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Banana Pseudostem As A Potential Functional Ingredient For Food Products - A Review of Recent Research

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Banana pseudostems are biological by-products obtained during banana harvesting. Due to its huge amount, the disposal of the underutilized pseudostems is causing environmental problems. Research has been carried out to generate innovative ideas in producing functional food products from banana pseudostems. Functional foods are foods fortified or enriched with functional food ingredients to improve the nutritional and functional values of food. These foods are often consumed as a part of dietary to promote human health by improving their disease preventive ability. This review highlights the nutritional compositions, physicochemical properties and functional characteristics of banana pseudostems. Furthermore, details on the bioactive compounds and antioxidant capacity of banana pseudostems as well as the application of banana pseudostem as a potential therapeutic agent were discussed. This review also covers recent progress on the potential utilization of banana pseudostems in the development of functional food products and its effect on the quality of the end products. Overall, the information on banana pseudostems in this review could be of great interest to the research community and clinical nutrition community. The information collected would be very helpful to the food industry on the development of less expensive health functional food products in the future, which is the expected benefit to consumers.

Keywords: banana pseudostem, nutritional values, nutraceutical values, functional foods, food product quality

INTRODUCTION

Banana plants, which belong to the family of Musaceae, are native to the Malaysia-Indonesia region of South-East Asia (Subagyo and Chafidz, 2018). Banana is the fourth most important food product in the world after rice, corn and milk (Rana et al. 2018). The banana fruit is one of the most heavily consumed fruits in the world, with a global annual production of 116 million tons (FAOSTAT, 2018). However, each banana plant only produces a single bunch of fruit. Banana pseudostems, which occupied 61% of the total weight of banana plants, are unable to be used for the next harvest (Ma, 2015). Due to this character, several tonnes of bare pseudostems per hectare were produced in the banana plantations after each harvesting seasons (Ma et al. 2017). The banana pseudostems are usually cut, then burned or left on the plantation to decay, which could ultimately leads to environment issues and economic loss (Ho et al. 2012; Ma et al. 2017). The large amount of agricultural waste also gives rise to disposal problems among farmers. Therefore, the exploitation of banana pseudostem will be significantly beneficial for the environment, and thus bring additional profits to the grower. For that reason, the utilization of banana waste, pseudostems and the processing methods to enhance its economic value has gained more attention in recent years.

The pseudostem, which is not a true stem of the banana plant, is composed of large overlapping leaf stalk bases that are tightly rolled around each other to form a clustered and cylindrical structure with almost 48 cm in diameter, apart from tightly clasping and slightly swollen at the base (Ho et al. 2017). Elanthikkal et al. (2010) reported that banana fruit only represents about 12% of the total plant weight. The remaining 88% by weight of the banana plant (i.e. pseudo-stem and leaf) turns into waste and this leads to environmental problems in banana farming. Sokchea et al. (2018) reported that approximately 40% of banana plants are considered as waste to decompose in the field and about 60 to 80 tons/ha of banana pseudostem are generated annually and this leads to environmental problems in banana farming. Therefore, a better way to solve the problem of banana pseudostems is worth pursuing.

Banana pseudostems are an excellent source of minerals, e.g., potassium, sodium, phosphorus, magnesium, zinc, copper and iron, and are also rich in dietary fiber (Ho et al. 2012; Raju et al. 2019). Humans have consumed banana pseudostems for centuries not only for nutrition but also for their health treatment purposes (Ahmad et al. 2018). Several studies have shown that banana pseudostems have an abundance of bioactive compounds, e.g., phenolic and flavonoid compounds that contribute to antioxidant properties, which could be beneficial to human health (Ramu et al. 2017). Many studies have shown that banana pseudostems have the potential to reduce the risk of diabetes and cancer (Bhaskar et al. 2011b; Ramu et al. 2016; Kandasamy et al. 2016; Nguyen et al. 2017; Abdel Ghany et al. 2019) as well as to relieve the symptoms of an allergic reaction (García Mesa et al. 2019). In addition, banana pseudostem also exhibits a broad spectrum of antimicrobial activity (Jouneghani et al. 2020).

Consequent to several reported research on the health benefits of banana pseudostems to humans, studies on the utilization of banana pseudostem as a functional ingredient in food products have gained much popularity from the scientific community. However, fresh banana pseudostem is highly perishable and rapidly deteriorates because it contains about 94% of moisture. Therefore, banana pseudostem should be processed by drying to reduce the moisture content (Sharma et al. 2017). In order to utilize banana pseudostem, it has to be processed into flour before incorporated into food products to maximize food products' quality, including both nutritional and sensory characteristics.

Functional foods or functional ingredients is known to affect beneficially one or more target functions in the body beyond adequate effects in a way that is relevant to either an improved state of health and well-being and/or reduction of risk of disease (Bellisle, 1998; Gur et al. 2018). Apart from the basic nutritional functions that can be obtained from functional foods, it is also able to provide physiological benefits and/or reduce the risk of chronic diseases (Sofi et al. 2017). Currently, functional foods or functional food ingredients represent one of the most intensively investigated and widely promoted areas in the food and nutrition sciences (Adefegha, 2018) to ensure food security.

In this review, we discussed the nutritional composition, bioactive compounds as well as the potential use of banana pseudostem for pharmaceutical and food applications. It is envisaged that the details discussed in this review could exploit the potentiality of banana pseudostem in the international and national markets.

NUTRITIONAL COMPOSITIONS

Banana pseudostems possess a high nutritional value, particularly non-starch polysaccharides. Besides, banana pseudostems have also been recorded as a rich source of minerals (Aziz et al. 2011; Yuliatmoko et al. 2019). Ho et al. (2018) studied the proximate composition of the prepared banana pseudostem flour. They observed that the banana pseudostem dried at 60 ºC for overnight contained 7.84% moisture, 1.11% crude fat, 2.70% crude protein, 6.75% ash, 24.33% crude fiber and 81.60% total carbohydrate. Similar values for moisture (6.2%), crude fat (1.8%) and crude protein (3.6%) in banana pseudostem flour were also observed in the study by Sangroula (2018). However, ash and crude fiber were found to be two-fold higher and lower, respectively than the report by Ho et al. (2018). The calorie value of banana pseudostem was 347.79 kcal/100g. On the other hand, a decrease in crude fiber (from 28% to 26%) was observed by Ambrose and Naik (2016) when the banana pseudostem center core was dried at 70 ºC compared to 60 ºC, as the higher drying temperature may disrupt its cellular matrix. In another study by Aziz et al. (2011), they found that the proximate composition of the tender core from banana (*Musa acuminata* × *balbisiana Colla* cv. Awak) pseudostem flour has higher moisture (8.82%), crude fat (1.18%), crude protein (3.52%) and ash (10.08%) than the native banana pseudostem flour (8.34% moisture, 0.24% crude fat, 0.89% crude protein and 3.03% ash).

Banana pseudostem is easily subjected to enzymatic browning after harvest, which will influence the sensory attributes and economic value of the products made of banana pseudostem (Ma et al. 2017). The enzymic oxidation browning (i.e. polyphenol oxidase and peroxidase activities) can be inhibited by thermal blanching pre-treatment (Castro et al. 2008). The composition of the banana pseudostem may be greatly influenced by several factors, such as plant species, types of cultivars as well as processing methods (Ma et al. 2017). Ma et al. (2017) studied the effect of thermal blanching treatment (i.e. with or without 3 min blanching at 70 ºC water prior to cabinet drying at 40 ºC or 50 ºC) on the proximate composition of two banana species (*Musa balbisiana* and *Musa acuminate*) pseudostem. Their results showed that *Musa balbisiana* dried at 50 ºC after pre-treatment had the lowest moisture content (4.4%), but highest in ash (14%). However, pre-treatment did not affect the proximate compositions (i.e. 3.1–3.4% crude protein, 3.0–4.0% crude fat and 66.3–68.00% carbohydrate content) of *Musa balbisiana* to the most. Further comparison on the proximate composition between *Musa balbisiana* and *Musa acuminate* in which *Musa acuminata* pseudostem presented a higher crude protein (6.1%) and ash (15.9%), but no significant difference ($p>0.05$) was observed in the crude fat and carbohydrate content between these two banana species (Ma et al. 2017). However, Yuliatmoko et al. (2019) reported that a decreasing trend was observed in the ash content of banana pseudostem treated with thermal blanching (26.01%) as compared to untreated pseudostem (31.20%) and pseudostem soaked in sodium bisulfite solution (30.65%). This may be attributed to mineral loss, as some minerals could leach into water during the blanching process (Gombart et al. 2020).

Inadequate dietary intake of minerals is often associated with a weakened immune system and increased susceptibility to disease infection. It is well-documented that banana pseudostems contain an abundance of minerals in which the core and leaf fold of banana pseudostem contain several important minerals, in particular potassium, sodium, calcium, magnesium and phosphorus (Ho et al. 2012; Kumar et al. 2013; Ma et al. 2017, Ho et al. 2018; Thorat et al. 2018). Minerals play an important role in maintaining a proper function of the human body and good health (Bhat et al. 2010). According to Kumar et al. (2013), banana pseudostem is a rich source of potassium that could reduce the risk of hypertension by controlling the blood pressure. It also helps to lighten the risk of stroke, coronary heart disease and kidney stones besides enhancing bones health (Górska-Warsewicz et al. 2019). It has been reported that banana pseudostem is rich in potassium (680.00–1,078.20 mg/100 g dry matter), sodium (104.00–1,049.73 mg/100 g dry matter) and calcium (318.00–1,335.33 mg/100 g dry matter) (Ho et al. 2012; Ho et al. 2018; Sangroula, 2018). However, these reported values were higher than that reported by Ma et al. (2017) for banana pseudostem flour processed with or without thermal blanching process for potassium (5,015.0–6,962.8 mg/100 g of dry matter), sodium (0.7–13.6 mg/100 g of dry matter) and calcium (115.3–261.9 mg/100 g of dry matter), except for potassium. These findings indicate that banana pseudostem has the potential as a new plant source of functional ingredients for both food and pharmaceutical industries in the development of calcium-rich foods and supplement. Besides minerals, banana pseudostem is also found to be rich in vitamin B_6 (5.10 mg/ kg) and presents a mild amount of B1 (2.82 mg/kg) which helps in regulating the blood glucose by producing insulin and haemoglobin (Kumar et al. 2013; Ma, 2015).

A regular intake of dietary fiber in daily diet has been proven to have numerous benefits for human health, such as improving the digestive system by increasing the population of probiotic, cholesterol reduction, regulating blood glucose and weight reduction as well as helping to decrease the risk of several chronic diseases (i.e. coronary heart disease, diabetes and obesity) (Ma et al. 2017; Puspitarini et al. 2019). According to Lakshman et al. (2015), banana pseudostem central core is rich in fiber and highly beneficial for those who are on a weight loss management. The levels of insoluble (64.49%), soluble (2.58%) and total dietary fibers (67.07%) were all higher in native banana pseudostem flour than pseudostem tender core flour (46.09%, 1.89% and 47.98%, respectively) (Aziz et al. 2011). Yuliatmoko et al. (2019) investigated the effect of pre-treatment processing (i.e. blanching and soaking in sodium bisulfite solution) on the compositions of dietary fiber. They reported that the pre-treatment had significantly ($p<0.05$) increased the soluble dietary fiber (5.90% and 2.74% for blanching and soaking in the sodium bisulfite solution, respectively), but decreased the amount of insoluble and total dietary fiber by 6.87% and 6.42%, respectively. Inversely, Ma (2016) discovered that there was a significant ($p<0.05$) increase in the insoluble dietary fiber (20.3%) of banana pseudostem when thermally blanched at 70 ºC for 3 min prior to drying at 50 ºC, while no significant difference ($p>0.05$) in the soluble dietary fiber was observed.

The pseudostem was reported to be rich in non-starch polysaccharides or commonly referred as dietary fibers, which include cellulose (31.27%), hemicelluloses (14.98%) and lignin (15.07%) (Cordeiro et al. 2004; Mukhopadhyay et al. 2008). According to Cordeiro et al. (2004), the outer covering of pseudostem is mostly cellulosic material, while the core or pith is rich in non-starch polysaccharides but low in lignin content. In addition, cellulose was the dominant constituent in the dried sheath of pseudostem, which accounts for approximately 50% (Manilal and Sony, 2011). This is in agreement with the report from Aziz et al. (2011), whereby the native banana pseudostem flour contains 42.09% of cellulose, followed by 18.56% of hemicellulose, and the least reported was lignin (5.13%). These results were significantly higher than the fiber constituted in the pseudostem tender core for cellulose (27.42%), hemicellulose (11.87%) and lignin (4.60%). This was due to the concomitant different layers of leaf sheaths of banana pseudostem. Accordingly, Manilal and Sony (2011) observed that the lignin content of fibers was increased toward the outer sheath that could be due to the presence of mature cells in the outer layer of the stem. This is inversely for the pectin content, whereby the pectin content was found to decrease toward the external sheaths. However, there are some variations for the hemicellulosic and cellulosic contents in different sheath layers (Manilal and Sony, 2011).

Ho et al. (2018) reported that banana pseudostem flour produced by drying at 60 ºC for overnight in a ventilated dryer has a total sugar of 8.54% which showed a lower value than that reported by Ma et al. (2017) for banana pseudostem flour (9.2–22.8%) produced by blanching for 3 min at 70 ºC, followed by cabinet drying at 40 ºC or 50 ºC. Earlier, Bhaskar et al. (2011a) reported that the carbohydrate composition of banana pseudostem was found to be rich in low molecular weight sugars of which glucose (87.0%) is present as the predominant sugar, followed by xylose (8.3%) and arabinose (4.5%). Besides, glucose, xylose and mannose were found to be the major neural sugars in the soluble, insoluble and total non-starch polysaccharide fractions of the pseudostems, followed by arabinose, galactose, rhamnose and fucose (Ma, 2015).

Ma et al. (2017) discovered that the banana pseudostem has 22.9% to 37.6% of total starch, which is comparable with the report from Ho et al. (2012) on the starch (28.3%) of banana pseudostem. Moreover, the starch of the banana pseudostem was identified as high-quality starch (Shiva et al. 2018), such as indigestible starch or resistant starch (i.e. starch that escape from the digestion system in small intestine and passes to the large intestine for fermentation). Then this indigestible starch acts as dietary fiber which enhances the health of the digestive system. Ho et al. (2012) also reported that banana pseudostem has high resistant starch (12.81%). Resistant starch is positively correlated to the composition of protein, total dietary fiber and insoluble dietary fiber, but inversely correlated to carbohydrate and soluble dietary fiber (Deepa et al. 2010). In addition, Ho et al. (2017) reported that the starch granules of the banana pseudostem are irregular in shape and form discontinuous matrix due to the disruption of fiber components. It is interesting to note that an increase of the total starch was observed in the banana (*Musa balbisiana*) pseudostem after blanching at 70 ºC (Ma et al. 2017). This similar trend was also observed by Yuliatmoko et al. (2019), whereby the pre-treatment of banana pseudostem by thermal blanching and soaking in sodium bisulfite solution has significantly increased the amount of resistant starch to 13.13% and 12.18%, respectively as compared with banana pseudostem without pre-treatment (2.8%). This indicates that pre-treatment (i.e., blanching and soaking with sodium bisulfite solution) could increase the production of total starch and resistant starch in banana pseudostem.

PHYSICAL AND FUNCTIONAL PROPERTIES

The beneficial uses of flours from plant sources in the pharmaceutical and food industries rely specifically on their physical and functional properties. Since banana pseudostem comprises more than 90% of water, it is highly perishable and has a short shelf life (Ambrose and Naik, 2016). Drying is one of the most cost-effective techniques of preserving foods, which involve the removal of water (Thorat and Bobade, 2018; Muhamad and Redzuan, 2019). However, the processing of raw banana pseudostem into flour by drying can affect its physical properties. The physical properties, especially the color of the raw materials determine the selection of a product by consumers, whereby the process affects the color of the end products (Welli et al. 2020). Different drying methods such as sun, solar, and tray drying at 50 ºC to 70 ºC were employed in processing flour from banana pseudostem (Lakshman et al. 2015). These authors found that 70 ºC was the most suitable drying temperature for processing flour from banana pseudostem, which resulted in a better quality in terms of its physical and functional properties(Lakshman et al. 2015). However, pseudostem dried at 70 ºC presented the darkest color (74.91) among the flour prepared by tray drying, but lighter than the other flour samples prepared by sun and solar drying methods (Lakshman et al. 2015). On the other hand, Ambrose and Naik (2016) dried the banana pseudostem center core in a cabinet dryer at 50 ºC, 60 ºC and 70 ºC. The authors reported that the banana pseudostem center core flour produced through drying at 60 ºC was the best in terms of color and quality of the flour (Ambrose and Naik, 2016).

Ho et al. (2017) reported that the banana pseudostem flour produced had brown color, with 76.67 degree of lightness. The results reported by Ho et al. (2017) for the color of banana pseudostem flour presented a darker color than the findings by Ma et al. (2017), which revealed 80.57–86.44 degree of lightness for the banana pseudostem flour produced through thermal blanching process. Earlier, Castro et al. (2008) mentioned that blanching can inactivate enzyme (i.e. polyphenoloxidase and peroxidase activities) and thus, inhibit color deterioration of the treated crops. This is in agreement with the study performed by Yuliatmoko et al. (2019) that the banana pseudostem flour produced by soaking in the sodium bisulfite solution prior to drying had a higher lightness value than the untreated pseudostem and pseudostem pretreated by thermal blanching. This means that pretreatment using chemical resulted is more effective in deactivating oxidative enzyme.

Bulk density, the basic parameters measured in dried food products is defined as the ratio of the total mass to the total volume of a material, including air and water. Knowledge of the bulk density of food materials is an important parameter in storage, transport, mixing and packaging operations (Mayor et al. 2011). According to Ho et al. (2017), drying process significantly reduces bulk density (0.43 g/mL) in banana pseudostem flour. The increasing trend of bulk density (0.327–0.519 g/cm^3) in dried banana center core flours was found, proportional to the increase in the temperature of drying (Lakshman et al. 2015). Yuliatmoko et al. (2019) observed that the microscopic structure of the flour from the pretreated banana pseudostem has more porous and is hollower than the pesudostem flour without treatment. In addition, the higher values of bulk density could facilitate storage efficiency, as well as reducing shipping and packaging costs as it implied less transportation space and fewer requirements for packaging material (Suhaimi, 2020).

In terms of functional properties, according to Ambrose and Naik (2016), banana pseudostem dried in the cabinet at different temperatures (50–70 ºC) did not affect the water holding capacity. The water holding capacity depends on the capillary, pore size and charges on the protein molecules. It has been reported by Justiz-Smith et al. (2008) that the fiber of banana pseudostem has a high Young's S-modulus and water absorption capacity. Moreover, the banana pseudostem shows significant physical properties, such as relative tensile strength and stiffness (Subagyo and Chafidz, 2018). However, the study conducted by Lakshman et al. (2015) showed that different drying conditions resulted in a different water holding capacity (4.87–11.88 g/g) and oil absorption capacity (0.18–0.28 mL/g) of banana center core flour. In another study performed by Aziz et al. (2011) showed that the pseudostem tender core flours exhibited a significantly higher water holding capacity (18.28 g water/g of dry matter), swelling power (13.82 g swollen granules/g of dry matter) and solubility (33.28%), but lower oil holding capacity (3.88 g oil/g of dry matter) than the native banana pseudostem flour (9.48 g swollen granules/g of dry matter, 10.66 g water/g of dry matter, 3.44%, 5.48 g oil/g of dry matter, respectively). In addition, Yuliatmoko et al. (2019) observed that blanching treatment had significantly increased the water holding capacity by 10.81%, the swelling capacity by 13.87% and the cation exchange capacity was 9.75meq/kg. On the other hand, Ambrose and Naik (2016) reported that the sample dried at 70 ºC has the lowest oil absorption capacity as compared to samples dried at 50 ºC and 60 ºC. A higher oil absorption capacity is preferred for fried food products as it prevent fat leaching to the food surface causing reduction of cooking oil intake in the digestive system and maintain the amount of fat during frying, which favours flavour retention (Suhaimi, 2020).

NUTRACEUTICAL PROPERTIES

As discussed in the earlier section of this review, banana pseudostems are rich in dietary fibers. Diet rich in dietary fiber provides many health benefits, including lower risk for developing coronary heart disease, stroke, hypertension, diabetes, obesity and certain gastrointestinal diseases (Anderson et al. 2009). Nowadays, functional foods are no longer confined to classical nutrients. Recent advancements in food science and technology have led to a better understanding on nutraceutical properties of food, particularly plants. This led to numerous studies on the nutraceutical properties of banana pseudostem that focus on the quantification of important phytochemicals and their antioxidant activities.

Phytochemicals

Phytochemicals are naturally occurring compounds in plants. Generally, phytochemicals are classified into six major categories based on their chemical structures and characteristics (Huang et al. 2016). These categories include carbohydrate, lipids, phenolics, terpenoids, alkaloids and other nitrogen-containing compounds (Huang et al. 2016). Phytochemicals are believed to be largely responsible for the protective health benefits of plant-based foods, beyond those conferred by their vitamin and mineral contents (Zhao et al. 2015). Approximately, 20% of known plant have been utilized in pharmaceutical studies, exerting positive remarks in healthcare system, such as supplying beneficial phytochemicals to supplement the needs of the human body by acting as natural antioxidants (Altemimi et al. 2017). More than that, phytochemicals may also serve as natural preservatives in food products since they possess antioxidant and antimicrobial properties (Lee and Paik, 2016).

The type of phytochemicals extracted from pseudostem depends heavily on the solvent used (Altemimi et al. 2017). A study done by Kandasamy et al. (2016) demonstrated the difference in the type of extracted phytochemicals using different solvents. Non-polar solvents (e.g. hexane and chloroform) showed the highest concentration of phytochemicals from the group of terpenoids, alkaloids and steroids. On the other hand, polar solvents (e.g. acetone, methanol and ethyl acetate) showed the highest concentration of phytochemicals from the group of phenolics, flavonoids and tannins.

The extractions of these phytochemicals were more favorable using alcohol solvent, e.g., methanol and ethanol as compared to that of water (Suhaimi, 2020). The results of qualitative phytochemical assay on banana pseudostem extract revealed the presence of various types of phytochemical active (Table 1). When compared with phytochemical extraction with alcohol solvent, water usually contains less phytochemical variety and amount, except for flavonoid. Flavonoid was reported to be in high concentration in the water extract of banana pseudostem (OnyeMa et al. 2017; Abdel Ghany et al. 2019).

Ramu et al. (2017) published a quantitative analysis on the phytochemical constituents in dried banana (*Musa spp. cv Nanjanagudu rasabale*) pseudostem and phenolic acid constituents in its extracts. The results showed that the most abundant phytochemical in dried banana pseudostem powder were saponins (305.45 mg/100 g) and phenols (188.64 mg/100 g). Other phytochemicals were present at a lower concentration, namely tannins (107.86 mg/100 g), flavonoids (78.60 mg/100 g), alkaloids (62.32 mg/100 g), phytates (34.56 mg/100 g) and oxalates (25.56 mg/100 g). Previous studies revealed the present of various types of phenolic acids, such as gallic acid, p-hydroxybenzoic acid, chlorogenic acid, sinapic acid and caffeic acid in the alcoholic extracts of the dried banana pseudostem powder (Saravanan and Aradhya, 2011a; Ramu et al. 2017). Table 2 compares the phenolic acid constituents reported by Ramu et al. (2017) with the findings reported previously by Saravanan and Aradhya (2011a). Since both studies used the same banana cultivar, variation in the measurement could be due to various factors, namely extraction conditions, maturity of the pseudostems and environmental factors where the banana trees are grown.

Antioxidant activities

Antioxidants play an important role in health maintenance. These compounds protect human cells against free radicals, which may react with the biomolecules of human cells and play a vital role in the development of oxidative stress-induced diseases, targeting every part of the human body (Pham-Huy et al. 2008). Due to this, there is a huge interest in exogenous plant antioxidants. Considering the high amount of phytochemicals in banana pseudostem, various antioxidant activity assessments were carried out to determine its level antioxidant activities of banana pseudostem extracts. Saravanan and Aradhya (2011a) used several *in vitro* antioxidant assay models, such as superoxide radical scavenging activity, β-carotene-linoleate model, lipid peroxidation, inhibition activity, metal chelating activity, hydrogen peroxide scavenging activity and nitric oxide scavenging activity to compare the antioxidant activities of potency. The established protocols to determine the antioxidant activities are namely 1,1-diphenyl-

Table 1: Qualitative analysis of various extracts of banana pseudostem.

Phytochemicals	*Musa paradisiaca* L. Pseudostem[1]		*Musa acuminata* Pseudostem[2]	
	Methanolic extract	Water extract	Methanolic (50%) extract	Water extract
Alkaloids	+	+	+	+
Anthraquinone	++	++	N.R.	N.R.
Cardiac glycoside	++	-	+	-
Flavonoids	++	+++	++	+++
Phenols	N.R.	N.R.	+	+
Protein	N.R.	N.R.	++	++
Saponins	N.R.	N.R.	+	+
Steroids	N.R.	N.R.	++	++
Tannins	+	+	+	-
Terpenoids	N.R.	N.R.	++	+

N.R. present not reported; - represent absent; + present in low concentration; ++ present in moderate concentration; +++ represent in high concentration

[1]Results were adopted from Abdel Ghany et al. (2019)

[2]Results were adopted from OnyeMa et al. (2017)

Table 2: Phenolic acid constituents of various extracts of banana (*Musa* spp. cv Nanjanagudu rasabale) pseudosteam.

Phenolic acid	Banana pseudostem extract (μg/mg)				
	Ethyl acetate[1]	Acetone[1]	Methanol[1]	Methanol[2]	Ethanol[2]
Caffeic acid	-	50.07	6.72	25.33	19.11
(+)-catechin	12.01	17.53	5.46	9.34	4.12
Catechol acid	8.21	8.44	12.99	N.R.	N.R.
Chlorogenic acid	4.51	-	-	6.09	11.87
Cinnamic acid	-	12.98	7.03	N.R.	N.R.
p-coumaric acid	N.R.	N.R.	N.R.	7.58	2.09
Epicatechin	N.R.	N.R.	N.R.	3.07	0.72
Ferulic acid	14.22	16.88	6.51	N.R.	N.R.
Gallic acid	29.97	38.62	40.57	5.82	31.13
Gentisic acid	6.71	37.93	51.36	N.R.	N.R.
p-hydroxybenzoic acid	N.R.	N.R.	N.R.	11.48	62.68
Protocatechuic acid	32.60	42.17	36.64	N.R.	N.R.
Quercetin	N.R.	N.R.	N.R.	4.39	6.06
Sinapic acid	N.R.	N.R.	N.R.	14.91	37.06
Pyrocatechol	3.16	23.11	10.27	N.R.	N.R.
Tannic acid	38.14	6.67	2.23	N.R.	N.R.
Vanillin	N.R.	N.R.	N.R.	14.80	7.17

N.R. present not reported; - represent absent

[1]Results were adopted from Saravanan and Aradhya (2011a)

[2]Results were adopted from Ramu et al. (2017)

2-picrylhydrazyl radical scavenging activity (DPPH), 2,2'-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid radical scavenging assay (ABTS) and ferric reducing antioxidant power (FRAP). Table 3 summarizes the findings reported in the recent studies on antioxidant properties of banana pseudostem extracted using solvents different with polarities.

In addition to the aforementioned protocols, other methods were also utilized to determine the various banana cultivars. Ramu et al. (2017) used enzymatic (dismutase, catalase, ascorbate peroxidase and glutathione reductase) antioxidant potential to evaluate the antioxidant activities of banana pseudostem extract. Both studies concluded that banana pseudostem is a potential source of phytochemical and natural antioxidant, and considering the encouraging conclusions, the potential of banana pseudostem for health benefits is justified.

HEALTH BENEFITS

Banana pseudostem has also been utilized as a traditional medicine for treating various human ailments, such as diarrhoea, dysentery, cholera, otalgia and haemoptysis (Sharma et al. 2017). The promotion of banana pseudostem as food has surged in the recent years, as studies on the health benefits of banana pseudostem have been positive and encouraging. The associated health benefits are summarized in Table 4.

Urolithiasis

Urolithiasis is the process of stone formation in the urinary tract. Two common factors that lead to the development of stones are the decrease in urine volume and increase in the excretion of stone-forming components, such as calcium, oxalate, urate, cystine, xanthine and phosphate (Yachi et al. 2018). An early attempt to understand the mechanism of banana pseudostem in treating urolithiasis was carried out by Ponnambalam and Sellappan (2014). The elements analysis on spray-dried extract of banana (*Musa balbisiana*) pseudostem showed a high amount of potassium and sodium. These elements were attributed to the diuretic activity of the extract, whereby it increases the urine volume or flow. The increase in the urine volume or flow helps to prevent further deposition of urinary stones, and existing urinary stones are dissoluted and eliminated from the urinary tract of patients suffering from urolithiasis (Ponnambalam and Sellappan, 2014).

A more recent *in vitro* and *in vivo* study by Sethiya et al. (2017) showed that the chloroform extract of wild banana (*Ensete superbum*) pseudostem possessed anti-urolithiatic activity, whereby the extract inhibited the formation of calcium oxalate crystal. In the study, rats were subjected to ethylene glycol-induced urolithiasis and those treated with the extract showed a significant reduction in the level of urine calcium, creatinine, magnesium, uric acid, and serum calcium. The authors hypothesized that the anti-urolithiatic activity in the extract is due to the presence of β-carboline alkaloids. Similar results were obtained by Panigrahi et al. (2017) when the hydro-ethanol extract of banana (*Musa paradisiaca*) pseudostem was used to treat rats with ethylene glycol-induced urolithiasis.

Diabetes

Diabetes is a metabolic disease categorized by high level of glucose in the blood and disturbed insulin metabolism. A diabetic person may have insufficient insulin, ineffective insulin, or a combination of both conditions (Withney and Rofles, 2015). If left untreated, patients may face organ damage, in particular the eyes and kidneys. Bhaskar et al. (2011b) conducted an *in vivo* study to show the effectiveness of banana pseudostem in treating diabetes. Streptozotocin-induced

Table 3: Antioxidant activities of banana pseudosteam.

Antioxidant Activities Protocols	Banana (*Musa* spp. cv Nanjanagudu rasabale) pseudostem extract[1]			Banana pseudostem (*Musa acuminata* X *balbisiana* cv. Awak) powder[2]
	Methanol	Ethanol	Water	
DPPH	0.22 ± 0.17	0.43 ± 0.34	0.20 ± 0.67	4.94 ± 0.22
ABTS	11.98 ± 1.87	21.87 ± 0.40	10.64 ± 1.50	N.R.
FRAP	1.23 ± 1.01	3.33 ± 0.33	1.06 ± 0.46	42.70 ± 3.94

N.R. present not reported.
[1]Results were adopted from Ramu et al. (2017). In all cases, the results were expressed as mmol equivalents of Trolox equivalents per kg of sample.
[2]Results were adopted from Ho et al. (2017). Results for DPPH and FRAP were expressed as mmol of Trolox equivalents per kg of sample and mmol of Fe (II) per kg of sample, respectively.

Table 4: Health benefits of banana pseudostem.

Health benefits	References
Urolithiasis	Ponnambalam and Sellappan (2014); Panigrahi et al. (2017); Sethiya et al. (2017)
Diabetes	Bhaskar et al. (2011b); Ramu et al. (2016); Nguyen et al. (2017)
Antimicrobial	Kumar et al. (2014); OnyeMa et al. (2017); Abdel Ghany et al. (2019); Jouneghani et al. (2020)
Cancer	Kandasamy et al. (2016); Abdel Ghany et al. (2019)
Gut health	Sharma et al. (2017)
Allergy	García Mesa et al. (2019)

diabetic rats were treated with banana (*Musa* sp. var. elakki bale) pseudostem, and diabetic symptoms, such as hyperglycemia, polyuria, polyphagia, polydipsia, urine sugar, body weight of the rats, glomerular filtration rate and fructosamine and advanced glycation end-product contents were monitored. The findings from the study revealed that banana pseudostems have anti-diabetic and anti-advanced glycation end-product (AGEs) properties; hence, it could be a potential food supplement for diabetics.

To identify the compounds responsible for the anti-diabetic property, Ramu et al. (2016) managed to extract stigmasterol and β-sitosterol from the banana (*Musa* sp. cv. Nanjangud Rasa bale) pseudostem. Upon treatment with these compounds, diabetic symptoms, such as polyphagia, polydipsia, polyuria, urine glucose and reduced body weight were ameliorated in alloxan-induced diabetic rats. The finding from the study revealed that these compounds restored the β-cells to produce insulin. Nguyen et al. (2017) reported the presence of phenolic compounds, i.e., p- hydroxybenzoic acid, gallic acid and ferulic acid in the extract of banana (*Musa* × *paradisiaca* L.) pseudostem, which exhibited a comparable inhibitory activity against α-glucosidae and α-amylase. These results are promising in considering the banana pseudostem or its bioactive components, such as stigmasterol, β-sitosterol, p-hydroxybenzoic acid, gallic acid and ferulic acid as potential anti-diabetic food supplements for diabetics.

Antimicrobial

Antimicrobial resistance happens when microorganisms are mutated due to the exposure to antimicrobial drugs (World Health Organisation, 2020). With the rapid rising of antimicrobial resistance, the seek for novel antimicrobial compounds is ever more important. For generations, plants or their extracts are known to have a great potential in treating common infectious diseases, owing to their antimicrobial activity (Ríos and Recio, 2005). Several studies were carried out to examine the presence of anti-microbial activity in banana pseudostem. Studies by Kumar et al. (2014), OnyeMa et al. (2017) and Abdel Ghany et al. (2019) showed that banana pseudostem has antimicrobial activity.

A more comprehensive study was carried out by Jouneghani et al. (2020) to investigate the antimicrobial activity of banana pseudostem of several cultivars, such as Dole, Saba, Fougamou, Namwah Khom, Pelipita and Mbwazirume. The authors (Jouneghani et al. 2020) tested the banana pseudostem extracts on eight (8) human bacteria (*Bacillus cereus*, *Micrococcus luteus*, *Staphylococcus aureus*, *Streptococcus faecalis*, *Aeromonas hydrophila*, *Escherichia coli*, *Salmonella enterica* subsp. *enterica* and *Shigella sonnei*) and one (1) fungal pathogen (*Candida albicans*), where the findings showed that the extracts embrace a broad-spectrum of antimicrobial properties as demonstrated by the inhibition of selected pathogens were successfully inhibited. Therefore, the effectiveness of banana pseudostem extract used as a traditional medicine to treat infections, such as diarrhoea and dysentery should be thoroughly investigated.

Cancer

Cancer is an uncontrolled growth of abnormal cells. Conventional therapies for cancer treatment are sometimes fruitless due to their drug resistance of cancer cell and toxicity of normal growing cells (Vasan et al. 2019). On top of these, cancer treatment side effects, such as fatigue, pain, sleep problems, and nausea and vomiting are pushing patients toward alternative cancer treatments, namely acupuncture, Ayurveda and natural herbal remedies (Buckner et al. 2018). Recently, two (2) *in vitro* studies were carried out to investigate the antitumor activity of banana pseudostem.

The study by Kandasamy et al. (2016) demonstrated that the extract of banana (*Musa* AAB var. Nanjanagudu Rasabale) pseudostem may serve as a potential source of natural remedy for treating cancer. The extract obtained exhibited cytotoxicity toward human liver hepatocellular carcinoma (HepG2). This antitumor activity is attributed to chlorogenic acid, 4-epicyclomusalenone and cycloeucalenol acetate found in the banana pseudostem extract. Abdel Ghany et al. (2019) tested the banana (*Musa paradisiaca* L.) pseudostem exudates on both HepG2 and colon carcinoma (HCT-116) and the results were encouraging to come to the conclusion that the exudate is a good antitumor activity.

Gut health

The human gut microbiota has been estimated to exceed 10^{14} (Macchione et al 2019). The microbiota offers various health benefits to the host, such as strengthening the gut integrity (Natividad and Verdu, 2013), harvesting energy (den Besten et al. 2013), protecting against pathogens (Bäumler and Sperandio, 2016) and regulating host immunity (Gensollen et al. 2016). According to Umu et al. (2017), gut microbiota can be modulated to improve host health through some interventions. The intervention can be done by consuming prebiotics, the dietary subtances that mostly consisting of nonstarch polysaccharides and oligosaccharides poorly digested by human enzymes, which act as substrates to nurture a selected group of microorganisms (beneficial bacteria) living in the gut, thus conferring benefit(s) upon host health (World Gastroenterology Organisation Global Guidelines, 2011; Umu et al. 2017; Davani-Davari et al. 2019). Fructo-oligosaccharide, galacto-oligosaccharide and trans-galacto-oligosaccharide are the most common prebiotics (Davani-Davari et al. 2019). Sharma et al. (2017) have succeeded in producing bioprocessed banana pseudostem juice that contains prebiotics in the form of glucooligosaccharides and D-allulose.

Allergy

An allergic reaction is an immune system response to allergen. The eight (8) major allergenic foods include milk, eggs, fish, crustacean shellfish, tree nuts, peanuts, wheat and soybean (Kitty et al. 2015). To treat allergic reaction, antiallergic and antiasthmatic drugs were used to relieve the symptoms of allergic reaction (García Mesa et al. 2019). Despite the availability of these drugs, natural alternatives from plants were highly sought after. An *in vivo* study by García Mesa et al. (2019) showed that the banana (*M. paradisiaca*) pseudostem powder produced is safe to be consumed (no sign of death and toxicity among the rats treated with the powder) and the minimum inhibitory dose is around 2 mg/kg. The work by these authors is the first experimental evidence that banana pseudostem powder has an antiallergic potential. Further study to understand this mechanism and the identification of possible bioactive compounds responsible for this effect should be carried out.

Uses of banana pseudostem as a functional ingredient in food products

Bakery products

In the bakery industry, wheat flour is commonly blended with a high-dietary fiber flour to reduce the utilization of large quantities of wheat flour as well as to increase the dietary fiber intake of the consumer. Replacing dietary flour into food can also help to reduce malnutrition (Ho et al. 2012). Several studies have been done on the incorporation of banana pseudostem flour into food products, such as bread, cookies and biscuits (Ho et al. 2013, Ambrose and Lekshman, 2016; Sangroula, 2018; Tiroutchelvame et al. 2019). These authors mainly used banana pseudostem flour as a composite flour in the bakery production (Ho et al. 2013, Ambrose and Lekshman, 2016; Sangroula, 2018; Tiroutchelvame et al. 2019). In most applications, the incorporation of banana pseudostem flour does alter the appearance or texture of the end product. On the other hand, it helps in improving the nutritional compositions of the food, such as increasing the level of dietary fiber and resistant starch as well as supplying considerable amount of functional bioactive components (Welli et al. 2020). Ho et al. (2013) reported that bread incorporated with banana pseudostem flour has a negative effect on the color and specific volume of the bread, which resulted in a lighter crust but darker crumb color and lower specific volume than the bread without banana pseudostem flour. The positive effects observed by Ho et al. (2013) were in the application of hydrocolloids (i.e. sodium carboxymethylcellulose) in the bread incorporated with banana pseudostem flour, which resulted in an improvement in the crumb structure and an increase in the loaf volume. This could be due to the disruption of the pseudostem fiber. Furthermore, Ho et al. (2017) reported that with the aids of the scanning electron microscope, bread containing banana pseudostem flour appeared to have different binding patterns between protein and starch granules wherein the cell walls of the pseudostem appeared to align and form part of the bread structure, with irregular and discontinuous matrix around the starch granules. The continuity of starch-protein network was disrupted by the cell wall (fiber) of the pseudostem, which finally caused lower volume of the bread (Ho et al. 2017).

In terms of nutritional values, Ho et al. (2013) reported that bread prepared with banana pseudostems had significantly ($p<0.05$) improved the proximate composition (i.e. moisture, ash and crude fiber), dietary fiber (i.e. soluble, insoluble and total dietary fiber), total phenolics content (from 139.24 mg GAE/100g in the white bread to 204.16 mg GAE/100g in the bread containing banana pseudostem flour) and antioxidant properties. Furthermore, bread containing banana pseudostem flour and sodium carboxymethylcellulose has received the highest consumer acceptability (Ho et al. 2013). A few years later, Ho et al. (2015) reported that the replacement of 10% of wheat flour with banana pseudostem flour (*Musa acuminata* × *balbisiana* cv. Awak) in white bread had increased the macro-mineral (i.e. calcium, phosphorus and potassium) and micro-mineral (i.e. magnesium, iron and manganese). According to these authors, the replacement of 10% of wheat flour with banana pseudostem flour provided bread with a lower glycemic index that resulted from a low starch hydrolysis rate and hydrolysis index.

Ambrose and Lekshman (2016) studied the effect of the incorporation of banana pseudostem center core flour (5%, 10% and 15%, dry weight basis) for wheat flour or refined wheat flour (95%, 90% and 85% dry weight basis, respectively) on the physical and sensory acceptability of cookies. In general, the incorporation of banana pseudostem center core flour for wheat flour or refined wheat flour in cookies preparation resulted in a lower value of diameter, thickness and spread factor than the controlled cookies (i.e. cookies without banana pseudostem center core flour) (Ambrose and Lekshman, 2016). The authors also reported that the overall acceptability of cookies prepared by the incorporation of banana pseudostem center core flour with refined wheat flour was at par with the controlled cookies (i.e. cookies without banana pseudostem center core flour); however, cookies made with the incorporation of wheat flour and banana pseudostem center core flour received lower scores than the controlled cookies.

In addition, Sangroula (2018) revealed that refined wheat flour can be incorporated with banana pseudostem flour at up to the level of 2.5% in the development of high fiber biscuits without any adverse effect on sensory acceptability. The author also reported that biscuits with 2.5% of banana pseudostem flour contained a higher ash (5.0%), crude fiber (1.7%), crude fat (18.6%) and minerals such as calcium (57.7 mg/100 g), potassium (274.2 mg/100 g) and sodium (95.9 mg/100 g) than the wheat biscuit without banana pseudostem flour (2.0, 1.1 and 16.26% and 52.3, 210.4 and 28.6 mg/100 g, respectively). In terms of physical properties, there are increasing trend recorded for the parameters, namely weight, volume, diameter and thickness, but decreasing trend for spread ratio and density due to the increase of the incorporation of banana pseudostem flour in biscuits preparation (Sangroula, 2018). The author found that biscuits with 2.5% of banana pseudostem flour had 3.72% moisture, acid value of 0.33 mg KOH/g oil and peroxide value of 7.25 meq O_2/ kg fat after three months of storage in which all the parameters were within the acceptable limits (Sangroula, 2018).

Recently, Tiroutchelvame et al. (2019) used banana pseudostem central core flour in biscuits production. They observed that the fiber content (2.8%, 3.1% and 3.5%) of the biscuits was increased, proportional with the increasing of the amount of banana pseudostem central core flour (i.e. 3, 5 and 8 g/100 g based on the weight of wheat flour basis) in biscuit making. Surprisingly, the protein content of the biscuits supplemented with banana pseudostem central core flour was found to increase, concomitant with the increasing level of supplementation; 2.8% of protein in the controlled sample (i.e. biscuits without banana pseudostem central core flour) as compared to the increase of protein from 3.9% to 4.6% for biscuits with banana pseudostem central core flour (Tiroutchelvame et al. 2019).

Beverages

Feriotti and Iguti (2011) investigated the physicochemical composition of juice (liquid fraction) extracted from pseudostems. The results showed that banana pseudostem is suitable to be developed as sports drink and functional beverages due to its high mineral content (i.e. 874 mg/L potassium, 88 mg/L sodium, 357.8 mg/L chloride, 130 mg/L calcium and 16 mg/L magnesium). According to these authors, the amount of minerals in banana pseudostem juice is comparable with that of coconut water, which is considered a natural isotonic beverage. These results confirmed that the banana pseudostem juice could be used as a raw material in the preparation of isotonic drink. Moreover, the extracted juice also contained 0.191% total sugar, 0.0141% protein and 0% amount of fat (Feriotti and Iguti, 2011). Five (5) minutes of pasteurization at 85 ºC was enough to eliminate the bacteria population (11,800 CFU/mL) in the pseudostem juice (Feriotti and Iguti, 2011). However, they observed that the juice produced from banana pseudostem rapidly turned brownish on extraction due to the presence of tannins (1.32 mg/L) which are highly susceptible to enzymatic browning reaction catalyzed by enzyme polyphenol oxidase (Feriotti and Iguti, 2011).

On the other hand, Saravanan and Aradhya (2011b) focused on utilizing banana pseudostem in the production of polyphenol-rich Ready-To-Serve (RTS) beverage. They reported that the banana pseudostem juice contained 58.11 mgGAE total phenolic content and 12.59 mgCE/200 µL total flavonoid content. The juice also exhibited a high antioxidant activity in all the assays tested, such as DPPH radical scavenging activity (40.22%), superoxide radical scavenging activity (26.75%), metal chelation activity (24.45%), total reducing power (0.249 OD at 700nm) and total antioxidant capacity (58 mmol ascorbic acid equivalents) (Saravanan and Aradhya, 2011b). The authors also observed that there is a strong positive correlation between the total phenolic content and total flavonoid content of this RTS banana pseudostem juice with antioxidant activity assays (Saravanan and Aradhya, 2011b). RTS with 25% of banana pseudostem juice incorporation had 15 ºbrix total soluble solid and 0.3% acidity, which received the highest acceptability by consumer (Saravanan and Aradhya, 2011b). Therefore, RTS beverage from banana pseudostem juice could be used to produce functional beverage in the near future.

Accordingly, Chandrakala et al. (2017) has utilized different concentrations of spice extracts (i.e. ginger, cinnamon, clove and cardamom) in preventing the enzymatic browning of juices produced from banana pseudostem. The authors discovered that there is a significant ($p<0.05$) effect of spice type on enzyme polyphenol oxidase, whereby juices treated with ginger at the concentration of 4% and 8%, and clove at the level of 12% demonstrated a higher inhibition of enzyme polyphenol oxidase activity. In terms of color, the highest lightness (L*) value was found for juice treated with cardamom at the level of 12%, but was insignificant with the other juice samples (Chandrakala et al. 2017).

A method for the biotransformation of banana pseudostem juice (extract) into a functional juice with health benefits was developed by Sharma et al. (2017). The functional juice was produced through a bioprocess which involves the employment of immobilized biocatalyst with dextransucrase activity. The produced functional juice contains approximately 5 g/L of prebiotic glucooligosaccharides and approximately 7 g/L of D-allulose. The authors also discovered that this functional juice has a non-digestible nature and potential as prebiotic whereby oligosaccharides have shown a considerable resistance to dextransucrase hydrolysis and they are also able to stimulate probiotics growth. In addition, nearly calorie-free functional rare sugar was obtained through the bioprocessing of banana pseudostem juice (Sharma et al. 2017).

Shiva et al. (2018) has successfully developed functional ready to drink (RTD) beverages from banana pseudostem sap with flavored ginger rhizome and nannari root extracts. Ginger rhizome and nannari root extracts at the concentration of 4% were found to be appropriate for the preparation of ginger and nannari-flavored RTD banana pseudostem beverages. Nutrients analysis revealed that the flavored RTD banana pseudostem beverages had a significant amount of nutrients, namely total sugar (10.62 to 10.83 g/100ml), total carbohydrate (13.92 to 16.08 g/100 ml), vitamin C (0.673 to 0.707 mg/100 ml), sodium (0.920% to 0.935%), potassium (8.13% to 8.30%), zinc (1.034 mg/ L to 1.117 mg/ L), copper (0.9183 mg/ L to 0.9190 mg/ L) and manganese (0.9544 mg/ L to 1.0144 mg/ L) (Shiva et al. 2018). This RTD containing ginger rhizome extract was found to be most stable in terms of the retention of nutrients and sensory attribute (i.e. color, appearance, flavor, consistency, taste and overall acceptability) after 6 months of storage (Shiva et al. 2018).

Another study was performed by Swarnalakshmi et al. (2019) on the development of lemongrass-based isotonic drink with the incorporation of extracts from banana pseudostem and mint through retort processing. The isotonic drink was found to have a good carbohydrate content of 11.70% and antioxidant activity of 127.01 mg/100 mL of the sample. The protein content of 0.06% in the drink was found to be the least of all the nutrients. Moreover, the pseudostem was an excellent source of calcium, which comprised 39.08 mg/100 g of the product. Also, it was found to be less than 10 colony forming unit per mL on the total plate count for the sample stored at the 10^{th} and 15^{th} day, which showed that the product would still remain fresh for 30 to 45 days when refrigerated. On the other hand, in ambient room temperature (25-28 ºC, it should best be consumed before two (2) weeks without the use of preservatives (Swarnalakshmi et al. 2019).

Other food products

In general, banana pseudostem consumption is uncommon. However, in some parts of the world, such as India and Malaysia, the pith or the tender core of the banana pseudostem is consumed as vegetables after boiling it and adding spices (Ho et al. 2012; Lakshman et al. 2015).

Earlier, Adinugraha et al. (2005) have successfully synthesized sodium carboxymethylcellulose (CMC) utilizing banana pseudostem. The authors found that the technical grade CMC obtained from banana pseudostem has 98.63%, which is yet to meet the specifications required by the Food Chemical Codex (Codex, 1996). Therefore, the produced CMC must be further purified to be used for food consumption.

Different flavors of candy have been developed from the central core of banana pseudostem. The nutritional values of the developed candy were tested (Desai et al. 2016). This candy has additional benefits, as it contains an appreciable amount of iron and vitamin (i.e. vitamin B_3 and B_5) (Patil and Kolambe, 2011).

Raju et al. (2019) have substituted 5% to 15% of potato with banana pseudostem flour in cutlet preparation, aimed at improving its nutritional value and sensory acceptability. The substitution of potato with banana pseudostem flour increased the cooking yield and pH but decreased moisture, ash and crude fiber contents (Raju et al. 2019). In sensory aspects, cutlet containing banana pseudostem flour received better acceptability than the controlled cutlet (i.e. cutlet without banana pseudostem flour) (Raju et al. 2019).

Welli et al. (2020) fortified canna starch with banana pseudostem flour, aimed to improve the dietary fiber, resistant starch content and antioxidants of a food bar. Overall, food bars prepared with the fortification of banana pseudostem at 25% levels had the highest ash, crude fat, and crude protein, soluble dietary fiber, insoluble dietary fiber, total dietary fiber and resistant starch. Besides that, the authors also found that the higher the substitution of banana pseudostem flour on the food bar, the higher the tendency of total phenolic compounds (123.19 mg/100 g) and antioxidant activity (11.44% radical scavenging activity) amounts. However, the food bar containing 15% of banana pseudostem flour received the highest score for color (3.12), aroma (3.00), flavor (3.04) and texture (3.16) attributes.

CONCLUSION

Based on the review, it is crystal clear that banana pseudostem has tremendous popularity these days besides holding extraordinary promise for the coming future. The by-product of banana plantations can be considered as functional foods due to its high nutrients content, especially dietary fiber and mineral content. In addition, banana pseudostem is also recognized for its bioactive compounds, such as gentisic acid, caffeic acid, ferulic acid and cinnamic acid that possess good antioxidants and health functionalities. Based on the nutraceutical properties of banana pseudostem described in this review, this agricultural waste should be considered as a potential functional food ingredient in the search for healthier foods.

Several studies have been performed by researchers to investigate the potential of flour processed and juice extracted from banana pseudostem in the food and beverage application. The findings from these studies showed that the incorporation of banana pseudostem flour into food products successfully improves the nutritional values; however, it could be detrimental to some of the physical properties of the food product if is utilized in excess amount. Therefore, the optimization of supplemented banana pseudostem flour needs to be standardized in order to scale up the food products at the food industry level. In addition, future investigations should focused more on the development of tailor-made banana pseudostem flour in a variety of functional foods to fulfill the functional needs of the consumers, so that the effective utilization of this agricultural waste will reduce the environmental pollution, and simultaneously increasing the economic values of the banana pseudostems.

CONFLICT OF INTEREST

Authors declare there is no conflict of interest in this review.

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AUTHOR CONTRIBUTIONS

All authors wrote and approved the manuscript.

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