REVIEW ARTICLE
J. Food Sci. Technol. Nepal, Vol. 6 (10-18), 2010
ISSN: 1816-0727

# Utilization of Pineapple Waste: A Review

ATUL UPADHYAY[1], JEEWAN PRAVA LAMA[2] and SHINKICHI TAWATA[3*]

[1]Department of Biochemistry and Applied Bioscience, The United Graduate School of Agricultural Sciences, Kagoshima University, Kagoshima 890-0065, Japan.
[2] Department of Food Technology and Quality Control, Ministry of Agriculture and Cooperatives, Kathmandu, Nepal.
[3]Faculty of Agriculture, University of the Ryukyus, Senbaru, Nishihara-cho, Okinawa 903-0213, Japan.

*Waste utilization in fruits and vegetable processing industries is one of the important and challengeable jobs around the world. It is anticipated that the discarded fruits as well as its waste materials could be utilized for further industrial purposes viz. fermentation, extraction of bioactive components, extraction of functional ingredients etc. Researchers have focused on the utilization of pineapple waste primarily for extraction of bromelain enzyme and secondarily as low-cost raw material for the production of ethanol, phenolic anti-oxidants, organic acids, biogas and fiber production. Pertinent scientific and technological implications would produce better and more profitable markets for pineapple wastes. This review is the collection of previous reports along with our ongoing work on utilization of pineapple wastes.*

**Keywords:** Pineapple waste, Industrial waste utilization, Low-cost substrate

## Introduction

The pineapple (*Ananas comosus*) is one of the most important fruits in the world and is the leading edible member of the family *Bromeliaceae*. This fruit juice is the third most preferred worldwide after orange and apple juices (Cabrera *et al*., 2000). The plant can grow up to a height of 75-150 cm with a spread of 90-120 cm. It is short, having a stout stump with narrow, fibrous and spiny leaves. The plant develops to a cone-shaped juicy and fleshy fruit with crown at the top (Morton, 1987; Tran, 2006). According to FAO online data base, the area under pineapple plantation in 2007 was almost 9, 20,349 ha with an estimated production of more than 18 million tons (FAO, 2007). Commercially, it is mainly produced as canned fruits and consumed worldwide (Tran, 2006). Besides, it is also processed as juices, concentrates, and jams. Pineapple slices have also been preserved after freezing (Larrauri *et al*., 1997). Furthermore, bromelain, the proteolytic enzyme present in the stem of pineapple, is finding wide applications in pharmaceutical and food uses (Hebbar *et al.,* 2008).

## Pineapple waste

Tropical and subtropical fruits processing have considerably higher ratios of by-products than the temperate fruits (Schieber *et al*., 2001). Pineapple by-products are not exceptions and they consist basically of the residual pulp, peels, stem and leaves. The increasing production of pineapple processed items, results in massive waste generations. This is mainly due to selection and elimination of components unsuitable for human consumption. Besides, rough handling of fruits and exposure to adverse environmental conditions during transportation and storage can cause up to 55% of product waste (Nunes *et al*., 2009). These wastes are usually prone to microbial spoilage thus limiting further exploitation. Further, the drying, storage and shipment of these wastes is cost effective and hence efficient, inexpensive and eco-friendly utilization is becoming more and more necessary. Compositional analysis of pineapple wastes have been carried out (**Table 1**).

**Table 1. Chemical composition of pineapple waste**

| Parameters | Ensiled[a] | Fresh[a] | Dry[a] | Peel[b] | Whole[c] | Skin[c] | Crown[c] | Pulp[c] |
|---|---|---|---|---|---|---|---|---|
| Moisture % | 72.49 | 71.07 | 27.43 | 92.2 | - | - | - | - |
| Total solid % | 27.51 | 29.03 | 72.57 | 7.8 | - | - | - | - |
| Volatile solids % | 87.12 | 96.12 | 95.9 | 89.4 | - | - | - | - |
| pH | 4 | 4.7 | 4.7 | - | - | - | - | - |
| Ash % | 12.88 | 3.88 | 4.1 | 10.6 | 0.7 | 0.6 | 0.4 | 0.2 |
| | | | as % dry basis | | | | | |
| Cellulose | 9 | 11.2 | 12 | 19.8 | 19.4 | 14.0 | 29.6 | 14.3 |
| Hemicellulose | 4.7 | 7 | 6.5 | 11.7 | 22.4 | 20.2 | 23.2 | 22.1 |
| Pectin | 5.1 | 6.7 | 7.1 | - | - | - | - | - |
| Ether soluble solids | 4 | 6.1 | 6.7 | - | - | - | - | - |
| Protein | 0.91 | 3.13 | 3.3 | - | 4.4 | 4.1 | 4.2 | 4.6 |
| Reducing sugar | 5 | 25.8 | 27.8 | - | 6.5 | - | - | - |
| Non-reducing sugar | 1.7 | 5.7 | 4.9 | - | 5.2 | - | - | - |
| Total sugar | - | - | - | - | 11.7 | - | - | - |
| Lignin | 9 | 11.52 | 11 | - | 4.7 | 1.5 | 4.5 | 2.3 |

[a]Rani *et al*., (2004), [b]Bardiya *et al*., (1996), [c]Bankoffi and Han, (1990)

*Corresponding author, E-mail : b986097@agr.u-ryukyu.ac.jp

Except for high quality fruits that are selected for shipment, most pineapples are consumed fresh or as canned products. However, low quality fruits do not fetch market and are left on farms. Besides, during pineapple processing, large amount of unusable waste material are generated (Tanaka *et al*., 1999). Reports have shown that 40-80% of pineapple fruit is discarded as waste having high biological oxygen demand (BOD) and chemical oxygen demand (COD) values (Bankoffi and Han, 1990).

**Disposal of waste**

Fruit residues may cause serious environmental problems, since it accumulates in agro-industrial yards without having any significant and commercial value. Since disposal of these wastes is expensive due to high costs of transportation and a limited availability of landfills they are unscrupulously disposed causing concern as environmental problems. Furthermore, the problem of disposing by-products is further aggravated by legal restrictions. A high level of BOD and COD in pineapple wastes add to further difficulties in disposal. Researcher have focused on co-digestion of pineapple waste along with several other fruit and vegetable wastes, manure, and slaughter house wastes to reduce volatile solids by 50 to 65% (Alvarez and Liden, 2007). Recently, composting of pineapple wastes using earthworm is reported (Mainoo *et al*., 2009). They have reported that vermicomposting rapidly decomposed about 99% of pineapple pulp wet mass while peel had a loss in weight by almost 87%. The pH of the waste changed from acidic to a neutral to alkaline during composting. However, cost effectiveness is yet to be studied.

**Utilization of pineapple waste**

It is anticipated that discarded fruit as well as the waste material can be utilized for further industrial processes like fermentation, bioactive component extraction, etc. There has been numerous works on the utilization of waste obtained from fruit and vegetable, dairy and meat industries. In this regard, several efforts have been made in order to utilize pineapple wastes obtained from different sources. The wastes from pineapple canneries have been used as the substrate for bromelain, organic acids, ethanol, etc. since these are potential source of sugars, vitamins and growth factors (Larrauri *et al*., 1997; Nigam, 1999a,b; Dacera *et al*., 2009). Several studies have been carried out since decades on trying to explore the possibility of using these wastes. In past, sugar has been obtained from pineapple effluent by ion exchange and further use it in syrup for canning pineapple slices (Beohner and Mindler, 1949). This paper would try to collect and gather information regarding the utilization of pineapple wastes.

***Bromelain:*** Bromelain is probably the most valuable and the most studied component from the pineapple waste. It has been investigated since 1894 (Devakate *et al*., 2009) and was first identified in 1891 by Marcano (Balls *et al*., 1945). It is a crude extract of pineapple that contains, among other components, various closely related proteinases, demonstrating, *in vitro* and *in vivo*, antiedematous, anti-inflammatory, antithrombotic (Bhui *et al*., 2009), fibrinolytic activities and has potential as an anticancer agent (Chobotova *et al*., 2009). It is also used in food industry as meat tenderizer and as a dietary supplement (Maurer, 2001). Bromelain is primarily present in stem, known as stem bromelain (EC 3.4.22.32) and also in fruit (EC 3.4.22.33), however small amount of bromelain is also found in pineapple waste (Hebbar *et al*, 2008). They used reverse micellar systems to extract and purify bromelain from crude aqueous extract of pineapple wastes (core, peel, crown and extended stem).

Researchers have described the effectiveness of commercial extraction of proteolytic enzyme from pineapple over papain from papaya (Balls *et al*., 1945). Bromelain, unlike papain, does not disappear as the fruit ripens. Crude commercial bromelain from pineapple stem has been purified by successive use of ion-exchange chromatography, gel filtration, and ammonium sulfate fractionation (Murachi *et al*., 1964). Recently, purifications of bromelain from crude extract are reported using aqueous two-phase system (Babu *et al*., 2008) and metal affinity membranes (Nie *et al*., 2008).

Processing under harsh conditions of sterilization, precipitation and auto-digestion reduces the proteolytic activity of bromelain, thereby reducing medicinal properties. Thus, stability of bromelain has always been a subject of interest. Immobilization of stem bromelain via the lone histidine of metal affinity support had better thermal stability (Gupta *et al*., 2007). Thermal stability of bromelain was enhanced after complexing with tea polyphenols (Liang *et al*., 1999). However, even without addition of preservatives, natural stability of fruit bromelain was retained to almost 80% when stored at -4 $^{o}$C for 180 days (Bhattacharya and Bhattacharya, 2009).

***Ethanol:*** Interest in the economic conversion of renewable resources into alcohol using low cost substrate, such as pineapple waste, has been increasing since the last decade. Waste from pineapple cannery has been examined for ethanol production (**Table 2**).

**Table 2. Alcohol production from pineapple waste**

| Organism | Yield (% of theoretical values) | Productivity (g/l/h) | Reference |
|---|---|---|---|
| *Z. mobilis* | 92.4 | 2.81 | Tanaka *et al*., 1999 |
| *S. cerevisiae* | 92.5 | 3.75 | Nigam, 1999a |
| *S. cerevisiae* | 86.3 | 42.8 | Nigam, 2000 |

Organisms like *Saccharomyces cerevisiae* and *Zymomonas mobilis* were used for ethanol fermentation (Ban-Koffi and Han, 1990). However, they have claimed that fermentable sugars which included sucrose, glucose and fructose were relatively low and pretreatment of the substrate with enzymes like cellulase and hemi-cellulase were necessary for alcohol production. Both organisms were capable of producing about 8% ethanol from pineapple waste in 48 h after pretreating with enzymes cellulase and hemi-cellulase.

Nigam (1999b) has used respiration deficient strain *Saccharomyces cerevisiae* ATCC 24553 for continuous ethanol production from pressed juice of pineapple cannery waste. No pretreatment of juice was done and the liquid effluents collected from various stages of processing were added. At a dilution rate of 0.05 $h^{-1}$, the ethanol production was 92.5% of the theoretical value. Immobilization of the yeast in k-carrageenan increased the volumetric ethanol productivity by 11.5 times higher than yeast cells at a dilution rate of 1.5 $h^{-1}$ (Nigam, 2000). The other study used *Zymomonas mobilis* ATCC 10988 as fermenting organisms for ethanol production (Tanaka *et al*., 1999). The raw material used here was pineapple cannery waste as well as the juice of rotten or discarded fruit. Ethanol production was 59.0 g/l without supplementation and regulation in pH.

A new technique to produce ethanol from the extraction of liquid from the pineapple fruit and pineapple plant waste has been developed (ICIS, 2006). This technique allows the extraction of ethanol from the plant waste without requiring the producer to choose between food or fuel uses as the end product.

***Phenolic antioxidant:*** Search for new natural antioxidants has been increased dramatically over the past years and in this regard agro-industrial by-products are extensively being explored. The low cost of these residues, which otherwise would be discarded as waste in the environment, may be one of the reasons. Phytochemicals, especially phenolic, in fruits and vegetable are suggested to be the major bioactive compounds for the health benefits. These compounds are derivatives of the pentose phosphate, shikimate and phenylporpanoid pathways in plats (Randhir *et al*., 2004). The chemistry of phenolic compounds in relation to their antioxidant activity and their occurrence in various food, their bioavailability and metabolism has been described (Balasundram *et al*., 2006).

**Table 3. Phenolic antioxidant from pineapple fruit and wastes**

| Source | Amount | Reference |
|---|---|---|
| Fruit | 40.4 mg/ 100 g as GAE | Sun *et al*., 2002 |
| Fruit | 2.58 mg/100g as CAE | Gorinstein *et al*., 1999 |
| Juice | 358 mg/L as GAE | Gardener *et al*., 2000 |
| Residue | 1.3 mg/g GAE | Oliveira *et al*., 2009 |
| Shell | 22.7 mg/g dry matter | Larrauri *et al*., 1997 |
| Peel | 2.01 mmol FRAP/100g wet weight | Guo *et al*., 2003 |
| PSW | 269.8 mg/100g GAE | In communication |
| Peel | 111.1 mg/g dry matter GAE | (Unpublished) |

The phenolic content of pineapple has been reported by several researchers (Table 3). Fruit phenolic content was found as 40.4 mg/100g as gallic acid equivalent with the highest ethyl acetate bound phenolic (Sun *et al*., 2002), 2.58 as chlorogenic acid equivalent (Gorinstein *et al*., 1999), while juice had 358 mg/L as gallic acid equivalent (Gardener *et al*., 2000). Methods employed for the extraction by different researchers are found to be different. Sun *et al*., (2002) extracted fruit in 80% acetone followed by base digestion and ethyl acetate extraction, while Gardener *et al*., (2000) centrifuged the juice before estimating the total phenolic content. Extraction of crude polyphenols using aqueous methanol/ethanol or acetone is quite popular and frequently done (Gorinstein *et al*., 2002; Larrauri *et al*., 1997). The concentrations of solvent used also have impact on the amount of phenolic extracted. Extraction with 50% acetone and 70% ethanol has proven to be the best solvents for phenolic compounds (Alothman *et al*., 2009). However, in some cases, concentration of high polar compound is achieved by extracting with hexane before carrying out ethyl acetate extraction (Oliveira *et al*., 2009).

Phenolic antioxidants from the wastes are also found to be in higher amounts. The methanol extraction yield and total phenolic contents of pineapple residue (pulp, seeds and peel) were 30.2% and 10 mg/g GAE (Oliveira *et al*., 2009). They co-related the antioxidant activities of the phenolic compounds using DPPH free radical scavenging activity and superoxide anion scavenging activity. Phenolic such as myricetin, salicyclic acid, tannic acid, *trans*-cinnamic acid and *p*-coumaric acid has been identified in the high dietary fiber powder form pineapple shell (Larrauri *et al*., 1997). The FRAP value for pineapple peel has been reported as 2.01 mmol/100 g wet weight (Guo *et al*., 2003). Our previous work with the waste obtained from the bromelain manufacturing process has shown that phenolic acids, such as syringic and ferulic, might be responsible for the antioxidant and antimicrobial activities of the water extract (Upadhyay *et al*., 2011a). We have synthesized potent fungicides from cinnamic, *p*-coumaric and ferulic acids that were isolated from pineapple stems (Tawata *et al*., 1996). We have also proposed that phenolic antioxidant from pineapple waste may be converted to more potent compounds by cytochrome P4502C9 isozyme *in vitro* (Upadhyay *et al*., 2009). Besides, our laboratory focus on the underutilized parts of various plants (Tawata and Upadhyay, 2010; Chompoo *et al*., 2011; Upadhyay *et al*., 2011b) and in this regard we have also identified anti-inflammatory and anti-diabetic potential of pineapple stem waste. Our ongoing work on phytochemicals from pineapple peel and leaf showed a high antioxidant activity with high phenolic compounds. The leaf also has significant amount of phytosterol content, particularly beta-sitosterol, stigmasterola and campestrol. Furthermore, the highest amount of phenolic from pineapple peel was extracted in 30 minutes using 75% ethanol at 75 $^{o}$C (Unpublished data).

Phenolic compounds from pineapple wastes (residual pulp, peels and skin) have been enhanced using certain bioprocesses (Correia *et al*., 2004a). Total phenolics were increased by two times when the fungus *Rhizopus oligosporus* was incubated for 12 days in 1:1 pineapple: soybean flour mixture. Another bioprocess where mixture of pineapple residue and soy flour (9:1 and 5:5) using *R. oligosporus* has revealed that extracts obtained after 2 days with 9:1 treatment showed potent á-amylase inhibition while the extract obtained after 10 days with 5:5 treatment exhibited *Helicobacter pylori* inhibition (Correia *et al*., 2004b). They have linked these activities with the phenolic compounds present in the system.

The ethanolic extract of pineapple leaves containing phenolics have shown to inhibit the increase in blood glucose in diabetic rats as well as inhibit the increase in postprandial triglycerides (Xie *et al*., 2005). The other report on the ethanolic extracts of pineapple leaves have shown to content high amount of phytochemicals including *p*-coumaric acid, 1-*o*-*p*-coumaroylglycerol, caffeic acid and 1-*o*-caffeoylglycerol (Xie *et al*., 2006). They reported that leaves extract application inhibited the development of insulin resistance in high-fat diet-fed and low-dose streptozotozin treated daibaetic rats. The extract also inhibited the development of insulin resistance in HepG2 cells. The ethanolic extract of pineapple leaves with high phenolics has significantly inhibited the increase in serum triglycerides by 40% in fructose-fed mice (Xie *et al*., 2007). The extract selectively activated lipoprotein lipase coenzyme A reductase activity by 20-49% in vitro thereby indicating the hypolipidemic effect of the extract. The phenolics responsible for these activities were characterized by Ma *et al*. (2007), who reported eight phenylpropane-diglycerides, together with two hydroxycinnamic acids, three hydroxycinnamoylquinic acids, four phenylpropan-emonoglycerides, three flavones and six phenylpropanoid glycosides.

***Organic acid:*** Organic acid production from fruit waste in the search of low cost substrate has been a research of interest. In this regard, pineapple wastes have been utilized for the production of various organic acids particularly citric, lactic and ferulic acid using fermentation technology (Table 4).

**Table 4. Organic acid from pineapple wastes**

| Organic acid | Yield g/100 g substrate | Organism/Method | Reference |
|---|---|---|---|
| Citric acid | 11.3 | *Aspergillusniger* | Kumar *et al*., 2003 |
| | 7.9 | *A. niger* | Kumar *et al*., 2003 |
| | 20.24 | *Yarrowialipolytica* | Imandi *et al*., 2008 |
| | 16.4 | *A. niger ACM 4993* | Tran *et al*., 1998 |
| | 19.4 | *A. niger ACM 4992* | Tran *et al*., 1998 |
| | 16 | *A. foetidus* | Tilay *et al*., 2008 |
| | 16.1 | *A. foetidus ACM 3996* | Tran and Mitchel., 1995 |
| Lactic acid | 92g/L | *Lactococcuslactis* | Ueno *et al*., 2003 |
| | 0.78-0.82 g/ g glucose | *Lactobacillus delbrueckii* | Idris and Suzana, 2006 |
| | 19.3g/L | | Jin *et al*., 2005 |
| | 14.7 g/L | *Rhizopusarrhizus* *R. oryzae* | Jin *et al*., 2005 |
| Ferulic acid (esterified) | 0.018% | Alkali extraction; Chromatographic | Tilay *et al*., 2008 |

***Citric acid:*** This commercially valuable product is widely used in food, pharmaceutical and beverage industries as substrate to acidify and enhance flavor. Some researchers have investigated the production of citric acid by *A. niger* under solid state fermentation conditions using pineapple waste (from juice extractor) as substrates (Kumar *et al*., 2003). They also investigated the effect of methanol on the fermentation, which increased the yield from 37.8% to 54.2%. The other groups of researchers studied the production of citric acid by *Yarrowia lipolytica* under solid state fermentation conditions using pineapple waste (from local juice manufacturer) as the sole substrate (Imandi *et al*., 2008). They optimized the culture conditions and the citric acid production was 202.35 g/kg dried pineapple waste. The other work used wet pineapple waste as the substrate for the production of citric acid (Tran and Mitchell, 1995). It was found that solid state fermentation using *Aspergillus foetidus* ACM 3996 produced higher amount of citric acid than from other waste sources such as apple pomace, rice or wheat brans. In one other report, researchers have used four species of *Aspergillus* to compare the production of citric acid under solid state fermentation. Under optimized conditions, a yield of 19.4g citric acid/100g dry fermented pineapple waste was obtained (Tran *et al*., 1998)

***Lactic acid:*** Lactic acid has an important position in the family of carboxylic acids because of its application in both food and non-food industries. It is used as a preservative and acidulant in food industries. However, commercial production of lactic acid is costly due to the raw materials used (exploitation of biological waste). Some researchers have used pineapple syrup, a food processing waste, as low cost substrate for the production of lactic acid using *Lactobacillus lactis* and enzyme invertase to hydrolyze sucrose into glucose and fructose. They have reported the yield of 20 and 92 g/l from 20 and 100 g total sugars/l (Ueno *et al*., 2003). Idris and Suzana (2006) used liquid pineapple waste as substrate to ferment to lactic acid using *Lactobacillus delbrueckii* under anaerobic conditions for 72 h. They used calcium alginate as the immobilization matrix to produce maximum yield of 0.7822-0.8248 g lactic acid/g glucose under different conditions of temperature and pH. Fungal production of lactic acid from pineapple waste resulted in 19.3 and 14.7g/L lactic acid with *Rhizopus arrhizus* and *R. oryzae* (Jin *et al*., 2005).

***Ferulic acid:*** Ferulic acid is the most abundant hydroxycinnamic acid found in plat cell walls. This phenolic antioxidant is widely used in the food and cosmetic industry. Pineapple peel has been used for the alkali extraction of ferulic acid (Tialy *et al*., 2008).

***Energy and carbon source:*** Pineapple wastes generally comprise of organic substances and hence the disposal problem could be attenuated by anaerobic digestion and composting. Some of these wastes could have industrial applications for gas generations (Mbuligwe and Kassenga, 2004). Biomethanation of fruit wastes is the best suited waste treatment as it both adds energy in the form of methane and also results in a highly stabilized effluent with almost neutral pH and odorless property (Bardiya *et al*., 1996). They utilized pineapple waste for the production of methane using semi-continuous anaerobic digestion which could produce up to 1682 ml/day of biogas with methane content of 51% in maximum. Rani and Nand (2004) reported that different conditions of pineapple peels gave biogas yields ranging from 0.41-0.67mg/kg volatile solids with methane content of 41-65%.

Solid pineapple waste has been used to produce volatile fatty acids and methane (Babel *et al*., 2004). They reported that at higher alkalinity, up to 53g volatile fatty acids were produced from one kg of pineapple waste. Acetic, propionic, butyric, i-butyric and valeric acids were produced along with methane. Reports on utilizing pineapple waste as the carbon substrate to produce hydrogen gas from municipal sewage sludge is found (Wang *et al*., 2006). The waste contained carbon and nitrogen source for cell growth and hydrogen production. In other report, pineapple fruit wastes have been suggested as a source of carbon for bacterial production of cellulose by *Acetobacter xylinum* (Kurosumi *et al*., 2009). Pineapple waste, as one of the substrates in mixed fruit wastes, has been utilized for biogas generation (Lane, 1984; Prema *et al*., 1992). When using 15% pineapple peel in the mixed fruit peel waste, bio-hydrogen gas was generated at 0.73m$^3$/kg of volatile solid destroyed (Vijayaraghavan *et al*., 2007).

The sugars contained in pineapple cannery effluent have been utilized for the production of single cell protein using continuous cultivation (Nigam, 1999b). The dilution rate had significant effect on biomass as well as protein content. There was an increase in biomass and protein content of *Candida utilis* with increasing dilution rate.

***Anti-dyeing agent*** **:** Dyes used in textile industries have been a threat to environmental problem since these are visible in small quantities due to their brilliance when mixed and thrown with large volumes of waste water from different steps in the dyeing and finishing processes (Robinson *et al*., 2001; Babu *et al.*, 2008). Some works on utilizing pineapple waste to remove the dyes have been reported. Pineapple stem is used as low-cost adsorbent to remove basic dye (methylene blue) from aqueous solution by adsorption (Hameed *et al*., 2009). In another report, pineapple leaf powder has been used as an unconventional bio-adsorbent of methylene blue from aqueous solution (Weng *et al*., 2009)

***Fiber:*** Fibers from pineapple fruit has been reported by several researchers (Lund and Smoot, 1982; Bartolome and Ruperez, 1995; Gorinstein *et al*, 1999). However, some studies have focused on utilizing fibers of pineapple wastes. Researchers have reported that dietary fiber powder prepared from pineapple shell has 70.6% total dietary fiber with better sensory properties than commercial dietary fibers from apple and citrus fruits (Larrauri *et al*., 1997). The pineapple leaves have been used to make coarse textiles and threads in some Southeast Asian countries (Tran, 2006). Alkaline pulping methods were found to be superior over semi-chemical mechanical pulping with yields below 40%. A yield of 2.1g fibger/100 g pineapple pulp waste has been reported (Sreenath *et al*., 1996). Furthermore, pineapple leaf fibers are investigated in making fiber-reinforced polymeric composites because of high cellulosic content, abundance and inexpensiveness (Devi *et al*., 1997; Luo and Netravalli, 1999; Arib *et al*., 2006). They investigated the tensile, flexural, and impact behavior of pineapple leaf fiber-reinforced polyster composites as a function of fiber loading, fiber length, and fiber surface modification. They found that the mechanical properties of the composites are superior to other cellulose-based natural fiber composites.

***Removal of heavy metals:*** Pineapple fruit residues have been used as an effective biosorbent to remove toxic metals like mercury, lead, cadmium, copper, zinc and nickel (Senthilkumaar *et al*., 2000). They have reported that the addition of phosphate groups in the fruit residues increased the adsorbent capacities at lower pH. Reports on the removal of heavy metals like chromium, copper, lead, nickel and zinc from contaminated sewage sludge using citric acid obtained from fermented pineapple wastes with *A. niger* are found (Dacera and Babel, 2008). The applicability of such contaminated sewage sludge after removal of heavy metals as land fill has shown to have high potentials (Dacera *et al*., 2009). Pineapple waste water has also been used as cheap substitute of nutrients for *Acinetobacter haemolyticus*, which was used to reduce the contamination of chromium VI (Zakaria *et al.*, 2007).

***As animal feed:*** Feed production has become a new industry. The utilization of agro-industrial wastes as animal feed seems to mitigate the difficulties of forage shortage during critical seasons. Several studies have focused on exploiting pineapple wastes as feed for ruminants. The outer peel or skin and core from the pineapple canning industries, called bran, and the leaves are being utilized as feed for ruminants (Tran, 2006). The nutritive value of pineapple peel has been reported (Negesse *et al*., 2009). In China, pineapple waste from the field or from the cannery are being used as dairy feed (Sruamisri, 2007). Cattle preferred fermented pineapple waste with higher acidity to fresh waste. Dried and ensiled pineapple waste can be used as supplemental roughage and could replace 50% roughage in the total mixed ration for dairy cattle (Sruamisri, 2007). Besides, researchers have also focused on the performance and the apparent digestibility of pineapple by-product when used as feed. On feeding twenty four cross bred local goats for 80 days, it was found that dehydrated pineapple by-products would increase the digestibility with increase in weight of the animals (Costa *et al*., 2007). A survey reports that in Nigeria, pineapple waste are also used for feeding small ruminants and that they could be used after proper processing (Onwuka *et al.*, 1997).

Another report on suitability of pineapple waste as animal feed and pulp for human consumption is also found (Cabrera *et al*., 2000). However, some researchers have reported that by-product of pineapple processing industry is not considered attractive as an animal feed because of high fiber content and soluble carbohydrates with low protein content (Correia *et al*., 2004a)

**Concluding remarks**

Pineapple waste contains many reusable substances of high value. The wastes from canneries have high exploitation potential with encouraging future. Industrial applicability in case of bromelain extraction is very popular; new and emerging technologies, such as green technology for biogas or bioethanol production is highly likely with pineapple residues. Furthermore, dietary fibers and phenolic antioxidants could be used as impending nutraceutic resource, capable of offering significant low-cost nutritional dietary supplement for low-income communities. The booming market of functional food has created a mammoth vista for utilization of natural resources. If novel scientific and technological methods are applied, valuable products from pineapple wastes could be obtained. In this regard, cheap substrates, such as pineapple wastes have promising prospect. Thus, environmentally polluting by-products could be converted into products with a higher economic value than the main product. However, verification of this hypothesis is indispensible in order to apply pineapple cannery waste as industrial raw materials.

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