We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

Chapter

Banana Bioactives: Absorption, Utilisation and Health Benefits

Rinah K. Netshiheni, Adewale O. Omolola, Tonna A. Anyasi and Afam I.O. Jideani

Abstract

Banana is an important fruit consumed globally and cultivated in humid and subtropical climes. The fruit comprises nutrients in its pulp and peel with beneficial properties. Banana in its unripe form, consists of indigestible compounds, resistant starch and dietary fibres. The starchy fruit degrades to fructose and sucrose when ripe, thus reducing its starch content. Aside its carbohydrate profile, essential macro and micro minerals, vitamins and phenolic compounds are other nutrients present in pulp and peel of the fruit. Resistant starch, an indigestible compound available in banana fruit, escapes absorption in the small intestine and is transported to the large intestine where digestion takes place. This occurrence makes banana a preferred fruit for consumers suffering from diabetes. Polyphenols, present in minute concentration in the fruit, functions as antioxidants, thus contributing immensely to the prevention of metabolic degenerative diseases. This chapter further examines available nutrients present in banana fruit, their absorption and utilisation in the body. The chapter also brings to the fore, the health benefits of consumption of ripe, unripe and processed banana products.

Keywords: banana, bioactives, nutrigenomics, antioxidants, banana utilisation

1. Introduction

1.1 Overview on banana

Banana is one of the world's most important fruit consumed globally. The fruit (**Figure 1**) grows well in a scale of about 1000 m altitude and sometimes even in the subtropics with higher altitudes. Its name *Musa* is derived from the word "*Mouz*" which is an Arabic name. The name was given to banana plant to honour a Roman physician named *Antonia Musa* who lived in the first century [1]. Sadia and Azizuddin [1] reported that *Musa* belongs to the family *Musaceae* and is divided into four edible cultivars namely: *Rhodochlamys, Eumusa, Callimusa* and *Australimusa*. There are presently diploid, triploid or tetraploid genome groups with the main genome groups represented as AA, AB, AAA, AAB and ABB [1]. Plantain, a cultivated banana variety and often referred to as the cooking-type banana is obtained from *Musa acuminata* (genome "A") and *Musa balbisiana* (genome "B") species [2]. Plantain belongs to the AAB genome, while the commercial export market Cavendish subgroup consists of the AAA genome [1]. Cooking and dessert banana contain substantial amount of nutrients thus qualifying the fruit to be the world's

Figure 1.
The diversity of banana and plantains with various genome compositions [2].

fourth leading agricultural crop [3]. Banana is said to be among human foods which was introduced in the first century. The fruit is cultivated in more than 130 countries throughout tropical and subtropical regions with over a harvested area of approximately 10 million hectares [4]. Furthermore, countries in Latin America such as Ecuador and Columbia have been reported to be major producers of the fruit, while the United States and European Union import the highest amounts of banana [4].

Plantains when compared with unripe dessert bananas differ in terms of plantains being larger in size, possessing more finger body mass and also having higher starch content [5]. Plantains are economically important and serve as a major staple food [6] in some countries such as India and other countries of Latin America and African origin [3]. Plantains are considered as a very important source of energy and starch [7] and are described as sweet acid starchy bananas majorly consumed upon frying or boiling [3]. Similarly, dessert banana serves as a source of energy for athletes due to its potential benefits for sports application [1]. Hence, in some countries, the fruit is used in the production of a variety of energy drinks as well as dried banana bars for athletes. In addition, the fruit also prevents athletes from muscular contractions as it contains significant amount of vitamins and minerals [8]. The works of Doymaz [9] and Pareek [10] showed that banana and plantain contains low amount of protein and substantial amounts of carbohydrates (hemicellulose, starch and pectin), vitamins A and C, potassium, calcium, sodium and magnesium. Dessert and cooking banana plant parts: roots, leaves, flowers, stem and pseudostems have long being used in traditional and indigenous medicine due to their therapeutic properties in various countries of the world such as Africa, America, Asia and Oceania [11]. These beneficial plant parts have been employed in the treatment of various ailments such as snakebite, inflammation, intestinal colitis, dysentery and diarrhoea [8]. Presently, several authors have investigated the potential of banana in mitigating type I and II diabetes mellitus [9, 12], its role in the inhibition of carbohydrate-digesting enzymes (α-glucosidase and α-amylase), glucose absorption [13] and its antioxidant activity [14]. Compared with plantain, most available reports are on changes in chemical composition of dessert banana cultivars during ripening [5, 15–17]. Plantains are rich in nutrients and their biochemical composition varies with growth stage and maturity [5]. Overall, pulp and peel of both cooking and dessert banana can serve as natural sources of amine compounds, antioxidants, carotenoids and polyphenols [11].

Production of banana can be limited by biotic and abiotic stress factors. Thus, improving the nutritional quality, ability of the fruit to adapt to different geographical conditions and production of new disease resistant varieties using genetic engineering are very important [18]. The science behind genetic modification of bananas therefore aims at increasing productivity and nutritional value and this could be one of the sustainable strategies to address food insecurity in the near future [19].

DOI: http://dx.doi.org/10.5772/intechopen.83369

2. Nutritional composition of banana fruit

Banana and plantain consist of a high nutritional value (**Table 1**) which contributes to an improved absorption of numerous nutrients with minimal fat absorption [18]. Bananas are effective in maintaining plasma glucose and possibly improving endurance exercise performance [20]. Banana fruit is a rich source of phytochemicals, including unsaturated fatty acids and sterols. In the works of Wall [21], composition of 'Dwarf Brazil' banana was reported to be 12.7 mg/100 g vitamin C, 12.4 mg/100 g retinol activity equivalent (RAE) vitamin A, 17.9% total soluble solids (TSS) and a moisture content of 68.5%. Wall [21] further reported concentrations of 4.5 mg/100 g vitamin C, 8.2 mg RAE/100 g vitamin A, 20.5% TSS and moisture content of 73.8% for 'Williams' banana cultivar with the author also showing that cultivars of banana have different nutrient concentrations. An average-sized banana was found to contain 450–467 mg of potassium (K) [22]. Banana is rich in fibre with a medium-sized banana containing about 6 g of fibre. Dessert and cooking banana have been implicated to contain vitamin B, C, macro and micro essential minerals, α- and β-carotene as well as higher concentrations of lutein than provitamin A pigments [20] and all in varying concentrations. As stated in the works of Pareek [10], it was reported in Hawaii that 'Apple' bananas

Genome	Cultivars
AA	'Inarbinal', 'Paka', 'Matti', 'Anakomban', 'Pisang Jari Buaya', 'Pisang Lilin', 'Senorita', 'Kadali', 'Sucrier' ('KulaiKhai', 'Lady's Finger', 'Orito', 'Pisang Mas')
AAA	'Ambon', 'Cavendish' ('Dwarf Cavendish', 'Giant Cavendish', 'Grand Naine', 'Williams'), 'Gros Michel' ('Cocos', 'Highgate', 'Lowgate'), 'Ibola', 'Basrai', 'Lujugira-Mutika' ('Beer', 'Musakala', 'Nakabulu', 'Nakitembe', 'Nfunka'), 'Pisang MasakHijau' ('Lacatan'), 'Red' ('Green Red'), 'Robusta' ('Harichal', 'Malbhog')
AAAA	'Pisang Ustrali'
BB	'Bhimkol', 'Biguihan', 'Gubao', 'Pa-a-Dalaga', 'Tani'
BBB	'Abuhon', 'Inabaniko', 'Lap Chang Kut', 'Mundo', 'Saba Sa Hapon', 'Saba', 'SabangPoti', 'Turrangkog'
AB	'Kunnan' ('Adukkan', 'Poonkalli', 'PoovillaChundan'), 'Ney Poovan' ('Kisubi', 'Safed Velchi'), 'SukaliNdizi' ('Kumarangasenge')
AAB	'False Horn' ('French', 'French Horn'), 'Laknau', 'Maia Maoli', 'Moongil', 'Mysore' ('Sugandhi'), 'Nendran', 'Pisang Raja', 'Plantain Horn', 'Pome' ('Pachanadan', 'Pacovan', 'Prata Ana', 'Virupakshi'), 'Popoulu', 'Ilohena', 'Rasthali', 'Silk'
ABB	'Bluggoe' ('NallaBontha', 'Pisang Batu', 'Punda'), 'Pisang Awak' ('KlueNamwa', 'Karpuravalli', 'PeyKunnan', 'Yawa'), 'Monthan', 'Peyan', 'KlueTeparot', 'Pelipita', 'Kalapua', 'Cardaba'
AAAB	'Atan'
AABB	'Kalamagol', 'Laknau Der',
ABBB	'Bhat Manohar'
AS	'Aso', 'Kokor', 'Ungota', 'Vunamami'
AT	'Umbubu'
AAT	'Kabulupusa', 'Karoina', 'Mayalopa', 'Sar'
ABBT	'Giant Kalapur', 'Yawa 2'
Unkown	'Fei'

Source: [10].

Table 1.
Musa cultivars by genomic classification.

recorded a concentration of 12.7 mg/100 g FW for vitamin C that was almost threefold than 'Williams' (4.5 mg/100 g); a β-carotene concentration of 96.9 μg α-carotene/100 g and 104.9 μg α-carotene/100 g, while 'Williams' averaged 55.7 μg β-carotene/100 g and 84.0 μg α-carotene/100 g. 'Apple' bananas were also reported to have more phosphorus (P), calcium (Ca), magnesium (Mg), manganese (Mn) and zinc (Zn) than 'Williams' [10]. Similar data for fully ripe banana fruit (**Table 2**) were reported by the United States Department of Agriculture [23]. Other nutrients implicated to be present in cultivars of *Musa* spp. includes biogenic amines and polyphenols.

2.1 Carbohydrates

Banana and plantain are known to contain sugars, starch, fibre and cellulose compounds especially in its pulp. The peel portion of banana and plantain are rich in fibre. In banana fruit, inherent starch accumulates during development, with minimal changes in the principal carbohydrate metabolites observed during the preclimacteric phase [24]. Subsequently, the fruit starch is converted to sucrose, glucose and fructose as senescence sets in and progresses. Ripening in banana generally involves a decrease in starch concentration from 15 to 25% to less than 5% in the ripened pulp, together with an additional increase in sugar content [25, 26]. At the onset of senescence, sucrose is the predominant sugar, with glucose and fructose predominating as ageing sets in [27]. The concentration of sugars in banana and plantain is associated with respiratory climacteric stage [1]. Starch conversion to sucrose is catalysed by activity of sucrose phosphate synthase, while acid hydrolysis causes starch conversion to non-reducing sugars from sucrose. It was observed that harvest maturity largely affects the conversion of starch to sugar. Changes like these have been reported in both diploid (*Musa* AA) [28] and triploid (*Musa* AAA) banana fruits [29]. Similarly, during the ripening stage of dessert banana, starch is completely broken down, unlike for plantains where starch is not totally broken down [30]. Due to the presence of pectin in banana, it was reported that consumption of the fruit can mitigate intestinal diseases [1]. Furthermore, green banana produces antidiarrheal activity in children which will help to fight against the incidence of diarrhoea, one of the main causes of high mortality and morbidity in children of third world countries. Research further revealed that low fasting blood glucose and glycogenesis in the liver can be increased due to presence of fibres in banana fruit [1]. Dessert and cooking banana in their ripe state are reported to be rich in resistant starch (RS), while at their unripe state, the fruit contains mostly digestible starch [31].

2.2 Protein and Amino Acids

In the works of John and Marchal [32], whole nitrogen in 'Cavendish' pulp has been reported to be 210 mg/100 g (FW) and 750 mg/100 g (DW). The protein signified a total nitrogen content of about 60–65%. This is in agreement with what was reported by the USDA [23], wherein the protein content for *M. acuminata* was 1.09 g/100 g (FW). John and Marchal [32] found an increased protein value of 4–7 g/100 g (DW) and 1.3–1.8 g/100 g (FW) upon development of 'Cavendish' banana, and also for 'Dwarf Cavendish' from 4 to 8 g/100 g (FW), with the concentration increasing as ripening progresses. Unripe bananas are rich in proteins, with chitinase enzymes being the most abundant protein [32]. During ripening of bananas, starch phosphorylase, malate dehydrogenase and pectate lyase are accumulated. Dopamine, a water-soluble antioxidant reported in both pulp and peel of 'Cavendish' banana is one of the catecholamines that suppress the oxygen

Nutrient/content	Amount/value
Water (g)	74.91
Energy (kcal)	89.00
Protein (g)	1.09
Total lipid (fat) (g)	0.33
Carbohydrate, by difference (g)	22.84
Total dietary fibre (g)	2.60
Total sugars (g)	12.23
Calcium (mg)	5.00
Iron (mg)	0.26
Magnesium (mg)	27.00
Phosphorus (mg)	22.00
Potassium (mg)	358
Sodium (mg)	1.00
Zinc (mg)	0.15
Vitamin C, total ascorbic acid (mg)	8.70
Thiamine (mg)	0.031
Riboflavin (mg)	0.07
Niacin (mg)	0.67
Vitamin B-6 (mg)	0.37
Folate, DFE (μg)	20.00
Vitamin B-12 (μg)	0.00
Vitamin A, RAE (μg)	3.00
Vitamin A (IU)	64.00
Vitamin E (α-tocopherol) (mg)	0.10
Vitamin D (D2 + D3) (μg)	0.00
Vitamin D (IU)	0.00
Vitamin K (phylloquinone) (μg)	0.50
Fatty acids, total saturated (g)	0.11
Fatty acids, total monounsaturated (g)	0.03
Fatty acids, total polyunsaturated (g)	0.07

Source: [23].

Table 2.
Nutritional and biochemical composition of Musa acuminata Colla per 100 g.

uptake of linoleic acid [33]. Similarly, various bioactive amines including putrescine, spermidine and serotonin are reported to be present in high concentrations in banana. In addition, bananas have been found to contain physiologically relevant amounts of biogenic amines, nitrogenous compounds that include serotonin, dopamine and norepinephrine that vary relative to the ripening cycle, as well as the cultivar-dependent phytosterols cycloeucalenone, cycloeucalenone, cycloeucalenol, cycloartenol, stigmasterol, campesterol and β-sitosterol [33]. Bananas have some potential health benefits for cancer, cholesterol metabolism and related markers of cardiovascular disease risk.

2.3 Vitamins

Dessert and cooking banana contain different forms of vitamins in varying concentrations among the known cultivars worldwide. According to the reports of USDA [23] and Wills et al. [34], the vitamin C levels for 'Cavendish' banana estimated using high-performance liquid chromatography (HPLC), ranged from 2.1 to 18.7 mg/100 g (DW/FW), which however, varies considerably among different cultivars. The average vitamin C (**Table 2**) content for 'Dwarf Brazilian' (*Musa* AAB 'Santa Catarina Prata') was found to be 12.7 mg/100 g and 4.5 mg/100 g for 'Williams' [13]. These results agree with the report of Wenkam [35], who reported vitamin C values of 5.1 mg/100 g (DW/FW?) for 'Williams' and 14.6 mg/100 g (DW/FW?) for 'Dwarf Brazilian' banana cultivar.

Dessert banana contains substantial levels of provitamin A carotenoids (PVAC), but few cultivars with orange- or yellow-coloured pulp are known to have higher concentration of carotenoids [15]. Vitamin A deficiency has been reported to be a public health concern identified in almost 118 countries in the world, with highest prevalence in Asia and Africa, as their diets are mainly cereals and tubers [1]. Researchers from Australia (Queensland University of Technology) have concocted Cavendish banana with high amounts of β-carotene, a precursor of vitamin A. The carotenoids mostly found in fully developed bananas are lutein, α- and β-carotene. The fruit pulp is also rich in carotenoids, while the peel contains low amounts [36]. It is reported that during ripening the amount of carotenoids increase [20, 34]. Similar observation was reported by Kanazawa and Sakakibara [37], which contradicts the report of Gross and Flugel [38] who found carotenoid content decreasing during initial stage of ripening. As can thus be seen, different cultivars of *Musa* spp. contain different amounts of carotenoids. Banana and plantain fruits with orange flesh are rich in VAC [38, 39]. One variety of banana, 'Karat' of Micronesia, was reported to accumulate β-carotene of about 2230 mg/100 g [39].

2.4 Minerals

Banana and plantain are very rich in K, an essential element for maintaining human blood pressure and for proper functioning of the heart [40]. The fruit is also rich in Mg, Fe, Cu and Mn [20]. In the works of Pareek [10], the average K content for Hawaii's bananas ('Dwarf Brazilian' and 'Williams') were reported to be 330.6 mg/100 g (FW). Similarly, it was reported that fruits cultivated in Tenerife, were observed to contain a K content of 5.09 mg/g (FW), P content of 0.59 mg/g (FW), Ca content of 0.38 mg/g (FW) and Mg content of 0.38 mg/g (FW) [10, 41], though it was reported by the authors that the area of origin had a major effect on the occurrence of the minerals. Varietal differences had no effect on concentration of minerals present except for Fe. In the works of Forster et al. [42], differences were observed in the mineral content of bananas grown in both Ecuador and Tenerife. High Na, K, Mg and Fe contents were found for bananas grown in Tenerife, while high Ca, Cu, Zn and Mn contents were reported for bananas grown in Ecuador. This difference was attributed to agricultural practices, geographical location and soil composition [42]. Mineral composition of banana samples according to degree of ripeness was reported for the fruits obtained from Nigeria: 73.47% ash, 0.68% Zn, 0.146% Mn for unripe samples; 77.19% ash, 0.80% Zn, 0.271% Mn for ripe samples and 79.22% ash, 0.78% Zn for overripe samples [43]. Similarly, the peel of banana cultivars obtained from Cameroon contained relatively high minerals: K (50.0 mg/g DW), P (22.2 mg/g DW), Mg (11 mg/g DW) and Ca (18 mg/g DW) [44]. Generally, bananas contain low amounts of Ca, however, Micronesian cv. 'Krat' is relatively high in Ca [39].

3. Banana phytochemicals and bioactives

Phytochemicals have been reported to be an immense source of anticancer medications and chemopreventive agents [45]. These plant chemicals exert some of their actions through interactions with essential enzymes that regulate the activities in genes. Banana contains various bioactive compounds such as phenolics, carotenoids, alkaloids, glycosides, phlobatannins, tannins, terpenoids, saponins, steroids, biogenic amines and phytosterols, which are highly desirable in diet as they exert health beneficial effects [11, 32, 46]. These composites are helpful in protecting the body against oxidative stress due to their antioxidative activities [47], controlling gene expression in cell proliferation and apoptosis and important in controlling blood pressure [48]. The incorporation of banana pulp and peel in various food products could add value since they have health benefits [47]. Thus, banana pulp and peel can be used as natural sources of antioxidants and provitamin A. Banana peel is reported to have higher antioxidant capacity than banana pulp [49–53]. Furthermore, phenolic content of banana peel was higher compared to other fruits such as avocado, pineapple, papaya, passion fruit, water melon and melon [50]. However, it is recommended that to effectively recover and utilise phenolic compounds from banana peels, it is important to evaluate its chemical profile, factors affecting the levels of phenolic compounds in the peels such as antinutrients, and potential use of these compounds as food ingredients or nutraceuticals. It is important to understand how these bioactive compounds found in fruits and vegetables limit or prevent oxidative stresses as a free-radical scavengers or metal-chelating agents. In the report of Liu [53], it was emphasised that there has to be a balance between oxidants and antioxidants for normal functioning of the body cell and/or sustaining optimal physical condition in the human body. Too much oxidants in the human body result in damage to the biomolecules such as proteins, lipids carbohydrates and DNA. Hence, to understand the mechanism of action of antioxidant, it is imperative to understand the formation of free radicals and their ability to damage macromolecules and nucleic chains.

Phenolic compounds have been implicated to be present in banana fruits. Although, banana peels contain more tannin compared with its pulp, tannins in the fruit confer an unpleasant astringent taste on the fruit. The astringency in ripe fruit is reduced, which is associated with a change in the structure of the tannins, rather than a reduction in their levels, as they form polymers [28]. When banana fruit is cut, oxidative browning occurs due to the presence of polyphenols. Report of different studies has shown that banana peels of different cultivars contain varying concentrations of total phenolic compounds (TPC). In the works of Nguyen et al. [54], it was reported that total phenolics, flavonoids and antioxidant activity of banana pulp and peel flours, Cv. 'Kulai Hom Thong' was shown to contain 3.0 mg of gallic acid equivalent (GAE)/gFW, while 'Kulai Khai' was reported to contain 0.9 mg of (GAE)/gFW. Similarly, banana cv. 'Pisangmas' from Malaysia was reported to contain TPC ranging from 0.24 to 0.72 mg GAE/g FW, depending on the extraction method [32]. Sulaiman et al. [52], also reported significant differences in the antioxidant activity, total phenolic and mineral contents of eight Malaysian banana cultivars. Flavonoids epicatechin and myricetin 3-O-rhamnosyl-glucoside were identified in flour of organic acid pretreated "Mabonde", "Luvhele" and "M-red" cultivars at different concentrations [55]. Authors Bennett et al. [56] and Borges et al. [57] also reported the presence of catechin and gallic acid in pulp and peel of ripe and unripe banana cultivars. Similarly, plantain a banana cultivar belonging to the AAB, ABB or BBB group [58] have also been reported to contain high concentration of hydroxycinnamic acids (ferulic acid–hexoside with 4.4–85.1 μg/g DW) in its pulp [32]. Plantain peels are rich in flavonol glycosides and rutin ranging from 242.2 to 618.7 μg/g DW.

Polyphenols are extremely diverse group of secondary metabolites, having sweet-smelling ring with one or more hydroxyl groups. Polyphenols have large range of structures and functions and can be classified as subgroups of flavonoids, phenolic acids, tannins, stilbenes and coumarins. These secondary metabolites are very essential in the metabolism, reproduction and growth of plants. Polyphenols also protect plants against pathological parasites, predators, fungal infections and viruses [53].

3.1 Banana volatiles

Tropical flavours including coconut, mango, mandarin as well as the combination of fruit and vegetable flavours are gaining popularity, with the African marula fruit and mangosteen being strong super fruit contenders [59]. Banana fruit flavour has been attributed to the presence of esters with inherent alcohols which contribute to flavour enhancement [60]. Alcohols and insignificant carbonyl composites present in banana are called green and woody notes [61], while the ester fraction contributes to fruity notes [62–64]. The presence of esters cause the sweet-smelling profile in ripe bananas, while that of unripe banana is determined by the presence of pentyl and hexyl alcohols, aldehydes and ketones [65]. Components of the fruity notes present in banana fruit includes 3-methylbutyl acetate, isoamyl butanoate and isoamyl isovalerate [66–68]. Esters constitute a major fraction of emitted volatiles from fresh banana fruits [64]. Esters can also be used to differentiate cooking bananas from desert bananas; in that cooking bananas lack esters, whereas the same form a major component of flavour present in desert bananas [69].

Aroma in banana fruit is characterised by the presence of various volatile compounds varying in concentration among cultivars [70, 71]. Pino [72] reported the presence of 250 volatiles in fresh and processed banana products, though few of these volatiles have been isolated as flavour contributors. Essential components affecting taste of banana fruit includes D-glucose, D-fructose and sucrose for sweetness, while citric, L-malic, oxalic and succinic acids have been implicated for sourness [65, 73]. Determination of volatiles that has unique character of the fruit is important as it produces the principal characteristic flavour of the fruit [74, 75]. The most appealing property of banana required by most consumers apart from their nutritional and health benefits is the flavour [76, 77].

3.2 Nutrigenomics of banana nutrients

With the ever changing nutrition-related health problems in developing economies, there is a gradual shift in nutrition research that focuses on how nutrition can be maximised in maintaining homeostasis at the cellular, tissue, organ and system level of the body [75]. This, however, requires the understanding of nutrient interactions at the molecular level. Nutrigenomics is the research into nutritional genomics, which also include nutrigenetics. In the works of Neeha and Kinth [78], nutrigenomics is defined as the study of the interaction between nutrients and genes, proteins and metabolic processes such as DNA and RNA synthesis and glycogenesis. Nutrigenomics focuses on the effects of nutrients on genome, proteome and metabolome as well as the interactions among these nutrients and nutrient-regimes in the body [78]. Through the application of molecular biology and genomic tools, researchers have identified genes responsible for the production of nutritionally significant proteins such as digestive enzymes, transport molecules and cofactors at their site of use [79]. Studies on genetic improvement of banana fruit is advancing at a rapid pace, using modern biotechnology which includes genetic engineering. Other programmes such as the use of banana as edible vaccine delivery system and biofortification of bananas to increase their β-carotene, α-tocopherol and iron contents are on the way [79]. These improvements will be most beneficial for regions of the world that consume bananas as their major staple. However, genetic improvement of banana fruit is a major challenge as cultivated banana fruits are basically sterile or possess low fertility with conventional breeding, though possible in delivering a few acceptable cultivars [79]. In the WHO [80] guideline on vitamin A supplementation in infants and children 6–59 months of age, about 19 million pregnant women and 190 million preschool age children from parts of Africa and South-East Asia were reported to be affected by vitamin A deficiency (VAD). Similarly, VAD is reported to be responsible for about 6% of child mortality below the age of five in Africa and 8% in South-East Asia [79]. Some banana cultivars have been implicated for the presence of dietary provitamin A carotenoid (PVAC) due to their characteristic orange-coloured fruit flesh. Carotenoid composition of the PVAC implicated banana cultivars has shown the presence of *trans*-α-, *trans*-β-, *cis*-β-carotene and lutein [21]. These notable differences in PVAC composition of the fruit could have significant consequences on the nutritional profile of banana varieties [79]. Banana bioactive compounds have potential for preventing various diseases when used as an ingredient in the food industry [81, 82].

4. Utilisation of banana bioactives as nutraceuticals and food ingredients

According to the Science Forum, nutraceuticals is defined as a "diet supplement that delivers a concentrated form of a biologically active component of food in a non-food matrix to enhance health" [83]. Anyasi et al. [58] in their study further added that nutraceutical can also be extracted from a different product derived from the food and pharmaceutical industry, herbal and dietary supplement market, and the pharmaceutical/agribusiness and nutrition conglomerates. Raw banana shows higher amount of functional ingredients such as dietary fibre, resistant starch and total starch, which allows banana to impart health benefits to humans when incorporated in food products [84]. **Table 3** highlighted the effects of banana bioactive compounds as a value-added ingredient in food processing. It is important to understand fruit maturity during preparation of banana flour to produce desirable food products. Ripe banana can be considered for industrial processing, which could result to products that are comparable to those obtained from apple, juice, fruit drinks, fermented drinks, stewed fruit, puree, marmalade, jam, flakes, confectionery, pastry, sorbets and ice-cream. Raw bananas can be considered as a source for new food innovation and development for partial or preprocessed food products like snacks and breakfast cereals [82]. Mixed pulp and peel flour from green banana has higher ash, total fibre and total phenolics than traditional wheat flour [85]. The addition of banana flour increases the indigestible fraction and the content of phenolic compounds in spaghetti [86]. Crackers containing greater amount of green banana flour showed increased antioxidant capacity [87]. The influence of green banana flour as a substitution for cassava starch on the nutrition, colour, texture and sensory qualities of snacks was reported for raw banana flour [87]. In the study, increased nutritional value including dietary fibre, polyphenol content and antioxidant capacity of the snacks was noted. Unripe banana peel can be incorporated in a sponge cake without imparting negative effects on the sensory quality [88]. The application of banana by-products, an underutilised renewable food biomass with potential in food and nutraceutical industry as a means of promoting green

Products	Maturity/cultivars	Effects on antioxidant activity	References
Pasta	Raw/*Musa paradisiaca*	Increased indigestible fraction and total phenolic content	[86]
Sponge cakes	Raw/*Musa cavendish*	Yielded more polyphenols and exhibit high antioxidant capacity	[88]
Cassava snacks	Raw/Musa AAA *Cavendish*	Increased antioxidant activity, including ferric-reducing power and superoxide radical scavenging capacity	[87]
Banana muffins	Raw	Exhibit antimicrobial activity	[90]
Orange juice	Raw mango peel/*Musa acuminate Colla* AAA	Increased capacity to scavenge free radicals of orange juice	[93]

Table 3.
Use of banana bioactive compounds as value-added product.

technology was reported [89–91]. Banana by-products such as peels are readily available for use as a source of raw materials, as they are regarded as waste during processing of foods such as jams, chips and noodles for green technology industry. Since the discovery of banana as a fruit for human consumption, there are no reports in the literature which show that it contains hazardous phytochemicals. Therefore, banana by-products preparation for usage in the food industry does not require excessive treatment as compared with other fruits by-products with potent hazardous constituents [89]. Banana peel extracts are rich in antioxidant capacity using multiple antioxidant assays. These peels are helpful in exhibiting antimicrobial activity against a wide range of bacteria and fungi [92].

5. Health benefits associated with banana bioactives

Banana is a very common fruit in most continents of the world and is consumed essentially as food. It is the fifth most significant food source with respect to world trade. Banana has more than a few bioactives which include biogenic amines, phenolics, phytosterols and carotenoids [46, 93]. These compounds are of immense benefit to consumers due to countless positive effects they have on human health (**Table 4**). The positive effects of these compounds on human health is expected because they have antioxidative properties, hence they are efficient in reducing oxidative stresses. Banana pulp has been reported to have high anti-tumour and antioxidant potentials [57]. Consumption of bananas is advantageous to body muscles due to its high content of K. Banana is usually suggested for patients suffering from anaemia due owing to its high content of Fe. Banana is low in Na, hence it helps in regulating blood pressure [46]. The presence of syringic acid in banana was reported [92]. This compound has an antidiabetic effect and could be used in managing glycoprotein abnormalities [92]. The consumption of catechin rich banana can help build up resistance to oxidation of low density lipoprotein (LDL), brachial artery dilation, increase plasma antioxidant activity and fat oxidation [94]. The gallic acid in banana was reported to exhibit hepatoprotective effects [95]. Serotonin in banana helps to avoid depression by altering mood and calming the body. The consumption of carotenoid rich banana is also effective in the treatment of vitamin A deficiency disorders and chronic diseases [39]. Dopamine and ascorbic acid present in banana is useful in reduction of plasma oxidative stress and enhancement of resistance to oxidative modification of LDL [56, 96]. In many

Bioactive compounds	Uses	References
Phenolic compounds—gallic acid, catechin, epicatechin, tannins and anthocyanins, gallocatechin, epigallocatechin, quercetin, myricetin, kaempferol, ferulic, sinapic, salicylic, gallic, p-hydroxybenzoic, vanillic, syringic, gentisic and p-coumaric acids	Act as protective scavengers against oxygen-derived free radicals and reactive oxygen species responsible for ageing and various diseases	[56, 98–101]
Carotenoids—lutein, β-carotene, α-carotene, violaxanthin, auroxanthin, neoxanthin, isolutein, β-cryptoxanthin and α-cryptoxanthin	Act as antioxidants, especially in scavenging singlet oxygen, decreases the risk of certain cancers, heart problems and eye diseases; improves immunity	[102–105]
Biogenic amines—serotonin, dopamine and norepinephrine	Reduce the plasma oxidative stress and enhance the resistance to oxidative modification of low density lipoproteins; contributes towards the feelings of well-being and happiness; plays an important role in the human brain and body as a neurotransmitter with great impact on our mood, ability to concentrate and emotional stability	[106, 107]
Phytosterols—cycloeucalenone, cycloeucalenol, cycloartenol, stigmasterol, campesterol and b-sitosterol	Lowers cholesterol level in the blood and reduce its absorption in the intestine; act as immune system modulators and also have anticancer properties	[108–110]

Table 4.
Bioactive compounds present in banana and their utilisation.

animal trials, banana has been shown to be useful in the treatment of diabetes, due to its antihyperglycemic effect [97]. Banana is also utilised as a source of energy for sports athletes as it forms a valuable constituent in various energy drinks and dried banana bars [1]. Consumption of the fruit has also been used in the prevention of muscular contractions in athletes due to its vitamins, K and Mg contents [1].

6. Current trends in banana bioactive utilisation

A number of essential bioactive compounds in bananas have been reported by different researchers. Banana holds adequate quantity of valuable bioactive compounds for health promotion. Several studies have established and verified antioxidant activity of these compounds and efficaciously used bananas in treatment of diseases and promotion of wellbeing [46]. Bananas are being currently used to produce variety of food items which are of benefit to human health. Moreover, bananas are being composited with other food products to improve the micro and macro-nutrient values, especially for food low in micro and macro-nutrients [75, 97].

7. Conclusion

Bananas are cultivated and utilised at different stages throughout the globe because the fruit contains both therapeutic and nutritional properties. Banana is composed of a substantial amount of beneficial bioactives which are essential for health and disease prevention. Bioactive compounds (phenolics, biogenic amines and phytosterols) in bananas could be enriched through genetic engineering, while developing bio-fortified cultivars for improvement of micronutrients. Banana peel contains substantial amounts of dietary fibre and bioactives at various stages of maturation. Industrial utilisation of the fruit in variety of food products will reduce occurrence of health related diseases even as its use in genomics will mitigate the effect of micro nutrient deficiency in the body.

Author details

Rinah K. Netshiheni[1], Adewale O. Omolola[2], Tonna A. Anyasi[3]* and Afam I.O. Jideani[3]

1 Department of Nutrition, School of Health Sciences, University of Venda, Limpopo, South Africa

2 Department of Agricultural and Rural Engineering, School of Agriculture, University of Venda, Limpopo, South Africa

3 Department of Food Science and Technology, School of Agriculture, University of Venda, Limpopo, South Africa

*Address all correspondence to: tonna.anyasi@univen.ac.za; tonna.anyasi@gmail.com

References

[1] Sadia Q, Azizuddin S. Therapeutic potentials and compositional changes of valuable compounds from banana-a review. Trends in Food Science & Technology. 2018;**79**:1-9

[2] Khawas P, Das AJ, Dash KK, Deka SC. Thin-layer drying characteristics of Kachkal banana peel (Musa ABB) of Assam. India. International Food Research Journal. 2014;**21**:975-982

[3] Campos NA, Swennen R, Carpentier SC. The plantain proteome, a focus on allele specific proteins obtained from plantain fruits. Proteomics. 2018;**1700227**:1-5. DOI: 10.1002/pmic.201700227

[4] Simmonds NW. The Evolution of the Banana. London (GBR): Tropical Science Series Longmans; 1962. p. 170

[5] Ganapathi TR, Suprasanna PS, Bapat VA, Kulkarni VM, Rao PS. Somatic embryogenesis and plant regeneration from male flower buds of banana. Current Science. 1991;**76**:1128-1231

[6] FAOSTAT (Food and Agriculture Organization of the United Nations). 2013. Available from: http://faostat.fao.org/ [Accessed: 26 April 17]

[7] Emaga TH, Robert C, Ronkart SN, Wathelet, Paquot M. Dietary fibre components and pectin chemical features of peels during ripening in banana and plantain varieties. Bioresource Technology. 2008;**99**:4346-4354

[8] Seenappa M, Laswai HS, Ferando SP. Availability of L-ascorbic acid in Tanzanian banana. Journal of Food Science and Technology. 1986;**23**:293-295

[9] Doymaz I. Evaluation of mathematical models for prediction of thin-layer drying of banana slices. International Journal of Food Properties. 2010;**13**:486-497

[10] Pareek S. Nutritional and biochemical composition of Banana (Musa spp.) cultivars. In: Simmonds MSJ, Preedy VR, editors. Nutritional Composition of Fruit Cultivars. London, UK: Academic Press, Elsevier BV; 2016. pp. 49-81. DOI: 10.1016/B978-0-12-408117-8.00003-9

[11] Pereira A, Maraschin M. Review Banana (*Musa spp*) from peel to pulp: Ethnopharmacology, source of bioactive compounds and its relevance for human health. Journal of Ethnopharmacology. 2015;**160**:149-163

[12] da Silva AR, Cerdeira CD, Brito AR, Salles BCC, Ravazi GF, Moraes GDI, et al. Green banana pasta diet prevents oxidative damage in liver and kidney and improves biochemical parameters in type 1 diabetic rats. Archives of Endocrinology Metabolism. 2016;**60**:355-366

[13] Famakin O, Fatoyinbo A, Ijarotimi OS, Badejo AA, Fagbemi TN. Assessment of nutritional quality,glycaemic index, antidiabetic and sensory properties of plantain (Mu*sa paradisiaca*)-based functional dough meals. Journal of Food Science and Technology-Mysore. 2016;**53**:3865-3875

[14] Jaber H, Baydoun E, El-Zein O, Kreydiyyeh SI. Anti-hyperglycemic effect of the aqueous extract of banana infructescence stalks in Streptozotocin-induced diabetic rats. Plant Foods for Human Nutrition. 2013;**68**:83-89

[15] Ayoola IO, Gueye B, Sonibare MA, Abberton MT. Antioxidant activity and acetylcholinesterase inhibition of field and *in vitro* grown *Musa* L. species.

Journal of Food Measurement and Characterization. 2017;**11**:488-499

[16] Onwuka GI, Onwuka ND. The effects of ripening on the functional properties of plantain and plantain based cake. International Journal of Food Properties. 2005;**8**:347-353

[17] Cheirsilp B, Umsakul K. Processing of banana based wine products using pectinase and alpha-amylase. Journal of Food Process Engineering. 2008;**31**:78-90

[18] Yang SF, Hoffman NE. Ethylene biosynthesis and its regulation in higher plants. Annual Review of Plant Physiology. 1984;**35**:155-189

[19] Marriott J, Robinson M, Karikari SK. Starch and sugar transformation during the ripening of plantains and bananas. Journal of the Science of Food and Agriculture. 1981;**32**:1021-1026

[20] Arvanitoyannis IS, Mavromatis A. Banana cultivars, cultivation practices, and physicochemical properties. Critical Reviews in Food Science and Nutrition. 2009;**49**:113-135

[21] Wall MM. Ascorbic acid, vitamin a, and mineral composition of banana (*Musa sp*.) and papaya (*Carica papaya*) cultivars grown in Hawaii. Journal of Food Composition and Analysis. 2006;**19**:434-445

[22] Lee PJ. Facts about Banana Potassium. 2008. Available from: http://ezinearticlescom/?Facts-About-Banana-Potassium&id=1762995 [Accessed: October 2009]

[23] USDA (United States Department of Agriculture). 2012. Nutrient Database. http://www.nal.usda.gov/fnic/foodcomp/Data/SR17/wtrank/sr17a306.pdf [Accessed: October 2017]

[24] Wardlaw CW, Leonard ER, Barnell HR. Metabolic and Storage Investigations of the Banana. Trinidad: Low Temperature Research Station, Memoir 11. Imperial College of Tropical Agriculture; 1939

[25] Desai BB, Deshpande PB. Chemical transformations in three varieties of banana Musa paradisica Linn fruits stored at 20°C. Mysore Journal of Agricultural Science. 1975;**9**:634-643

[26] Lizada MC, Pantastico EB, Abdullah Shukor AR, Sabari SD. Ripening of banana. In: Abdulla H, Pantastico EB, Hassan H, editors. Banana. Kuala Lumpur, Malaysia: ASEAN Food Handling Bureau; 1990. pp. 65-84

[27] Barnell HR. Studies in tropical fruits. Carbohydrate metabolism of the banana fruit during storage at 53°F. Annals of Botany New Series. 1943;**9**:1-22

[28] Hubbard NL, Mason Pharr D, Huber SC. Role of sucrose phosphate synthase in sucrose biosynthesis in ripening bananas and its relationship to the respiratory climacteric. Plant Physiology. 1990;**94**:201-208

[29] Madamba SP, Baes AU. Mendoza Jr B. effect of maturity on some biochemical changes during ripening of banana Musa sapientum cv. Lakatan. Food Chemistry. 1977;**2**:177-183

[30] Montenegro EH, Postharvest Behaviour of Banana (*Musa sp. cv. 'Latundan'*) Harvested at Different Stages of Maturity [BS thesis]. Philippines: Laguna, UPLB; 1988

[31] Khoozani AA, Bekhit AA, Birch J. Effects of different drying conditions on the starch content, thermal properties and some of the physicochemical parameters of whole green banana flour. International Journal of Biological Macromolecules. 2019;**130**:938-946

[32] John P, Marchal J. Ripening and biochemistry of the fruit. In: Gowen S,

editor. Bananas and Plantains. London: Chapman and Hall; 1995. pp. 434-467

[33] Toledo TT, Nogueira SB, Cordenunsi BR, Gozzo FC, Pilau EJ, Lajolo FM, et al. Proteomic analysis of banana fruit reveals proteins that are differentially accumulated during ripening. Postharvest Biology and Technology. 2012;**62**:51-58

[34] Wills RB, Poi A, Greenfield H, Rigney CJ. Postharvest changes in fruit composition of Annona atemoya during ripening and effects of storage temperature on ripening. Horticultural Science. 1984;**19**:96-97

[35] Wenkam NS. Food of Hawaii and the Pacific Basin, Fruits and Fruit Products: Raw, Processed and Prepared: Volume 4: Composition. Hawaii Agricultural Experiment Station Research and Extension Series. 1990. p. 96

[36] Seymour GB. The effects of gases and temperature on banana ripening [Ph.D. thesis]. University of Reading; 1985

[37] Kanazawa K, Sakakibara H. High content of dopamine, a strong antioxidant in Cavendish banana. Journal of Agricultural and Food Chemistry. 2000;**48**:844-848

[38] Gross J, Flugel M. Pigment changes in peel of the ripening banana (*Musa* cavendish). Gartenbauwissenschaft. 1982;**47**:62-64

[39] Englberger L, Schierle J, Aalbersberg W, Hofmann P, Humphries J, Huang A, et al. Carotenoid and vitamin content of karat and other Micronesian banana cultivars. International Journal of Food Sciences and Nutrition. 2006;**57**:399-418

[40] Ramu R, Shirahatti PS, Zameer F, Ranganatha LV, Prasad MN. Inhibitory effect of banana (*Musa* sp. var. Nanjangud rasa bale) flower extract and its constituents Umbelliferone and Lupeol on α-glucosidase, aldose reductase and glycation at multiple stages. South African Journal of Botany. 2014;**95**:54-63

[41] Hardisson A, Rubio C, Baez A, Martin M, Alvarez R, Diaz E. Mineral composition of the banana (*Musa acuminata*) from the island of Tenerife. Food Chemistry. 2001;**73**:153-161

[42] Forster MP, Rodríguez ER, Romero CD. Differential characteristics in the chemical composition of bananas from Tenerife (Canary Islands) and Ecuador. Journal of Agricultural and Food Chemistry. 2002;**50**:7586-7592

[43] Adeyemi OS, Oladiji AT. Compositional changes in banana (*Musa* spp.) fruits during ripening. African Journal of Biotechnology. 2009;**8**:858-859

[44] Emaga TH, Andrianaivo RH, Wathelet B, Tchango JT, Paquot M. Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. Food Chemistry. 2007;**103**:590-600

[45] Ketron AC, Osheroff N. Phytochemicals as anticancer and chemopreventive topoisomerase II poisons. Phytochemistry Reviews. 2014;**13**:19-35. DOI: 10.1007/s11101-013-9291-7

[46] Singh B, Singh JP, Kaur A, Singh N. Bioactive compounds in banana and their associated health benefits—A review. Food Chemistry. 2016;**206**:1-11

[47] Mathew NS, Negi PS. Traditional uses, phytochemistry and pharmacology of wild banana (*Musa acuminata* Colla): A review. Journal of Ethnopharmacology. 2017;**196**:124-140

[48] González-Aguilar G, Robles-Sánchez RM, Martínez-Téllez MA, Olivas GI, Lvarez-Parrilla E, de la

Rosa LD. Bioactive compounds in fruits: Health benefits and effect of storage conditions. Stewart Postharvest Review. 2008;**3**:8

[49] Vu HT, Scarlett CJ, Vuong QV. Phenolic compounds within banana peel and their potential uses: A review. Journal of Functional Foods. 2018;**40**:230-248

[50] Kondo S, Kittikorn M, Kanlayanarat S. Preharvest antioxidant activities of tropical fruit and the effect of low temperature storage on antioxidants and jasmonates. Postharvest Biology and Technology. 2005;**36**:309-318

[51] Sulaiman SF, Yusoff NA, Eldeen IM, Seow EM, Sajak AA, Supriatno B, et al. Correlation between total phenolic and mineral contents with antioxidant activity of eight Malaysian bananas (*Musa sp*.). Journal of Food Composition and Analysis. 2011;**24**:1-10

[52] Fatemeh SR, Saifullah R, Abbas FM, Azhar ME. Total phenolics, flavonoids and antioxidant activity of banana pulp and peel flours: Influence of variety and stage of ripeness. International Food Research Journal. 2012;**19**:1041-1046

[53] Liu RH. Potential synergy of phytochemicals in cancer prevention: Mechanism of action. Journal of Food Science. 2004;**134**:3479-3485

[54] Nguyen TB, Ketsa S, Van Doorn WG. Relationship between browning and the activities of polyphenol oxidase and phenylalanine ammonia lyase in banana peel during low temperature storage. Postharvest Biology and Technology. 2003;**30**(2):187-193

[55] Anyasi TA, Jideani AIO, Mchau GRA. Phenolics and essential mineral profile of organic acid pretreated unripe banana flour. Food Research International. 2018;**104**:100-109. DOI: 10.1016/j.foodres.2017.09.063

[56] Bennett RN, Shiga TM, Hassimotto NMA, Rosa EAS, Lajolo FM, Cordenunsi BR. Phenolics and antioxidant properties of fruit pulp and cell wall fractions of postharvest banana (*Musa acuminata* Juss.) cultivars. Journal of Agricultural and Food Chemistry. 2010;**58**:7991-8003

[57] Borges CV, Amorim VBO, Ramlov F, Ledo CAS, Donato M, Maraschin M, Amorim EP. Characterisation of metabolic profile of banana genotypes, aiming at biofortified *Musa* spp. cultivars. Food Chemistry 2014;145:496-504

[58] Anyasi TA, Jideani AIO, Mchau GRA. Functional properties and postharvest utilization of commercial and non-commercial banana cultivars. Comprehensive Review in Food and Technology. 2013;**12**:509-522

[59] Sloan AE. Border crossings. Food Technology. 2011;**65**:26-39

[60] Blanch GP, Herraiz M, Reglero G, Tabera J. Preconcentration of samples by steam distillation-solvent extraction at low temperature. Journal of Chromatography A. 1993;**655**(1):141-149

[61] Wang J, Li YZ, Chen RR, Bao JY, Yang GM. Comparison of volatiles of banana powder dehydrated by vacuum belt drying, freeze-drying and air-drying. Food Chemistry. 2007;**104**:1516-1521

[62] Brat P, Yahia A, Chillet M, Bugaud C, Bakry F, Reynes M. Influence of cultivar, growth altitude and maturity stage on banana volatile compound composition. Fruits. 2004;**59**(2):75-82

[63] Pérez AG, Cert A, Rios JJ, Olias JM. Free and glycosidically bound volatile compounds from two bananas cultivars: Valery and Pequeña Enna. Journal

of Agricultural and Food Chemistry. 1997;**45**:4393-4397

[64] Salmon B, Martin GJ, Renaud G, Fourel F. Compositional and isotopic studies of fruit flavours. Part I: The banana aroma. Flavour and Fragrance Journal. 1996;**11**(6):353-359

[65] Vermeir S, Hertog MLATM, Vankerschaver K, Swennen R, Nicolai BM, Lammertyn J. Instrumental based flavour characterization of banana fruit. LWT Food Science and Technology. 2009;**42**:1647-1653

[66] Cosio R, René F. Composés volatils de la banana. II Etude comparative de deux méthodes d'extraction appliquées à la pulpe de banane: Cavendish, poyo. Sciences des Aliments. 1996;**16**:515-528

[67] Jordan MJ, Tandon K, Shaw PE, Goodner KL. Aromatic profile of aqueous banana essence and banana fruit by gas chromatography–mass spectrometry (GC–MS) and gas chromatography–olfactometry (GC–O). Journal of Agricultural and Food Chemistry. 2001;**49**:4813-4817

[68] Schiota H. New ester components in the volatiles of banana fruit (*Musa sapientum* L.). Journal of Agricultural and Food Chemistry. 1993;**41**:2056-2062

[69] Aurore G, Ginies C, Ganou-parfait B, Renard CMG, Fahrasmane L. Comparative study of free and glycoconjugated volatile compounds of three banana cultivars from French West Indies: Cavendish, Frayssinette and plantain. Food Chemistry. 2011;**129**:28-34

[70] Cano MP, de Ancos B, Matallana MC, Cámara M, Reglero G, Tabera J. Differences among Spanish and Latin-American banana cultivars: Morphological, chemical and sensory characteristics. Food Chemistry. 1997;**59**(3):411-419

[71] Pontes M, Pereira J, Câmara JS. Dynamic headspace solid-phase microextraction combined with one-dimensional gas chromatography–mass spectrometry as a powerful tool to differentiate banana cultivars based on their volatile metabolite profile. Food Chemistry. 2012;**134**:2509-2520

[72] Pino JA, Febles Y. Odour-active compounds in banana fruit cv. Giant Cavendish. Food Chemistry. 2013;**141**:795-801

[73] Kyamuhangire W, Myhre H, Sorensen HT, Pehrson R. Yield, characteristics and composition of banana juice extracted by the enzymatic and mechanical methods. Journal of the Science of Food and Agriculture. 2002;**82**(4):478-482

[74] Augusto F, Valente AL, dos Santos Tada E, Rivellino SR. Screening of Brazilian fruit aromas using solid-phase microextraction–gas chromatography-mass spectrometry. Journal of Chromatography A. 2000;**873**(1):117-127

[75] Davey MW, Keulemans J, Swennen R. Methods for the efficient quantification of fruit provitamin a contents. Journal of Chromatography A. 2006;**1136**:176-184

[76] Boudhrioua N, Michon C, Cuveher G, Bonazzi C. Influence of ripeness and air temperature on changes in banana texture during ripening. Journal of Food Engineering. 2002;**55**(2):115-121

[77] Balazs E. Tropical fruit as excellent resources for nutrigenomics. In: Proceedings of the Tropical Fruits in Human Nutrition and Health Conference 2008. 2009. pp. 3-5

[78] Neeha VS, Kinth P. Nutrigenomics research: A review. Journal of Food Science and Technology.

2013;**50**(3):415-428. DOI: 10.1007/s13197-012-0775-z

[79] Khanna H, Becker D, Whitelaw E, Harrison M, Bateson M, Harding R, et al. Biofortification of bananas. In: Proceedings of the Tropical Fruits in Human Nutrition and Health Conference 2008. 2009. pp. 9

[80] WHO Guideline. Vitamin a Supplementation in Infants and Children 6-59 Months of Age. Geneva: WHO; 2011

[81] Oleaga C, Ciudad CJ, Noel V, Izquierdo-Pulido. Nutritional genomics. A new approach in nutrition research. Recent. Advances in Pharmaceutical Sciences. 2012;**2**:49-68

[82] Aurore G, Parfait B, Fahrasmane L. Bananas, raw materials for making processed food products—Review. Trends in Food Science and Technology. 2009;**20**:78-91

[83] Zeisel SH. Regulation of 'nutraceuticals'. Science. 1999;**285**:1853-1855

[84] Alkarkhi AFM, Ramli SB, Yong YS, Easa AM. Comparing physicochemical properties of banana pulp and peel flours prepared from green and ripe fruits. Food Chemistry. 2011;**129**:312-318

[85] Castelo-Branco VN, Guimarães JN, Souz L, Guede MR, Silva PM, Ferrão LL, et al. The use of green banana (*Musa balbisiana*) pulp and peel flour as an ingredient for tagliatelle pasta. Brazil Journal of Food Technology. Campinas. 2017;**20**:2016-2019

[86] Ovando-Martinez M, Sáyago-Ayerdi S, Agama-Acevedo E, Goñi I, Bello-Pérez LA. Unripe banana flour as an ingredient to increase the undigestible carbohydrates of pasta. Food Chemistry. 2009;**113**(1):113-126

[87] Wang Y, Zhang M, Mujumdar AS. Influence of green banana flour substitution for cassava starch on the nutrition, color, texture and sensory quality in two types of snacks. LWT- Food Science and Technology. 2012;**47**:175-182

[88] Segundo C, Román L, Gómez M, Martínez MM. Mechanically fractionated flour isolated from green bananas (*M. cavendishii* var. nanica) as a tool to increase the dietary fiber and phytochemical bioactivity of layer and sponge cakes. Food Chemistry. 2017;**219**:240-248

[89] Padam BS, Tin HS, Chye FY, Abdullah MI. Banana by-products: An underutilized renewable food biomass with great potential. Journal of Food Science and Technology. 2014;**51**:3527-3545

[90] Rudrawar BD, Development JVV. Sensory and analytical study of spicy Banana muffins. International Journal of Science and Research. 2015;**4**:1291-1294

[91] Ortiz L, Dorta E, Lobo MG, Gonzalez-Mendoza LA, Diaz C, Gonzalez M. Use of banana (*Musa acuminata* Colla AAA) peel extract as an antioxidant source in orange juice. Plant Foods for Human Nutrition. 2017;**72**:60-66

[92] Muthukumaran J, Srinivasan S, Venkatesan RS, Ramachandran V, Muruganathan U. Syringic acid, a novel natural phenolic acid, normalizes hyperglycemia with special reference to glycoprotein components in experimental diabetic rats. Journal of Acute Disease. 2013;**2**:304-309

[93] Anyasi TA, Jideani AIO, Mchau GRA. Effect of organic acid pre-treatment on some physical, functional and antioxidant properties of flour obtained from three unripe

banana cultivars. Food Chemistry. 2015;**172**:515-522

[94] Williamson G, Manach C. Bioavailability and bioefficacy of polyphenols in humans. II. Review of 93 intervention studies. The American Journal of Clinical Nutrition. 2005;**81**:243-255

[95] Rasool MK, Sabina EP, Ramya SR, Preety P, Patel S, Mandal N, et al. Hepatoprotective and antioxidant effects of gallic acid in paracetamol induced liver damage in mice. Journal of Pharmacy and Pharmacology. 2010;**62**:638-643

[96] Kumar KS, Bhowmik D, Duraivel S, Umadevi M. Traditional and medicinal uses of banana. Journal of Pharmacognosy and Phytochemistry. 2012;**1**:2278-4136

[97] Alarcon-Aguilara FJ, Roman-Ramos R, Perez-Gutierrez S, Aguilar-Contreras A, Contreras-Weber CC, Flores-Saenz JL. Study of the antihyperglycemic effect of plants used as antidiabetics. Journal of Ethnopharmacology. 1998; **61**:101-110

[98] Mattila P, Hellström J, Törrönen R. Phenolic acids in berries, fruits, and beverages. Journal of Agricultural and Food Chemistry. 2006;**54**:7193-7199

[99] Balasundram N, Sundram K, Samman S. Phenolic compounds in plants and Agri-industrial by-products: Antioxidant activity, occurrence, and potential uses. Food Chemistry. 2006;**99**:191-203

[100] Harnly JM, Doherty RF, Beecher GR, Holden JM, Haytowitz DB, Bhagwat S, et al. Flavonoid content of US fruits, vegetables, and nuts. Journal of Agricultural and Food Chemistry. 2006;**54**:9966-9977

[101] Russell WR, Labat A, Scobbie L, Duncan GJ, Duthie GG. Phenolic acid content of fruits commonly consumed and locally produced in Scotland. Food Chemistry. 2009;**115**:100-104

[102] Subagio A, Morita N, Sawada S. Carotenoids and their fatty-acid esters in banana peel. Journal of Nutritional Science and Vitaminology. 1996;**42**:553-566

[103] Beatrice E, Deborah N, Guy B. Provitamin a carotenoid content of unripe and ripe banana cultivars for potential adoption in eastern Africa. Journal of Food Composition and Analysis. 2015;**43**:1-6

[104] Krinsky NI, Johnson EJ. Carotenoid actions and their relation to health and disease. Molecular Aspects of Medicine. 2005;**26**:459-516

[105] Fungo R. Pillay M. b-carotene content of selected banana genotypes from Uganda. African Journal of Biotechnology. 2013;**10**:5423-5430

[106] Bapat VA, Suprasanna P, Ganapathi TR, Rao PS. In vitro production of L-DOPA in tissue cultures of banana. Pharmaceutical Biology. 2000;**38**:271-273

[107] Romphophak T, Siriphanich J, Ueda Y, Abe K, Chachin K. Changes in concentrations of phenolic compounds and polyphenol oxidase activity in banana peel during storage. Food Preservation Science. 2005;**31**:111-115

[108] Marangoni F, Poli A. Phytosterols and cardiovascular health. Pharmacological Research. 2010;**61**:193-199

[109] Quilez J, Garcia-Lorda P, Salas-Salvado J. Potential uses and benefits of phytosterols in diet: Present situation and future directions. Clinical Nutrition. 2003;**22**:343-351

[110] Villaverde JJ, Oliveira L, Vilela C, Domingues RM, Freitas N, Cordeiro N, et al. High valuable compounds from the unripe peel of several *Musa* species cultivated in Madeira Island (Portugal). Industrial Crops and Products. 2013;**42**:507-512