Journal of Scientific & Industrial Research
Vol. 69, May 2010, pp. 323-329

Banana and its by-product utilisation: an overview

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Received 08 July 2009; revised 16 February 2010; accepted 22 February 2010

Banana serves as an ideal and low cost food source for developing countries where most of the population rely mostly on bananas for food. Banana plant parts are useful as insecticide, antioxidant, colour absorber, in preparation of various functional foods, wine, alcohol, biogas, cattle feed etc. This review discusses usefulness of banana fruits, peel, leaves, pseudostem, sheath, pith and male bud, and prospects of using these materials in industry.

Keywords: Banana, Banana male bud, Banana peel, Banana pith, Banana pseudostem, Banana sheath

Introduction

Banana is the second largest produced fruit after citrus, contributing about 16% of the world's total fruit production[1] (Table 1). India is largest producer of banana, contributing to 27% of world's banana production. Incidentally, production of banana in India has surpassed mango production. In India[2], Tamil Nadu is the leading producer of banana, followed by Maharashtra (Table 2).

Biological Evolution and Nomenclature of Banana Plant

Banana is one of the most widely grown tropical fruits, cultivated over 130 countries, along the tropics and subtropic of Capricorn. Edible bananas are derived from *Australimusa* and *Eumusa* series, which have different origins from same genus. Most of the edible bananas are either derived solely from *Musa accuminata* or are hybrid between two wild diploid species, *M. acuminata Colla* and *M. balbisiana Colla*; which contributed to A and B genomes, respectively. Plant has an origin from India and eastern Asian region (Malaysia and Japan) and some varieties are found to be genetically linked with some species from Africa. Polyploidy and hybridization of A and B genomes has given rise to diploid (AA, AB, BB), triploid (AAA, AAB, ABB, BBB) and tetraploid (AAAA, AAAB, ABBB, AABB) bananas. Various other varieties also exist naturally or developed by hybridisation of these genomes, which have different nomenclatures[3,4]. Three common species of Musa (*M. cavendishii*, *M. paradisiaca* and *M. sapientum)* are widely grown in the world. *M. cavendishii,* pure triploid acuminate (AAA group) known as dessert banana, is sweeter and less starchy than *M. paradisiaca*, while *M. sapientum,* known as true banana, is usually eaten raw when fully mature. Both *M. paradisiaca* and *M. sapientum* belong to AAB group [5] and are characterized by higher starch concentration compared to pure acuminate group. Cooking banana falls under ABB (*Pisang Awak, Bluggoe*) and BBB (*Saba* banana) group and has predominant *M. balbisuana* genes[4]. There is a great diversity of dessert bananas in terms of plant stature, fruit size and colour (yellow, green, red, and orange), namely *M. nana Lour* for Dwarf Cavendish, *M. rubra* Firming von Wall for red banana, *M. corniculata Lour* for horn plantain, and many others[4,6]. Most productive cultivars[7] are Cavendish bananas and giant French plantains (productivity value, >30 t/ha/yr). Out of over 50 varieties of banana cultivated across India, 20 are commonly grown (Table 2). This paper reviews dessert bananas, belonging to both AAA and AAB groups.

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Table 1— Production statistics (2007) of some major fruits of World[1]

Fruits	Production, tonnes	Share of total fruit production, %
Apple	64255520	12.86
Banana	81263358	16.26
Citrus (total)	115650545	23.14
Coconut	54716444	10.95
Grape	66271676	13.26
Orange	63906064	12.79
Lemon and lime	13032388	2.61
Peaches and nectarines	17457087	3.49
Pear	20105683	4.02
Plantain	34444795	6.89
World fruit production excluding melon	499711349	-

Table 2— Statewise banana production in India during 2007-08[2]

State	Production quantity, tonnes	Production share,%	Major varieties grown
Andhra Pradesh	2254.3	9.7	Dwarf Cavendish, Robusta, Poovan, Rasthali, Chakkarekeli, Thellachakkarekeli, Karpoora Poovan, Monthan, Amritpant
Assam	610.9	2.6	Jahaji (Dwarf Cavendish), Chini Champa, Malbhog, Borjahaji (Robusta), Honda, Manjahaji, Chinia, Kanchkol, Bhimkol, Jatikol, Digjowa, Kulpait, Bharatmoni
Bihar	1329.4	5.7	Dwarf Cavendish, Alpan, Chinia, Chini Champa, Malbhig, Muthia, Kothia, Gauria Thellachakkarekeli, Karpoora Poovan, Monthan, Amritpant
Gujarat	3157.7	13.6	Dwarf Cavendish, Srimanti, Mahalaxmi, Mahabanana, Locatan, Harichal G-9, Basrai
Jharkhand	51.6	0.2	Basrai, Singapuri
Karnataka	1513.3	6.5	G-9, Elaki, Dwarf Cavendish, Robusta, Nendran, Poovan, Monthan, Elakkibale
Kerala	493.9	2.1	Nendran, Palayankodan, Rasthali, Monthan, Red Banana, Robusta
Madhya Pradesh	788.2	3.4	Basrai
Maharastra	4962.9	21.4	Grand Naine, Dwarf Cavendish, Basrai, Robusta, Lal Velchi, Safed Velchi and Nendran
Orissa	297.1	1.3	Dwarf Cavendish, Robusta, Champa Patakapura (Rasthali)
Tamil Nadu	6116.5	26.4	G-9, Robusta, Virupakshi, Red Banana, Povan, Elakki, Rastali, Robusta, Karpooravalli, Sakkai, Matti, Red Banana, Peyan
West Bengal	892.2	3.8	Dwarf Cavendish, Mortaman, Champa,Amrit Sagar, Singapuri, Chini Champa, Giant Governor, Singapuri
Others	736.8	3.2	-

Banana Fruit

Banana is highly nutritious and easily digestible than many other fruits. Digestion time[8] of banana fruit is less (105 min) than apple (210 min). Bananas are popular for aroma, texture and easy to peel and eat, besides rich in potassium and calcium and low in sodium content[9-12] (Table 3).

Moisture Content

Moisture content in pulp increases during ripening process due to respiratory breakdown of starches into sugar and migration of moisture from peel to pulp[13]. However, in AAB variety, moisture content could be 68% due to presence of starchier balbisiana genome and incomplete conversion of starch into sugar (Table 3); even when banana is fully ripe, still some starch is left in pulp tissue[3].

Carbohydrates

During ripening process, starch is converted into sugar, through enzymatic breakdown process[14]. In AAB group, starch content declines from 20-30% to 1-2%, but starch amount could be as high as 11% depending on variety. Sugar content of fully mature banana is quite high that makes it an ideal substrate for wine making[15]. Carbohydrate type in banana is resistant starch and non-starch polysaccharides, which have low glycemic index or low digestibility[16]. This property makes it an excellent

Table 3— Pulp and peel composition (fresh weight basis) of dessert bananas (AAA and AAB variety)[9-12,20]

Composition	Pulp		Peel
	AAA	AAB	
Moisture, %	73.8±0.5	68.5±0.6	83.5
Vitamin A, µgRAE/100g	8.2±0.6	12.4±1.0	-
β-carotene, µg/100g	55.68±14.1	96.87±30.7	-
Vitamin C, mg/100g	4.5±0.3	12.7±0.7	-
Soluble solids, °Brix	20.5±0.4	17.9±0.7	-
Proteins, %	2.2	-	1.8
Fat*, %	0.1	-	1.7*
Glucose, %	5.0	-	2.4
Fructose, %	6.5	-	6.2
Sucrose, %	12	-	2.6
Maltose, %	0	-	0
Starch, %	10	-	1.2
Cellulose, %	9.1	-	8.4
Total Sugar, %	40	-	29
Potassium (K), mg/100g	318.95±28.2	342.3±67.7	78.1±6.58*
Phosphorus (P), mg/100g	21.7±2.4	26.3±2.0	
Calcium (Ca), mg/100g	4.9±1.06	7.2±1.21	19.2±0.00
Magnesium(Mg), mg/100g	30.8±4.4	39.4±5.0	
Sodium (Na), mg/100g	17.35±3.68	16.0±8.22	24.3±0.12
Iron (Fe), mg/100g	0.83±0.19	0.75±0.22	0.61±0.22
Manganese (Mn), mg/100g	0.20±0.08	0.67±0.41	76.20±00
Zinc (Zn), mg/100g	0.23±0.05	0.39±0.32	-
Copper (Cu), mg/100g	0.26±0.18	0.26±0.14	-
Boron (B), mg/100g	0.14±0.03	0.16±0.06	-
Bromine (Br), mg/100g	-	-	0.04±0.00
Rubidium (Rb), mg/100g	-	-	0.21±0.05
Stronsium (Sr), mg/100g	-	-	0.03±0.01
Zirconium (Zr), mg/100g	-	-	0.02±0.00
Niobium (Nb), mg/100g	-	-	0.02±0.00

*dry weight basis

ingredient for different functional and convenience foods like cookies[17] and chips[18].

Proteins

Bananas protein (1-2.5%), depending on genome type, variety, altitude, and climate[19,20], increases over ripening process[21] (3.8-4.2%).

Fat

Fat content in pulp remains almost constant (1%) during ripening process. Peel contains lipid (2.2-10.9 %) and is rich in polyunsaturated fatty acids, particularly linoleic acid and α-linolenic acid[22].

Pectins

Ripe pulp contains pectin (0.7-1.2%). During ripening, insoluble protopectin is converted into soluble pectin that causes loosening of cell wall and texture degradation leading to softening of fruit[23,24]. Gel forming ability of pectin has a varied use as additives in jams, jellies and marmalades, as thickeners, texturizers, emulsifiers, fat or sugar replacer[25].

Phenolic Compounds and Pigments

Bananas are rich in phenolic compounds and flavanoids, which have antioxidant properties. Astringent taste of unripe banana is due to phenolic compounds. Bananas are rich in dopamine, an antioxidant[26,27]. Browning is caused by polyphenol oxidase, monophenol monooxygenase and o-diphenoloxidase activities on dopamine, which produces tannins resulting in brown spots on peel. When stored below 13°C, brown patches develop on peel[28]. Polyphenol content (24.4-72.2 GAE/100 g) for Cavendish banana, indicates high antioxidant activity[27].

Banana peel is green when fully mature, gradually turns yellow and in some cases brown spots are found. Similar changes also observed in pulp. Some amount of

Table 4— Chemical composition of different morphologic regions of banana plant[37,38]

	Pseudo stem	Petioles/ mid rib	Leaf blade	Floral stalk	Leaf sheaths	Rachis
Glucose	74.0†	68.1†	60.0†	79.8†	74.2†	31.8†
Xylose	13.1†	23.6†	17.5†	9.3†	13.8†	14.0†
Galactose	2.5†	1.1†	3.8†	2.9†	2.2†	1.7†
Arabinose	9.1†	4.9†	15.5†	5.1 †	7.5†	4.1†
Mannose	1.3†	1.5†	2.3†	2.2†	1.5†	2.9†
Rhamnose	-	0.8†	0.9†	0.7†	0.8†	0.7†
Lignin	12.0†	18.0†	24.3†	10.7†	13.3†	10.5†
Cellulose	34-40.0†	31.0†	20.4†	15.7†	37.3†	31.0†
Holocellulose	60-65†	62.7†	32.1†	20.3†	49.7†	37.9†
Ash	14.0†	11.6†	19.4†	26.1†	19.0†	26.8†
Potassium	33.4*	9.4*	11.6*	23.1*	21.4*	28.0*
Calcium	7.5*	32.3*	8.0*	0.6*	5.5*	0.6*
Magnesium	4.3*	2.9*	1.1*	0.5*	1.9*	0.3*
Silicon	2.7*	7.0*	24.9*	7.8*	2.7*	1.2*
Phosphorous	2.2*	0.7*	0.7*	0.7*	0.9*	1.7*
Pentosans	-	16.2†	12.1†	8.0†	12.4†	8.3†
Starch	-	0.4†	1.1†	26.3†	8.4†	1.4†
Proteins	-	1.6†	8.3†	3.2†	1.9†	2.0†

† Expressed in terms of % molar proportion; *Expressed in % ash basis

β-carotene (40-4960 µg/100g), found in pulp and peel of fruit, might explain colour changes from off white, yellow and, in some cases, orange colour of pulp[29,30]. But change in peel colour is largely due to degradation of chlorophyll or unmasking of carotenoids[31,32], rather than carotenoid synthesis.

Vitamins and Minerals

Pulp is rich in vitamin A, B-vitamins (thiamine, 40 µg; riboflavin, 70 µg; niacin, 610 µg; pantothenic acid, 280 µg; pyridoxine, 470 µg; folic acid, 23 µg) and ascorbic acid[33]. Potassium is most abundant mineral present in edible portion of banana, followed by magnesium, calcium, and phosphorus (Table 3). Amount of iron is high, whereas copper is found in very small quantity. Due to its nutritive value, processed banana when accompanied with some legume based products, can be served as excellent baby food and snack food[34].

Uses of Other Parts of Banana Plant

Musacea plants can be used to generate energy through decomposition[35], and used as good composting material[36]. Banana waste materials are rich in nutrients and minerals[37,38] (Table 4).

Banana Peel

Banana peel is a rich source of starch (3%), crude protein (6-9%), crude fat (3.8-11%)[24], total dietary fibre (43.2-49.7%), and polyunsaturated fatty acids, particularly linoleic acid and α-linolenic acid, pectin, essential amino acids (leucine, valine, phenylalanine and threonine), and micronutrients (K, P, Ca, Mg)[22]. Except for lysine, content of all essential amino acids are higher than FAO standard. Maturation of fruits involves, increase in soluble sugar, decrease in starch and hemicelluloses, and slight increase in protein and lipid content. Degradation of starch and hemicelluloses by endogenous enzymes may explain increase in soluble sugar content[22]. Skins can also be utilised for extraction of banana oil (amyl acetate)[11] that can be used for food flavouring. Banana peels are also a good source of lignin (6-12%), pectin (10-21%), cellulose (7.6-9.6%), hemicelluloses (6.4-9.4%) and galactouroninc acid. Pectin extracted from banana peel also contains glucose, galactose, arabinose, rhamnose, and xylose[24]. Micronutrients (Fe and Zn) were found in higher concentration in peels compared to pulps[39]. So, peels could be a good feed material for cattle and poultry[24,40-42]. Banana peel can also be used in wine[43], ethanol production[44-46], as substrate for biogas production[47] and as base material for pectin extraction. Peel ash can be used as fertilizer for banana plants and as source of alkali for soap production[48]. Ethanol extract of *M. sapientum* peels can be used as an inhibitor for mild steel corrosion[49]. Peel can also be used in wastewater treatment plants[50].

Banana Leaves and Sheaths

Leaves are used extensively for weaving baskets, mats, food wrapper for marketing and cooking, coverings over food, tablecloths, and plates for eating as well as cup for drinking soup. Old leaves are used in wrapping up banana bunches (bunch covers) for protection against bats and birds. Rural people use large leaves of triploid bananas as umbrella during rainy season[51]. Dried banana leaves are used as fuel, and substrate to grow oyster mushrooms[52]. In India (Orissa, West Bengal and Kerala), people use banana leaves for traditional ritual and rites and preparing special dishes by roasting or steaming ingredients wrapped in banana leaves. Traditionally, in banana growing areas of India and Sri Lanka, people take food on banana leaves. Banana leaves are also a good source of lignin (127 sa), which is higher than banana pseudostem (107 sa). Leaves can be given to ruminants with addition of some protein extract for better digestibility[53]. Waste materials from banana plant (leaf blade, floral stalk, leaf sheaths and rachis) are unsuitable for pulping due to relatively high amount of ash content (19-27%). Good amount of pentosans are present in petiole, leaf blade, and leaf sheaths. Protein content in leaf blade is substantial[37,38] and hence could be ideal for cattle feed.

Banana Pseudostem, Pith and Male Bud

Various products like chips, fig, ready to serve drink, flour, jam, confections, dehydrated slices, and pickles can be made from male bud, immature fruit and pseudo stem. Paper board, tissue paper, etc., can be prepared out of banana pseudo stem. Banana fibres can be used as natural sorbent, bio-remediation agent for bacteria in natural water purifier, for mushroom production, in handicrafts and textiles when mixed with paddy straw. It is also used in production of marine cordages, high quality paper cardboards, tea bags, string thread, high quality fabric material, paper for currency notes, and good rope for tying purposes. Fibres from pseudo stem, leaf sheath and rachis are used in making fibre based products. Pseudo stem fibre bundles have higher specific strength modulus and lower strain at break than leaf sheath and rachis fibre bundles, having values comparable to other lignocellulosic fibres. Banana fibre being a natural sorbent has high potential in absorbing spilled oils in refineries[51,52,54]. With fairly low amount of ash and lignin and high amount of holocellulose, pseudo stem and petioles are suitable for pulping in paper industry. Banana and banana pseudo stem contain pathogenesis-proteins[55] possessing antimicrobial properties. Lectins, found in banana plant tissues, can be effectively used for human consumption[56,57]. Pseudo stem can be recycled to be used as bio-fertilizer[58]. It contains good amount of cellulose and starch and can be used as cattle feed[53]. Outer covering of pseudostem is mostly cellulosic material while core or pith is rich in polysaccharides and other trace elements but lower in lignin content[37]. Waste banana pith can be used as colour absorbent in wastewater containing textile dyes[59-61]. Pith is used as food after boiling and addition of spices in many parts of India. Banana sheath (Composition: dry matter, 6.4; crude protein, 3.4; crude fibre, 31.4; cellulose, 34.6; hemicelluloses, 15.5; and lignin, 6%) can be a suitable feed for ruminant[62]. Floral stalk contain high amount of starch (26%) and can be used in pharmaceutical and food industry[37,38]. Glucose is abundant in most of the plant parts except for rachis. Sucrose can be obtained from banana through saccharification[63]. In Malaysia and India, male bud is cooked and consumed as vegetable[64,65]. Juice from male bud of banana provides remedy for stomach problems[52].

Conclusions

Whole banana plant is useful in food, feed, pharmaceutical, packaging, and many other industrial applications. In India, many of the social and religious ceremonies require whole banana tree, apart from leaves and fruits. Fruit of this plant is not only a rich source of carbohydrate, antioxidants, but also a good source of mineral, especially potassium and iron, an ideal food for weaning mother and infants. Peel is rich in vitamins, pectin, sugar, and lignin and can be used as cattle feed, base material for alcohol production, biogas production and for pectin extraction. Fibre obtained from banana pseudostem and sheath can be utilised as biodegradable binding ropes. Pith can be utilised as colour absorber and even as food when properly processed. Leaves are good lignocellulosic source and have varieties of uses from feed to wrapping materials for specialised food product and even as thatching material in banana growing places. Apart from starch recovered from plant, juice too has nutraceutical properties and has a potential use in pharmaceutical industry.

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