subtilis	0.5±0.016	8.52±0.016	2.26±0.004	11.65±0.004	23±0.57	17±0.48	ND	ND
Klebsiella pneumonia	ND	ND	ND	ND	22±0.46	27±0.65	14±0.10	12±0.20
Xanthomonas axonopodis	ND	ND	ND	ND	22±0.37	22±0.45	ND	ND
Escherichia coli	ND	ND	ND	ND	ND	ND	12±0.10	12.3±0.12
Bacillus cereus	ND	ND	ND	ND	ND	ND	14±0.5	15±0.6
Staphylococcus aureus	ND	ND	ND	ND	ND	ND	14±0.11	14±0.22
Azotobacter	ND	ND	ND	ND	19±0.56	22±0.56	ND	ND

All values were shown as mean±standard deviation of mean (SD); ND: not documented; n-hex. E.: n-hexane extract; Ea. E.: ethyl acetate extract; W.E.: water extract; E.E.: ethanolic extract; M. E.: methanolic extract.

of probiotics such as improvement in lactose intolerance, immune enhancement, reduced risk of rotavirus-induced diarrhoea, and colon cancer[58].

Peh *et al.*, studied the potential of *A. comosus* peel as a growth medium for *Lactobacillus* species. This study was aimed to prove that the peel can be treated through fermentation by probiotics, namely, *lactobacillus.* For the growth of three strains of probiotics, the *Lactobacillus* sp. FTDC 8264, FTDC 3666 and FTDC 8133 and *A. comosus* waste were utilised as the sole source of carbon for the fermentation media. As well as probiotic strains were grown in the *A. comosus* peel to investigate its prebiotic potential. Then these strains were propagated in MRS broth before fermentation in pineapple peel waste substrate by using shake flask fermentation technique and then incubated at 37 ºC for 24 h. The viability of probiotics was assessed at varying temperature and pH by using a spectrophotometer at 600 nm. Results reported that the best growth was obtained at 37 ºC and pH 6. Overall, *A. comosus* peel may be applicable as a cheap, cost effective material for the production of culture medium to grow probiotics bacteria[59].

Sah *et al.*, evaluated the effect on the activity and viability of *Paracasei* (ATCC BAA52), *Lactobacillus paracasei* ssp., *Lactobacillus casei* (ATCC 393) and *Lactobacillus acidophilus* (ATCC 4356) with the addition of *A. comosus* peel powder in yogurts stored at 4 ºC for 28 days. It was analyzed that the probiotic count was one log cycle higher in supplemented yogurt as compared to non-supplemented yogurt ranging 7.68 and 8.03 log cfu/g. It was also observed during storage that the degree of proteolysis was considerably greater in supplemented yogurt than non-supplemented yogurt. Stronger antioxidant and antimutagenic activities were evaluated in the crude water soluble peptide extract of the probiotic yogurt as compared to control non-supplemented yogurt. Finally, *A. comosus* peel was proposed as a crucial prebiotic ingredient in the production of yogurts with increased nutrition and functionality[19].

Diaz-Vela *et al.*, aimed to evaluate *A. comosus* peel as a source of carbon during fermentation by the use of bacteria with probiotic potential. Pineapple peels flour is indicated as a rich carbon source for the growth of lactic acid bacteria as it contains over 60% of fibre with 20% of total soluble carbohydrate content. It was observed that the performance rate of *Pediococcus pentosaceus* was better during fermentation. Results reported that *A. comosus* peel can be considered as a functional ingredient due to its fermentable properties and high content of total dietary fibre and antioxidant properties[29].

Hemalatha *et al.*, reported that pineapple waste consists of high reducing sugars (30.5 mg/100g) and ash (1.8 mg/100g) content. It also showed high content of crude fibre, non-reducing sugars, carbohydrates, and proteins which work as a nutrient medium for the growth of probiotics and yeast fermentation to produce ethanol and single cell protein. Thus, *A. comosus* peel waste may be applicable as functional food for maintaining good personal health[60].

Campos *et al.*, aimed to study the prebiotic activity of *A. comosus* by-products (peel and stem) extracts for the development of a new functional ingredient. The two different genera *Lactobacillus sp.* and *Bifidobacterium sp* and six different probiotic strains were used for the initial screening. A positive growth

Table 9 — Fiber composition of *A. comosus* peel (g/100 g dry weight)

	Pardo *et al.*,[32]	Huang *et al.*,[15]
Insoluble dietary fiber (IDF)	46.20±0.50	36.3±0.79
Soluble dietary fiber (SDF)	35.67±0.37	5.90±0.19
Total dietary fiber (TDF)	81.8	42.2±0.89
Hemicelluloses	28.69±0.35	ND
Cellulose	40.55±1.02	ND
Lignin	10.01±0.38	ND
Pectin	2.49±0.20	ND

towards pineapple extracts was observed with all the microorganisms except *Lactobacillus acidophilus.* The range of activity was the same as promoted by the fructo-oligosaccharide, a positive control. HPLC was used to understand and establish the relationship between arrangement and activity and for determining the compounds. The general high prebiotic activity of pineapple peel was shown through two peaks of oligosaccharides which comprised 2000 MW and 600 Da in HPLC analysis which was acknowledged as two monosaccharides, glucose and fructose and galactomannans. The prebiotics bioavailability was evaluated after monitoring gastrointestinal conditions, and the analyzed results showed that *A. comosus* peel was a potential prebiotic ingredient[61]. Different types of fibre composition in *A. comosus* peel are shown below in Table 9.

Intestinal function

Huang *et al.*, reported high levels of water insoluble fiber-rich fraction (WIFF) (~42%, wt/wt) present in *A. comosus* peel which majorly comprises cellulose, hemicelluloses, and pectic substances. The study was conducted on male golden Syrian hamsters fed on a diet added with varying amounts of WIFF (2.5, 5, or 10%) or treated with 5% cellulose. All the groups of hamsters were evaluated for fecal bacterial enzyme activities, number of microbes in cecum, short-chain fatty acid concentration, and other biochemical markers in fecal and cecum of hamsters. A significant decline in the ammonia content of daily fecal matter, decreases the gastrointestinal transit time and lessen the activities of several enzymes like β-D-glucosidase, β-D-glucuronidase, mucinase, and urease in feces. In addition, it also increases the total amount of short chain fatty acid in the cecal content and enhances the growth of gut microfloras such as *Lactobacillus spp* and *Bifidobacterium spp*. Overall, the result indicates that supplementation of WIFF could enhance the ecosystem function of hamsters cecum by decreasing the excretion of toxic compounds by intestinal microflora. Hence, WIFF of pineapple peel could be projected as a promising agent for functional ingredient beneficial for human health and intestinal function[31].

Glucoregulation

Diabetes mellitus is a multifaceted metabolic disorder with several subtypes caused by different underlying causes for the hyperglycemia. Type I diabetes results in the death of pancreatic beta cells while other types of diabetes are caused by deficiency of insulin. Worldwide, from all diabetics around 5% is of type I, 90% is of type II and 5% is of other types[62]. According to the International Diabetes Federation (IDF), approximately 463 million adults of 20-79 years are suffering from diabetes and due to rapid urbanisation and nutritional transition, the prevalence rate is increasing and by the year 2045 it is estimated that this will rise to 700 million[2].

Riya *et al.*, studied to evaluate the *in vitro* anti-diabetic activity of *A. comosus* peels ethyl acetate and methanolic extract in cell free and cell based systems and concluded that the active compounds present were sinapic acid, daucosterol, 2-methylpropanoate, 2,5-dimethyl-4-hydroxy-3(2*H*)-furanone, methyl 2-methylbutanoate, and triterpenoid ergosterol. Presence of calcium, magnesium, and potassium was analysed in micronutrient assessment. Pineapple ethyl acetate extract (PAE) exhibited higher α-glucosidase inhibitory properties in comparison to acarbose while pineapple methanol extract (PAM) did not show any activity. But neither PAE nor PAM showed α-amylase inhibitory properties. Anti-glycation properties were also analysed with ethyl acetate extract and reported that pineapple peel can be utilized as a nutraceutical against diabetes and its complications[63]. Das *et al.*, synthesised *Ananas comosus*-AgNPs (AC-AgNPs) and highlighted the antidiabetic potential in the formulation of drugs for dealing with diabetes and other illnesses[64].

High blood pressure and cardiovascular effect

An increase in blood pressure above a certain measured level, that is, systolic 140 mmHg and diastolic 90 mmHg is defined as increased blood pressure. It leads to pathological changes in medium sized and petite arteries, which ultimately results in high blood pressure. Due to thickening of the blood vessels walls, diameter of the blood vessels is reduced that leads to stroke or heart attack[65].

Previous studies have investigated that *A. comosus* peel consists of gallic acid in abundant quantities[39,66]. Jin *et al.*, investigated the short-term and long-term effect on L-NAME induced hypertensive mice and the underlying regulatory mechanism behind it. Thus, treated with gallic acid and assessed significant reduction in SBP level, septum and left ventricular posterior wall thickness. The association of this effect was with the GATA-binding factor 6 (GATA6) transcription factor with the suppression of gene expression of hypertrophy markers. The long-term or short-term treatment of gallic acid attenuated reduction in the expression of histone deacetylase 1 and 2 in H9c2 cells and cardiac fibrosis in rats. Overall, the study concluded that gallic acid may act as a potential therapeutic agent for curing cardiovascular diseases with hypertension and cardiac fibrosis[67].

Zanwar *et al.*, reported significant reduction in LDL and triglyceride along with the increase in HDL cholesterol that shows antihyperlipidemic action of gallic acid in high fat diet induced mice. The possible roles of gallic acid in cardioprotective activity include antihyperglycemic, antilipid peroxidative, and antioxidant effects[68].

Mancuso *et al.*, reviewed that cell stress response were improved through the up-regulation of cytoprotective systems, scavenging of free radicals and inhibition of expression or cytotoxic enzymes activity such as nitric oxide synthase, cyclooxygenase kinase, caspases, proto-oncogene Akt, and ferulic acid act as potent antioxidant. On the basis of this evidence ferulic acid has been anticipated for the treatment of cardiovascular diseases[69].

Emmanuel *et al.*, studied the *in vivo* and *in vitro* anti-hyperlipidemic activity of the methanolic extract prepared from *A. comosus* peel on wistar rats. Four groups of albino rats were used in which group A was of control group and group B-D were treated with varying quantities of crude pineapple peel extract (200, 300, and 500 mg/kg b.w.). The blood sample was collected after 28 days of experiment from all the groups of rats fasted for 24 h to analyze lipid profile and antioxidant levels. The results of *in vivo* antioxidant analysis showed that no significant difference was observed in the case group when compared to the control group. The assessment of serum HDL showed a potential increase in the test group (200 and 500 mg/kg) as compared to control group. Concluding that *A. comosus* peel may be applied as a positive agent for the prevention of lipid peroxidation and it is also helpful in the reduction of oxidative stress and it also possess the potential role in increasing HDL cholesterol which represents that *A. comosus* peel were used to maintain of lipid profile and other cardiac diseases[70].

Musial *et al.*, aimed to evaluate the effect *A. comosus* peel and passion fruit mesocarp on lipid metabolism in hypercholesterolemic rats. The experimental rats were fed with a high calorie diet for 30 days. Consequently, for the next 15 days animals were treated with *A. comosus* peels (DHA), simvastatin (DHS) or mesocarp (DHM). A noteworthy reduction in cholesterol level of DHA, DHS, and DHM treated rats were assessed. Whereas, only DHS treated mice showed a reduction in plasma cholesterol level. Increased triglyceride level was noted only rats consuming a high calorie diet and hypo-triglyceridemia was reported with any of the treatments. Hypocholesterolemia and no signs of liver toxicity in rats were observed when treated with *A. comosus* peel and mesocarp of passion fruit[71].

Genotoxicity

The effect on destruction of genetic material of a cell (DNA, RNA) that affects its integrity is referred to as genotoxicity. Mutagens that are responsible for mutation are genotoxins. The word genotoxin is used for the substance that leads to genotoxicity. This may include carcinogens or cancer causing agents, birth defects or teratogens (functional and physical defects in foetus) causing agents and mutagens or mutation causing agents. Genotoxicity ultimately results into the mutation in various cells and other body systems that result into other problems such as cancer or other different diseases[72].

Lubaina *et al.*, concluded that due to its higher phenolic compound content, *A. comosus* peel exhibits potent antioxidant activity. Among the aqueous and ethanol extracts of pineapple peel, ethanol extract has the greatest quenching power in terms of DPPH, FRAP, Hydroxyl radical scavenging activity, and superoxide radical scavenging activity. Hence, pineapple peels may be used for the prevention of oxidative stress[66].

Carcinogenicity

The cells of the body may be affected by a disease termed as cancer. Subsequently, developing cancer injures DNA of the cells and this injury accumulates eventually[65]. According to Li *et al.*, in this era throughout the world cancer is a major chronic disease that causes death. Hence, it is one of the most important public health problems. Lung, colorectal, breast, and liver cancers are the most common type of cancer diagnosed in the world[73].

Rashad *et al.*, aimed to investigate the capability of *Kluyveromyces marxianus* NRRL Y-8281 for the manufacturing of important products from wastes of pineapple. The analysis of fermented and unfermented pineapple wastes extract shows highest antioxidant activity in fermented extract. *In vitro* cancer treating activity was assessed against four human cancer cell lines that revealed both extracts showed no effect against HL-60 or normal HFB4 cells and HepG2 but exert cancer curing effect against A549, MCF-7, and HCT116 cell lines closed to the values of doxorubicin drug. In general, it was concluded that the pineapple waste extract fermented or unfermented can be applied for pharmacological strategies against cancer[20].

Sah *et al.*, evaluated antiproliferative activity of yogurt accompanied with *A. comosus* peel powder and non-supplemented yogurt against HT29 colon cancer cells through the induction of apoptosis and cell cycle arrest in G2/M phase and resulted in higher antiproliferative activity of yogurt accompanied with pineapple peel than non-supplemented yogurt. Thus *A. comosus* peel could be utilized as a crucial ingredient in the formulation of nutraceuticals, pharmaceuticals, and functional foods[74]. Li *et al.*, reported the strongest inhibitory effect of *A. comosus* peel against A549 (human lung) cells and HT-29 (colon) cells and indicated that pineapple peel can be applicable as a cancer protecting agent against different cell lines[73].

Fertility and teratogenicity

Setyawati *et al.*, added pineapple peel in *Calliandra calothyrsus* Meissn, a high protein source for non-ruminants which cannot digest this protein due to its high antinutritional content (condensed tannin). A source of protease (bromelain) from pineapple peels were supplemented to ameliorate the applicability of *Calliandra* in the diet as bromelain can degrade the tannin-protein complexes. The diet was designed according to the standardized diet of local male rabbits (*Lepus sp*) and feeding research was done. In the four treatment groups, animals were divided into a control group (R0), *calliandra* leaf meal (15%) and pineapple peel containing feed (30 %) (R1), *calliandra* leaf meal (30%) and pineapple peel containing feed (30%) (R2), calliandra leaf meal (45%) and pineapple peel containing feed (30%) (R3) and all of them were treated for three months. Result showed that increased level of *Calliandra* leaf with 30% of pineapple peels exaggerated testicular histology, reduced the seminiferous tubule diameter, and increased level of blood testosterone in male rabbits[22].

Applications of *A. comosus* peel in food industry

Peel of pineapple has been used in the food industry for the development of vinegar, an important preservative, by utilizing *Saccharomyces cerevisiae* and *Acetobacter spp*., isolated from soil samples and identifying their biochemical, morphological, and culture characteristics. Initially, *Saccharomyces cerevisiae* wine is produced, then *Acetobacter spp*. are inoculated into it which is incubated for 11 days at room temperature for aerobic fermentation and 4.60% of vinegar is produced.

Antibacterial activity has been assessed against *Escherichia coli*, *Pseudomonas aeruginosa, Salmonella paratyphi* and *Staphylococcus aureus* with an inhibition zone of 16, 19, 19, and 20 mm respectively[75]. In another study by Poadang *et al.*, colloidal silver nanoparticles (AgNPs) was synthesized by means of using pineapple peel extract as a stabilizer and reductant afterwards assessment for antibacterial activities was performed with disc diffusion assay against selected pathogenic bacteria. Results showed an effective inhibition of the growth of *Pseudomonas aeruginosa* and *Staphylococcus aureus*[57].

Room-zammaron *et al.*, developed gummy candies enriched with freeze and hot air dried and varied size papaya and pineapple peels powder. Comparative study was done for assessing the modification in soluble solids, pH, water activity, colour, instrumental texture, and sensory perception of cases enriched with pineapple peel and controls without including pineapple peel powder. Result showed a stable acidity, soluble solids, water activity, and pH with the insertion of 5 g/100g of each fruit peel powder. A better sensory, physicochemical, colour, instrumental, and textural characteristics was observed with the freeze-dried peels with smaller particle size powder due to its easily homogenised activity[30].

Carvalho *et al.*, aimed to develop cereal-bars with the inclusion of *sapucaia, chichá*, and *gurguéia* nuts and supplemented with pineapple peel. Three formulations A, B and C were prepared on the basis of the proportions of vegetable fat and pineapple peel powder. It was revealed that formulation B prepared with *Chichá* and *sapucaia* nuts incorporated with pineapple peel was highly acceptable cereal-bar. This study verified that the utilization of almonds of *sapucaia, chichá*, and *gurguéia* nuts with pineapple peel is viable for the development of nutritional cereal bars[76].

Orodu & Inengite, extracted oil from pineapple peel and revealed that it is fit for human consumption as it showed a higher range of free fatty acid content and acid value; within the range of peroxide value (PV); below the range of saponification value and iodine value when compared to Nigerian Industrial Standards[77].

Wu *et al.*, added pineapple peel fibre (PPF) into steamed bread and dough. That resulted in less extensible and stiffer dough without or with fermentation. An increased hardness and gumminess but decreased elasticity, cohesiveness, and specific volume were observed in steamed bread with the inclusion of 0-15% of PPF. Sensory evaluation was conducted which revealed that fiber-rich steamed bread can be developed by incorporating 5-10% of PPF[78]. Peel of pineapple was also utilized for the generation of vinegar, wines, bio-ethanol, and hand sanitizer[30,79-81].

Conclusion

A. comosus peel consists of several major natural antioxidants like as flavonoids, phenolic compounds, terpenoids, carotenoids, cumarins, saponin, lignin, plant sterol, and ascorbic acid. The main polyphenols present in *A. comosus* peel comprises of catechin, epicatechin, gallic acid, myricetin, salicylic acid, *p*-coumaric acid, trans-cinnamic acid, tannic acid and ferulic acid. Due to its excellent physicochemical property, it possesses great medicinal and therapeutic applications like hypoglycaemic, hypocholestrolemic, antihypertensive, antimutagenic, anticarcinogenic, antioxidative, antimicrobial, anti-inflammatory and excellent prebiotic potential with positive effect in intestinal function due to presence of insoluble fiber. It has been used in food industry for various purposes such as vinegar manufacturing, added as reductant and stabilizer for the production of silver nano-particles, supplemented in gummy candies, yogurt, cereal-bars, formation of dough and steamed bread by incorporating its fibrous peel which aid in better digestion. Peels of *A. comosus* are highly effective against the number of pathogenic microorganisms which leads to a number of disease conditions. *A. comosus* peel promotes good health by curing a wide variety of chronic and non-chronic diseases. In future studies, it is encouraged to elucidate the mechanism of action and metabolic pathways regarding this peel extract on human health.

Conflict of interest

Authors declare that there is no conflict of interest.

References

1 Pathak P D, Mandavgane S A and Kulkarni B D, Fruit peel waste: Characterization and its potential uses, *Curr Sci*, 2017, **113**(3), 444-454.

2 International Diabetes Federation (IDF) Atlas, Available from www.diabetesatlas.org 2019.

3 Sarkar T, Nayak P and Chakraborty R, Pineapple [*Ananas comosus* (L.)] product processing techniques and packaging: A review, *IIOAB J*, 2018, **9**(4), 6-12.

4 Horticultural Statistics at a Glance, 2018, www.agricoop.nic.in

5 Varzakas T, George Z and Francis V, Plant food residues as a source of nutraceuticals and functional foods, *Foods*, 2016, **5**(4), 88.

6 Upadhyay A, Jeewan P L and Shinkichi T, Utilization of pineapple waste: A review, *J Food Sci Technol Nepal*, 2010, **6**, 10-18.

7 Chaudhary V, Kumar V, Vaishali S, Singh K, Kumar R, *et al.*, Pineapple (*Ananas comosus*) product processing: A review, *J Pharmacogn Phytochem*, 2019, **8**(3), 4642-4652.

8 Tochi B N, Wang Z, Xu S Y and Zhang W, Therapeutic application of pineapple protease (Bromelain): A review, *Pak J Nutr*, 2008, **7**(4), 513-520.

9 Bresolin I R A P, Bresolin I T L, Silveira E, Tambourgi E B and Mazzola P G, Isolation and purification of Bromelain from waste peel of pineapple for therapeutic application, *Braz Arch Biol Technol*, 2013, **56**(6), 971-979.

10 Debnath B, Singh W S and Manna K, A phytopharmacological review on *Ananas comosus*, *Adv Tradit Med*, 2021, 1-8.

11 Lawal D, Medicinal, pharmacological and phytochemical potentials of *Annona comosus* Linn. peel- A review, *Bayero J Pure Appl Sci*, 2013, **6**(1), 101-104.

12 Gunwantrao B B, Bhausaheb S K, Ramrao B S and Kharade S S, Antimicrobial activity and phytochemical analysis of orange (*Citrus aurantium* L.) and pineapple (*Ananas comosus* (L.) Merr.) peel extract, *Ann Phytomed*, 2016, **5**, 156-160.

13 Damasceno K A, Gonçalves C A A, Pereira G D S, Costa L L, Campagnol P C B, *et al.*, Development of cereal bars containing pineapple peel flour (*Ananas comosus* L. Merril), *J Food Qual*, 2016, **39**(5), 417-424.

14 Deo S and Sakhale B K, A Review on potential of bioactive compounds obtained from processing waste of various fruits and vegetables, *Int J Pure Appl Biosci*, 2018, **6**(5), 680-686.

15 Huang Y L, Chow C J and Fang Y J, Preparation and physicochemical properties of fiber-rich fraction from pineapple peels as a potential ingredient, *J Food Drug Anal*, 2011, **19**(3), 318-323.

16 Uchoi D, Raju C V, Lakshmisha I P, Singh R R and Elavarasan K, Antioxidative effect of pineapple peel extracts in refrigerated storage of Indian Mackerel, *Fish Technol*, 2017, **54**, 42-50.

17 Rudra S G, Nishad J, Jakhar N and Kaur C, Food industry waste: Mine of nutraceuticals, *Int J Sci Environ Technol*, 2015, **4**(1), 205-229.

18 Kodagoda K H G K and Marapana R A U J, Utilization of fruit processing by-products for industrial applications: A review, *Int J Food Sci Nutr*, 2017, **2**(6), 24-30.

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

20 Rashad M M, Mahmoud A E, Ali M M, Nooman M U and Al-Kashef A S, Antioxidant and anticancer agents produced from pineapple waste by solid state fermentation, *Int J Toxicol Pharmacol Res*, 2015, **7**(6), 287-96.

21 Sah B N P, Vasiljevic T, McKechnie S and Donkor O N, Effect of pineapple waste powder on probiotic growth, antioxidant and antimutagenic activities of yogurt, *J Food Sci Technol*, 2016, **53**(3), 1698-1708.

22 Setyawati I, Ermayanti N G A M, Suarni N M R, Narayani I and Suaskara I B M, Testicular histology and blood testosterone levels of male rabbit after given concentrated diets containing calliandra leaf meal and pineapple peels, *J Phys Conf Ser IOP Publishing*, 2018, **983**(1), 012197.

23 Figuerola F, Hurtado M L, Estévez A M, Chiffelle I and Asenjo F, Fibre concentrates from apple pomace and citrus peel as potential fibre sources for food enrichment, *Food Chem*, 2005, **91**(3), 395-401.

24 Quirós-Sauceda A E, Palafox-Carlos H, Sáyago-Ayerdi S G, Ayala-Zavala J F, Bello-Perez L A, *et al.*, Dietary fiber and phenolic compounds as functional ingredients: Interaction and possible effect after ingestion, *Food Funct*, 2014, **5**(6), 1063-1072.

25 Saura-Calixto F, Dietary fiber as a carrier of dietary antioxidants: An essential physiological function, *J Agric Food Chem*, 2011, **59**(1), 43-49.

26 Poquet L, Michael N C and Williamson G, Transport and metabolism of ferulic acid through the colonic epithelium, *Drug Metab Dispos*, 2008, **36**(1), 190-197.

27 Chitturi S, Talatam V G and Vuppu S, Studies on protein content, protease activity, antioxidants potential, melanin composition, glucosinolate and pectin constitution with brief statistical analysis in some medicinally significant fruit peels, *Der Pharm Lett*, 2013, **5**(1), 13-23.

28 Romelle F D, Rani A and Manohar R S, Chemical composition of some selected fruit peels, *Eur J Food Sci Technol*, 2016, **4**(4), 12-21.

29 Diaz-Vela J, Alfonso T, Cruz-Guerrero A E and Pérez-Chabela M L, *In vitro* evaluation of the fermentation of added-value agroindustrial by-products: cactus pear (*O puntia ficus-indica* L.) peel and pineapple (*Ananas comosus*) peel as functional ingredients, *Int J Food Sci Technol*, 2013, **48**(7), 1460-1467.

30 Romo-Zamarrón K F, Pérez-Cabrera L E and Tecante A, Physicochemical and sensory properties of gummy candies enriched with pineapple and papaya peel powders, *Food Nutr Sci*, 2019, **10**(11), 1300-1312.

31 Huang Y L, Tsai Y H and Chow C J, Water-insoluble fiber-rich fraction from pineapple peel improves intestinal function in hamsters: Evidence from cecal and fecal indicators, *Nutr Res*, 2014, **34**(4), 346-354.

32 Pardo M E S, Cassellis M E R, Escobedo R M and García E J, Chemical characterisation of the industrial residues of the pineapple (*Ananas comosus*), *J Agric Chem Environ*, 2014, **3**(2), 53-56.

33 Roda A and Lambri M, Food uses of pineapple waste and by-products: A review, *Int J Food Sci Technol*, 2019, **54**(4), 1009-1017.

34 Wijayati N, Rini A R S and Supartono S, Hand sanitizer with pineapple peel extract as antibacterial against *Staphylococcus aureus* and *Escherichia coli*, *Proceeding of ICMSE,* 2016, **3**(1), C-40.

35 Dias P G I, Sajiwanie J W A and Rathnayake R M U S K, *Investigation of functional properties and phytochemical screening of selected fruit peel powders*, International Research Conference of UWU, 2019, 594.

36 Olakunle O O, Deborah J B and Irene O J, Antifungal activity and phytochemical analysis of selected fruit peels, *J Biol Med*, 2019, **3**(1), 040-043.

37 Sharma S A, Krishnakumar V and Arulraj J, Impact of *Ananas comosus* extract supplementation on the growth and biochemical profile of cyprinus carpio fingerlings, *Trends Fish Res*, 2019, **8**(2), 2319–4758.

38 Dabesor A P, Asowata-Ayodele A M and Umoiette P, Phytochemical compositions and antimicrobial activities of *Ananas comosus* peel (M.) and *Cocos nucifera* kernel (L.) on selected food borne pathogens, *Am J Plant Biol*, 2017, **2**(2), 73-76.

39 Li T, Shen P, Liu W, Liu C, Liang R, *et al*, Major polyphenolics in pineapple peels and their antioxidant interactions, *Int J Food Prop*, 2014, **17**(8), 1805-1817.

40 Kaur A, Jain Y, Mittal K and Mittal N, Synergistic effect of pineapple peels & green tea on antioxidant levels of pineapple peels infused kangra green tea, *Global J Biosci Biotechnol*, 2018, **7**(3), 392-395.

41 Ban-Koffi L and Han Y W, Alcohol production from pineapple waste, *World J Microbiol Biotechnol*, 1990, **6**(3), 281-284.

42 Novaes L C L, Ebinuma V C S, Mazzola P G and Júnior A P, Polymer-based alternative method to extract bromelain from pineapple peel waste, *Biotechnol Appl Biochem*, 2013, **60**(5), 527-535.

43 National Center for Biotechnology Information, PubChem Database, Gallic acid, CID=370, available from: https://pubchem.ncbi.nlm.nih.gov/compound/Gallic-acid (accessed on Feb. 10, 2020).

44 National Center for Biotechnology Information, PubChem Database, Ferulic acid, CID=445858, available from: https://pubchem.ncbi.nlm.nih.gov/compound/Ferulic-acid (accessed on Feb. 10, 2020).

45 National Center for Biotechnology Information, PubChem Database, Myricetin, CID=5281672, available from: https://pubchem.ncbi.nlm.nih.gov/compound/Myricetin (accessed on Feb. 10, 2020).

46 National Center for Biotechnology Information, PubChem Database, Salicylic acid, CID=338, available from: https://pubchem.ncbi.nlm.nih.gov/compound/Salicylic-acid (accessed on Feb. 10, 2020).
47 Available from: https://www.phytochemicals.info/ phytochemicals/ tannic-acid.php (accessed on Feb. 20, 2020).
48 National Center for Biotechnology Information, PubChem Database, Cinnamic acid, CID=444539, available from: https://pubchem.ncbi.nlm.nih.gov/compound/Cinnamic-acid (accessed on Feb. 20, 2020)
49 Available from: https://www.selleckchem.com/products/p-coumaric-acid.htmL (accessed on Feb. 20, 2020).
50 Halliwell B, Antioxidants: The basics-what they are and how to evaluate them, *Adv Pharmacol*, 1996, **38**, 3-20.
51 Hossain M A and Rahman S M M, Total phenolics, flavonoids and antioxidant activity of tropical fruit pineapple, *Food Res Int*, 2011, **44**, 672–676.
52 Putri D A, Ulfi A, Purnomo A S and Fatmawati S, Antioxidant and antibacterial activities of *Ananas comosus* peel extracts, *Mal J Fund Appl Sci*, 2018, **14**(2), 307-11.
53 Erukainure O L, Ajiboye J A, Okafo O Y, Kosok R S B, Owolab O F O, *et al.*, Antioxidant effect of pineapple (*Ananas cosmosus*) peel extract on alcohol-induced oxidative stress in splenic tissues of male albino rats, *J Food Biochem*, 2012, **36**(6), 643-647.
54 Saraswaty V, Risdian C, Primadona I, Andriyani R, Andayani D G S, *et al.*, Pineapple peel wastes as a potential source of antioxidant compounds, *IOP Conf Ser Earth Environ Sci*, 2017, **60**(1), 012013.
55 Larrauri J A, Rupérez P and Calixto F S, Pineapple shell as a source of dietary fiber with associated polyphenols, *J Agric Food Chem*, 1997, **45**(10), 4028-4031.
56 Kalaiselvi M, Ravikumar G, Gomathi D and Chandrasekar U, *In vitro* free radical scavenging activity of *Ananas comosus* (l.) Merrill peel, *Int J Pharm Pharm Sci*, 2012, **4**(2), 604-609.
57 Poadang S, Yongvanich N and Phongtongpasuk S, Synthesis, characterization, and antibacterial properties of silver nanoparticles prepared from aqueous peel extract of pineapple, *Ananas comosus*, *Chiang Mai Univ J Nat Sci*, 2017, **16**(2), 123-133.
58 Roberfroid M B, Prebiotics and probiotics: Are they functional foods?, *Am J Clin Nutr*, 2000, **71**(6), 1682S-1687S.
59 Pyar H A S S A N, Liong M T and Peh K K, Potentials of pineapple waste as growth medium for lactobacillus species, *Int J Pharm Pharm Sci*, 2014, **6**(1), 142-145.
60 Hemalatha R and Anbuselvi S, Physicohemical constituents of pineapple pulp and waste, *J Chem Pharm Res*, 2013, **5**(2), 240-242.
61 Campos D, Ribeiro T, Teixeira J, Pastrana L and Pintado M E, Assessment of potential prebiotic activity of pineapple by-products (peels and stems) extracts and maintenance of bioavailability through *in vitro* gastrointestinal tract system, *International Symposium of the International Scientific Association of Probiotics and Prebiotics*, 2018.
62 Mekala K C and Bertoni A G, Epidemiology of diabetes mellitus. In *Transplantation, Bioengineering, and Regeneration of the Endocrine Pancreas*, (Academic Press), 2020, 49-58.
63 Riya M P, Antu K A, Vinu T, Chandrakanth K C, Anilkumar K S, *et al.*, An *in vitro* study reveals nutraceutical properties of *Ananas comosus* (L.) Merr. var. Mauritius fruit residue beneficial to diabetes, *J Sci Food Agric*, 2014, **94**(5), 943-950.
64 Das G, Patra J K, Debnath T, Ansari A and Shin H S, Investigation of antioxidant, antibacterial, antidiabetic, and cytotoxicity potential of silver nanoparticles synthesized using the outer peel extract of *Ananas comosus* (L.), *PloS one*, 2019, **14**(8), e0220950.
65 Gupta E, Purwar S, Sundaram S and Rai G K, Nutritional and therapeutic values of *Stevia rebaudiana*: A review, *J Med Plants Res*, 2013, **7**(46), 3343-3353.
66 Lubaina A S and Reshma G S, Potential of pineapple peel as natural resource of antioxidants, *Trends Biosci*, 2018, **11**(7), 1288-1293.
67 Jin L, Lin M Q, Piao Z H, Cho J Y, Kim G R, *et al.*, Gallic acid attenuates hypertension, cardiac remodelling, and fibrosis in mice with NG-nitro-L-arginine methyl ester-induced hypertension via regulation of histone deacetylase 1 or histone deacetylase 2, *J Hypertens*, 2017, **35**(7), 1502-1512.
68 Zanwar A A, Badole S L, Shende P S, Hegde M V and Bodhankar S L, Role of gallic acid in cardiovascular disorders, in *Polyphenols in human health and disease*, (Academic Press), 2014, 1045-1047.
69 Mancuso C and Santangelo R, Ferulic acid: Pharmacological and toxicological aspects, *Food Chem Toxicol*, 2014, **65**, 185-195.
70 Emmanuel E U, Onagbonfeoana E S, Adanma O C, Precious O C, Faith A I, *et al.*, *In vivo* and *in vitro* antioxidant and hypolipidemic activity of methanol extract of pineapple peels in wistar rats, *Int J Biosci*, 2016, **8**(6), 64-72.
71 Musial D C, Ostrowski A P, Ostrowski M, Bracht L and Broetto-Biazon A C, Comparative study of hypocholesterolemic potential of pineapple and passion fruit peels in rats and mice, *Rev Bras Pesq Aliment*, 2015, **6**(1), 64-69.
72 Shah S U, Importance of Genotoxicity & S2A guidelines for genotoxicity testing for pharmaceuticals, *IOSR J Pharm Biol Sci*, 2012, **1**(2), 43-54.
73 Li F, Li S, Li H B, Deng G F, Ling W H, *et al.*, Antiproliferative activity of peels, pulps and seeds of 61 fruits, *J Funct Foods*, 2013, **5**(3), 1298-1309.
74 Sah B N P, Vasiljevic T, McKechnie S and Donkor O N, Antioxidant peptides isolated from synbiotic yoghurt exhibit antiproliferative activities against HT-29 colon cancer cells, *Int Dairy J*, 2016, **63**, 99-106.
75 Tumane P M, Sanchari S, Wasnik D D and Kolte N A, Production of vinegar from pineapple peels using *Acetobacter* species isolated from soil sample and its antibacterial activity, *Int J Life Sci*, 2018, **64**, 948-956.
76 de Carvalho M G, Costa J M C C, Rodrigues P, Carmo M, Sousa P H M, *et al.*, Formulation and sensory acceptance of cereal-bars made with almonds of chichá, sapucaia and gurguéia nuts, *Open Food Sci J*, 2011, **5**(1), 26-30.
77 Orodu V E and Inengite A K, Extraction and physicochemical analysis of oil extracted from pineapple (*Ananas comosus*) peels, *World J Pharm Res*, 2018, **7**(18), 154-166.
78 Wu M Y and Shiau S Y, Effect of the amount and particle size of pineapple peel fiber on dough rheology and steamed bread quality, *J Food Process Pres*, 2015, **39**(6), 549-558.

79 Itelima J, Onwuliri F, Onwuliri E, Onyimba I and Oforji S, Bio-ethanol production from banana, plantain and pineapple peels by simultaneous saccharification and fermentation process, *Int J Environ Sci Dev*, 2013, **4**(2), 213-216.

80 Roda A, De Faveri D M, Dordoni R and Lambri M, Vinegar production from pineapple wastes –preliminary saccharification trials, *Chem Eng Trans*, 2014, **37**, 607-612.

81 Graham O S, Mohammed M, Wilson L A and Wickham L D, Effects of pectolytic enzymes and antioxidants on the quality of dry wines made from pineapple (*Ananas comosus* L. Merr) peel, *J Food Agric Environ*, 2004, **2**(2), 135-142.