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Bio-Valorization Potential of Banana Peels (*Musa sapientum*): An Overview

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ABSTRACT

Recent breakthrough in industrial biotechnology offer important economic opportunities for the utilization of agro-industrial residues such as Banana Peels (BP). BP as a complex biological material is an important by-product of several cottage and major hospitality industries. Chemically, it contains cellulose, hemicelluloses, lignin and simple sugars. Due to its availability and value, it is capable as an ideal substrate for microbial process for production of valued-added products. Several efforts have been made to produce protein enriched animal ration, industrial enzymes, citric acid and other industrially viable products. Pre-treatment operations have resulted in improved substrate utilization by microorganisms. Solid State Fermentation (SSF) and submerged state fermentation (SmF) are two promising techniques majorly employed for bioconversion of BP for its value addition. The article reviews recent developments in process and products developed for valorizing BP through biotechnological approach. Information on most recent applications and developments are carefully documented.

Key words: Banana peels, industrial biotechnology, solid state fermentation, submerged state fermentation

INTRODUCTION

The current world economy is no doubt faced with unprecedented decline and uncertainties and this is evident in how major economies of the world have followed the downward trend in recent times. One of the major options capable of rescuing the scenario is agriculture. Agro wastes constitute major byproducts of various agricultural activities such as cultivation, harvesting and processing. Agro-wastes, including Banana Peel (BP) have been on the increase due to improved cultivation techniques and sophisticated processing conditions by allied industries that generates thousands of tones of this solid agro-waste which is generally discarded (Umoh, 1998; Milala *et al*., 2009; Amarnath and Balakrishnan, 2007a). Currently, BP constitute about 20-40% of waste generated in high banana planting regions of Africa, the Americas, India and Southeast Asia (Umoh, 1998; Thomas *et al*., 2002). This high percentage creates highly challenging situation in effective management of this solid waste.

Chemically, BP contained appreciable level of lingo-cellulosic materials and other components such as carbohydrates, vitamins, bioactive compounds and minerals (essential and non essential)

thereby qualifying it for various bioconversion processes (Johann *et al.*, 2007; Dzomeku *et al.*, 2007). This highly sophisticated technological approach is a viable option in effective management of BP waste since many countries are opposed to landfill and other environmentally implicated solid waste management approaches (Ravi *et al.*, 2011). In recent times, BP has been utilized for various industrial applications including bio-fuel production, bio-sorbents, pulp and paper, cosmetics, energy related activities, organic fertilizer, environmental clean up and biotechnology related processes (Morton, 1987; Gunaseelan, 2004; Bori *et al.*, 2007). In the light of numerous applications of this feedstock, this review will focus mainly on the biotechnological applications of BP where it functions as the major complex carbon source. Biological products emanating from BP include biogas, protein enriched animal feed (Rahman and Huque, 2002), enzymes, bio-sorbents, bio-ethanol, citric acid and bioactive compounds (Karthikeyan and Sivakumar, 2010; Aarti and Anita, 2010; Ashraf *et al.*, 2010; Ponnuswamy *et al.*, 2011).

One of the recent leaps in biotechnological application of BP is the production of protein enriched animal feed. This was due mainly to increased generation of the waste caused by improved cultivation practices, yield as well as the recent drive for conversion of waste to wealth. However, full utilization of the waste has been hampered due to recovery challenges facing submerged state fermentation (SmF) and scale up problem of Solid State Bioconversion (SSB). Nevertheless, the recent production of valuable enzymes from the waste may assist in offsetting the costs associated with these bioconversion techniques thereby making the whole process sustainable economically in future (Arotupin, 2007; Vijayaraghavan *et al.*, 2011; Somda *et al.*, 2011b). Similarly, enzymatic saccharification of cellulose, though uneconomical are increasingly being adopted for extraction of fruit juices, starch and oil from agro sources. The ease of enzyme recovery from bio-converted solid residues makes the system appropriate for nitrogen enrichment.

Several bioactive compounds and anti-nutritional factors which are present in BP have made its sole use for bioconversion very challenging. Many of these active compounds were capable of being used for treatment of various health issues effectively thereby making the supply of BP more stringent and challenging when needed for biotechnology related activities. However, this challenge seems to be on low side due to improved cultivation techniques.

As mentioned earlier, the scope of this paper will center on the biotechnology utilization of BP which covers its use for bio-ethanol production, animal feed protein enrichment and other industrially important products. Various lingo-cellulosic materials such as sugarcane bagasse, paper and pulp, cassava waste, saw dust etc have been used in recent times to produce bio-fuels (Pandey *et al.*, 2000; Akinyele *et al.*, 2011; Amarnath and Balakrishnan, 2007b). To this end Brazil and the USA are the two major ethanol producers accounting for over 62% of the world production (Kim and Dale, 2004). In Brazil for example, commercial scale fuel ethanol is mainly based on sucrose from sugarcane while in the USA corn starch is the main feedstock adopted for bio-ethanol production (Nibedita *et al.*, 2011). These methodologies are undesirable since large amount of human food are used thereby causing staple food shortages amidst global hunger and famine. This makes Agro-wastes such as BP the most reliable source of feed stocks.

In Malaysia, the major agro-waste being generated is Palm Oil Mill Effluent (POME) and such remained the most researched byproducts from industrial activities. Several value added products are being produced from it but effective management remained daunting due to efficacy and efficiency of conversion. However, BP as one of highly cultivated fruit in Malaysia (Ratule *et al.*, 2007) appears to generate solid wastes which may be managed efficiently with the potential in producing bio-products by biotechnology approach, hence offsetting huge costs associated with

POME management and its associated environmental implications. This study therefore aims at analyzing the biotechnological potentials of BP in bio-ethanol, animal feed protein enrichment, enzyme, bio-methane production and other industrially important products.

Raw material: Banana is a tropical fruit grown in over 122 countries worldwide. Until 2004, the cultivated area of 3.8 million hectares and a total production of 56.4 million metric tones of the fruit were produced ranking it fourth behind rice, corn and milk (John and Marchal, 1995; Chai *et al.*, 2004; Arumugam and Manikandan, 2011). In Malaysia however, banana is the second most widely cultivated fruit and occupies 27,500 ha out of 250,000 ha dedicated for fruit cultivation thereby constituting 11.0% of the total fruit area in the country. A total of 530,000 metric tones of the fruit were produced through small farm holders and large scale farmers (Chai *et al.*, 2004; Husain and William, 2010). The top ten world producers of banana are presented in Table 1. The distributions showed that Asian countries (India, Philippines, China, Indonesia and Thailand) had more productions while Latin America countries (Ecuador, Brazil, Columbia, Costa Rica, Mexico) were seconding. Banana wastes (peel) contained important constituents (Table 2), these qualifies it for several biotechnological processes involving the use of chemical and biological systems capable of transforming lignocellulosic materials to value added products. Carbohydrate composition of banana peels are presented in Table 3.

Agro-residues are important raw materials used for animal feeding, domestic heat generation, compost and firing of boilers. Valuable portions of BP contained promising constituents based on varieties and geographic divide and climatic conditions in the producing regions of the world (Kim and Dale, 2004). Annually, large amount of agro related wastes are disposed of indiscriminately into the water bodies, left to rotten constituting environmental problems and spread of diseases. Similarly large amount of vegetable wastes are recorded in developing countries due to poor handling and inefficient transportation. In India for example, the estimated fruit and vegetable production was 150 million tones and the total waste generated was 50 million tones which amount to one third of annual production. Out of this high value, about 6.5 metric tones is BP (FAO, 2009). Common practices in high banana producing countries is to leave the peels to decay as compost on farm lands or uncontrolled dumping in landfills where it rotten out without meaningful reuse (Arumugam and Manikandan, 2011). Several countries have banned open air dumping of solid waste and this policy is a common practice in many countries in Europe, Americas and Asia countries (Nibedita *et al.*, 2011).

Table 1: Top ten banana producing nations

Country	Production (in million metric tons)
India	26.2
Philippines	9.0
China	8.2
Ecuador	7.6
Brazil	7.2
Indonesia	6.3
Mexico	2.2
Costa Rica	2.1
Colombia	2.0
Thailand	1.5
Worldwide	95.6

Source: Food and Agricultural Organization of the United Nations (FAO, 2009)

Table 2: Minerals and nutritional composition of *Musa sapientum* peel

Items	Quantity	Reference
Element concentration (mg g^{-1})		
Potassium	78.10	Anhwange *et al*. (2009), Debabandya *et al*. (2010)
Calcium	19.20	Anhwange *et al*. (2009), Debabandya *et al*. (2010)
Sodium	24.30	Anhwange *et al*. (2009), Debabandya *et al*. (2010)
Iron	0.61	Anhwange *et al*. (2009), Debabandya *et al*. (2010)
Manganese	76.20	Anhwange *et al*. (2009), Debabandya *et al*. (2010)
Bromine	0.04	Anhwange *et al*. (2009), Debabandya *et al*. (2010)
Rubidium	0.21	Anhwange *et al*. (2009), Debabandya *et al*. (2010)
Strontium	0.03	Anhwange *et al*. (2009), Debabandya *et al*. (2010)
Zirconium	0.02	Anhwange *et al*. (2009), Debabandya *et al*. (2010)
Niobium	0.02	
Phosphorous	18.30	Thomas *et al*. (2002)
Magnesium	17.95	Thomas *et al*. (2002)
Copper	0.03	Thomas *et al*. (2002)
Zinc	0.39	Thomas *et al*. (2002)
Sulphur	12.00	Essien *et al*. (2005)
Ascorbic acid	18.00	Essien *et al*. (2005)
Parameter concentration (%)		
Moisture	78.90	Karthikeyan and Sivakumar (2010), Essien *et al*. (2005)
Ash	8.50	Anhwange *et al*. (2009), Xue *et al*. (2011)
Organic matter	91.50	Anhwange *et al*. (2009)
Protein	8.10	Karthikeyan and Sivakumar (2010), Essien *et al*. (2005), Xue *et al*. (2011)
Crude lipid	12.10	Karthikeyan and Sivakumar (2010), Essien *et al*. (2005), Xue *et al*. (2011)
Carbohydrate	59.00	Karthikeyan and Sivakumar (2010), Xue *et al*. (2011)
Crude fibre	8.20	Karthikeyan and Sivakumar (2010), Essien *et al*. (2005), Xue *et al*. (2011)
Dry matter	14.08	Karthikeyan and Sivakumar (2010), Anhwange *et al*. (2009)
Hydrogen cyanide	1.33	Anhwange *et al*. (2009)
Oxalate	0.51	Anhwange *et al*. (2009)
Phytate	0.28	Anhwange *et al*. (2009)
Saponins	24.00	Anhwange *et al*. (2009)
Amino acid score (mg L^{-1})		
Thr	89.4	Thomas *et al*. (2002)
Val	112.1	Thomas *et al*. (2002)
Met+Cys	86.1	Thomas *et al*. (2002)
Ile	90.4	Thomas *et al*. (2002)
Leu	71.0	Thomas *et al*. (2002)
Tyr+Phe	72.3	Thomas *et al*. (2002)
His	106.6	Thomas *et al*. (2002)
Lys	37.1	Thomas *et al*. (2002)
Trp	69.0	Thomas *et al*. (2002)

Trp: Tryptophan, Val: Valine, Met: Methionine, Ile: Isoleucine, Leu: Leucine, Thr: Threonine, Cys: Cysteine, Tyr: Tyrosine, Phe: Phenylalanine, His: Histidine, Lys: Lysine

Banana peels contains several important micro and macronutrients as presented in Table 2. The composition of almost all essential amino acid (leucine, valine phenylalanine and threonine) at levels above Food and Agriculture Organization (FAO) standard as well as crude fat and polyunsaturated fatty acids (particularly linoleic and α-linolenic acid) makes it an important basal

Table 3: Carbohydrate composition of banana peels

Carbon source	Concentration	Reference
Glucose	2.4 nmol L^{-1}	Debabandya *et al.* (2010)
Fructose	6.2 nmol L^{-1}	Debabandya *et al.* (2010)
Sucrose	2.6 nmol L^{-1}	Debabandya *et al.* (2010)
Maltose	0 nmol L^{-1}	Debabandya *et al.* (2010)
Starch	1.2 nmol L^{-1}	Debabandya *et al.* (2010)
Cellulose	8.4 nmol L^{-1}	Debabandya *et al.* (2010)
Total sugar	29 nmol L^{-1}	Debabandya *et al.* (2010)
Lignin	6-12%	Debabandya *et al.* (2010)
Pectin	10-21%	Debabandya *et al.* (2010)
Hemicelluloses	6.4-9.4%	Debabandya *et al.* (2010)

material included in animal feed. Upon ripening, several degradative reactions caused by endogenous enzymes are believed to affect starch and hemicelluloses composition of the peels and this explains its elevated sugar content (Thomas *et al.*, 2007; Debabandya *et al.*, 2010). This chemical conversion process makes biodegradation of BP easy when needed for other biotechnological use. Moreover, pectin quality of the peels is promising having contained important simple sugars (glucose, rhamnose, arabinose and xylose) at appreciable levels (Thomas *et al.*, 2002).

Lignocelluloses are a renewable organic material contained by all plants (including BP). They consist of three important components: cellulose, hemicelluloses and lignin. Certain agro-residues may contain trace amounts of ash, proteins and pectin (Dashtban *et al.*, 2009). Cellulose on the other hand is a linear biopolymer of anhydroglucopyranose molecules, connected by **β**-1, 4 glycosidic bonds. The coupling of adjacent cellulose chains by hydrogen bonds, hydrophobic interactions and van Waal's forces leads to a parallel alignment of crystal-line structures known as micro fibril (Zhang *et al.*, 2006). Moreover, hemicelluloses, are heterogeneous polymers of five carbon, six carbon and sugar acids. Composition of hemicelluloses varies in nature depending on plant source (Saha, 2000, 2003). Lignin is a heterogeneous polymer in lignocellulosic materials and generally contains three aromatic alcohols (coniferyl alcohol, sinapyl and p-coumaryl). Lignin acts as a barrier for enzymes actions due to its linkage to both hemicelluloses and cellulose preventing lignocellulolytic enzymes from interior structure of lignocelluloses. Hence it is the most difficult component of lignocellulosic material to degrade (Sanchez, 2009; Himmel *et al.*, 2007).

Pretreatment: One of the most important activities performed in bioconversion of lignocellulosic materials is pretreatment. This operation is necessary in order to break strong C-C bonds that exist between the natural components. Therefore, fulfilling the purpose of all treatment methods which is to disintegrate complex biopolymers which will eventually expose them to chemical and biological attacks. The pretreatment is done to break lignocellulosic matrix which reduce the degree of crystallinity of the cellulose and increase the fraction of amorphous cellulose suitable for enzymatic and microbial attack (Sanchez and Cardona, 2008). Similarly, pretreatment processes assist in positive changes in the macro, micro and subatomic structures of BP thereby freeing up simple and compound sugars which are more accessible for effective bioconversion. For a pretreatment process to be effective there must be: (1) formation of monomeric sugars directly or subsequently by hydrolysis, (2) avoidance and/or degradation of fermentable sugars, (3) limits formation of inhibitory products, (4) reduction in energy demands and (5) economical (Nibedita *et al.*, 2011). The four fundamental pretreatment methods usually adopted for BP are: physical, chemical, physicochemical and biological. In other instances more than one pretreatment technique may be employed depending upon the kind of end products targeted microorganisms involved.

Chemical pretreatment is the most adopted technique for preparing BP for biotechnological processes. The sequential use of acid and alkaline (NaOH and HCl) have been reported to give satisfactory results in producing citric acid, single cell protein and enzymes (Ponnuswamy *et al.*, 2011; Karthikeyan and Sivakumar, 2010; Essien *et al.*, 2005). Essien *et al.* (2005) also included heat processing by subjecting the substrate to heating at 121°C for 10 min claiming the substrate perform better as compared to the agar type which was heated at same temperature for 15 min. Similarly, chemical pretreatment (NaOH and HCl) was done using swelling agent by refluxing ground peels at 121°C for 60 min and substrate washed thoroughly before drying (Yabaya and Ado, 2008).

Hydrothermal pretreatment was adopted by Oberio *et al.* (2011) to produce bio-ethanol from BP. this method, generally entails size reduction of BP, conditioning followed by continuous mixing with superheated water (180-200°C) for 15 min in order to destroy protecting lignin structure and make cellulose available for enzymes and microbial attack. Through this method, 28.2 g L^{-1} and 2.3 g L^{-1} h^{-1} ethanol concentration and productivity were recorded respectively as the highest values reported in recent times. Xue *et al.* (2011) carried out dilute acid pretreatment (1% (v/v) dilute sulfuric acid at 120°C for 20 min) on powdered BP to produce glutathione. A high Dry Cell Weight of 7.68 g L^{-1} and glutathione yield of 111.33 mg L^{-1} was reported with the initial sugar concentration of 20 g L^{-1} in the hydrolyzate of banana peels. Arumugam and Manikandan (2011) compared acid treatment with liquid hot water pretreatment. Dilute acid pretreatment significantly increased the sugar release by nearly 20% over the liquid hot water. Same trend was reported by Naresh *et al.* (2005) for release of fermentable sugars from BP and Kinnow waste. According to Aden *et al.* (2002) the main advantage of dilute acid pretreatment related to other pretreatment methods is the higher recovery of sugars derived from hemicellulose. The dilute acid pretreatment has the advantage of not only solubilizing hemicelluloses but also converting solubilized hemicelluloses to fermentable sugars and thus, eliminates or reduces the need for use of hemicellulase enzymes mixtures (Nigam, 2002).

Bioprocess techniques: Biotechnological processes involving cultivation of microbes on BP can be generally classified into two namely: Submerge state fermentation (SmF) and Solid State Fermentation (SSF). Substrates (BP) in SmF can be used as sole carbon source, co-substrate, part of mixed fruit peels or as hydrolysates form of BP. Solid state on the other hand can be such that BP is used as complex carbon source or as co-substrates (as inert solid support). Similarly, SSF can involve monoculture or co-culture of more than one microbial strain. The uses of the substrate mostly depend on the type, yield and economies surrounding the whole processes and product.

Application of BP in SmF: Numerous biotechnological products have been produced from BP and these include cellullolytic and non cellulolytic enzymes, bio-ethanol, Single Cell Protein (SCP), biogas etc. (Yabaya and Ado, 2008; Essien *et al.*, 2005; Ravi *et al.*, 2011; Enwefa, 1991; Nirmala *et al.*, 1996; Xue *et al.*, 2011). Table 4 shows some examples of bio-products from BP in SmF.

Single Cell Protein (SCP) or bio-protein remained one of the products of interest made from BP. Several liquid state efficient microorganisms (yeast, bacteria and filamentous fungi) have been employed. They included lignolytic and non-lignolytic fungi, highly flocculent, thermo-and osmo-tolerant yeast strains which produce several hydrolytic enzymes capable of degrading the celluloses, lignin and hemicelluloses of the BP after pretreatment operations. Essien *et al.* (2005) carried out

Table 4: Bio-products produced from BP by SmF

Products	Microbe cultivated	Reference
Mycelial protein production	*Aspergillus niger, Trichoderma harzianum, Saccharomyces uvarum, Aspergillus fumigatus, Mucor hiemalis*	Yabaya and Ado (2008), Ravi *et al.* (2011), Essien *et al.* (2005)
Ethanol production	*Saccharomyces cerevisiae* R-8, *S. cerevisiae* T-7 and *S. cerevisiae* R-2, *Debaryomyces hansenii* B-2 and *Saccharomyces kluyveri* K-6, *Saccharomyces uvarum, Saccharomyces cerevisiae*	Brooks (2008), Joshi *et al.* (2001), Aarti and Anita (2010), Manikandan *et al.* (2008) Tork *et al.* (2009)
Glutathione	*Candida utilis* SZU 07-01	Xue *et al.* (2011)
Biogas (Bio-methane)		Nirmala *et al.* (1996)
Enzyme	*Bacillus subtilis* MTCC 441, *Rhizopus microsporous*	Bhat *et al.* (2010a, b), Vijayaraghavan *et al.* (2011)

fermentation on BP by preparing Banana Peel Agar (BPA) comprising Banana peel extract, Agar powder and Distilled water (200 g, 15 g, 1000 mL) at this order respectively. The control was Malt Extract Agar (MEA). Biomass growth on both MEA and BPA was insignificant; however, MEA shows promising potential of BP in supporting protein enriched biomass for cattle feed protein enrichment. Ravi *et al.* (2011) produced bio-protein from BP using *Trichoderma harzianum* studying the effect of different carbon and nitrogen sources. Sucrose gave the best result in biomass yield (961.57 mg) and protein synthesis (0.73 g L^{-1}) while sodium nitrate was the best nitrogen source with 970.53 mg of biomass and 0.78 g L^{-1} protein production. Similarly, the cultivation of *Saccharomyces uvarum* on BP at different concentration (1.25-10% w/v) with ammonium sulphate as nitrogen source produced impressive biomass concentration, crude protein and cell protein (4.98, 0.89 and 2.90 g L^{-1}), respectively. High osmotic and sugar effects were opined to affect biomass yield at higher BP concentration (Enwefa, 1991). It is worthy of mention that BP is capable of supporting microbial growth with little supplementation.

The hydrolysis of BP chemically breakdown the hemicelluloses yielding monomeric sugars (xylose, glucose, mannose, arabinose, galactose) and its pentosan component contains mainly D-xylose and arabinose. BP hydrolysate however, may also contain toxic substances (depending upon the type of hydrolysis) which may cause lyses effects on fermentative and non-fermentative micro-organisms. Acidic and alkaline treatment as well as other pre-treatment techniques could be adopted to overcome these inhibitory effects (Ogier *et al.*, 1999; Somda *et al.*, 2011a).

Enzyme production from agro-wastes has been widely researched with promising results signaling their possibility of taking over from food based (e.g., use of corn to produce amylase) enzyme production which has been advocated against in many quarters. Bhat *et al.* (2010a) conducted two intensive researches producing α-amylase by using strains of *Bacillus subtilis* (MTCC 441). In one of the research, BP was used as sole carbon source after screening studies was conducted among various carbon and nitrogen sources by Central Composite Design (CCD). Further optimization study conducted by Artificial Neural Network (ANN) showed close relationship between predicted (1398.00 U mL^{-1}) and experimental values (1545.09 U mL^{-1}) (Bhat *et al.* (2010a). In the second investigation on *Bacillus subtilis* by same author, BP and corn pitch were utilized as substrates for α-amylase production. Enzyme production was 1799 U mL^{-1} for BP and 671 U mL^{-1} for corn pith. Further increase in enzyme activity was recorded after optimization studies by Taguchi method where BP gave 1580 and 530.32 U mL^{-1} activity was recorded for corn pith (Bhat *et al.*, 2010b).

Intensive research on BP hydrolysate is still at infancy but few researches conducted showed it's potential for bio-ethanol and glutathione production. Arumugam and Manikandan (2011)

conducted intensive investigation on BP hydrolysate for bio-ethanol production adopting dilute acid pretreatment and saccharification techniques. Dilute sulphuric acid was used for the former and α-amylase and gluco-amylase enzymes from *Bacillus subtilis* and *Aspergillus niger* were used for the latter. These pre-treatments released enough sugar for bio-ethanol production yielding 8.66% w/w when liquid hot water pre-treatment was combined with enzyme saccharification, whereas 13.84% w/w was recorded for combined dilute acid pre-treatment and enzyme saccharification. Similarly, Xue *et al.* (2011) conducted intensive study on BP for glutathione production by *Candida utilis* (SZU 01-01). In his findings, 85.69 mg L^{-1} of enzyme activity were recorded at initial stage while upon full media optimization, the production increased to 154.32 mg L^{-1}.

Application of BP in solid state fermentation: Solid State Fermentation (SSF) is an excellent and efficient biotechnological approach capable of producing important industrial products from agro-wastes which were previously causing environmental concerns. In recent times, there has been a resurgent interest in the adoption of SSF as a more robust approach in producing second generation bio-products from agricultural and non-agricultural waste products due to its many advantages over SmF (Ghildyal *et al.*, 1985; Ashok, 1991). Several SSF investigations have been conducted regarding BP where it was utilized as main carbon source while in other applications; it was used as co-substrates to augment fermentation systems for efficient bio-product synthesis (Johann *et al.*, 2006, 2007; Aarti and Anita, 2010; Arumugam and Manikandan, 2011; Ponnuswamy *et al.*, 2011; Omojasola and Jilani, 2009; Brooks, 2008).

Enzymes production from BP has been of interest to most researchers due mainly to its monomeric (simple) sugar content which are easily metabolizable by filamentous fungi, yeast and bacterial. A-amylase production potential of BP by various strains of *Bacillus subtilis* has been of interest to most investigators. In order to produce α-amylase from BP, Noreen *et al.* (2002) used yeast extract, corn steep liquor, Sodium Dodecyl Sulphate (SDS) and Tween-80 as supplements and enhancers respectively. An insignificant concentration of 0.1% yeast extract, 1% corn steep liquor, 0.15% SOS and 0.1% Tween-80 at pH 7 gave maximum enzyme yield of 10.25 U mL^{-1}. Upon characterization of the enzyme, maximum activity (12.18 U mL^{-1}) was recorded at 60°C and pH 6 with 3 hours stability under these conditions.

Ponnuswamy *et al.* (2011) also produced same enzyme from *Penicillium* sp. Utilizing BP as the substrate without any enrichment with mineral salts or other carbon sources throughout the investigation. His results showed that more enzymes were produced at SSF when compares to SmF productivity. However, the optimum enzyme activity was at pH 7 and 50°C being optimum temperature with 13% loss of activity after 30 min. In the case of Shaista *et al.* (2003) investigation on α-amylase, an effect of nitrogen (peptone) supplementation was tested. Results obtained showed 0.2% nitrogen augmentation for optimum enzyme activity (9.06 IU mL^{-1} min^{-1}) for 24 h at pH 7 and 35°C as optimum conditions. Johann *et al.* (2006) carried out investigations on laccase synthesis using BP as sole substrate adopting white rot fungus. A maximum activity of 1570 U L^{-1} was recorded signaling the potential of the substrate in supporting extracellular production of the enzyme. To test for the degrading capacity of the enzyme, in vitro decolouration of two structurally different dyes such as the anthraquinonic dye Remazol Brilliant Blue R (RBBR) and the triphenylmethane dye Methyl Green (MG) was carried out. RBBR was decolourised about 57% in 4 h, whereas MG presented a lower decolouration rate of 40.9% in 4 h. The researchers then opined that RBBR decolouration was considerably higher than that obtainable from commercial laccase (23.2% in 4 h), however, MG decolouration of 46% in 4 h was not so different from its

commercial counterpart. Further more, the SEM microphotographs of BP with and without fungus showed effective adherence of the fungi to the solid support. The investigators however concluded that hydrophobicity and surface charge are most important characteristics that influence adhesive behavior of filamentous fungi to the solid support.

Citric acid as one of the industrially important product has been produced on different substrates by different methods with varied in production and product performance (Sauer *et al*., 2008). Several agricultural residues such as grape pomace, apple pomace, banana waste, sugar beet, okara, jack fruit carpel and kiwi fruit peel have found their utilization via bioconversion processes (Angumeenal and Venkappayya, 2005; Hang and Woodams, 1995; Khare *et al*., 1995; Vandenberghe *et al*., 2000; Sassi *et al*., 1991; Shojaosadati and Babeipour, 2002).

Based on the success of other workers, Karthikeyan and Sivakumar (2010) then conducted an intensive research to investigate citric acid potentials of BP. Table 5 presented Bio-products produced from BP by SSF. Important parameters that affect citric acid production such as moisture content, temperature, pH, inoculum level and incubation time were investigated. Optimum temperature was 28°C while the moisture content was 70%, initial pH 3, 10^8 spores mL^{-1} and 72 h incubation were other optimum conditions suitable for maximum (180 g kg^{-1}) citric acid production by *Aspergillus niger*.

Microbial strains mostly cultivated on BP: In recent years, large numbers of micro-organisms which include bacteria, yeasts and fungi have been cultivated on BP. However, none of these strains has enjoyed universal adoption among investigators. Yeast cells are wide adopted for bio-ethanol; filamentous fungi are preferred for protein enriched animal feed while bacteria cells were commonly used for enzyme production. A list of different micro-organisms cultivated on the BP for varying purpose by different researchers is given in Table 6.

Table 5: Bio-products produced from BP by SSF

Products	Microbes	Reference
α-Amylase	*Bacillus subtilis*, *Penicillium* sp., *Bacillus subtilis* (CBTK 106)	Shaista *et al*. (2003), Noreen *et al*. (2002), Ponnuswamy *et al*. (2011)
Laccase	*Trametes pubescens* (CBS 696.94)	Johann *et al*. (2007)
Citric acid	*Aspergillus niger*	Karthikeyan and Sivakumar (2010)

Table 6: Microbial cells cultivated on BP

Microorganism	Reference
Bacillus subtilis, *B. subtilis* MTCC 441, *B. subtilis* (CBTK 106)	Shaista *et al*. (2003), Noreen *et al*. (2002), Bhat *et al*. (2010a, b)
Penicillium sp.	Ponnuswamy *et al*. (2011)
Trametes pubescens (CBS 696.94)	Johann *et al*. (2007)
Aspergillus niger	Karthikeyan and Sivakumar (2010), Yabaya and Ado (2008)
Trichoderma harzianum	Ravi *et al*. (2011)
Saccharomyces uvarum	Enwefa (1991), Aarti and Anita (2010)
Aspergillus fumigates	Essien *et al*. (2005)
Mucor hiemalis	Essien *et al*. (2005)
Saccharomyces cerevisiae R-8, *S. cerevisiae* T-7 and *S. cerevisiae* R-2, *Saccharomyces kluyveri* K-6	Brooks (2008)
Debaryomyces hansenii B-2	Brooks (2008)
Candida utilis SZU 07-01	Xue *et al*. (2011)

Other biotechnologically derived products from BP: Nirmala *et al.* (1996) carried out an investigation on the potentiality of using BP as a substrate for biogas production. In the research, narrow-mouth aspirator bottles were used as digesters capable of maintaining temperature at 37°C at laboratory level for the whole conversion period. Each digester composed of 1.6-1.8 L of active cattle dung slurry (10% w/v) which was added as inoculum (starter cutlture) to each digester. Upon achieving 40% methane, cattle dung was gradually replaced by chopped BP, BP powder or pineapple waste. Biogas produced in the digester was measured by downward displacement of saline water. Results obtained showed a decrease in methane production after 20 days while the production was stable between 29 and 40 days of bio-methanation. In comparison, chopped BP produced more biogas among all the treatments but biogas production from other substrates was more stable over same period of conversion.

CONCLUSION

Conclusively, the utilization of BP in biotechnological process has cut across wide range of products which have potential for industrial application and commercialization. However, the economic viability depends solely on efficient use of the agro-waste. The use of raw BP may have been successful as animal feed but this has not been achieved yet with bio-conversion with improved protein content. The seasonal harvesting of banana plant remained an impediment to constant availability of the feedstock for bio-ethanol production thereby damping its viability for industrial production of the renewable bio-fuel. In addition, the present environmental legislation in most developing countries is not efficient for effective collection of BP residue from major producers. If such situation prevails for long it may remain a lifetime challenge for commercialization of several bio-products from the waste.

Current bio-processing techniques look incapable to produce commercial values of secondary products from BP due to environmental implications of effluents that may be generated due to chemical pretreatments of wastes before conversion. Hence, more environmental friendly pre-treatment technologies capable of breaking down all the complex components of BP without production of inhibitory compounds are needed.

Several available lignin degrading and edible bacidiomycetes have not been fully explored for their potentials in producing protein enriched animal feed from BP. Therefore, more research is needed in this area to ascertain their potentiality for commercialization. In addition, cultivation of edible mushroom on pretreated BP should be focused to further reduce overdependence on animal protein.

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