Chapter 1

Introduction

1.1 The background and the biology of *Musa*

Banana belongs to the family *Musaceae*, genus *Musa*, is a general term embracing a number of species or hybrids in this genus. The name *Musa* is from the Sanskrit, Moca, via its Arabic counterpart, *mauz*. Bananas descended from two wild ancestors: *Musa acuminata* and *Musa balbisiana*.[1] It is originated in Southeast Asia, and is the native of India and the Western Pacific.[2] It was further introduced in Africa in ancient times and taken by European explorers to the Americas and other parts of the world.[3, 4] Currently, throughout the world, it is widely cultivated in tropical and subtropical regions as one of the important staple food and commodities.[5] The majority of edible banana cultivars are derived from inter and/or intra specific hybridization of diploid (2n = 2x = 22; AA; BB or AB), triploid (2n = 3x = 33; AAA; AAB; or ABB) and tetraploid (2n = 4x = 44; AAAA; AAAB; AABB; or ABBB) from subspecies of *Musa acuminata* Colla (A genome) and *Musa balbisiana* Colla (B genome).[6-8]

As per the report of Daniells [9] India is ponder to be the major centre for *Musa acuminata* hybridization with native *Musa balbisiana* and the region is well known for the extensive variety of AAB and ABB cultivars. *Musa balbisiana* is considered to be more drought and disease resistant than *Musa acuminata* and such characteristics are often found in B genome cultivars. The formation of heterogenomic triploid hybrids with the 'AAA' genotype occurred within *Musa acuminata* leading to the development of cultivars that encompassed the sweet bananas. Crosses of the diploid and triploid types of *Musa acuminata* with *Musa balbisiana* led to the formation of heterogenomic triploid hybrids that are mainly plantains (AAB) and other cooking bananas (ABB). Table 1.1 describes some genome nomenclature for some common cultivars of India.

Table 1.1 Examples of genome nomenclature for some common cultivars (with emphasis on cultivars grown in India)[10]

Genomic group	Sub-group	Common cultivars
AA	Sucrier	Chingan, Matti, Kadali, Anai koomban
AB	Ney poovan	Ney poovan, Safed velchi, Soneri, Devabale, Puttabale, Elakki bale

	Dwarf Cavendish	Basrai, Loton, Kabuli, Vamankeli, Pachavazhai, Pachabale, Kuzhivazhai, Mauritus, Bhusaval
AAA	Giant Cavendish	Harichal, Bombay green, Pedda pacha arati, Bongali jahaji
	Red and Green red	Chenkadali, Lalkel, Venkadali, Sevvazhai, Anupan, Red banana
	Mysore	Poovan, Lal velchi, Champa, Karpura chakkarakeli
	Silk	Rasathali, Mutheli, Morthoman, Marlaban, Malbhog, Sabari, Sonkel, Rasabale, Amrithapani, Nanjangudu rasabale
AAB	French Plantain	Nendran, Rajeli, Ethakai, Myndoli
	Pome	Virupakshi, Sirumalai, Vannan, Malavazhai, Dacca martaban
ABB	Bluggoe	Monthan,Bankel, Madhurangabale, Peyan, Khasadia, Kanchkala
	Pisangawak	Kostha bontha, Pey kunnan, Manuva kola
AABB		CO-1 (A new hybrid)

1.2 The production

Banana and plantains, one of the most favorite fruits, widely grown in many countries, being the fourth most important food crop in the world as well as in India is a staple food and export commodity.[11] It contributes to the food security of millions of people in the developing world. Gazing at the recent world banana production scenario of 2013-2014, globally, banana (*Musa* sp.) is grown in 5.034 million ha area producing 106.84 million tonnes of banana and plantain with 21.2 MT/ha productivity.[12] India is the largest producer of plantain and bananas with annual production of 29.78 MT from an area of 0.83 million ha with 37 MT/ha productivity accounting 27.8% of the world's production followed by China (Fig. 1.1) in the year 2013-2014.[12] The most important banana producing states in India including its percentage productivity is shown in Fig. 1.2. In India, *Musa* species is well adopted in the regions varying from tropics to humid sub-tropics and semi-arid subtropics. Both plantains and banana are the staple foods for rural and urban consumers in India and an important source of income.[13]

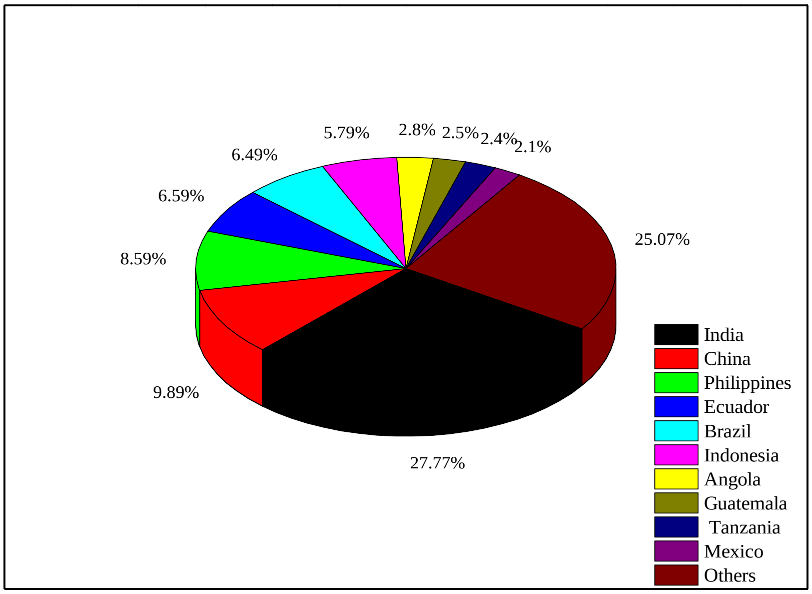

Fig. 1.1 The world banana production scenario (2013-2014)[12]

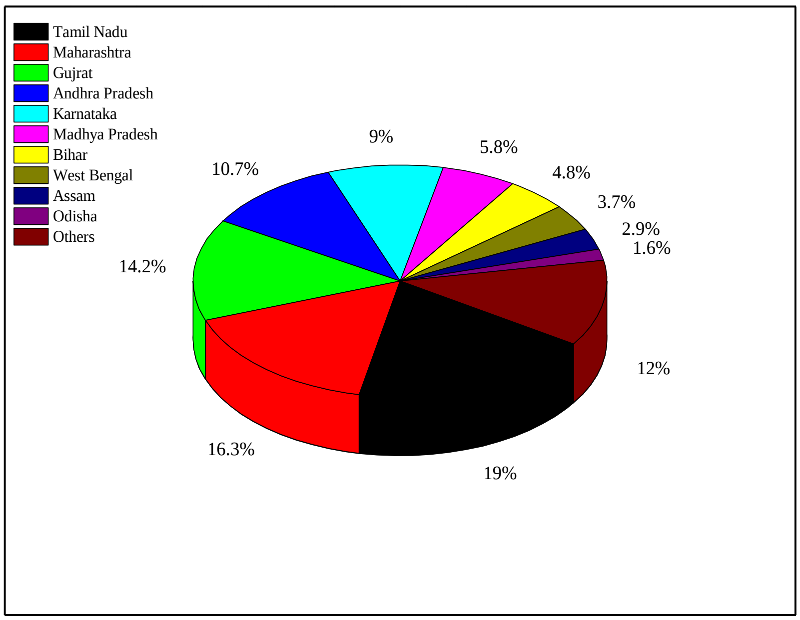

Fig. 1.2 Major banana producing states of India (2013-2014)[12]

Coming across the difference between banana and plantains, many people tend to get confused these two varieties. Daniell[9] stated that the word banana refers to all members of the genus *Musa* whereas plantain refers to a subset of banana. Usually the term plantains are starchy, low in sugar variety that is cooked before serving as it is unsuitable to consume raw. It is more or less used in many savory dishes like a potato especially frying and baking.[14] Ever since India is recognized as one of the leading centers of origin and diversity of *Musa* species at global level alongside South East Asian countries, this species is well adopted in the regions varying from tropics to humid sub-tropics and semi-arid subtropics.[15] As reported by Wainwright and Burdon[16] both plantains and banana are the staple foods for rural and urban consumers in India and an important source of income. Traditionally, bananas are usually eaten raw as desert while plantain and cooking bananas on the other hand are habitually grown for cooking as a part of staple diet or for processing of more durable products such as flour that can be stored for later use. Alternatively plantains embrace immense cultural significance in India. According to the book, "The Popular Religion and Folklore of Northern India," plantains are considered sacred. They are used in marriage ceremonies and many other religious rituals, as tradition they hold the plantain branch and sits near the sacred fire around which the bride and groom walk.[17]

1.3 Banana the potential food for health

A healthy diet consists of eating a variety of foods from five food groups but in the correct proportions. These include foods containing starch, fruit and vegetables, milk and dairy food, protein, fats and sugars. Bananas fall in the fruit and vegetable group as well as the food group which mostly contain starch. Sweet dessert bananas are generally eaten raw (fruit), while cooking bananas and plantains are boiled, steamed, fried or roasted (food). Any food containing carbohydrates should be the main part of our daily meals. In unripe bananas the carbohydrates are mostly starches. In the process of ripening the starches are converted to sugars; a fully ripe banana has only 1-2% starch.[18] According to UNCST[19] eating a variety of good foods that provides nutrients to maintain health, feels good, and has energy. These nutrients include protein, carbohydrates, fat, water, vitamins, and minerals. Plantains and banana belong to the food group which is a reliable source of starch, energy and dietary fibre.[20]

Plantain has more calories weight than fruit banana. 100 g plantain consists of 122 calories, while banana has 89 calories and banana resistant starch consumption promotes lipid oxidation.[21] Indeed, they are very reliable sources of starch and energy ensuring food security for millions of households worldwide. Bananas have been classified as one of the antioxidant foods by Kanazawa and Sakakibara[22] They are known as a weak primary antioxidant source but a powerful secondary antioxidant source.[23-25] Recently, much attention has been focused on the activity of natural antioxidants present in fruits, because these components may potentially reduce the level of oxidative stress,[26] i.e. preventing free radicals from damaging proteins, DNA and lipids.[27] Besides, they are also scientifically proven for their synergistic effects and protective properties against various degenerative disorders including cancer, stroke, cardiovascular, Alzhemier's disease and Parkinson's disease.[28, 29] These tropical fruits have strong ability to protect themselves from the oxidative stress caused by the intense sunshine and high temperature by increasing their antioxidant levels. They are known as a powerful secondary antioxidant source. The antioxidant compounds identified in bananas include ascorbic acid, tocopherol, beta carotene, phenolic groups, dopamine and gallocatechin.[30]

Astringent taste of unripe banana is due to phenolic compounds. Bananas are also rich in dopamine antioxidant. According to Ramcharan and George[31] the role of banana and plantain is becoming more important with the increasing emphasis today on diets that are low in sodium but high in potassium and vitamins. Both banana and plantains are good source of potassium, vitamin A, vitamin C, vitamin B6 and low in sodium. Bananas contribute about 2.7% of the total potassium and fiber consumed by the average adult.[32]

The carbohydrate type in banana is resistant starch and non-starch polysaccharides, which have low glycemic index or low digestibility.[33] This property makes banana excellent ingredient for different functional and convenience foods like cookies and chips.[34] According to the report of Kumar et al.[35] bananas are an excellent source of potassium. Potassium can be found in a variety of fruits, vegetables, and even meats, however, a single banana provides with 23% of the potassium that is needed on a daily basis. The contribution to the intake of sugars, fiber, vitamins, and minerals from the consumption of bananas is high, with a very low contribution to the intake of fat. Bananas, consumed cooked or raw, either as the green, half ripe or ripe fruit, are one of the most significant sources of calories for the human diet worldwide and orange-fleshed bananas are rich in provitamin A and other carotenoids. Provitamin A carotenoids (including beta-carotene) are important for protecting against vitamin A deficiency and anemia (as vitamin A is involved in iron metabolism). Carotenoid-rich foods may also protect against diabetes, heart disease, and certain cancers.[36] Worldwide, vitamin A deficiency is the most common form of malnutrition after protein deficiency. In parts of Asia, Africa and Latin America, vitamin A deficiency occurs in millions of children[37] and therefore plantain and banana could be an important source of provitamin A for the people of those regions.

Englberger et al.[38] stated that bananas are an ideal food for young children and families for many regions of the world, because of their sweetness, texture, portion size, familiarity, availability, convenience, versatility, and cost. Foods containing high levels of carotenoids have been shown to protect against chronic disease, including certain cancers, cardiovascular disease, and diabetes. Because the coloration of the edible flesh of the banana appears to be a good indicator of likely carotenoid content, it may be possible to develop a simple method for selecting carotenoid rich banana cultivars in the community. Thus, banana cultivars rich in provitamin A carotenoids may offer a potential food source for alleviating vitamin A deficiency, particularly in developing countries. Many factors are associated with the presently known food sources of vitamin A that limit their effectiveness in improving vitamin A status.

1.4 Effect of ripening stages on the biochemical and nutritional properties of banana

Maturation is the stage of development leading to the attainment of physiological or horticultural maturity. It is a developmental stage of the fruit on the tree, which will result in a satisfactory product after harvest. Physiological maturity refers to the stage in the development of the fruits and vegetables when maximum growth and maturation has occurred. It is usually associated with full ripening in the fruits. The Physiological mature stage is followed by senescence. Commercial maturity is the state of plant organ required by a market. It commonly bears little relation to physiological maturity and may occur at any stage during development stage. Harvest Maturity may be defined in terms of physiological maturity and horticultural maturity, it is a stage, which will allow fruits and vegetables at its peak condition when it reaches to the consumers and develop acceptable flavour or appearance and having adequate shelf life.

The effects of ripening on the chemical composition and functional properties of plantains and banana at different levels of ripening stages have been studied by various researchers. According to the report of Tapre and Jain[39] dramatic changes in banana peel colour and pulp texture occur during the rise in respiration during storage of climacteric fruits. The changes occurred during ripening are in physical, mechanical and chemical properties of banana fruits. Skin colour changes from green to yellow, firmness is decreased, fruit gets softened and starch is converted into sugar.[40-42] Mainly colour changes in banana during ripening are based on the peel colour rather than the pulp colour and hence colour of banana peel has been used in the assessment of the stages of ripeness of banana. Knowing the physical and mechanical properties of banana fruit and changes in these parameters during different ripening stages is the most important attributes to design handling, sorting, peeling, processing and packaging system. Knowing these properties of agricultural products would help designer engineers to apply forces and dimensions of machine's units properly to protect fruits from bruises, injuries, decay lesions and numerous other defects that emanate as results of post-harvest processing treatments. In many fruits such as banana and mango, the level of ripeness associates with physical and mechanical properties of fruits.

Tapre and Jain[39] in their studies reported significant increase in moisture content of the pulp was observed from early development stage to mature stage. The increase in pulp moisture content during ripening may be due to carbohydrate breakdown and osmotic transfer from the peel to pulp.[43] An increase of water content in pulp of two cooking banana hybrids with progress in maturity was attributed to utilization of carbohydrates during breathing and osmotic transfer from peel to pulp.[44] A significant decrease in ash and protein content with increase in maturity has been reported by various authors.[45, 46] Adeyemi and Oladiji[47] reported that ash content of ripening plantain is affected by developmental stage and unripe plantain contains higher ash content compared to ripe ones. Another reason for variation in ash might be due to differential absorption capacity of minerals at different stages of development. Goswami and Borthakur[48] observed a decline in protein content in culinary banana with maturity and attributed to protein breakdown and the resulting amino acids being utilized in gluconeogenesis. They also reported lower amount of fat content in culinary banana which was higher during early developmental stages and gradually decreased with increasing maturity. The crude fiber content in unripe and ripe plantain and increased significantly with progress of maturity. The increase in fiber content at matured stage over tender stage might be due to increase in soluble and insoluble dietary fractions.[49] In plantains and bananas the various reports on total carbohydrates content increased from early developmental stage to matured stage. The variation in carbohydrate contents during growth might be due to degradation of starch for synthesis of sugars.[44]

The most prominent chemical change that occurs during postharvest ripening of banana, cooking banana and plantain is the hydrolysis of starch and the accumulation of sugars, i.e. sucrose, glucose and fructose (Palmer, 1971) which are responsible for sweetening the fruit as it ripens.[50] According to Sakyi-Dawson et al.[44] during ripening of plantains and bananas the starch content decreased considerably with fruit growth and development and the decrease in starch content of the cooking banana was faster than that of the plantains. In dessert bananas (e.g. Cavendish) the breakdown of starch and the synthesis of sugars are usually complete at full ripeness, while in plantains the breakdown is slower and less complete and continues in overripe and senescent fruits.[42] The decrease in starch content is explained by the degradation of starch and the formation of free sugars under the action of enzymes. Yang and Hoffman[51] stated that during ripening process, starch is converted into sugar, through enzymatic breakdown process.

Cordenunsi and Lajolo[52] also reported that the disappearance of the starch reserve during banana ripening appears to be relatively rapid because of the activities of several enzymes working together. Amylase, glycosidase, phosphorylase, sucrose synthase and invertase can act in the degradation of starch and the formation and accumulation of soluble sugars. Starch levels can vary with maturity stage of fruit variety and cultivation and ripening conditions.[45] Since the sugar content of fruits increases during ripening, it can effectively be used as an indicator of ripening or to predict the stage of fruit ripening.[53] Yang and Hoffman[51] stated that during ripening process, starch is converted into sugar, through enzymatic breakdown process. In *Musa* AAB group, starch contains declines from 20-30% to 1-2%, but starch amount could be as high as 11% depending on plantain variety. According to Emaga et al.[54] ripe banana pulp contains (0.7-1.2%) pectin. During ripening, insoluble proto-pectin is converted into soluble pectin that causes loosening of cell wall and texture degradation of fruit. Hence, stages of ripening of banana plays important role in chemical, physical and functional properties of the fruit. Even within a cultivar, there is large plant-to-plant variation and within-plant also variation might occur in nutrient composition for fruit harvested from the same field.[55]

1.5 Utilization of banana and plantain as value added products

India being the first major producer of banana, 20-30% of the production is wasted every harvest season during transport or lack of compliance with the normal commercialization standards for fresh fruits. Wide ranges of processing operations are employed before plantain is consumed and they include boiling, roasting or baking, frying and drying.[56] Cooking bananas are used in a wide range of food dishes of varying regional importance. They appear to be a potential market for a wider range of snack products produced from these commodities in the target countries, including the production of several popular alcoholic and non-alcoholic beverages. The conversion of cooking bananas into flour, wine, beer, and weaning food products (extruded and high protein, low cost) is the way of adding value to the crop as well as extending the shelf life of derived foods.[57] Flour is an important raw material in the baking and confectionery industry. The demand for flour in bakery products is increasing globally and banana flour is currently being exploited in baking and complementary weaning foods.[57] New economical strategy to increase utilization of banana includes the production of banana flour when the fruit is unripe, and to incorporate the flour into various innovative products such as slowly digestible cookies[34] and high-fibre breads.[58]

Shiau and Yeh[59] stated that it would be possible to utilize the green pulp as a functional ingredient in starch-rich products such as the yellow noodles. Saifullah et al.[60] prepared banana pulp noodles by partial substitution of wheat flour with green Cavendish banana pulp flour and studied pH, color, tensile strength and elasticity, and in-vitro hydrolysis index (HI) and estimated glycaemic index (GI). In their study they found that banana flour noodles had higher tensile strength and elasticity modulus than control noodles. They also reported that in-vitro starch hydrolysis study, it was found that GI of banana flour noodles was lower than control noodles. Value addition of banana and plantain can be done in many different ways, such as frozen puree, juice, figs, jams and canned banana slices.[61] Seasonal gluts and perishability of ripe bananas and plantains caused great economic losses and therefore there is tremendous interest in the development of modes of processing and preserving these fruits.

1.6 Banana peel

1.6.1 Prospects for utilization as by-products

The peel of banana represents 40% of the total weight of fresh banana[62] and has been underutilized and discarded as waste. Like its pulp flour counterpart, banana peel flour can potentially be used in new products with standardized composition for various industrial and domestic uses.[63] Peels are the major by-products of all fruits and vegetables obtained during processing; some studies have shown that these are good sources of polyphenols, carotenoids and other bioactive compounds which possess various beneficial effects on human health.[64] But these wastes are either uneconomically utilized or disposed of as they are, thereby causing serious pollution problems. Of particular interest is the finding that banana peel extract contained higher antioxidant compounds than that of the fruit thus promising a more intense utilization of the peels in food and nutraceuticals. Potential applications of banana peel however depend on its chemical composition as well as physicochemical and functional properties.[63] Banana peel waste is a byproduct of banana processing during the production of food such as banana chips and baby foods. The edible part of banana constitutes only 12% weight of the plant; the remaining parts become agricultural waste and cause environmental problems.[65] However, the problem can be recovered by utilizing its high value compounds, including the dietary fiber fraction that has a great potential in the preparation of functional foods.[66]

1.6.2 Chemical properties and bioactive compounds present in banana peel

The peels of a variety of fruits and vegetables have gained much attention as a natural source of antioxidants and phytochemical contents which are rich in compounds with free radical scavenging activity. Banana and plantain peels are the major agricultural wastes which have been used as medicine, animal feeds, blacking of leathers, soap making, fillers in rubber. Banana peel being an key source of many functionally important bioactive compounds are still underutilized and very little scientific effort has been put to identify its functionality in terms of application to food and nutraceuticals. Banana peel can potentially offer new products with standardized composition for various industrial and domestic uses.[67, 68] As reported by Emaga et al.[54, 63]

banana peel is rich source of dietary fiber (50% on a dry matter basis), protein (8-11%), crude fat (3.8-11%), lipid (2.2-10.9%) pectin, essentials amino acids (leucine, valine, phenylalanine and threonine), polyunsaturated fatty acids mainly (linoleic acid and α-linolenic acid) and micronutrients like (potassium, phosphorous, calcium, magnesium etc.) They also reported that all essential amino acids content are higher than FAO standard except for lysine. Pectin extracted from banana peel also contains glucose, galactose, arabinose, rhamnose, and xylose. Maturation of fruits involves, increase in soluble sugar, decrease in starch and hemicelluloses, and slight increase in protein and lipid content in fruit peel. Degradation of starch and hemicelluloses by endogenous enzymes may explain increase in soluble sugar content. Archibald [69] in his study has reported that banana peel can also be utilized for extraction of banana oil (amyl acetate) which can be potentially 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.

Banana peel has been considered as a potential source of phytochemicals and antioxidants compared to its fruit.[70-72] Someya et al.[70] investigated the total phenolic contents to be more abundant in peel than in fruit which was consistent with the antioxidant activity. The peel extract showed stronger antioxidant activity than the fruit extract when the incubation times were compared. Gallocatechin content found in fruit peel has been reported to be in higher amount than in fruit. The higher gallocatechin content of the banana peel may account for the better antioxidant effects. The result of Singhal and Ratra[73] on *Musa acuminata* peel extract indicated that banana peel is potential source of bioactive compounds like flavonoids and polyphenols with wide range of medicinal properties particularly with high free radical scavenging activity. The study also reported that banana peel extract help to increase the total leukocyte and the percentage of lymphocyte which showed a good biological activities and can be effective in various diseases. Fatemeh et al.[74] found the total polyphenols and flavonoids contents of peel in the higher side as compared to the fruit pulp in all stages of fruit ripening. Similarly, the ability of banana peel extracts to scavenge DPPH radicals was reported with the higher value which is associated with the stronger antioxidant activity.

Study on inhibition of lipid peroxidation by ethanolic extract of few varieties of banana peel by Baskar et al.[75] reported the Poovan variety of peel extract exhibited high inhibition towards radical scavenging activity. Lipid peroxidase are unstable and decompose to form reactive carboxyl compounds which are responsible for cancer, causes age related diseases and also damage the DNA which can be significantly controlled by using peel of banana.

The micronutrient contents (iron and zinc) found in peels of banana is comparatively higher than that of fruit.[76] The study on banana peel by Anhwange[77] found that peel contains reasonable amount of minerals including potassium, calcium, sodium, iron and manganese, among which content of potassium was highest. The consumption of banana peel may help in the regulation of body fluids and maintained normal blood pressure. It may also help in controlling kidney failure, heart oddities and respiratory flaw. Feming[78] have state that the percentage of iron content in banana peel is an ideal source for carrying oxygen to the cells and production of energy, synthesis of collagen and for proper functioning of the immune system, cell growth and heart.

1.6.3 Utilization of peel as value added products

Like its pulp flour, peel can also be used for developing umber of high value added products. Ramli et al.[79] developed yellow noodles by partial substitution of wheat flour with green banana peel flour and the study reported that partial substitution of banana peel into noodles may be useful for controlling starch hydrolysis of yellow noodles. Banana peel noodles had a lower estimated glycemic index values as compared to noodles prepared with wheat flour. The modified noodle product described in their study may broaden the range of low glycemic index food products and increase utilization of waste products from banana agro-industries. Wachirasiri et al.[66] in their research developed banana peel dietary fibre concentrate, and reported that banana peel is a good source of dietary fibre exhibiting 50 g/100 g dry matter. Their result indicated that dietary fibre concentrate obtained from banana peel provides an opportunity to enhance the functionality. The use of banana peel dietary fibre concentrate as a low-caloric functional ingredient for fibre enrichment and incorporation of them within the food system may give high value added food products.

Amylases are well known for applications ranging from starch and food processes industry to medical applications. Krishna et al.[80] in their study reported the potential of banana peel was evaluated for α-amylase production using the fungal culture of *Aspergillus niger* NCIM 616 in solid submerged (SmF) and solid state (SSF) fermentation. The effect of different parameters, such as, substrate concentration, water content, layer thickness and external salt addition was studied in terms of the amylase activity. The study suggested that banana peel could be used as a potential raw material for α-amylase production. Paul and Sumathy[81] suggested that banana peel could employ as a promising substrate for the production of amylase by *Bacillus subtilis*.

Rehman et al.[82] have confirmed that banana peel proved to be a good source for producing xylose. Xylitol is the first rare sugar that has global market for having beneficial health properties and being an alternative to current conventional sweeteners. Banana peel was used as a substrate for xylitol production by acid hydrolysis. Detoxification of peel hydrolysate by neutralization, charcoal treatment and vacuum evaporation increased the xylitol yield. Xylitol extracted from banana peel can be used to replace sugars in different products such as bakery and confectionary products without affecting their physico-chemical characteristics and shelf stability. Jadhav et al.[83] utilized banana peel for producing lipase an important enzyme which is extensively used in food and dairy industry for the hydrolysis of milk fat, cheese ripening, flavour enhancement and lipolysis of butter fat and cream. The authors concluded that peel of banana can potentially be used for the production of bacterial enzymes like lipase and amylse which hold an important place in food industry.

The attempt made by Byarugaba-Bazirake et al.[84] for producing wine vinegar from banana peel took 28 days and the final product obtained had physicochemical characteristics of 6.0% (v/v) acetic acid, 5^{o}Brix, and pH of 2.9 which complied with the standard ranges of brewed vinegar after complete fermentation. The aroma of the vinegar produced was appreciated by the consumers who were acquainted with vinegar. The study therefore, showed that banana peel can be used as an ideal substrate for production good quality vinegar. This will not only increase the economical and food value of banana peel but also provides a way of utilizing banana waste. Simmonds[85] reported that vinegar has been prepared by fermenting a mash of banana pulp and peel. Vinegar production from banana may enhance minimize cost of production and eco-friendly.

1.6.4 Extraction of cellulose from peel and its utilization

Cellulose the homopolysaccharide representing about $1.5x10^{12}$ tons of total annual biomass production composed of glucose-glucose linkages (β-1,4-linked-glucopyranose unit) arranged in linear chains where C-1 of every glucose unit is bonded to C-4 of the next glucose molecule and nanostructures.[86-88] It is one of the most important biopolymers in existence and is derived from readily available biomass.[89] Due to its availability, biocompatibility, biodegradability and sustainability cellulose is widely used.[90] Cellulose fibers exhibit a unique structure hierarchy derived from their biological origin. They are composed of assemblies of nanofiber diameter ranging 2 to 20 nm and a length of more than a few micrometers.

The study of cellulose nanofibers as a reinforcing phase in nanocomposites started almost 15 years ago. Since then, cellulose nanofibers unlock the door in the direction of promising research on cellulose based nano materials with increasing area of potential applications including packaging material, [91-92] transparent material,[93-94] paper production[95-96] and biomedical applications.[97-98] Cellulose nanofibers could also be used as a rheological modifier in foods, paints, cosmetics and pharmaceutical products.[99] Many studies have been done on isolation and characterization of cellulose nanofibers from various sources viz. pineapple leaf fibers,[97] wood fibers,[100] cotton,[101] potato tuber cells,[102] prickly pear fruits,[103] wheat coconut husk fibers,[104] branch-barks of mulberry,[105] banana rachis,[106] pea hull fiber[107] and sugar beet.[108] There has been growing interest in researching the potentiality of using cellulose based nanofibers as a reinforcing material.

Cellulose nanopaper (CNP) obtained from CNF is similar to conventional paper but constitutes a network of nanofibers having pore size in the range of nanometer. It possesses excellent mechanical properties with high optical transparence, low thermal expansion and has good oxygen barrier characteristics.[109, 110] It has potential to be used as a strong sheet like material as well as light weight reinforcement material in biocomposites. Irimia-Vladu[111] used CNP to replace traditional glass and plastic in energy devices and termed as “Green” electronics to produce eco-friendly electronics by developing new green and efficient routes. The structure of CNP shows tightly packed nanofibers and interacts strongly with each other, contributing outstanding mechanical properties and thus CNP from CNF are considered as green and potential alternative for multiple applications depending on the requirements of final use applications including food packaging.[112] Peel of banana is an excellent source of cellulosic fiber which can be used as a biomaterial, as peel represents 40% of total fruit weight of banana. Unfortunately, peels are being often discarded and leading to a serious pollution problem. The utilization of this cellulose rich biomass would not only increase value of this agro-waste but also help to overcome environmental pollution issues.

1.7 Encapsulation of bioactive compounds by co-crystallization and its application in functional food formulation

In the last decades consumer demands in the field of food production have changed considerably. Consumers more and more believe that foods contribute directly to their health.[113] Today foods are not intended to only satisfy hunger and to provide necessary nutrients for humans but also to prevent nutrition-related diseases and improve physical and mental well-being.[114] One of the greatest challenges food research is facing in this century lies in maintaining sustainable food production and at the same time delivering high quality food products with an added functionality to prevent life-style related diseases such as, cancer, obesity, diabetes, heart disease, stroke etc. Functional foods that contain bioactive components may provide desirable health benefits beyond basic nutrition and play important roles in the prevention of life-style related diseases.[115]

Numerous food products are marketed with enhanced quantities of bioactive food compounds and these products are collectively referred to as functional foods.[116] Functional foods provide health benefits over and above normal nutrition. Functional foods are different from medical foods and dietary supplements, but they may overlap with those foods developed for special dietary uses and fortified foods. They are one of the fastest growing sectors of the food industry due to increasing demand from consumers for foods that promote health and well-being.[117]

Functional foods must generally be made available to consumers in forms that are consumed within the usual daily dietary pattern of the target population group. Consumers expect functional foods to have good organoleptic qualities (e.g. good aroma, taste, texture and visual aspects) and to be of similar qualities to the traditional foods in the market.[118, 119] The demand for bioactive ingredients will continue to grow as the global market for functional foods and preventative or protective foods with associated health claims continues to rise. Bioactive food components are components in foods or dietary supplements, other than those necessary to meet the basic nutritional needs, which are responsible for changes in health status.[120] In this case, it is important to understand that the bioactive compounds are not nutrients[121] even if they are contained in foods or their constituents. Bioactive compounds are non nutritional constituents that typically occur in small quantities in foods. Generally, these compounds are found in millions of species of plants, animals, marine organisms and microorganisms, and can be obtained by extraction and biotechnological methods. Extracted bioactive compounds can be incorporated to produce new functional foods, enhancing its shelf life, nutritional quality and increasing consumer acceptance of these commodities. Among the most used bioactive compounds are antioxidants, antimicrobials, probiotics and flavors, in addition to nutraceutical substances.[122, 123]

The incorporation of bioactive compounds into food products provides many advantages in food preservation and contributes to the development of functional foods. However, bioactive compounds may have certain disadvantages such as off flavors and an early loss of functionality.[122, 124] Phenolic compounds, which are highly researched for their antioxidant and anti-inflammatory activities, have a basic structure containing at least one aromatic ring with several hydroxyl groups. In general, these compounds are relatively unstable in comparison to other secondary plant metabolites. Given the potential health benefits of bioactive food compounds and the emphasis of the nutrition community on food first behaviors, functional foods formulated with bioactive compounds are being developed with matrices to improve compound stability, bioactivity, and bioavailability such that they are easily degraded during food processing and digestion.[116, 125, 126] However, in some foods, polyphenols exist as conjugates with proteins resulting in soluble and insoluble protein-polyphenol complexes which have a stabilizing effect on polyphenols.[127] Polyphenolic compounds when included in a food product, they may impart an astringent or bitter taste, or introduce a degree of brown colouring. For example, grape seed extracts are difficult to incorporate into functional foods due to their dark brown colour and low water solubility.[115] In addition, the challenges for applications of polyphenols in food system are the initial protection of the bioactivity of the polyphenols, as they may lose their antioxidative properties or bioactive functionalities during processing of food, due to their sensitivity to oxygen, temperature, light,[128] and to the gastrointestinal tract environment (pH, enzymes).[129] Furthermore the development of appropriate formulations to increase solubility of polyphenols according to a specific food matrix is necessary.

Looking at the present scenario of bioavailability of polyphenols and antioxidants, encapsulation technology becomes an actual choice and is a promising technique that can solve the disadvantages of the use of bioactive compounds as food additives. Encapsulation is a rapidly expanding technology with a lot of potential applications in areas including pharmaceutical and food industries. Encapsulation may be defined as a process to entrap one substance (active agent) within another substance (wall material). The encapsulated substance, except active agent, can be called the core, fill, active, internal or payload phase. The substance that is encapsulating is often called the coating, membrane, shell, capsule, carrier material, external phase, or matrix.[130, 131] Encapsulation is a useful tool to improve delivery of bioactive molecules (e.g. antioxidants, minerals, vitamins, phytosterols, lutein, fatty acids, lycopene) and living cells (e.g. probiotics) into foods.[130, 132]

The main objective of encapsulation is to protect the core material from adverse environmental conditions, such as undesirable effects of light, moisture, and oxygen, thereby contributing to an increase in the shelf life of the product, and promoting a controlled liberation of the encapsulate.[133] In the food industry, the encapsulation process can be applied for a variety of reasons as summarized by Desai and Park[134] as follows:

(i) protection of the core material from degradation by reducing its reactivity to its outside environment;

(ii) reduction of the evaporation or transfer rate of the core material to the outside environment;

(iii) modification of the physical characteristics of the original material to allow easier handling;

(iv) tailoring the release of the core material slowly over time, or at a particular time

(v) to mask an unwanted flavor or taste of the core material

(vi) dilution of the core material when only small amounts are required, while achieving uniform dispersion in the host material

(vii) to help separate the components of the mixture that would otherwise react with one another. Food ingredients of acidulants, flavoring agents, sweeteners, colorants, lipids, vitamins and minerals, enzymes and microorganisms, are encapsulated using different technologies.

Natural antioxidants may be added to a wide range of processed foods. Co-crystallization is an encapsulation process in which the crystalline structure of sucrose is modified from a perfect to an irregular agglomerated crystal, to provide a porous matrix in which a second active ingredient can be incorporated.[135] Spontaneous crystallization of supersaturated sucrose syrup is achieved at high temperature (above 120^{o}C) and low moisture (95-97^{o}Brix). If a second ingredient is added at the same time, the spontaneous crystallization results in the incorporation of the second ingredient into the void spaces inside the agglomerates of the microsized crystals with a size less than 30 mm.[136] The main advantages of cocrystallization are improved solubility, wettability, homogeneity, dispersibility, hydration, anticaking, stability and flowability of the encapsulated materials.[137] Other advantages are that the core materials in a liquid form can be converted to a dry powdered form without additional drying, and the products offer direct tableting characteristics because of their agglomerated structure, and thus offer significant advantages to the candy and pharmaceutical industries.[134] In this technique the granular product obtained possesses a very low hygroscopicity, a good fluidity, and a better stability. Furthermore, the co-crystallization offers a good economic alternative and remains a flexible technique because of its simplicity.

1.8 Dehydration of banana and plantains

Drying is an alternative method to preserve the food quality and to reduce post harvest losses. Generally, drying of foods is characterized by two separate phases: the constant rate and the falling rate periods. During drying, moisture present in the food diffuses from the internal to the food surface and evaporates into the air stream and at the same time the heat is transferred from the air to the food. When moisture is removed, the volume of food decreases. Moisture gradient occurring inside the food during drying generates stresses in the cellular structure of the food resulting in the structure collapse which respond to the physical changes of shape and dimension or the volume change of material.[138]

Hot air drying is one of most widely used methods for food preservation. The advantage of dehydrated foods is that decreased moisture content reduces thermodynamic water activity, thus preventing the growth of microorganisms that cause spoilage reactions.[139] Due to the complexity of food, drying can occur simultaneously by different mechanism. Although drying processing effectively extends the shelf life of agricultural products, loss of sensory and nutritive qualities is considered inevitable during traditional drying process due to the undesirable textural and biochemical changes, higher drying rate, lower drying temperature and oxygen deficient processing environment etc., these characteristics may help to improve the quality and nutritive value other dried products. [140]

Presently, vacuum drying has been applied to dry various food materials, the vacuum drying kinetics of many fruits and vegetables has been investigated and the effect of vacuum drying conditions on the drying process and the qualities of dried products has been evaluated.[141] The most common method used in the drying of heat-sensitive products is the vacuum drying method. Vacuum drying is widely used to dry various heat-sensitive products in which the colour, structure, and vitamins are impaired with increasing temperatures.[142] Vacuum drying results in better product quality with respect to characteristics such as flavour, fragrance, and rehydration.[143] Vacuum drying also has advantages such as a reduction in processing temperature, improvement in the drying rate, and a reduction in shriveling.[144] The vacuum drying process has been successfully used for the drying of fruit, vegetables, and heat-sensitive products. A high quality product is obtained due to the retention of flavour and nutritive value in the structure of materials. Vacuum reduces the boiling point of water keeping the product temperature low, as well as creating a pressure gradient that enhances the drying rate. Load size, power level and vacuum pressure influence drying rate.

Rajkumar et al.[145] found in his study that dehydration of food materials, especially fruits and vegetables, with antioxidant properties, is a difficult food process operation, mainly because of undesirable changes in quality of the dehydrated products. Further direct exposure to solar radiation results in undesirable colour changes, lowering quality of the dried products significantly. Therefore, use of hot air in controlled cabinet drying through convective air is far more rapid and provides uniformity and hygiene for industrial food drying processes become inevitable. According to Drouzas and Schubert[143] vacuum drying is a potential dehydration technique mainly used for heat sensitive food products due to drying at lower pressure and temperature under low oxygen environment. Better product quality such as taste, flavour, or rehydration ratio can be achieved by high degree vacuum treatment. The lower pressure allows the drying temperature to be reduced and results in higher quality than the classical convective air drying process at atmospheric pressure.[146] Modeling the drying process and predicting the drying behaviour under different conditions is necessary to have a better drying understanding of the mechanism. Fick's law of diffusion has been used to describe the drying kinetics of fruits during falling rate period.[147]

1.8.1 Mathematical modeling

The dynamics of food drying process involves simultaneous heat and mass transfer, where water is transferred by diffusion from inside of the food material towards the air-food interface, and from the interface to the air stream by convection. Heat is transferred by convection from the air to the air-food interface and by conduction to the interior of food.[148] This phenomenon has been modeled with different levels of complexity. Most of the mathematical models have presented physical and thermal properties of the drying material as a function of time for any air temperature and air velocity; therefore, several models have been necessary. In particular, the solution of these equations must allow for the prediction of the process parameters as a function of input parameters, air temperature and air velocity at any time in the dryer equipment.[149] Due to the dynamic behavior and complexity of the drying process of the agricultural products, mathematical and regression approaches are considered faulty. Thus, a model should be stable and precise enough in case uncertainty exists in the inputs. Artificial intelligence methods, such as neural networks, have gained momentum and are suitable for identifying plant and fruit responses.[150] Modeling of drying of banana has been reported by several authors using Fick's law of diffusion. The optimization of dehydration processes in the agro-food industry has led to choosing the technological variables involved in the process itself.

Nowadays, many researchers have investigated artificial neural networks (ANN) as the artificial learning tool in a wide range of biotechnology applications including optimization of bioprocesses and enzyme production from microorganisms.[151] ANN is biologically inspired and mimics human brain. They are consisting of a large number of simple processing elements named neurons. These neurons are connected with connection link. Each link has a weight that multiplied with transmitted signal in network. Each neuron has an activation function to determine the output. There are many kind of activation function. Usually nonlinear activation functions such as sigmoid and step functions are used. ANNs are trained by experience, when applied a new input to the network it can generalize from past experiences and produce a new result.[152]

The simple structure of ANN normally consists of an input layer, a hidden layer and an output layer. By applying algorithms that mimic the processes of real neurons, the network can learn to solve many types of problems. From the perspectives of process modeling, ANN has been applied to solve complex engineering problems where it is difficult to develop models from the fundamental principles, particularly when dealing with non-linear systems which also exist in bioconversion process.[151] It provides a mathematical alternative to the quadratic polynomial for representing data derived from statistically designed experiments. ANN is also able to handle a large amount of data to approximate functions to any desired degree of accuracy, thus make it attractive as empirical model.[153]

The choosing of an appropriate neural network topology (i.e., number of hidden neurons, learning rate and momentum) that strongly affects predictability of network is critical and usually carried out by trial and error method. Genetic algorithm (GA) as an optimization technique can be used for overcoming this limitation of neural network. GA is inspired by the natural selection principles and Darwin's species evolution theory. GA offers several advantages over the conventional optimization method such as less susceptibility to be stuck at local minima, requiring little knowledge of the process being optimized and capability to find the optimum conditions when the search space is very large.[154]

Genetic Algorithm (GA) is one of the search methods and optimization techniques which aim at an optimal value of a complex objective function by simulating biological evolutionary processes based, as in genetics, on crossover and mutation. The principles of GA are based on natural competitions of beings for appropriating limited natural source.[155] Morimoto et al.[156] combined an artificial neural network and genetic algorithm method for optimal control of the fruit-storage process. They also used genetic algorithm for optimizing heat treatment for fruit during the storage. They determined the drying characteristic of carrot under different drying air conditions and to estimate its dynamical drying behavior using the neural network while a mathematical model of drying procedure was optimized using the genetic algorithm.

Chen-Hua et al.[157] stated that at present, ANN is widely used in science. They not only could learn by inspection of data rather than having to be told what to do, but also could construct a suitable relationship between input data and the target responses without any need for a theoretical model with which to work. Therefore, ANN could be applied to almost every aspect in food processing, from raw material assessing, thermal processing, freezing, fermentation, enzymatic hydrolysis, ultra-filtrating and drying to composition detecting, quality-assessing and safety-evaluating. Accurate modeling and control of food processing operations could be beneficial in increasing the process efficiency and maintaining the uniform quality of the final product. Hernandez[158] optimized the operating conditions for heat and mass transfer in mango and cassava drying by means of ANN inverse, taking into account air temperature, air velocity and shrinkage as a function of moisture content, time and air humidity as input parameters. Fathi et al.[159] reported that artificial neural networks (ANNs) have turned out as a powerful method for numerous practical applications in food science. Neural network models are constructed by interconnecting many non-linear computational adaptive processing elements, known as neurons or nodes, operating in parallel and arranged in patterns similar to biological networks.

According to Morimoto[156] GA as an optimization technique can be used for overcoming this limitation of neural network. GA is inspired by the natural selection principles and Darwin's species evolution theory. GA offers several advantages over the conventional optimization method such as less susceptibility to be stuck at local minima, requiring little knowledge of the process being optimized and capability to find the optimum conditions when the search space is very large.

1.8.2 Moisture sorption isotherm (MSI)

Proper designing of packaging and storage system are merely important for food types that are susceptible to deteriorative reactions like lipid oxidation and microbial spoilage during long term storage .To serve the purpose, MSI study is considered as one of the most potent tools for determining suitable packaging and storage conditions and to optimize product quality retention and biological stability.[160] The relationship between total moisture content and the water activity of the food at a constant temperature gives MSI. Adsorption and desorption isotherms are termed when the material reaches equilibrium by wetting or drying, respectively.[161] An adsorption isotherm is achieved by keeping a dry material in an increasing relative humidity atmosphere and measuring the gain in weight due to water uptake. On the contrary, desorption isotherm is calculated by keeping an initially wet material under the same relative humidity conditions and loss in weight is measured.[162] MSI of most foods including the starchy ones follow nonlinear Langmuir adsorption model, which are generally type II isotherm and are sigmoidal in shape.[163] For the prediction of food MSI, numerous empirical and semi-empirical mathematical models have been suggested in the literature.[164, 165] MSI studies on some starchy flours have also been studied by various researchers.[163, 166-169]

Al-Muhtaseb et al.[162] stated that sorption isotherms is highly important in food science and technology for the design and optimization of drying equipment, design of packages, predictions of quality, stability, shelf-life and for calculating moisture changes that may occur during storage. The moisture levels at which some dehydrated foods have good storage stability have been found to agree closely with the moisture levels calculated from the sorption isotherm at different ambient temperature and RH%.[170] A common way of presenting the relationship between aw and water content is a sorption isotherm.[171]

Ogbonnaya[172] stated that information on moisture sorption regime is generally required for the storage and enhancement of stability of stored agricultural products, both in raw and processed forms. Moisture sorption isotherm is needed for the prediction and practice of drying and other thermo-related processing of dates. It is also required in the determination of critical values for processing such as equilibrium moisture content, critical moisture content and other moisture regimes. Moisture sorption study is important for the determination of the minimum moisture required for stability of processed dates and therefore necessary information during packaging and selection of packaging materials.

Several methods have been developed for moisture sorption prediction in food.[173] However, actual determination of moisture characteristics in some crops is required in order to find the best-fit model for the particular crop. In addition, the information is required to predict the fundamental behaviour of the product during handling, processing and storage. The food sorption isotherm describes the thermodynamic relationship between water activity and the equilibrium of the moisture content of a food product at constant temperature and pressure.[174] Many mathematical models to describe the water sorption behaviour of foods can be found in the literature.[175] The Guggenheim- Anderson-de Boer (GAB) Model is considered to be the most versatile and the best one for fitting the sorption data for the majority of food products in a water activity range of 0-0.85.

Water plays an important role with respect to the properties of food systems. The water in food influences physical or textural characteristics of the product as well as its chemical stability.[176] Sorption properties of food (equilibrium moisture content and monolayer moisture) are essential for the design and optimization of many processes such as drying, packaging and storage.[162] The water activity of the flour as a hygroscopic material exerts a strong influence on its quality and technological properties. During the processing and storage of agricultural products, physical, chemical and microbiological changes occur. The changes are influenced particularly by the moisture content and water activity of food material. The relationship between moisture content and water activity in food at constant temperature and pressure is often expressed as a moisture sorption isotherm. It can give information on the sorption mechanism and the interaction of food with water. The food sorption isotherm describes the thermodynamic relationship between water activity and the equilibrium of the moisture content of a food product at constant temperature and pressure.[177]

Upgrading of specific banana properties is of great importance in view of its wide range applications in conjuction with the widespread consumption of banana all over the world. This improvement is feasible by means of selection of appropriate cultivars, harvesting time and preservation approaches under specific conditions which can result in banana fruit improvement both qualitatively and quantitatively. Thus, on the basis of the preceding sections reviewed bananas and plantains can be termed as a “potential health food,” providing health benefits beyond basic nutrition. As one of the most popular fruits produced and consumed all over the world, plantains contain significant amounts of phytochemicals, antioxidants and micronutrients (vitamins and carotenoids). These constituents can be affected by differences in cultivars, agricultural practices, harvesting time and processing methods. However, fresh and processed plantains and bananas are available throughout the year, are significant dietary sources of polyphenols and vitamins, which have been shown to contribute to their observed health effects.

Peels of plantains and banana which is often considered as waste and discarded is a richer source of many functionally important nutrients and bioactive compounds. They are rich in antioxidants, polyphenols, minerals, vitamins, sugars, amino acids, dietary fibre and pectin. Peels has a potential application in food, pharmaceutical industries and cattle feed formulation because of their functionality. Therefore, looking at the backdrop of promising utilization of plantains and banana peel they cannot be considered as a “waste” rather they can be prospectively utilized for developing economic and eco friendly value added products.

1.9 Scope and objectives of the present investigation

In the light of the above backgrounds, surveyed literature and discussions, it was noticed the culinary banana (*Musa* ABB) of Assam and North East India (locally known as *kachkal*) falls under the category of fruit-vegetable and is one of the commonly consumed vegetable next to potato in the daily diet of local people. This nutritionally rich crop of local importance has not gain much attention and is underutilized and underestimated even though its nutritional value is of worth. It is excellent source of starch which can be modified to RS for its better utilization and value addition. It is considered as one of the potential storehouses of carbohydrates, starch, polyphenols, micronutrients and functionally important bioactive compounds. Knowing the fact that peel of *kachkal* is an abundant source of cellulose, they can be considered as a potential candidate for development of reinforcing composites. As mentioned earlier many researchers have reported their work on cellulose nanofibers from different sources, however there is hardly any work reported on cellulose nanofibers from banana peel. Keeping in view the immense importance of this crop the present study was carried out with following objectives:

- To study the biochemical composition of pulp and peel of culinary banana at various developmental stages and to identify the optimum stage of harvesting
- To study the resistant starch development from pulp and its application in food model
- To study the isolation and characterization of cellulose nanofiber from peel and its application in developing nanopaper
- To study the encapsulation of natural antioxidant from culinary banana pulp and peel
- To study the drying characteristics by hot air oven, optimization of process parameters in vacuum drying for pulp slices and peel paste and storage study of culinary banana flour

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