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By-Products and Value Addition of Banana: An Overview

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Abstract

Banana one of the most popular consumed fruits in the tropical and sub-tropical region. Most of the edible bananas present now a days are derived solely from *Musa accuminata* Colla or *Musa balbisiana* Colla or a hybrid between the two wild diploid species. The main objective of this research work is to provide an overview of various by-products from banana. 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 plant, apart from leaves and fruits. Banana, consisting of numerous well-known varieties and cultivars, has been explored and the by-products such as pseudostem, rhizome, leaves, fruit stalks, and peels from the common varieties to some extent are potential raw materials in areas of food and non-food industries, providing each different application. Banana by-products which have been assessed and found to have potential application for food additives, nutraceuticals, food supplements, feeds, renewable fuel, fibers, source of bioactive and other organic chemicals, fertilizers as well as contaminant absorbers.. The exponential increase of world's population and the trend towards the utilization of eco-friendly and viable agricultural by-products creates a steady platform for the continuation of innovation on development of products from the banana by-products and waste, thus, making it a sustainable income generating commodity. Generating wealth from waste such as from the banana by-products should be regarded as one of the ways to create an eco-friendly environment for the future generations.

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Introduction

Banana one of the most popular consumed fruits in the tropical and sub-tropical region (Singh *et al.*, 2017; Bailey *et al.*, 1989; Aurore *et al.*, 2009; Mohapatra *et al.*, 2010), belongs to the Musaceae family have been considered as one of the ancient families within Zingiberales, consisting of large rhizomatous monocarpic herbs with large pseudostem formed by folding leaf sheath (Dahlgren *et al.*, 1985; Sethiya *et al.*, 2019). Musaceae could be easily distinguished form other families of order Zingiberales by the presence of tall pseudostem, long inflorescence, fiver fertile stamens and reduced staminode in male flower (Dahlgren *et al.*, 1985).

Banana is one of the earliest crops cultivated in the history of human agriculture. The origin of this particular plant family stretches from India to Papua New Guinea which includes the Southeast Asian region (Arvanitoyannis and Mavromatis, 2009; De Lange *et al.*, 2009). Its mass cultivation and consumption in the recent decades made it the world second largest fruit crop. World leading banana and plantain producers are India, China, Uganda, Ecuador, Philippines, and Nigeria. Most of the edible bananas are cultivated mainly for their fruits, thus banana farms could generate several tons of underused by-products and wastes. Therefore, without proper agricultural waste management practice, huge amount of valuable untapped commodity will be lost and causing serious ecological damages (Essien *et al.*, 2005; Shah *et al.*, 2005; Yabaya and Ado, 2008). Utilizing these plants more than just for food purposes and explore the possibilities of utilizing banana plants in human daily life will definitely merit farmers and reduce the ecological impact and generate value addition.

Banana by-products have been traditionally used for wrapping foods, clothes, serving foods, making various kinds of dumplings, poojas and offering to gods. They were also used in various festivals and ceremonial occasions and usage expand in through cultural diversification across the globe. In modern agricultural classifications, banana were placed into fruit crop or cash crop along with oil palm, sugarcane, pineapples, mangoes and rice. Some of these crops produce large amount of ligno-cellulostic waste materials usually called as agricultural wastes or biomass. These agricultural wastes/biomass management is a continuous challenge and recent trends support the utilization and value addition of these wastes to fulfill the needs of renewable energy, fibere composites, textiles, food alternatives, livestock feeds and biochar for soil fertility management.

Studies on the cellulostic fibers from other agricultural wastes such as from the oil palm industries indicated the great potential of these by-products to become a commercial raw material in making highly demanded products such as paper and fiber composites (Bakar *et al.*, 2007; Wan Rosli *et al.*, 2007). Numerous studies have been done to improve the usage of banana by-products to meet the escalating demand of raw materials supply in various industries (Clarke *et al.*, 2008; Doran *et al.*, 2005; Emaga *et al.*, 2008a; Kuo *et al.*, 2006). These researches paved new and alternative ways in creating new products and applications with value added approach at the cost of recycling banana agricultural wastes.

Due to increasing concern to save earth and reduce pollution, new products with value-added applications from alternative bio-resources as means to develop a sustainable civilization. Due to the high demand for food products, energy, and other essential needs, gradual improvement in the current technological development towards utilizing alternative resources in many industries is necessary to cater the needs of the ever-increasing world population (Mohammadi, 2006).

Biological evolution and nomenclature

Banana is widely cultivated over 130 countries along the tropics and sub tropics (Mohapatra *et al.*, 2010). Original bananas were seeded and mostly non edible forms. The slow decline in seed fertility, increases in parthenocarpy as well as human selection of characters (pulpiness, fruit colour and taste) may leads to the evolution of edible banana varieties (Uma *et al.*, 2005a; Uma *et al.*, 2005b). Most of the edible bananas present now a days are derived solely from *Musa accuminata* Colla or *Musa balbisiana* Colla or a hybrid between the two wild diploid species. These two diploid ancestral parents contribute to A and B genomes respectively and considered as the Adam and Eve of present day bananas (Uma *et al.*, 2005a; Uma *et al.*, 2005b; Mohapatra *et al.*, 2010; Simmonds and Shepherd, 1955).

The banana plant seems to be originated from India as well as eastern Asian regions (Malaysia and Japan). Polyploidy, hybridization and various combinations of A and B genome has resulted in the development and emergence of broad spectrum of genomic groups; diploid (AA, AB, BB), triploid (AAA, AAB, ABB, BBB) and tetraploid (AAAA, AAAB, ABBB, AABB) varieties of banana.

The edible banana (eaten as dessert) and plantain (banana for cooking) may have combinations of these sets of genome which can range from triploid (AAA, BBB, AAB, ABB) to a diverse tetraploid blends. As such, they are grouped based on their 'ploidy' as *Musa acuminata*, *Musa balbisiana* or *Musa acuminata* x *balbisiana*, which is synonymous to the previous classification called *Musa* x *paradisiaca* that represents hybrids (Nelson *et al.*, 2006). Hundreds of years of natural and selective cultivation made it possible to transform edible bananas into several hundred varieties with a number of improvements such as the reduction in their seed size, sterility, oversized pulp, and spontaneous development of fruit without the need for fertilization (Arvanitoyannis and Mavromatis 2009; Ploetz *et al.*, 2007). There are approximately 1200 seedless fleshy fruits varieties and cultivars of banana and plantain in the world and mainly planted for food purposes (Aurore *et al.*, 2009).

Various other varieties also co-evolved or exist naturally with theses genomes and have slightly different nomenclatures (Simmonds, 1962; Robinson, 1996). Three common species of Musa (*M. cavendishi*, *M. paradisiaca* and *M. sapientum*) are widely cultivated across the world. *Musa cavendishi* is the pure triploid acuminate (AAA) is also known as desert banana characterized by sweeter and less starchy than *M. paradisiaca*. *Musa sapientum* is known as the true banana could be eaten raw when fully mature. Both *M. paradisiaca* and *M. sapientum* belongs to AAB group characterized by higher starch content compared to pure acuminate group (Mohapatra *et al.*, 2010; Stover and Simmonds, 1987). Cooking bananas falls under ABB and BBB genome with prominent *M. bulbisiana* genes. A great diversity of dessert banana exist due to plant size and various morphological characters. Productivity is high for Cavendish bananas and giant French plantains (>30 t/ha/yr).

Taxonomical classification (*Musa acuminata*; banana)

Kingdom: Plantae-- planta, plantes, plants, vegetal
Class: Insecta

Superdivision: Spermatophyta
Division: Magnoliophyta
Class: Liliopsida
Order: Zingiberales
Family: Musaceae
Genus: Musa

Species: *Musa acuminata*

Production and global market

Banana is grown in all countries in the tropics and sub tropics and has been sustainably cultivated and contributed to the economic development.

India remains the largest banana producing country in the world, which produce more than 25 % of the world's banana production (FAO 2010a). Despite being the top ranked world's banana producers, most of the banana produced in India are used for its domestic market and only about 0.04 % is exported.

Thus, total exports of banana from India are dreadfully low as compared to other leading global banana exporting countries such as Ecuador, Costa Rica, Philippines and Colombia, which accounts for more than 60 % of the world's exports.

The top importers of banana are the United States and the European Union. The largest plantain producing countries are mostly African countries where plantain is one of the staple foods in the region. According to FAO (2010a), Uganda is the largest plantain producer with an estimated production of 9.6 million tonnes, followed by Ghana and Rwanda.

The common internationally traded dessert bananas are mostly from the cultivated AAA group varieties such as "Cavendish", "Gros Michel", and "Grande Naine". Other well-known varieties which are endemic to a certain region includes "Yangambi Km5, AAA" found mostly in eastern Africa, "Red banana, AAA" and "Mysore AAB" found in southeast Asia as well as "Silk AAB" and "Bluggoe ABB" which are found across the tropical region (Ploetz *et al.*, 2007).

Indian production scenario

Banana is the second most important fruit crop in India after mango, good export potential and popular among all classes of people due to its year round availability, affordability, varietal range and nutritional properties. Out of more than 50 varieties of banana cultivated across India, around

20 are commonly grown in various Indian States (Duran *et al.*, 2007).

Musa (banana)

The bispecific origin of edible banana first mentioned by Kurz (1867) and experimentally proved by Simmonds and Shepherd (1955) by cross the two parent varieties; *M. acuminate* and *M. bulbisiana*. Supported by morphological and cytological evidences, it was assumed that the edible bananas were evolved from the two ancestors in five main stages. The triploids were formed by the fertilization of diploid egg cell with haploid pollen leads to the formation of triploids as a main step in the banana evolution process. The triploids were popular among farmers and breeders due to many beneficial traits especially sturdiness, robustness and pulpiness. Parthenocarpy, sterility, polyploidy and vegetative propagation for perpetuation of useful traits has played a major role in the evolution of current banana varieties (Uma *et al.*, 2005b).

The generic name Musa is rooted in Sanskrit word Moca or may have derived from Arabic world Mauz, Mouz or Mauwz, which is used for banana (De Candolle, 1886; Nayar, 2010; Hakkinen, 2013). The Arabic name for banana 'Mauz' is also mentioned in Rheede's 'Hortus Malabaricus'.

The main difference between these two classification is the introduction of almost pure balbisiana clones in the Thai grouping, which did not appear in the original classification. Espino and Pimental (1991) used isozyme technology to differentiate clones of pure acuminate, pure balbisiana and their hybrids from one another.

They found broad bands of malate dehydrogenease activity which were unique to pure balbisiana, and other bands which indicated an acuminate genome.

They concluded that BB and BBB cultivars were unique and distinct from hybrid ABB clones. The cooking plantain Saba (BBB) is very close to pure balbisiana (73 to 75 points).

Major genomic groups and cultivars in world use

AA group

Sucrier; synonym is Pisang Mas in Malaysia and Indonesia and Bocadillo in South America. This is the most important edible cultivar of diploid acuminate cultivar with small, sweet, thin-skinned, golden yellow fruits. The bunches are small and yield is less than triploids, these varieties are resistant to Panama disease and can withstand wind. Pisang Mas is the most important banana cultivar in Malaysia.

Pisang Ambon Putih is the most important banana cultivar in Indonesia and it also ranks highly in Malaysia. The fruit has good flavour, excellent keeping quality and high yields and highly susceptible to Fusarium wilt disease.

Gros Michel sub group

The main cultivar is Gros Michel. A synonym is Pisang Ambon in Malaysia. The mutants form this variety includes Highgate and Cocos. The cultivar Gros Michel produce tall, vigorous plants bearing heavy, symmetrical bunches with attractive c

olour and long, slender fruit. Until 1950s, this was considered as the leading cultivar in the world trade after the plantations were decimated by race 1 of Fusarium wilt disease (*Fusarium oxysporoum* cubense-FOC). These plantations were replaced with the race-1 resistant AAA cultivars Valery and Grand Nain from the Cavendish subgroup,

Cavendish subgroup

This is the most popular subgroup in the world banana trade both for export in the tropics and local trade in the subtropics. There exist a great variation in the pseudostem height between cultivars in this group, Dwarf Cavendish (1.8 to 2.0 m) to Lacatan (4-5), with many cultivars at intermediate height levels.

Dwarf Cavendish type

The main cultivar is Dwarf Cavendish and synonyms of this are Canary Banana, Dwarf Chinese, Basrai in India. It is also known as Governor in the West Indies and Enano in Latin America. This variety is abundant, widespread and the shortest banana grown commercially. This variety is considered to be climatically adapted, stable against subtropical winds and high yielding in Australia, South Africa and Israel. This variety is susceptible to physiological disorder choke throat and has been replaced by taller Cavendish cultivars (Williams and Grand Nain) which are not susceptible to choke throat, higher yields and better fruit quality. All the sub-tropical countries except Israel, have heavy race 4 of Fusarium wilt disease which attacks Cavendish subgroup cultivars. Due to this reason Williams, Grand Nain and other Giant Cavendish type need to be replaced in heavily infected areas with tolerant mutant AAA selections.

Giant Cavendish type

The main clones of Giant Cavendish are Mons Mari (Queensland), Williams (New South Wales; South Africa), Grand Nain (Central America, Israel, South Africa) and Giant Governor in West Indies. Cultivars of this type are not excessively tall but are called Giant Cavendish to distinguish them from Dwarf Cavendish type. Grand Nain is a major export cultivar in world trade but it can be grown only in areas which are free of Fusarium wilt disease race 4. Since 2005, Williams has started to replace Grand Nain in many tropical export plantations in Central America and West Africa. This is due to more hardy nature of Williams and its more pack-friendly bunch.

Robusta type

The main clones of Robusta are Tall Mons Mari in Australia, Poyo in West Indies and West Africa, Valery in Latin America. These cultivars are generally taller than the Giant Cavendish cultivars. Valery used to be a major export cultivar in world trade is too tall and susceptible to race 4 of Fusarium wilt disease.

It has been replaced by Grand Nain and Williams in many exporting areas of Central America because the latter cultivars have the advantages of shorter plants, larger bunches and shorter life cycle.

Lacatan type

The main synonyms are Pisang Masak Hijau in Malaysia, Monte Cristo in Puerto Rico and Giant Fig in the West Indies. This very tall cultivar has limited commercial importance only in Jamaica and the West Indies. Cultivars, synonyms and mutants in the Cavendish subgroup are confusing. Between Dwarf Cavendish and Lacatan, there is a continuous transition of Cavendish types based mainly on morphological differences. Some types are recognized as distinct cultivars (Dwarf Cavendish and Williams) where as others are recognized as somatic mutations (Grand Nain to Israeli Grand Nain). According to the recorded off-types, the mutation rate was probably in the order of two in one million when using conventional planting material (Stover and Simmonds, 1987). The actual rate could be much higher since many off-types would have been remained undetected or unrecorded.

Red and Green Red subgroup

Neither of these clones is important commercially, but they are well known due to their wide distribution. These are only grown for home consumption and have low harvest index. Red has a red skin from which a mutation for green skin produced the clone Green Red.

Other AAA cultivars

A distinct group of AAA bananas are found in East African Highlands, from the Lujugira subgroup and mainly used for the production of beer of cooking purposes. Commonly known as East African Highland Cooking bananas. The cultivar Ibota and Caipira in Brazil is popularly used as a dessert cultivar with acid flavour and tolerant to many diseases including Sigatoka and nematodes (Lassoudiere, 2007).

AAAA group

Tetraploid of Musa acuminate banana have been produced by breeding AA diploid pollen parents with AAA triploid female parents which are not totally parthenocarpic and sterile. The traditional female parent used for this breeding process was the mutant of Gros Michel called Highgate. The progeny of a diploid x triploid cross are tetraploids. Some of the AAAA cultivars are IC.2, Bodies Altafort and FHIA SH 3436.

IC.2

This was the first banana to be released from breeding in Trinidad during 1928. Due to severe infestation with Panama disease, it has not been grown commercially since 1954.

Bodies Altafort

This was released from Jamaica in 1962 and is cross between Gros Michel and Pisang Lilin. This variety is tall, prone to lodging in wind and not grown commercially.

FHIA SH 3436

This was released from Honduras in 1982 and is a cross between burrowing nematode resistant diploid SH 3142 and Highgate variety. It has good resistance to black Sigatoka but found susceptible to race 4 of Fusarium wilt disease.

AB group

This group comprises number of diploid hybrids of south Indian origin. The main cultivar is Ney Poovan which is widely distributed and has good commercial domestic markets. Being diploid, the plants are slender and lacking vigour. The fruits are white fleshed with pleasant sweet acid flavour.

This variety is highly resistant to Fusarium wilt and leaf spot diseases. An interesting cultivar with similar characteristic in East Africa is called Safet Velchi.

AAB group

This group of triploid hybrids originated in India with a wide range of clones and somatic mutants. The AAB plantains generally have starchy flesh and at maturity they are usually unpalatable unless boiled. Other AAB cultivars have sweet fruit and are used as dessert cultivars.

Plantain subgroup

There are two main types: French plantain type and horn plantain type
French plantain type: There are nine known forms of French plantain which are grown in different parts of India, Africa and Central America. As a group they are characterized by persistence of male axis and male flowers and bracts.

Horn plantain type: These are characterized by the early degeneration of the male axis and flower parts. There is wide range of local names given to Horn plantains. They are produced in India, Africa, Central America, the Philippines and the Pacific.

In general, plantains are tolerant to Fusarium wilt disease, but are susceptible to black Sigatoka and banana weevil. They are very important sources of staple food for indigenous populations of south India, East, West and Central Africa and Central America. The plantains have become widely diversified due to somatic mutations over years.

AAB dessert bananas

Besides plantains, there is a wide range of important AAB dessert bananas in the tropics

Mysore: The most important banana clone in India representing 70% of all bananas produced in the country. The plant is large and vigorous, and resistant to Fusarium wilt disease and leaf diseases, and tolerance towards banana weevil, poor soils and drought. However, it is very sensitive to Banana Streak Virus (BSV). The fruit has attractive flavour, yellow colour and has good shelf life with limited distribution outside India.

Prata Ana: Widely planted in Brazil and used for breeding programmes. It is relatively short plant with sweet fruit and slight acidity. The taste is very popular in Brazil and fetches higher price than Cavendish bananas. It has good resistance to wind and cool conditions, but sensitive to Panama disease which limits its expansion.

Thap Maeo: A cultivar originating from Thailand, very similar to Mysore but less sensitive to BSV, resistant to black and yellow Sigatoka and Fusarium wilt disease, and higher tolerance to nematodes (Silva *et al.*, 2014).

Silk: Some synonyms of this are Apple in Hawaii, Silk Fig in the West Indies, Latundan in The Philippines, Pisang Rastali in Malaysia.

Silk is distributed almost as widely in the world as Dwarf Cavendish. Plants are moderately vigorous but do not bear heavily compared to Mysore. It is a popular dessert cultivar in the tropics especially in The Philippines, and has a white, apple flavoured fruit flesh that must only be eaten fully ripe.

Pome: A synonym of this clone is Lady Finger in Australia and Prata in Brazil. It is a common dessert cultivar I southern India. Plants are vigorous and hardy but not very prolific bearers.

Pisang Raja: A well-known dessert clone in Malaysia and Indonesia but unknown in Africa and India. Plants are vigorous and resistant Fusarium wilt disease and leaf spot. In Malaysia it is cooked and bunches have only six to nine hands.

Maia Maoli: An important clone in Hawaii and the Pacific. It has a compact bunch containing large compact fruits.

ABB group

Due to the predominance of *Musa balbisiana* genes, cultivars of this group are very vigorous and drought resistant. The fruits are green and waxy silver, the pulp is starchy and the plants are resistant to leaf spot. The main centres of origin for this group are southern India and the Philippines

Bluggoe

This is a starchy cooking banana with large fruits. It has at least 27 synonyms and several named mutants, including dwarf types, and an important source of food in Samoa, the Philippines, southern India and the West Indies. It is immune to common leaf spot, but susceptible to black Sigatoka, race 2 Fusarium wilt disease and Moko disease.

Pisang Awak

Synonyms of this cultivar include Pisang Klotok in Indonesia, Ducasse in Queensland and Kluai Namwa in Thailand. It is a common cultivar in Thailand where it is eaten fresh or cooked first. It is also common in north-east India and Malaysia, but not in south India. Pisang Awak is very vigorous and hardy, but it tends to be partially fertile and may produce seedy, inedible fruits if pollinated by wild diploids.

BB group

Although it was thought that the pure seedless diploid clones of *Musa balbisiana* did not exist in nature, morphological and cytological studies carried out in the Philippines clearly indicates the existence of BB cultivars. The most important of them is the early maturing cultivar called Abuhon (Valmayor *et al.,* 2002).

BBB group

There is a wide range of pure balbisiana clones which have been identified in South-east Asia.

Saba: Synonyms are Pisang Kepok in Indonesia, Pisang Nipah in Malaysia and Kluai Hin Thailand. Saba is the most important banana cultivar in the Philippines, but of lesser importance in other countries of South-east Asia. It is a cooking banana with medium to large fruits. The pulp is creamy white, and although the flesh become sweet on ripening, fruits are always cooked before consumption. The male bud of Saba is usually removed and eaten as a vegetable.

ABBB, AAAB and AABB group

These three groups are the only natural tetraploids to be found. Pure acuminate or balbisiana tetraploids in nature have not been described, and hybrid tetraploids are certainly not common. Bred tetraploids are now being produced in increasing numbers.

Klue Teparod (ABBB): This is a robust plant, immune to Fusarium wilt disease and leaf spot. The fruit flesh has an unpleasant spongy texture when raw. In Thailand and Burma, the fruits are cooked to make popular sweetmeats.

Atan (AAAB)

This cultivar resembles AAB triploids in some respects. Leaves are horizontal to drooping which is a typical weak petiole character of tetraploids.

Fruits are short, plump and tart, and the plant is resistant to Fusarium wilt disease.

Kalamagol (AAAB)

This may be the result of a natural cross between Latundan and *Musa balbisiana*, and was found in the Solomon Islands. It has very droopy leaves. Fruits are small and sweet and the plant is resistant to Fusarium wilt disease and leaf spot.

Goldfinger or FHIA 01 (AAAB)

This cultivar is a product of the conventional breeding programme. This variety is reputed to be tolerant to race 4 Fusarium wilt, black Sigatoka and burrowing nematode. It is more tolerant to cold temperatures than Cavendish subgroup cultivars.

Classification and taxonomy

Banana is actually one of the largest herb groups in the world (Ploetz *et al.*, 2007). The plant can grows up to 5–7 m consisting of a fleshy rhizome (corm), pseudostem (leaf petioles) and spirally arranged oblong leaves. The long oval shaped inflorescence, supported by a stalk, protrudes out from the tip of the pseudostem consisting of deep purple waxy bracts which enclosed the female (occupies the lower 5–15 rows) and male flowers (upper rows). The female flowers will eventually developed into "berry" fruits (hand) which will mature to be horned shaped with white or yellow flesh. Seeds are common in wild types but the cultivated varieties are generally seedless with almost invisible dots of ovules at the center (Arvanitoyannis and Mavromatis 2009). The term banana is commonly used to represent the dessert cultivar while the cooking cultivar is generally referred as plantain. They belong to the family Musaceae and various species of the genus Musa have been cultivated since time immemorial, and used as a source of fiber, foods, and ornaments (Kennedy, 2009; Subbaraya, 2006).

Plant morphology

In the publications of Simmonds (1962), Barker and Steward (1962), Purseglove (1972), Morton (1987), Ross (2001), Simmonds and Weatherup (1990), Espino *et al.*, (1992), Karamura and Karamura (1995), Rieger (2006), Pillay and Tripathi (2007); detailed morphological description of banana plant is provided.

Banana plant is a perennial monocotyledon with an approximate height of about 2-9 m. The part above the ground is called pseudostem (false stem), which is composed of concentric layers of leaf sheath and the part below the ground is called corm (also known as true stem). The meristem of apical bud initially gives rise to leave before it elongates to the pseudostem. Each pseudostem produces inflorescence only once. According to Barker and Steward (1962), leaves around the Musa gets tightly rolled from the centre of the pseudostem in a clockwise manner. The petiole is formed as the leaf sheath taper on the both sides. The can be erect, intermediate or dropping on the basics of the Musa sp.

Due to the popularity and intensive production modes, the banana is highly susceptible to disease and pest like any horticultural crop. Banana production across the globe is under the threat due to different climatic factors and pathogenic agents such as bacteria, nematodes, viruses and fungi (Opara *et al.*, 2010).

Production constraints

The banana usually produced shifting cultivation systems as well as permeant farming systems. In some countries their production is intensively managed to meet the demands across the globe. Pests and diseases increased considerable in banana production systems and can leads to yield losses up to 50%.

Considerable loses also caused by fusarium wilt and nematodes. Both weevil and nematode infestation interfere with nutrient uptake and transport which leads to slow growth, reduced fruit yield and susceptibility to wind lodging. Banana production system in South-India are characterized by complex, single cultivar to multiple cultivar, mixed cropping and mixed farming systems. Soil fertility is also an important production constraint in banana production in South-India. Numerous pets and diseases emerged on banana production, and lack of maintaining crop hygiene to bring down pest/disease incidence.

Pests of banana

The distribution and prevalence of pest/disease of banana is different in South-India due to complexity of the production system especially agroecological and socioeconomic factors. These factors should be taken into account when planning pest management strategies. Some of the pest are K-strategist (living longer and surviving; banana weevil), while other are V-strategist (rapid reproduction, short life span, ability to survive in unstable environments; nematodes). It is better to know the survivorship strategies of target pest for planning management strategies.

Banana by-products

Conventional use of banana by-products and waste

Banana is a unique perennial single harvest plant. Its visible part, the pseudostem and leaves dies after it bears fruit to make way for the young budding plant (suckers) to rejuvenate from the rhizome. The harvesting of the fruit in plantation requires the decapitation of the whole plant so that the young suckers can replace the mother plant and these cycles can continue for unlimited generations. Generally, banana by-products include the pseudostem, leaves, inflorescence, fruit stalk (floral stalk/rachis), rhizome and peels. Most of these by-products may serve as an undervalued commodity with a limited commercial value, application and in some cases, it is considered as an agricultural waste.

The pseudostem and leaves are commonly left to rot in farms to replenish some of the nutrients in the soil. Young shoots, pseudostem piths and inflorescence, although be consumed as vegetables by the indigenous people in parts of Southeast Asia and Indo-Malesian Region (Kennedy 2009), they may not be able to compete with the common leafy vegetables due to its undesirable taste. The values of the banana inflorescences were quite low because of the inconsistent demand and limited acceptance.

Banana leaves are still used as wrapping materials for traditional foods in Southeast Asia but its application only limited to some ethnic foods. A slightly better application of the banana waste was its utilization as an animal feed to minimize the cost of production (Akinyele and Agbro, 2007), but additional processing is required due to its high water content that greatly reduces its nutritional density. Low cost agricultural wastes are generally poor in essential nutrient but at the same time high in fiber content (Ulloa *et al.*, 2004).

In some places where "open fire burning" is still practiced, the burning of banana wastes may contribute to serious environmental issues. In addition, the piling up of banana waste in plantations is an eyesore, which will eventually obstruct farmers on their process to harvest mature and ripe fruits. Banana floral stalk and peels are not directly available at the farming site but may be available at the processing sites where the fruit is packaged or the fleshy pulp of the fruit is separated from its peels. Collectively, the waste that a single banana plant produces can make up to 80 % of the total plant mass. It is estimated that 220 tonnes of by-products are produced per hectare annually (Shah *et al.*, 2005) indeed requires an innovative idea to turn these readily available resource into a value added products.

Banana by-products and green technology

Renewable resource or biomass, are a naturally abundant resource, which may include any materials obtained from biological origin such as plants and animal materials, agricultural crops and biological residues or wastes (Xu *et al.*, 2008). These resources can be turned into raw materials or products having the potential capacity of being recyclable and easily biodegradable which in turn having positive environmental acceptability or 'green label' attributes plus commercial viability (Mohanty *et al.*, 2002). Renewable resources have paved way to the industry and have been used in decades to replace non-renewable resources especially petroleum and gas products, precious metals and minerals.

It is important that the utilization of low cost agricultural by-products and biological wastes could be expanded to all possible industries in order to achieve a sustainable development of technology. This could contribute to an additional source of revenue to farmers and processing industries without adversely affecting soil fertility and reduce the depletion of the non-renewable resources and protection of the forest (Reddy and Yang, 2005).

Green technology signifies an application, which is environmental friendly emphasizing on conserving the natural environment and resource as well as posing a minimal threat to the existing species on earth including humans. The technology should be independent from the existing agro-food commodity market, as the utilization of agro-food based products such as corn to drive green technology will eventually create food insecurity; ethical issues and unsustainable energy return (Pimentel and Patzek, 2005).

Potential food and nutraceutical from banana by-products

Source of starch, pectin and cellulose

Starch, pectin, and cellulose are used in the food industry as gelling agent, thickening agent and stabilizers. Starch, a group of carbohydrates, is commercially available and produced from plants such as corn, potato, rice, wheat, and cassava. Banana by-products that can be processed into edible starches includes the pith of pseudostem and the green culled banana which are removed during fruit selection and processing (Aziz *et al.*, 2011; Da Mota *et al.*, 2000; Zhang *et al.*, 2005).

Banana starches which are relatively low in amylase content, have high resistance to heating and amylase attack, low swelling properties, low solubility in water and low retrogradation, been proved slightly superior to modified and unmodified corn starch giving it a potentially higher market value (Zhang *et al.*, 2005).

Commercial pectin, a structural heteropolysaccharide classified under soluble dietary fiber, was produced mainly from fruits extract such as citrus peels, oranges, apples, and carrots. Comparing the quality of pectins isolated from various fruit wastes revealed that the pectin's methoxyl composition and gelling quality of banana is slightly lower than the pectin isolated from citrus peels such as pomelo and lime (Madhav and Pushpalatha, 2002). Pectin could be produced from discarded banana peels via acid extraction and precipitation by using alcohols or ammonium salts.

Natural biocolourant

The anthocyanins, a subclass of flavonoids are an important pigment group that is responsible for the red, purple, and violet colors of the banana inflorescence (Kitdamrongsont *et al.,* 2008). Anthocyanins are considered to be a good biocolorant due to its attractive colors, moderately stable in food systems, water-soluble (Ozela *et al.*, 2007; Torslangerpoll and Andersen, 2005), and proven to be beneficial to health (Bagchi *et al.*, 2004; Konzack and Zhang, 2004).

The content is slightly higher than the commercially available anthocyanins from red cabbage and by looking into the abundance of bracts produced (mass per hectare of land), it may provide sufficient and sustainable market outlook (Jenshi *et al.*, 2011; Pazmino Duran *et al.*, 2001). Natural bio-colorant such as the anthocyanins remains in demand not only due to its health promoting properties but also the increase in demand on natural foods (Rymbai *et al.*, 2011).

Biogeneration of flavour

Flavor plays a very important aspect in the food industry. They are formed through various chemical reactions during food processing and mostly through the reduction of carbon, nitrogen, and/or sulphur compounds along with the generation of volatile organic compounds (VOCs) such as aldehydes (Rappert and Muller, 2005). Biogeneration of aldehydes and alcohols used in the flavor industry can be carried out naturally through enzymatic pathways utilizing enzymes such as lipase, alcohol dehydrogenase (ADH), lipooxygenase (LOX), hydroperoxide lyase (HPLS) (Gigot *et al.*, 2010).

Source of dietary nutrients

There have been a few studies done on the by-products of banana and plantain in order to evaluate its nutrient content as a potential source of dietary food components such as carbohydrate, proteins, dietary fibers, and minerals for human consumption (Emaga *et al.,* 2007; Mohapatra *et al.,* 2010). Banana pith from the pseudostem has long been eaten as vegetables in some parts of the world such as India, Sri Lanka, and Malaysia (Kennedy, 2009; Subbaraya, 2006).

It contains considerable amount of starch, sugars, and minerals (Mohapatra *et al.*, 2010). In most of the Southeast Asian countries, banana inflorescence is consumed as vegetables and salad for a very long time.

Source of nutraceutical and bioactive compounds

The term “nutraceutical”, was first coined in 1989 by Stephen DeFelice and the original term was defined as “A food or parts of food that provide medical or health benefits, including the prevention and/or treatment of disease".

Tin *et al.*, (2010) have identified the presence of epigallocatechin and its derivatives form banana male flowers while in another study, Saravanan and Aradhya (2011) successfully isolated entisic acid, (+)-catechin, protocatechuic acid, caffeic acid, ferulic acid, and cinnamic acid from banana pseudostem. It has been accepted that polyphenolic compounds such as gallocatechin, caffeic acid, cinnamic acid and catechin posed antimicrobial activity (Chanwitheesuk *et al.,* 2005; Shan *et al.*, 2008), antioxidative (Chye and Sim 2009, Wong and Chye, 2009), neuroprotective (Lu *et al.,* 2005; Mandel *et al.,* 2008), chemopreventive (Raina *et al.*, 2008; Artali *et al.*, 2009), anticancer (Faried *et al.*, 2007; Shankar and Mulimani, 2007) and antiproliferative capacities (Jagan *et al.*, 2008).

Phytosterols are naturally occurring plant sterols that have been studied extensively. Several reports show their wide variety of positive health promoting effects including lowering of blood cholesterol (Moruisi *et al.*, 2006; Racette *et al.*, 2010; Weingärtner *et al.*, 2008) and reducing the risk of coronary heart diseases (Miller and Nichols, 2008).

Several bioactive steryl glucosides, namely campesteryl 3-β-dglucopyranoside, stigmasteryl 3-β-d-glucopyranoside and sitosteryl 3-β-d-glucopyranoside were identified from the dichloromethane extracts of *Musa acuminata* Colla cv. Cavendish (Oliveira *et al.*, 2005).

Natural food preservative

Food preservation plays a vital role in driving the food industry by extending the shelf life of foods. Current trends of industry show increase awareness towards the drawbacks of synthetic chemical preservatives and opt for minimally processed food or employing natural techniques in food preservation (Tiwari *et al.,* 2009).Natural antimicrobials from numerous plant sources including spices and herbs have been well documented in suppressing food spoilage microbes and foodborne pathogens (Kumar and Tanwar, 2011; Kumudavally *et al.*, 2011; Pillay and Ramaswamy, 2012; Padam *et al.*, 2012a) further strengthens the concept of natural ingredients for food preservation.

Antibacterial compounds such as ß-sitosterol, 12-hydroxystrearic acid and malic acid isolated from banana peels (*Musa paradisiaca*) shown to be a good suppressor of foodborne pathogens including *Staphylococcus aureus*, *Bacillus cereus*, *Salmonella enteritidis* and *Escherichia coli* (Mokbel and Hashinaga, 2005).

Banana peel water extract shows preservative capabilities by reducing lipid oxidation process in raw meat was comparable to synthetic antioxidant such as butylated hydroxy toluene (BHT).

Extracts from the male flowers of banana (*Musa paradisiaca*) were also demonstrated to contain antibacterial properties, which able to decontaminate and suppress the growth of *Listeria monocytogenes* and *Staphylococcus aureus* in chicken breast meat comparable to the commercial potassium sorbate (Tin *et al.*, 2010; Padam *et al.*, 2012b).

Banana chips

Nendran fruits of approximately 80% maturity are harvested and demanded. The fingers are peeled, treated with 0.1% potassium metabisulphite and cut into slices of 1.2-0.8 mm thickness and deep fried in suitable cooking oil, preferably coconut oil. Upon frying this will yield crisp, yellow colored chips, which are sprinkled with common salt and packed in polyethylene bags. Generally they have a storage life of 30-35 days under ambient conditions. Packing the chips in laminates with nitrogen gas can extend its life up to 4 months. Several other verities of banana chips like flavored, sweet, sweet and sour, tomato flavored, with pepper, etc. are also catching up in the market (Bornare *et al.,* 2014).

Banana fruit candy/stem candy

Banana fruit candy made from nendran with jiggery and ginger are widely sold in market in Kerala state. Banana stem (true stem) can also be made into candy through osmotic dehydration process followed by sun drying (Bornare *et al.,* 2014).

Banana fig

Banana figs are dried or dehydrated banana fruits with sticky consistency and very sweet taste. Fully ripe banana fruits of variety 'Karpuravalli' or 'Dwarf Cavendish' are peeled, treated with 0.1% potassium metabisulphite solution and dried either in sun or oven at 50°C.

These figs are packed in polyethylene bags or any other suitable containers. They have a shelf life of about 3-4 months under ambient conditions (Bornare *et al.,* 2014).

Banana flour

Banana flour is prepared from mature green bananas, which have a high starch content. It can be used as nutritious adjuvant in several food preparations like bread, cakes, biscuits, health drink and baby food formulations. It can also be blended with other cereal flours for making chapaties and roties (Indian bread). It has some medicinal property to cure ulcers. Under cool and dry conditions it can be stored up to one year without any adverse change in their composition (Bornare *et al.,* 2014).

Banana powder

Banana powder is prepared from fully ripe banana fruits either through drum drying or spray drying process. The moisture content of final product should be around 2-4%. This product has got high market value as it is extensively used in confectionary industry, ice cream preparations and baby food making. When suitably packed it will have a shelf life of more than 6 months (Bornare *et al.,* 2014).

Banana juice

Since banana puree is very thick, juice cannot be directly obtained from it. Therefore, the puree is treated with pectolytic enzyme and clear juice is obtained through filtration or centrifugation. After pasteurization and bottling it can have a shelf life of a minimum of 6 months under ambient conditions (Bornare *et al.,* 2014).

Banana fruit bar

Banana Fruit Bar is confectionary item prepared from ripe banana fruit of any variety. It is made by homogenizing banana pulp, sugar, citric acid and pectin in suitable proportions and dehydrating the mass in ghee coated ray at 70°C in an oven till sets into a sheet. It is then cut into suitable size and packed in polyethylene pouches (Bornare *et al.,* 2014).

Banana biscuits

Banana biscuits are made by mixing 60% banana flour and 30% maida. The dough is made using flour mixture and suitable proportions of sugar, saturated fat, baking powder, milk powder and essence. These biscuits are very tasty and highly nutritious (Bornare *et al.,* 2014).

Banana jam and jelly

Banana jam is made by cooking the fruit pulp with sugar along with pectin and citric acid in right proportions till gives a good set. Several varieties of banana are suitable for making jam. This is product, which has good commercial value and good market. Banana jelly is a semi solid product prepared by boiling clear strained fruit extract free from pulp after addition of required amount of sugar, citric acid and pectin. A perfect jelly should be transparent, attractive and sparkling in color with strong flavor of fruit (Bornare *et al.,* 2014).

Table.1 Characters used in the classification of bananas through a taxonomic scorecard. Modified after (Simmonds and Shepherd, 1955).

Character	*Musa acuminata*	*Musa balbisiana*
Pseudostem colour	More or less heavily marked with brown or black blotches	Blotches slight or absent
Petiolar canal	Margin erect or spreading, with scarious wings below, not clasping pseudostem	Margin inclosed, not winged below, clasping pseudostem
Peduncle	Usually downy or hairy	Glabrous
Pedicels	Short	Long
Ovules	Two regular rows in each loculus	Four irregular rows in each loculus
Bract shoulder	Usually high (ratio < 0.28)	Usually low (ratio > 0.30)
Bract curling	Bract reflex and roll back after opening	Bracts lift but do not roll
Bract shape	Lanceolate or narrowly ovate, tapering sharply from the shoulder	Broadly ovate, not tapering sharply
Bract apex	Acute	Obtuse
Bract colour	Red, dull purple or yellow outside, pink, dull purple or yellow inside	Distinctive brownish-purple outside; bright crimson inside
Colour fading	Inside bract colour fade to yellow towards the base	Inside bract colour continuous to base
Bract scars	Prominent	Scarcely prominent
Free tapel of male	Variably corrugated below tip	Rarely corrugated
Male flower colour	Creamy white	Variably flushed with pink
Stigma colour	Orange or rich yellow	Cream, pale yellow or pale pink

Table.2 Classification of edible bananas.

Genomic group	**Score**	**References**
AA diploid	15-23	Simmonds and Shepherd (1955); Stover and Simmonds (1987)
AAA triploid	15-23	
AAB triploid	24-46	
AB diploid	49	
ABB triploid	59-63	
ABBB tetraploid	67	
AA/AAA	15-25	Silayoi and Chomchalow (1987)
AAB	26-46	
ABB	59-63	
ABBB	67-69	
BB/BBB	70-75	

Table.3 Important banana varieties cultivated in different states of India.

State	Varieties grown
Andhra Pradesh	Dwarf Cavendish, Robusta, Rasthali, Amritpant, Thellachakrakeli, Karpoora Poovan, Chakrakeli, Monthan and Yenagu Bontha
Assam	Jahaji (Dwarf Cavendish), Chini Champa, Malbhog, Borjahaji (Robusta), Honda, Manjahaji, Chinia (Manohar), Kanchkol, Bhimkol, Jatikol, Digjowa, Kulpait, Bharat Moni
Bihar	Dwarf Cavendish, Alpon, Chinia , Chini Champa, Malbhig, Muthia, Kothia , Gauria
Gujarat	Dwarf Cavendish, Lacatan, Harichal (Lokhandi), Gandevi Selection, Basrai, Robusta, G-9, Harichal, Shrimati
Jharkhand	Basrai, Singapuri
Karnataka	Dwarf Cavendish, Robusta, Rasthali, Poovan, Monthan, Elakkibale
Kerala	Nendran (Plantain), Palayankodan (Poovan), Rasthali, Monthan, Red Banana, Robusta
Madhya Pradesh	Basrai
Maharashtra	Dwarf Cavendish, Basrai, Robusta, Lal Velchi, Safed Velchi, Rajeli Nendran, Grand Naine, Shreemanti, Red Banana
Orissa	Dwarf Cavendish, Robusta, Champa, Patkapura (Rasthali)
Tamil Nadu	Virupakshi, Robusta, Rad Banana, Poovan, Rasthali, Nendran, Monthan, Karpuravalli, Sakkai, Peyan, Matti
West Bengal	Champa, Mortman , Dwarf Cavendish, Giant Governor, Kanthali, Singapuri

Table.4 Starches, pectins and cellulose from banana by-products for food application.

	Banana by-products	Potential food application	References
Starches	Green culled banana	Food thickeners, gelling agents, fillers	Zhang et al. (2005), Aziz et al. (2011)
	Banana pith and pseudostem	Viscosity and swelling properties	Pelissar et al. (2012)
	Unripe fruit	Viscosity and swelling properties	Pelissar et al. (2012)
	Green banana	Substitution of cassava starch	Wang et al (2012)
	Green banana plantain	Production of starch based edible films	Zamudio-Flores et al. (2006)
Pectin	Banana peel	Food thickeners, gelling agent	Emagna et al. (2008)
Cellulose, Carboxymethyl cellulose, Microcrystalline cellulose	Banana pseudostem	Food thickeners, gelling agent, water retainer	Adinugraha et al. (2005) Elanthikkal et al. (2010)

Table.5 Important bioactive compounds as potential nutraceuticals from banana/plantain by-products.

Bioactive compounds	Banana by-products	Bioactivity	References
Cyanidin-3-rutinoside	Bracts	Antioxidant, Anticancer	Roobha et al. (2011)
Epigallocatechin and derivatives	Male flower	Antibacterial, Antioxidant	Tin et al. (2008); Tin et al. (2010)
ß-sitosterol, malic acid, succinic acid, palmatic acid, 12-hydroxystrearic acid, glycoside	Peels	Anti-inflamatory, Anti-cholesterol Antioxidants, Antibacterials	Mokbel and Hashinaga (2005)
Campesteryl 3-β-d-glucopyranoside, stigmasteryl 3-β-d-glucopyranoside and sitosteryl 3-β-d-glucopyranoside	Petioles, leaves, floral stalk	Anti-inflamatory, Anti-cholesterol	Oliveira et al. (2005)
Sterols, steryl glucosides, steril esters, tocopherols, phenolic compounds	Peels and pulp	Anti-inflamatory, Anti-cholesterol	Oliveira et al. (2008)
Putrescine, spermidine, serotonin, dopamine, tyramine, spermine	Pulp	Stimulants	Adao and Gloria (2005); Lima et al. (2008)
Entisic acid, (+)-catechin, protocatechuic acid, caffeic acid, ferulic acid, and cinnamic acid	Pseudostem	Antioxidants	Saravanan and Aradhya (2011)
Anthocyanins, catecholamines, tocopherols, phytosterols, ascorbic acid	Peel	Antioxidants	González-Montelongo et al. (2010)

Table.6 Utilization of banana by-products as substrate for the production of non-food cellulose, cellulolytic enzymes, and organic acids.

Products	**Banana by-products used as substrate**	**Microorganisms and microorganisms used**	**References**
Non-food cellulose	Pseudostem	Mix cultures from banana plantation soil	Zainol and Abdul Rahman (2008)
Cellulolytic enzymes, Crude cellulases	Pseudostem	*Phanerochaete chrysosporium*, *Pleurotus ostreatus*	Mena-Espino et al. (2011)
Exoglucanase	Floral stalk	*Bacillus subtilis*	Shafique et al. (2004)
a-amylase	Banana peels	*Helminthosporium oxysporium*, *Aspergillus niger*, *Aspergillus fumigatus*, *Aspergillus flavus*, and *Penicillium frequestans*	Adeniran and Abiose (2009)
	Floral stalk	*Aspergillus oryzae*	Ragunathan and Swaminathan (2005)
Laccase	Banana peels	*Trametes pubescens*	Osma et al. (2007)
laccase, lignin peroxidase, xylanase, endo-1, 4-_-d-glucanase and exo-1,4-_-nglucanase	Leaves and pseudostem	*Phylosticta spp*. MPS-001 *Aspergillus spp*. MPS-002	Shah et al. (2005)
Polygalacturonase	Leaf parts	*Streptomyces lindicus*	Jacob and Prema (2008)
Xylanase	Banana peels	*Trichoderma harzianum* 1073	Seyis and Aksoz (2005)
Organic Acid Citric Acid	Banana peels	*Aspergillus niger*	Vidhya and Neethu (2009)

Table.7 Banana by-products used as substrate for the cultivation of edible mushroom.

Banana by-product	Mushroom species	References
Leaves (*Musa sapientum*)	Straw mushroom (*Volvariella volvacea*)	Belewu and Belewu (2005)
Leaves and pseudostems	Oyster mushroom (*Pleurotus spp.*)	Bonatti et al. (2004); Silveira et al. (2008)
Banana peels	Shelf mushroom (Lentinus squarrosulus)	Adejoye and Masewonrun (2009)
Leaves	Agaric mushroom (*Psathyrella atroumbonata* Pegler)	Ayodele and Okhuoya (2007)

Table.8 Proximate analysis fruit and peel of Musa varieties (B1, B2, B3, B4, B5, B6, B7, B8, B9) in Kerala.

Sample	Moisture (%)	Crude protein (%)	Crude fibre (%)	Ether extract (%)	Total ash (%)	Gross energy (kcal/kg)
Robusta fruit (RF)	9.84 ± 0.34	6.12 ± 0.32	1.86 ± 0.28	1.17 ± 0.11	2.68 ± 0.24	3664 ± 121
Robusta peel (RP)	9.81 ± 0.22	7.85 ± 0.27	8.88 ± 0.21	4.05 ± 0.34	9.63 ± 0.34	4043 ± 58
Sundari fruit (SF)	10.61 ± 0.18	4.82 ± 23	1.2 ± 0.86	1.31 ± 0.22	2.84 ± 0.18	3612 ± 89
Sundari peel (SP)	9.68 ± 0.37	7.82 ± 0.35	6.43 ± 0.29	4.87 ± 0.32	8.67 ± 0.21	4005 ± 54
Etha fruit (EF)	8.98 ± 0.54	3.93 ± 0.46	1.05 ± 0.81	1.08 ± 0.17	2.28 ± 0.33	3673 ± 59
Etha peel (EP)	10.45 ± 0.88	8.28 ± 0.26	6.73 ± 0.39	4.87 ± 0.33	7.11 ± 0.11	3700 ± 75
Poovan fruit (PF)	11.52 ± 0.74	5.67 ± 0.21	1.36 ± 0.21	1.04 ± 0.45	2.51 ± 0.45	3589 ± 88
Poovan peel (PP)	10.03 ± 0.14	7.86 ± 0.19	7.36 ± 0.43	5.53 ± 0.35	7.08 ± 0.32	3747 ± 80
Najalipoovan fruit (NF)	6.95 ± 0.18	4.36 ± 0.23	1.22 ± 0.86	1.02 ± 0.22	2.35 ± 0.18	3756 ± 89
Najalipoovan peel (NP)	9.96 ± 0.37	8.3 ± 0.35	8.01 ± 0.29	6.45 ± 0.32	9.63 ± 0.21	3705 ± 54
Palayamkodan fruit (PaF)	9.71 ± 0.54	4.79 ± 0.46	1.02 ± 0.81	1.12 ± 0.17	3.21 ± 0.33	3623 ± 59
Palayamkodan peel (PaP)	9.48 ± 0.88	7.85 ± 0.26	8.5 ± 0.39	6.11 ± 0.33	9.98 ± 0.11	3684 ± 75
Chemkadali fruit (CF)	8.65 ± 0.74	4.36 ± 0.21	1.05 ± 0.21	1.35 ± 0.45	3.13 ± 0.45	3674 ± 88
Chemkadali peel (CP)	6.61 ± 0.14	4.36 ± 0.19	1.47 ± 0.43	1.13 ± 0.35	2.97 ± 0.32	3750 ± 80
Kannan fruit (KF)	8.13 ± 0.54	6.55 ± 0.46	8.02 ± 0.81	4.32 ± 0.17	10.22 ± 0.33	3610 ± 59
Kannan peel (KP)	7.85 ± 0.88	6.59 ± 0.26	5.78 ± 0.39	5.25 ± 0.33	8.44 ± 0.11	3992 ± 75
Kadali fruit (KaF)	12.1 ± 0.74	4.79 ± 0.21	1.11 ± 0.21	1.05 ± 0.45	2.31 ± 0.45	3560 ± 88
Kadali peel (KaP)	9.05 ± 0.14	6.87 ± 0.19	4.57 ± 0.43	5.30 ± 0.35	7.81 ± 0.32	3754 ± 80

B1; Robusta, B2; Sundari, B3; Etha, B4; Poovan, B5; Nalipoovan, B6; Palayamkodan, B7; Chemkadali, B8; Kannan, B9; Kadali
RF; Robusta fruit, RP; Robusta peel, SF; Sundari fruit, SP; Sundari peel; EF; Etha fruit, EP; Etha peel, PF; Poovan fruit, PP; Poovan peel, NF; Najalipoovan fruit, NP; Najalipoovan peel, PaF; Palayamkodan fruit, PaP; Palayamkodan peel, CF; Chemkadali fruit, CP; Chemkadali peel, KF; Kannan fruit, KP; Kannan peel, KaF; Kadali fruit, KaP; Kadali peel.
Numbers represent means ± one standard error (SE) of the mean

Table.9 Proximate analysis fruit and peel of Musa varieties (B1, B2, B3, B4, B5, B6, B7, B8, B9) in Kerala.

Sample	Moisture content (%)	Organic matter* (g)	Organic carbon* (g)	Crude ash* (g)	Acid insoluble ash* (g)	Acid soluble ash* (g)
Robusta fruit (RF)	7.54 ± 0.34	2.84 ± 0.38	1.65 ± 0.28	0.16 ± 0.12	0.11 ± 0.06	0.05 ± 0.01
Robusta peel (RP)	5.55 ± 0.29	2.42 ± 0.21	1.40 ± 0.21	0.58 ± 0.31	0.29 ± 0.11	0.29 ± 0.18
Sundari fruit (SF)	5.19 ± 0.22	2.80 ± 0.27	1.62 ± 0.20	0.20 ± 0.12	0.17 ± 0.04	0.03 ± 0.05
Sundari peel (SP)	8.56 ± 0.12	2.40 ± 0.15	1.39 ± 0.46	0.60 ± 0.11	0.37 ± 0.12	0.23 ± 0.09
Etha fruit (EF)	7.17 ± 0.31	2.71 ± 0.31	1.57 ± 0.23	0.29 ± 0.31	0.18 ± 0.23	0.11 ± 0.11
Etha peel (EP)	7.67 ± 0.37	2.28 ± 0.35	1.32 ± 0.25	0.72 ± 0.12	0.35 ± 0.09	0.37 ± 0.08
Poovan fruit (PF)	7.52 ± 0.51	2.05 ± 0.40	1.15 ± 0.43	0.95 ± 0.13	0.25 ± 0.05	0.70 ± 0.14
Poovan peel (PP)	4.15 ± 0.18	2.06 ± 0.20	1.19 ± 0.33	0.94 ± 0.31	0.49 ± 0.10	0.45 ± 0.08
Najalipoovan fruit (NF)	6.53 ± 0.28	2.06 ± 0.26	1.15 ± 0.31	0.94 ± 0.13	0.28 ± 0.06	0.66 ± 0.11
Najalipoovan peel (NP)	8.53 ± 0.24	2.51 ± 0.25	1.45 ± 0.23	0.49 ± 0.05	0.40 ± 0.03	0.09 ± 0.02
Palayamkodan fruit (PaF)	8.05 ± 0.17	2.73 ± 0.22	1.58 ± 0.33	0.27 ± 0.25	0.20 ± 0.12	0.07 ± 0.06
Palayamkodan peel (PaP)	6.52 ± 0.48	2.19 ± 0.19	1.27 ± 0.23	0.81 ± 0.09	0.47 ± 0.07	0.34 ± 0.10
Chemkadali fruit (CF)	4.15 ± 0.18	2.79 ± 0.20	1.62 ± 0.33	0.21 ± 0.31	0.15 ± 0.10	0.06 ± 0.08
Chemkadali peel (CP)	6.53 ± 0.28	2.49 ± 0.26	1.44 ± 0.31	0.51 ± 0.13	0.35 ± 0.11	0.40 ± 0.06
Kannan fruit (KF)	8.53 ± 0.24	2.76 ± 0.25	1.60 ± 0.23	0.24 ± 0.05	0.17 ± 0.03	0.07 ± 0.02
Kannan peel (KP)	8.05 ± 0.17	1.75 ± 0.22	1.01 ± 0.33	1.25 ± 0.25	0.50 ± 0.12	0.75 ± 0.06
Pachakadali fruit (PKaF)	6.52 ± 0.48	2.07 ± 0.19	1.20 ± 0.23	0.93 ± 0.09	0.19 ± 0.07	0.74 ± 0.10
Pachakadali peel (PKaP)	6.52 ± 0.48	1.75 ± 0.19	1.01 ± 0.23	1.25 ± 0.09	0.50 ± 0.07	0.75 ± 0.10

* Amount obtained for 3 g of dried plant samples
B1; Robusta, B2; Sundari, B3; Etha, B4; Poovan, B5; Najalipoovan, B6; Palayamkodan, B7; Chemkadali, B8; Kannan, B9; Kadali
RF;Robusta fruit, RP; Robusta peel, SF; Sundari fruit, SP; Sundari peel; EF; Etha fruit, EP; Etha peel, PF; Poovan fruit, PP; Poovan peel, NF; Najalipoovan fruit, NP; Najalipoovan peel, PaF; Palayamkodan fruit, PaP; Palayamkodan peel, CF; Chemkadali fruit, CP; Chemkadali peel, KF; Kannan fruit, KP; Kannan peel, PKaF; Pachakadali fruit, PKaP; Pachakadali peel.
Numbers represent means ± one standard error (SE) of the mean

Table.10 Proximate analysis leaf and stem of Musa varieties (N1, N3, N4 and N7) in Kerala.

Sample	Moisture (%)	Crude protein (%)	Crude fibre (%)	Ether extract (%)	Total ash (%)	Gross energy (kcal/kg)
Kindle leaf (KL)	10.16 ± 0.34	9.59 ± 0.32	27.87 ± 0.28	3.86 ± 0.11	6.24 ± 0.24	3713 ± 121
Kindle stem (KS)	8.48 ± 0.22	6.55 ± 0.27	21.21 ± 0.21	1.53 ± 0.34	29.42 ± 0.34	2675 ± 58
Poovan leaf (PL)	7.25 ± 0.18	8.72 ± 23	28.53 ± 0.86	6.37 ± 0.22	6.63 ± 0.18	3936 ± 89
Poovan stem (PS)	15.44 ± 0.37	3.06 ± 0.35	18.25 ± 0.29	2.03 ± 0.32	10.83 ± 0.21	3109 ± 54
Najalipoovan leaf (NL)	4.43 ± 0.54	10.05 ± 0.46	28.54 ± 0.81	4.61 ± 0.17	7.64 ± 0.33	3934 ± 59
Najalipoovan stem (NS)	11.55 ± 0.88	6.55 ± 0.26	37.09 ± 0.39	1.99 ± 0.33	16.48 ± 0.11	3095 ± 75
Palayamkodan leaf (PaL)	7.66 ± 0.74	10.02 ± 0.21	27.79 ± 0.21	5.12 ± 0.45	5.91 ± 0.45	3902 ± 88
Palayamkodan stem (PaS)	7.32 ± 0.14	6.55 ± 0.19	23.08 ± 0.43	1.93 ± 0.35	22.03 ± 0.32	3039 ± 80

N1; Kindle, N3; Poovan, N4; Nalipoovan, N7; Palayamkodan

KL;Kindle leaf, KS; Kindle stem, PL; Poovan leaf, PS; Poovan stem; NL; Najalipoovan leaf, NS; Najalipoovan stem, PaL; Palayamkodan leaf, PaS; Palayamkodan stem.

Table.11 Proximate analysis leaf and stem of Musa varieties (N1, N3, N4 and N7) in Kerala.

Sample	Moisture content (%)	Organic matter* (g)	Organic carbon* (g)	Crude ash* (g)	Acid insoluble ash* (g)	Acid soluble ash* (g)
Kindle leaf (KL)	7.54 ± 0.34	2.25 ± 0.38	1.30 ± 0.28	0.75 ± 0.12	0.24 ± 0.22	0.51 ± 0.08
Kindle stem (KS)	5.55 ± 0.29	1.63 ± 0.21	0.94 ± 0.21	1.37 ± 0.31	0.29 ± 0.11	1.08 ± 0.18
Poovan leaf (PL)	5.19 ± 0.22	2.37 ± 0.27	1.37 ± 0.20	0.63 ± 0.12	0.17 ± 0.04	0.46 ± 0.05
Poovan stem (PS)	8.56 ± 0.12	2.19 ± 0.15	1.27 ± 0.46	0.91 ± 0.11	0.37 ± 0.12	0.54 ± 0.09
Najalipoovan leaf (NL)	7.17 ± 0.31	2.25 ± 0.31	1.30 ± 0.23	0.75 ± 0.31	0.18 ± 0.23	0.57 ± 0.11
Najalipoovan stem (NS)	7.67 ± 0.37	2.06 ± 0.35	1.19 ± 0.25	0.94 ± 0.12	0.35 ± 0.09	0.59 ± 0.08
Palayamkodan leaf (PaL)	7.52 ± 0.51	2.51 ± 0.40	1.45 ± 0.43	0.49 ± 0.13	0.16 ± 0.31	0.33 ± 0.01
Palayamkodan stem (PaS)	4.15 ± 0.18	2.12 ± 0.20	1.23 ± 0.33	0.88 ± 0.31	0.49 ± 0.10	0.39 ± 0.08

* Amount obtained for 3 g of dried plant samples

N1; Kindle, N3; Poovan, N4; Nalipoovan, N7; Palayamkodan

KL;Kindle leaf, KS; Kindle stem, PL; Poovan leaf, PS; Poovan stem; NL; Najalipoovan leaf, NS; Najalipoovan stem, PaL; Palayamkodan leaf, PaS; Palayamkodan stem.

Numbers represent means ± one standard error (SE) of the mean

Table.12 Proximate analysis of male flower of Musa varieties (J1, J2, J3, J4) in Kerala.

Sample	Moisture (%)	Crude protein (%)	Crude fibre (%)	Ether extract (%)	Total ash (%)	Gross energy (kcal/kg)
Poovan flower (PF)	9.51 ± 0.34	13.52 ± 0.32	19.26 ± 0.28	5.23 ± 0.11	11.02 ± 0.24	3687 ± 121
Etha flower (EF)	9.56 ± 0.22	13.09 ± 0.27	14.95 ± 0.21	5.05 ± 0.34	9.53 ± 0.34	3725 ± 58
Palayamkodan flower (PaF)	9.22 ± 0.18	14.37 ± 23	25.55 ± 0.86	4.99 ± 0.22	11.78 ± 0.18	3669 ± 89
Najalipoovan flower (NF)	8.75 ± 0.37	13.51 ± 0.35	12.53 ± 0.29	5.22 ± 0.32	9.05 ± 0.21	3795 ± 54

J1; Poovan, J2; Etha, J3; Palayamkodan, J4; Najalipoovan
PF;Poovan flower, EF; Etha flower, PaF; Palayamkodan flower, NF; Najalipoovan flower;
Numbers represent means ± one standard error (SE) of the mean

Table.13 Proximate analysis of male flower of Musa varieties (J1, J2, J3, J4) in Kerala.

Sample	Moisture content (%)	Organic matter* (g)	Organic carbon* (g)	Crude ash* (g)	Acid insoluble ash* (g)	Acid soluble ash* (g)
Poovan flower (PF)	7.54 ± 0.34	2.14 ± 0.38	1.20 ± 0.28	0.86 ± 0.12	0.09 ± 0.22	0.75 ± 0.08
Etha flower (EF)	5.55 ± 0.29	2.23 ± 0.21	1.25 ± 0.21	0.77 ± 0.31	0.09 ± 0.11	0.68 ± 0.18
Palayamkodan flower (PaF)	5.19 ± 0.22	2.14 ± 0.27	1.20 ± 0.20	0.86 ± 0.12	0.24 ± 0.04	0.62 ± 0.05
Najalipoovan flower (NF)	8.56 ± 0.12	2.21 ± 0.15	1.24 ± 0.46	0.79 ± 0.11	0.14 ± 0.12	0.65 ± 0.09

* Amount obtained for 3 g of dried plant samples
J1; Poovan, J2; Etha, J3; Palayamkodan, J4; Najalipoovan
PF;Poovan flower, EF; Etha flower, PaF; Palayamkodan flower, NF; Najalipoovan flower;
Numbers represent means ± one standard error (SE) of the mean

Fig.1 The evolution of the banana complex:*M. acuminata*; B, *M. balbisiana*. Genotypes known to occur naturally are encircled, those known only from experiment are not encircled (adopted from Simmonds and Shepherd, 1955).

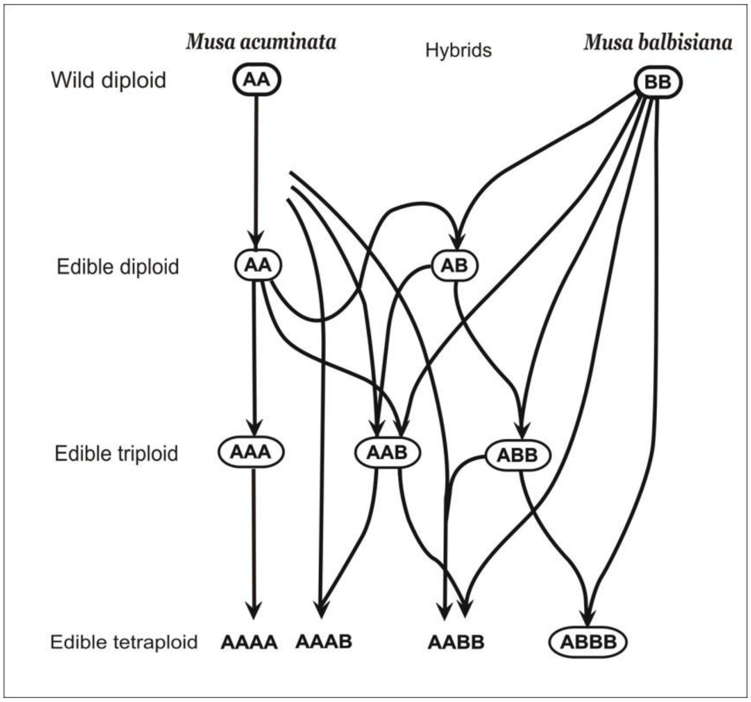

Fig.2 Description of pseudostem/suckers of banana.

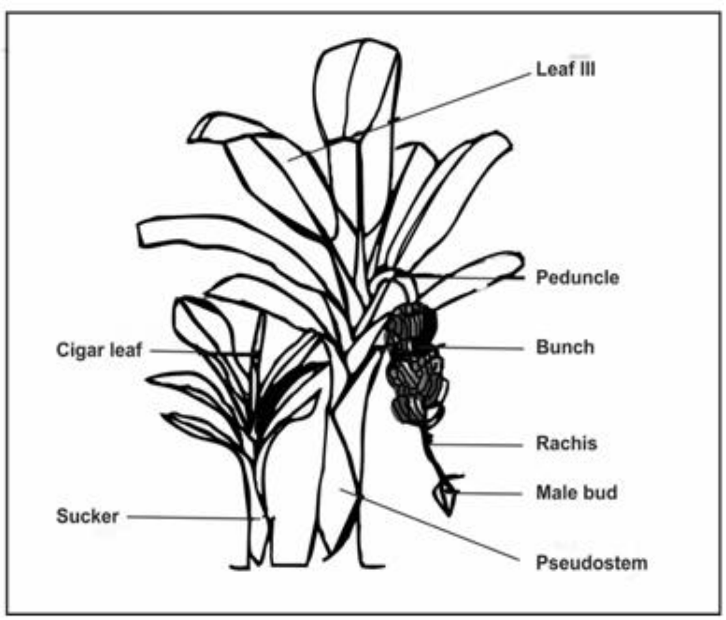

Fig.3 General morphology A) habitat (A1, suckers; A2, pseudostem; A3, petiole base; A4, inflorescence; A5, petiole; A6, leaf base; A7, 3rd leaf), B) inflorescence at early stages (B1, peduncle; B2, sterile bract; B3, female bud; B4, female flowers; B5, female bract), C) female flower (C1, ovary; C2, free tepal; C3, compound tepal; C4, stigma), D) compound tepal, E) free tepal, F) pistil with staminodes (F1, ovary; F2, staminodes; F3, style; F4, stigma), G) c.s of ovary, H) infructescence (H1, peduncle; H2, fruits; H3, rachis; H4, male bract; H5, male bud), I) male flower, J) rudimentary pistil with stamens (J1, rudimentary pistil; J2, stamens), K) fruit hand (K1, pedicel; K2, fruit; K3, fruit apex).

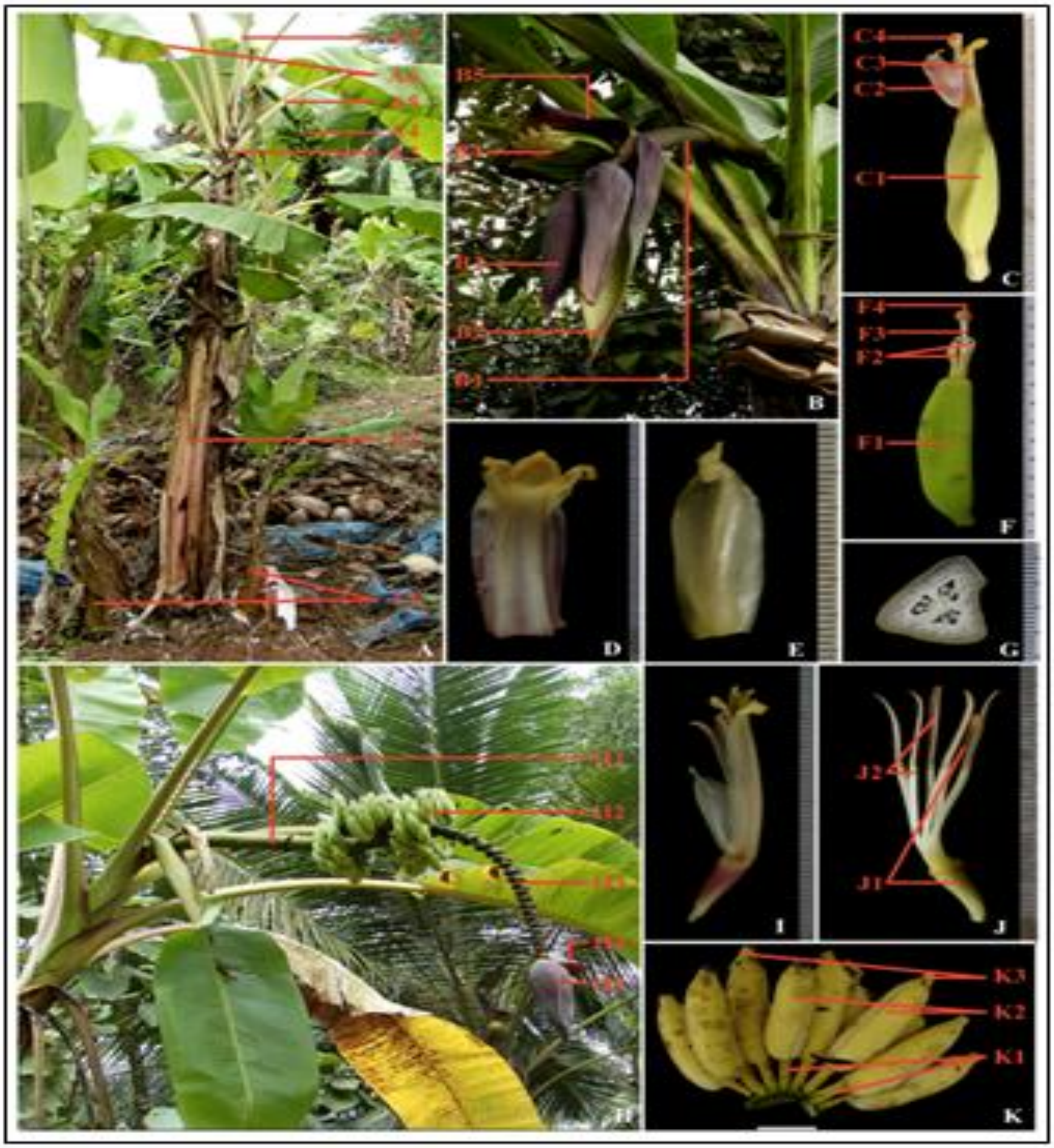

Fig.4 Different Research and development of nutraceutical/bioactive components from banana by-products. Adapted from Padam et al., 2014.

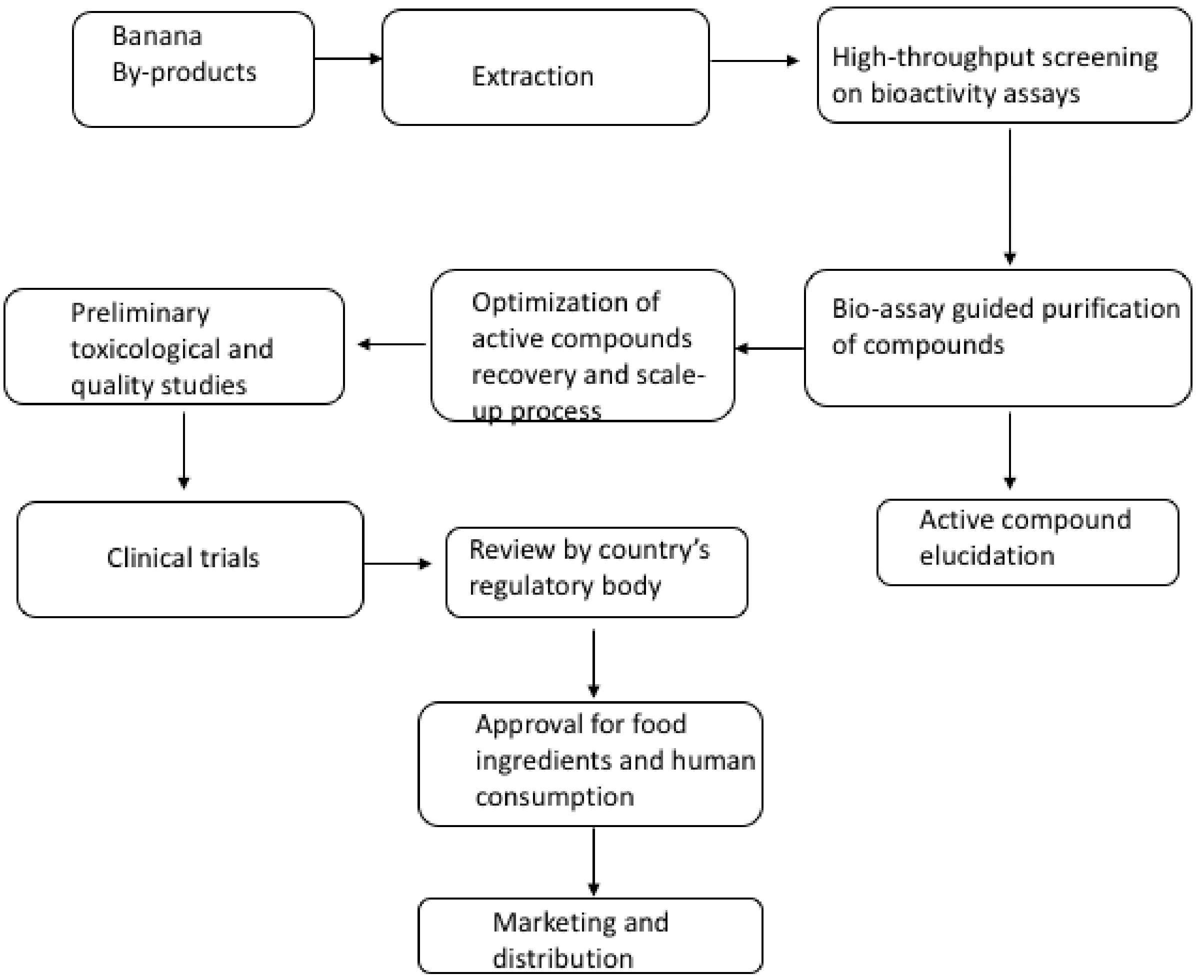

Fig.5 Different Schematic diagram illustrating the utilization of banana by-product processing for food and non-food. Adapted from Padam et al., 2014.

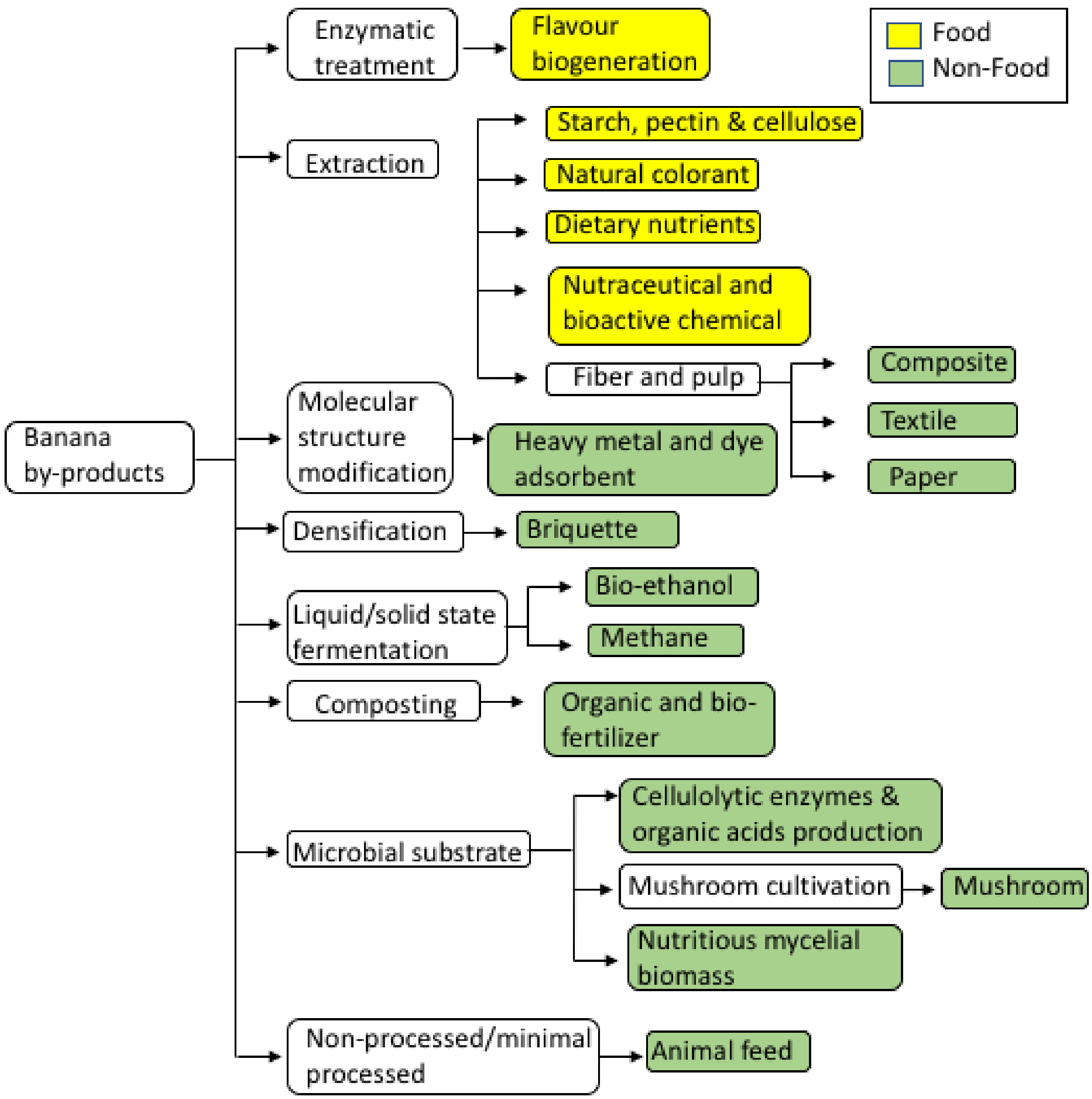

Fig.6 Schematic diagram illustrating various processed and unprocessed products derived from banana. Adapted from Mohapatra et al., 2011.

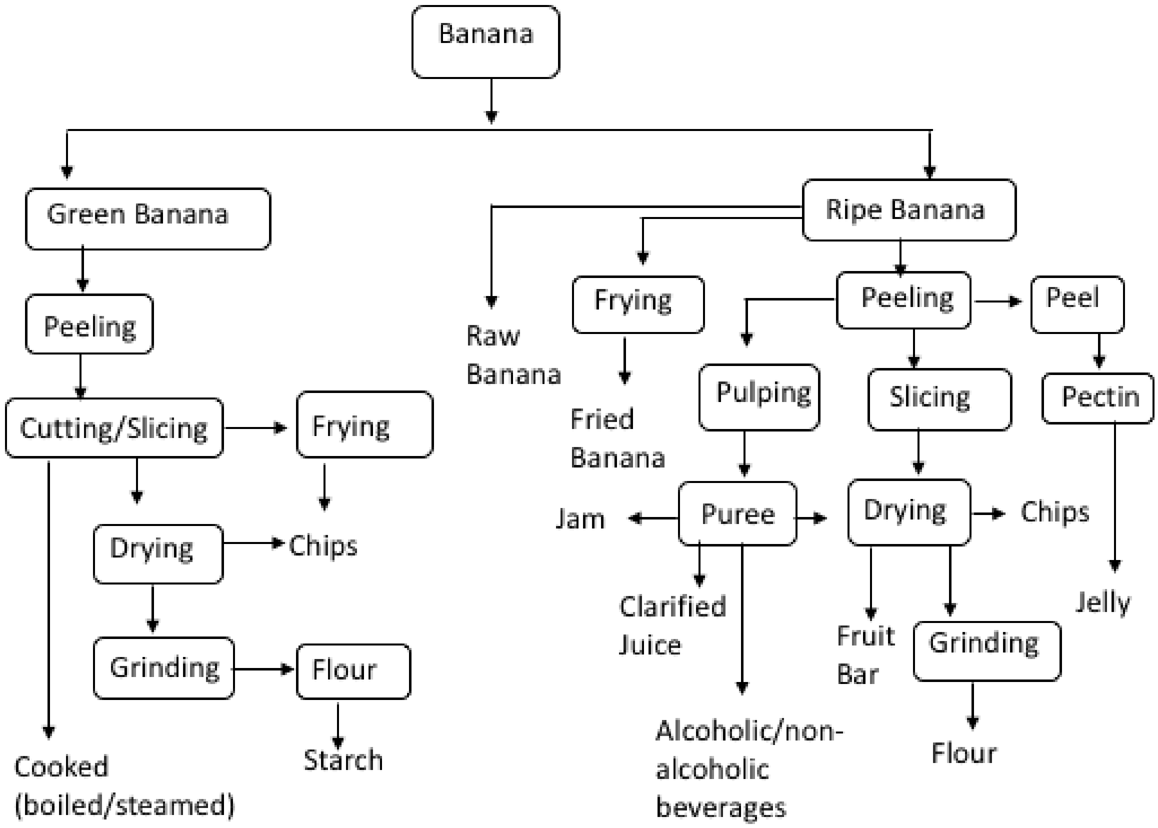

Fig.7 Description of Corm weevil (Cosmopolites sordidus) a) rhizome damage caused by the weevil, b) adult weevils, c) corm damage due to weevil attack, d); e); f); and g) larvae of weevil, h) adult weevil. Photo courtesy: NRCB.

Fig.8 Description of Pseudostem weevil (Odoiporus longicollis) a) larvae of the weevil, b) sap coming from the pseudostem during the early stage of attack by the weevil, c) section of the pseudostem showing the damage caused by the larvae, d) and e) damage on the outer pseudostem, f) eggs of the weevil, g) adult weevil black in colour, h) adult weevil red in colour. Photo courtesy: NRCB.

Fig.9 Description a) young banana plant covered with newspaper to protect from sunlight, b) rachis, c) and g) ripe banana fruit, d) wet snacks made from rice flour kept for drying in banana leaf, e) banana fruit bunch, f) developing banana fruit.

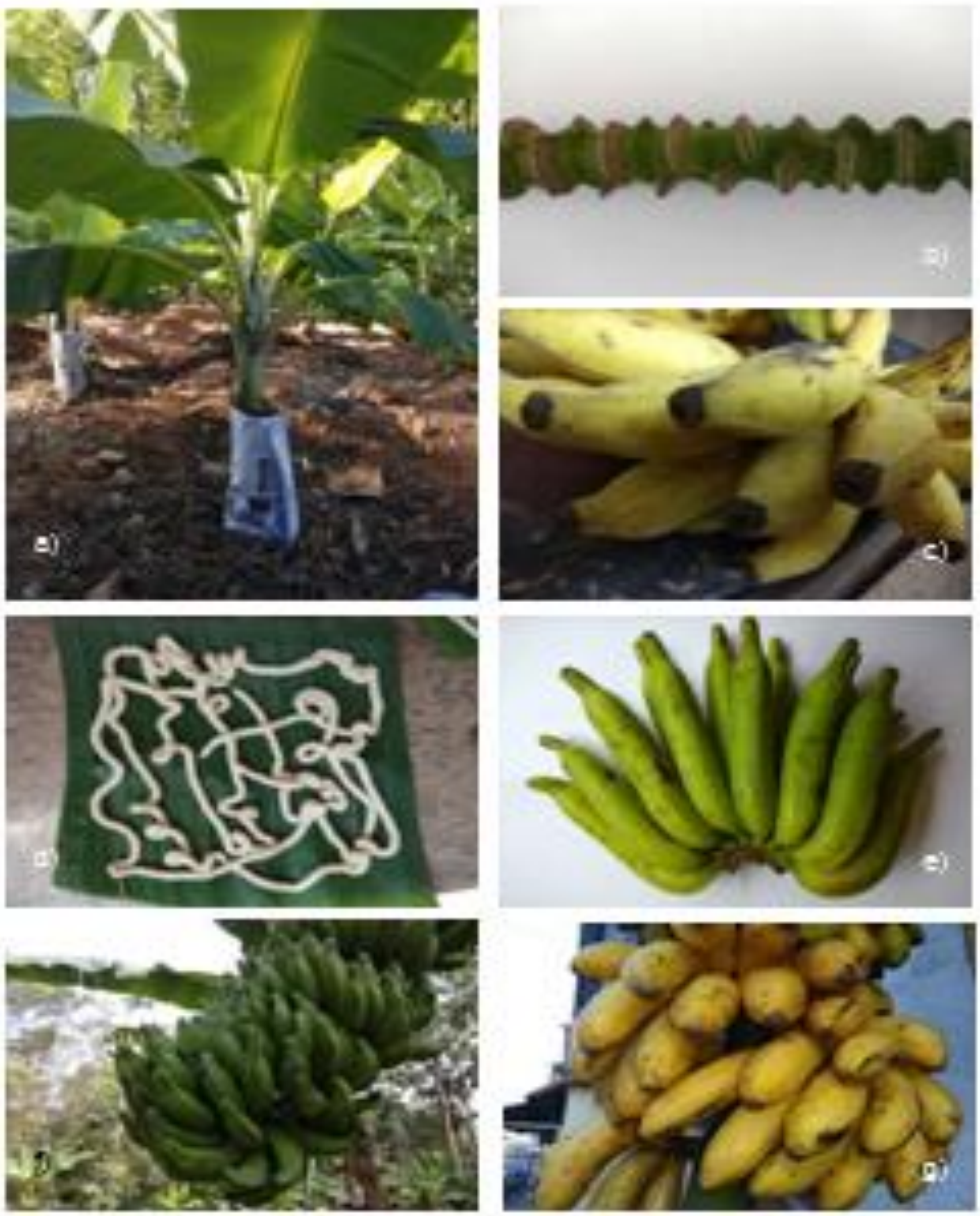

Fig.10 Description of a) banana rachis with small extra set of fruits b) mature banana fruits for sale in shop c) banana chips, d) handicraft made from banana fibre, e) processed banana fibre.

Fig.11 Banana value added products. Adapted from Anyasi et al., 2013.

Banana wine

Banana wine is produced by fermenting the enzyme treated clear banana juice with wine yeast viz. *Saccharomyces cerevisae* var. ellipaoiswua. The fermentation is carried out for about 3 weeks followed by filtration, clarification, and bottling. The pasteurized wine is stored in bottles for aging. The alcohol content of banana varies from 9-12% (Bornare *et al.*, 2014).

Health drinks and baby food

A highly nutritious and tasty health drink formulations and baby food formula has been developed by National Research Center for Banana (NRCB) using banana flour/powder after supplementing with suitable natural source of proteins, minerals, vitamins and fat. It has got a shelf life of about 6 months and suitable is for children and adults (Bornare *et al.*, 2014).

Animal feeds

The demand for food from animal sources triggered the increase in productivity of domestic animals utilizing feeds with higher nutritive value and cheap cost. Therefore, it is important to utilize inexpensive materials not only to sustain the market of animal products but also an effort to search for new sources of animal feed by recycling underutilized wastes (Ulloa *et al.*, 2004).

Enhancement of nutritional value of banana waste through microbial fermentation is an important step in order to create high nutritional quality feedstock from low quality materials; protein and sugar content can be increased comparable to the soybean meal, which is a common ingredient in most animal feeds (Hong *et al.*, 2004).

Direct substitution of banana leaves and pseudostem (*Musa paradisiaca*) as forage in the diet of Ovin Martinik sheep shows no significant difference in carcasses quality compared to sheep feeding on normal hay forage diet (Marie-Magdeleine *et al.*, 2009).

Banana leaves are the best fodder because of its low partition factor, high ATP and high microbial biomass in a feeding experiment of pseudostem and leaves of banana (*Musa paradisiaca*) for ruminants (Amarnath and Balakrishnan, 2007). Banana roots (rhizome) have been noted to treat rabbits with coccidiosis where the oral administration of crushed *Musa paradisiaca* roots significantly reduces the fecal worm egg count in just over 2 weeks of treatment (Matekaire *et al.*, 2005).

Proximate analysis

On comparing the proximate analysis of fruit and peel of Musa varieties in Kerala many factors such as moisture content, amount of crude protein and crude fibre, percentage of ether, ash percentage, gross energy was calculated. Here Pachakadali fruit has the largest moisture content of 12.1 ± 0.74 % and Najalipoovan fruit has lowest moisture content of 6.98 ± 0.08%. Etha peel has largest moisture content of 10.45 ± 0.88% and Chemkadali peel has the lowest moisture content of 6.61 ± 0.14%.Crude protein content in fruit is largest for Kannan fruit with 6.55 ± 0.46% and lowest for Etha fruit of 3.93 ± 0.46%. Crude protein content in peel is more for Kannan peel with 16.59 ± 0.26% and lowest for Chemkadali peel of 4.36 ± 0.19%.Crude fibre content in fruit is more for Kannan fruit of 8.02 ± 0.81% and lowest for Palenkodan with 1.02 ± 0.81%. Crude fibre content in peel is largest for peel of Sundari with 28.43 ± 0.29% and lowest for Chemkadali of 1.47 ± 0.43%. Ether extract from fruit is largest in Kannan with 4.32 ± 0.17% and lowest for Najalipoovan with 1.02 ± 0.22%. Ether extract from peel is largest for Kannan with 8.25 ± 0.33% and lowest for Chemkadali with 1.13 ± 0.45. The total ash content in fruit is largest for Kannan fruit with10.22 ± 0.33% and lowest for Etha fruit with 2.28 ± 0.33%.Total ash content in peel is largest for Pachakadali with 11.81 ± 0.32% and lowest for Chemkadali with 2.97 ± 0.32%. The gross energy content of fruit is largest for Najalipoovan with 3756 ± 89kcal/kg and lowest for Pachakadali with 3560 ± 88 kcal/kg. The gross energy content of peel is largest for Robesta with 4043 ± 58 kcal/kg and lowest for Palenkodan with 3684 ± 75 kcal/kg respectively.

For the nutritional analysis of pseudostem and leaf of 4 different varieties, the samples were collected and tested for various factors such as moisture, crude protein, crude fibre, ether extract, total ash, crude ash, acid insoluble ash. The amount of crude ash obtained in pseudostem and leaf is high in kindle and the least was found to be in Palayamkodan. In pseudostem, moisture content ranges from 7.32-15.44 in different varieties with high value of 15.44 in Poovan along with the highest ether extract (2), but contained the least crude protein content whereas as in all the other varieties the content remain the same. Crude fibre ranges from 18.25-37.09 with high value of 37.09 in Njalipoovan. The total ash content varies from the range of 10.83-29.42, with majority be in Kindle.

Non-food usage of banana by-products

Natural fibers

Fiber industries have been eyeing on an alternative sustainable material that would eventually replace the usage of wood and pulp from the trees to make timbers, boards, textiles, and papers. Agricultural by-products from various sources are the main candidates because of its availability and mass production all year round (Reddy and Yang, 2005). Fibers can be obtained from numerous sources of agricultural commodity and its by-products such as jute, cotton, rami, kenaf, sisal, palm oil, banana, sugar cane, corn and wheat.

Fibers from the banana plant are comparable in physical strength and cellulose content to fibers obtained from other fibrous commodities by-products (Uma *et al.*, 2005) and have been extensively characterized from their fruit stalk (Oliveira *et al.*, 2006; Zuluaga *et al.*, 2009), pseudostem (Cherian *et al.*, 2008) and leaves (Oliveira *et al.*, 2007). A few studies have been published emphasizing the potential of banana fibers as the raw materials in making composite boards (Chattopadhyay *et al.*, 2010; Ibrahim *et al.*, 2010; Idicula *et al.*, 2005; Sapuan *et al.*, 2007; Savastano *et al.*, 2009).

Paper production is one of the commercial applications of banana by-products. The initiative in utilizing available nonwoody agricultural waste as raw materials for paper production offers a great potential in reducing the dependence on natural timbers, which is becoming more expensive due to the limited availability (Bastianello *et al.*, 2009). It was found that pseudostem from *Musa acuminata* Colla, cv. Cavendish could be used for pulp and paper processing, where the fibres showed interesting potentialities in terms of burst index and breaking length either alone or in combination with other common pulps (Cordeiro *et al.*, 2005).

Renewable fuel

The demand of hydrocarbon fuel as energy has been increasing rapidly throughout the years. Although the demand for energy is booming exponentially, the production and the discovery of new reserves of natural fossil fuels did not increase complementary fitting with the high demand. Moreover, the environmental effects of burning fossil fuels have been extensively debated around the world and the idea of using greener and more sustainable fuel to gradually reduce and replace fossil fuels were greatly considered (Hill *et al.*, 2006). Other aspects such as food security issues, efficient agricultural land utilization and the usage of non-edible sugars as fermenting substrate further strengthens this concept (Corma *et al.*, 2011).

Methane is an important fuel that powers many industries as well as household kitchen. It exists as gas and it is highly combustible compared to ethanol. Industrial methane is produced through extraction from natural gas fields and fermentation of organic matters such as sewage sludge, agricultural biomass and manure (Paepatung *et al.*, 2009; Vijay *et al.*, 2006). The conversion of banana waste cellular material into methane requires an anaerobic digestion of the plant matter in an airtight reactor with specific digestion parameter control. Methane gas is produced generally starting on day 30 for 30–100 days (Chanakya *et al.*, 2009; Clarke *et al.*, 2008). The developed method in producing methane from banana waste is considered clean and safe, as it does not require addition of sewage sludge or manure.

Briquettes are made from a densification process that improves the handling properties of raw material and enhancing the energy content of the biomass. Most cellular plant waste including banana cannot be converted directly into energy through combustion because of their low density, high volume, high moisture content, and a very low energy density. This shortcoming directly affects the transportation and storage of these solid matters (Mani *et al.*, 2006). Without proper processing, it is bulky and creates an incomplete combustion that may pollute the environment as well as may not be a viable source of energy.

Potential substrate for the production of non-food cellulose, celluloytic enzymes, organic acids and edible mushrooms

Cellulose is considered the most abundant organic substrate on earth and the main building blocks of plants. Before natural cellulose can be utilized as raw materials to produce sugars, fuel and animal feed, it is necessary for it to be hydrolyzed either via acid hydrolysis or by enzymatic hydrolysis using cellulolytic enzymes such as cellulases. Commercial cellulases are produced by microorganism typically by bacteria and fungi. They are important group of enzymes that are required for the industrial scale cellulose processing (Shafique *et al.,* 2004).

Banana by products have been identified to be a potential economical substrate for cellulolytic enzyme production and have been proven to support the growth of several microorganisms used in the production of cellulase in a solid-state fermentation system (SSF). Among various groups of microorganisms used in solid-state fermentation, the filamentous fungi are the most exploited due to their ability to grow on complete solid substrates and production of wide range of valuable extracellular enzymes (Boberga *et al.*, 2008).

Apart from being used as a substrate for cellulase and cellulolyic enzyme production, by-products such as leaves and pseudostem of the banana were also noted to be a potential substrate for the cultivation of edible mushrooms.

Heavy metals and dye absorbers

Heavy metals are regarded as a threat to the environment and the availability of these hazardous metals in wastewater such lead, chromium, cadmium, mercury and zinc pose a great health threat to humans as it might contaminate the drinking water system. Heavy metals are hardly biodegradable and can easily accumulate in living tissues making it concentrated as it goes up the food chain (Metcheva *et al.,* 2010).

Synthetic dyes are commonly used in some chemical assays, textile industry, and commercial products. A number of commercially used synthetic dyes have been reported contributing to health problems, which justified the need to remove these dyes from wastewaters.

Banana pseudostem (*Musa paradisiaca* cv. ‘Pisang Awak’ ABB) and stalk waste as a potential absorber of methyl red as well as methylene blue in aqueous solutions (Mas Harris and Sathasivam, 2009; Hameed *et al.,* 2008). Natural heavy metal and dye absorbers made from renewable low-cost banana by-products are relatively cheaper compared to synthetic and inorganic absorbers but may not work well in extreme conditions (high pH and high temperature) (Harris and Sathasivam, 2009).

Source of bioactive compounds for non-food purposes

A few literatures emphasize on the existence of bioactive compounds, which may not be directly applicable for human consumption readily available or available through induction from the banana by-products (Luque-Ortega *et al.,* 2004; Otalvaro *et al.*, 2007). These bioactive components are potential substitutes for industrial chemicals and functional compounds in pharmaceuticals as well as could be further exploited into numerous applications. These isolated bioactive compounds, which are generally secondary metabolites (produced naturally or induced) of the banana by-products were reported to have antiprotozoan, antifungal, and antiviral activity.

Organic fertilizers and bio-fertilizers

The usage of organic fertilizers and bio-fertilizers have gained momentum as a substitute to chemically synthesized fertilizers due to its reported effectiveness, the increasing cost of some chemical fertilizers and the awareness towards the hazardous effects of chemical fertilizers to human and the environment (Aseri *et al.,* 2008; Doran *et al.,* 2005). The technology in developing organic fertilizers also aims to manage, recycle and convert biodegradable solid waste into nutrient rich plant growth medium (Sim and Wu, 2010). Organic fertilizers and bio-fertilizers from plant and animal materials are generally processed through composting and solid state fermentation (SSF). A microbial starter consists of mixture of decomposing microorganisms and soil enhancing bacteria or selected worm species is generally added to initiate the composting process.

Enzyme production by Solid State fermentation (SSF)

The Aspergillus niger was subjected to solid state fermentation in pseudo-stem and leaf vein of different banana varieties (Ethan, Poovan, Palayamkodan and Kaali, AMS1, AMS2, AMS3, AMS4, AMV1, AMV2, AMV3, AMV4) which was used as solid substrates for fermentation. Each substrate was taken in about half inch thickness in all the fermentation trays and hydrated with 40ml of basal salt solution and adjusted with moisture content from 43-81%. 1% of inoculums was inoculated after sterilization and incubated at room temperature for 10 days.

Enzyme activity in the extracted enzymes from different substrates was determined by DNS assay. All the eight samples were found to be good substrates as the alpha amylase activity was seen in all the eight boxes. Notably, the maximum amylase activity were seen in Ethan vein (AMV1) (1.1 x 10-3 µ mols/min) followed by Palayamkodan-vein (AMV3) (0.60 x 10-3 µ mols/min), Kaali-vein (AMV4) (0.54 x 10-3 µ mols/min), Palayamkodan pseudo-stem (AMS3) (0.48 x 10-3 µ mols/min), Ethan pseudo-stem (AMS1) (0.45x10-3 µ mols/min), Poovan vein (AMV2) (0.43 x 10-3 µ mols/min), Poovan pseudo-stem (AMS2) (0.28 x 10-3 µ mols/min), Kaali pseudostem (AMS4) (0.25 x 10-3 µ mols/min). Dried Ethan vein is the most efficient substrate which produced amylase with maximum activity under the culture condition.

Phirke and Kothari (2005) discovered that turning banana waste into growth stimulating soil conditioner through solid-state fermentation and recycling it as fertilizers for banana farming greatly reduced the planted suckers' mortality, improving plant biomass and increasing fruit yield. It has been confirmed by Doran *et al.*, (2005) that organic fertilizer prepared from composting banana waste also stand out to be a cheaper and economical fertilizer with a significant effect on growth and yield of banana crop compared to chemical fertilizers and poultry manure. Banana waste was also reported to be a suitable carrier of Azospirillum, Azotobacter and phosphate-solubilizer bacteria to the soil cultivated with banana gave positive effects towards the availability of soil and banana foliar phosphorus content (Rivera-Cruz *et al.*, 2008).

Challenges and future prospects

As a newly emerging candidate for industry-driven application, a number of challenges have been identified prompting immediate attention before banana by-products can become a sustainable agricultural commodity. The focus on the utilization of any by-products or waste should always be transformed into high valued processed raw materials or products that meet market demands and creating substantial economic impacts (Jayathilakan *et al.*, 2012).

This is also the most important key aspects in the management of agricultural waste, as it will greatly determine the sustainability and viability of the by-product itself as a future commodity (Adinugraha *et al.*, 2005; Ngoc and Schnitzer, 2009). In other words, the market value of the newly developed products must be able to cover internal and external expenses of its production. The quality of the product and processed raw materials from banana by-products must be comparable or better than its counterparts to ensure market competitiveness. The technology and innovation through creative improvement of the existing processes may also be a key to guarantee the survival of the by-products (Lew *et al.*, 2011).

There are also limitations that need to be resolved at the plantation level especially in establishing a proper collecting facility for these by-products to be kept and sorted according to the types and quality and a handling system that would prevent the degradation of the biomass and valuable components. Lignocellulosic materials, for instance, bio-fibrous from agricultural waste degrade after a storage time reducing the quality of the bio-fibers (Adinugraha *et al.*, 2005).

Standardized storage and handling procedures of the by-products are needed in order to ensure the quality of the by-products remain stable prior to further processing.

Training and education needed to be given to farmers and plantation administrators on the varieties of banana, which its by-products have been proven to be of potentially valuable. In the future, natural biomasses such as the banana by-products are potential substitutes for our depleting non-renewable resources such hydrocarbon fuel and plastics (Tock *et al.,* 2010). Currently, there is an ongoing trend in utilizing low cost renewable agricultural waste as a raw material in making value added products to curb land degradation, increasing agricultural productivity, and reducing waste (Mohammadi, 2006). Banana by-products, which are available abundantly around the world, are renewable and sustainable as long as the global banana industry maintains its momentum.

Shifting towards the utilization of agricultural wastes such as the banana by-products is also seen as an environmental friendly approach to reduce environmental problems due to the improper management of the wastes. Its versatility and usefulness as raw materials in many food and non-food industries provides good and solid prospects as the potential income generating commodity of the future. As a commodity, not only it will benefit both banana farmers and the industry but also provide alternatives in terms of generated products to consumers.

Diseases and pests of edible banana became problems when certain genotypes were grown as monocultures. Fusarium wilt and Sigatoka leaf spot were also affect the banana production in South-India. Bacterial wilt and Xanthomonas wilt are other bacterial diseases affecting the banana production. Bunchy top and bract mosaic are damaging virus diseases, which have a limited distribution at present. 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 plant, apart from leaves and fruits.

Recycling and the utilization of agricultural by-products and waste for the creation of commercially viable and income generating products is not a new topic, however, the need to utilize available and abundant resources to the fullest such as the banana by-products is deemed important as to reduce the emission of solid waste and loss of valuable untapped biomass. This is an ongoing issue that require constant attention and monitoring in order to be a developed nation, improving the standard of living while preserving as much as our natural resources. There are unlimited possibilities of utilizing these renewable resources innovatively in fulfilling the need in the areas, which have been previously discussed as well as identifying new areas yet to be explored. Bearing in mind, the immediate challenge would always be the innovation of research towards creating high value and quality products with economic impacts.

Banana, consisting of numerous well-known varieties and cultivars, has been explored and the by-products such as pseudostem, rhizome, leaves, fruit stalks, and peels from the common varieties to some extent are potential raw materials in areas of food and non-food industries, providing each different application. Banana by-products which have been assessed and found to have potential application for food additives, nutraceuticals, food supplements, feeds, renewable fuel, fibers, source of bioactive and other organic chemicals, fertilizers as well as contaminant absorbers should be further addressed for its safety aspects to meet the market requirement. Standardized collection procedure and processing of banana by-products needed to be resolved in order to create a viable setting for these unprocessed raw materials to be available for industrial scale processing. The exponential increase of world's population and the trend towards the utilization of eco-friendly and viable agricultural by-products creates a steady platform for the continuation of innovation on development of products from the banana by-products and waste, thus, making it a sustainable income generating commodity. Generating wealth from waste such as from the banana by-products should be regarded as one of the ways to create an eco-friendly environment for the future generations.

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