CHARACTERIZATION OF BANANA (Musa acuminata × balbisiana cv. AWAK) PSEUDO-STEM FLOUR AND ITS POTENTIAL IN THE DEVELOPMENT OF NOVEL FIBRE-RICH BREAD

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by

HO LEE HOON

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Dedicated to

My Beloved

Father and Mother,

(Mr. Ho Lian Ki and Mdm. Looi See Moey @ Moy)

Brothers and Sisters

(Lee Hwa, Leong Sua, Liang Huat,

Liang Heng, Lee Choo, Lee Lee and Liang Ee)

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Percentage
^{o}	Degreee
^{0}C	Degree celsius
*a**	Red/ green
$ABTS^{+\bullet}$	2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) radical cation
AD	Acid detergent
ADA	American Dietetic Association
ADF	Acid detergent fibre
APC	Aerobic plate count
AUC	Area under the curve
a_w	Water activity
*b**	Yellowness/ blue
B10BPF	BCtr substituted with 10% BPF
B10BPFCMC	B10BPF with sodium carboxymethyl cellulose addition
B10BPFXG	B10BPF with xanthan gum addition
BCtr	White wheat bread (control)
BD	Breakdown
BPF	Banana pseudo-stem flour
BU	Brabender units
C	Carbon
Ca	Calcium
CFU	Colony forming unit
CIE	Commission Internationale de I ’Eclairage
Co	Cobalt
CO_2	Carbon dioxide
Cu	Copper
CVD	Cardiovascular disease
CWF	Commercial wheat flour
DDT	Dough development time
$DPPH^{\bullet}$	DPPH radical (1,1’-diphenyl-2-picrylhydrazyl radical)
DS	Dough stability
DSC	Differential scanning calorimetry
e.g	Example
ERH	Equilibrium relative humidity
F10BPF	FCWF substituted with 10% banana pseudo-stem flour
F10BPFCMC	F10BPF with sodium carboxymethyl cellulose addition
F10BPFXG	F10BPF with xanthan gum addition
FCWF	Commercial wheat flour (control)
Fe	Iron
$FeCl_3$	Ferric chloride
$FeSO_4.7H_2O$	Ferrous sulphate
FRAP	Ferric reducing antioxidant power
FTIR	Fourier transform infrared spectroscopy
FV	Final viscosity
g	Gram
h	Hour

H_2SO_4	Sulphuric acid
Ha	Hectare
HCl	Hydrochloric acid
HI	Hydrolysis index
HNO_3	Nitric acid
HPC	Hydroxypropylcellulose
HPMC	Hydroxypropylmethylcellulose
I	Iodine
IDF	Insoluble dietary fibre
J/ G	Joule per gravitational
K	Potassium
KBr	Potassium bromide
Kcal	Kilocalories
KCl-HCl	Potassium chloride-Hydrochloric acid buffer
kg	Kilogram
KH_2PO_4	Dihydrogen orthophosphate
KOH	Potassium hydroxide
*L**	Lightness
M	Molarity
m	Meter
MC	Methylcellulose
MCC	Microcrystalline cellulose
Mg	Magnesium
mg	Miligram
mg/ L	Miligram per liter
min	Minute
mL	Mililiter
mM	Milimolar
Mn	Manganese
Mo	Molybdenum
MTI	Mixing tolerance index
MYC	Mold and yeast counts
N	Normality
Na	Sodium
Na CMC	Sodium carboxymethyl cellulose
Na_2CO_3	Sodium carbonate
NaOCl	Sodium hypochlorite
NaOH	Sodium hydroxide
ND	Neutral detergent
NDF	Neutral detergent fibre
nm	Nanometer
np.	No present
NSP	Non starch polysaccharides
OHC	Oil holding capacity
P	Phosphorus
PCA	Plate count agar
PDA	Potato dextrose agar
pGI	Estimated glycemic index
PT	Pasting temperature
PV	pasting viscosity

RDS	Rapidly digestible starch
RH	Relative humidity
rpm	Revolutions per minute
RS	Resistant starch
RS_1	Physical inaccessible starch
RS_2	Ungelatinized starch granules
RS_3	Retrograded starch
RS_4	Chemically modified starch
RVU	Rapid visco units
S	Sulphur
s.d	Standard deviation
SB	Setback
SCFA	Short chain fatty acid
SDF	Soluble dietary fibre
SDS	Slowly digestible starch
Se	Selenium
sec	Second
SEM	Scanning electron microscope
SOP	Standard operating procedure
Tc	Conclusion temperature
TDF	Total dietary fibre
TF	Total flavonoids
To	Onset temperature
Tp	Peak temperature
TPA	Texture profile analysis
TPC	Total phenolic compounds
TPTZ	2,4,6-tripyridyl-s-triazine
TSS	Total soluble solids
TTA	Total titratable acidity
v/ v	Volume per volume
w/ v	Weight per volume
w/ w	Weight/ weight
WA	Water absorption
WHC	Water holding capacity
x g	Gravity
XG	Xanthan gum
Zn	Zinc
ΔHg	Gelatinization enthalpy
λ	Wavelength
μL	Microliter

PENCIRIAN TEPUNG BATANG (PALSU) PISANG (Musa acuminata × balbisiana cv. AWAK) DAN POTENSINYA DALAM PEMBANGUNAN ROTI NOVEL KAYA-BERGENTIAN

ABSTRAK

Komposisi fiziko-kimia dan sifat-sifat berfungsi tepung batang (palsu) pisang (BPF) dibandingkan dengan tepung gandum komersial (CWF). Selulosa tidak terluntur dan terluntur telah disediakan daripada BPF. Pelbagai formulasi tepung campuran; CWF (FCWF), FCWF diganti dengan 10% BPF (F10BPF) dan F10BPF ditambah dengan 0.8% w/ w (berasas berat tepung) gam xanthan (XG) atau natrium karboksilmetil selulosa (Na CMC) masing-masing F10BPFXG atau F10BPFCMC disediakan. Formulasi tepung campuran disubjek kepada analisis pencampuran, *pasting*, dan profil terma. Roti novel komposit dengan penggantian-separa BPF kepada roti kawalan CWF (BCtr) pada peratusan 10% (B10BPF) dan B10BPF ditambah dengan 0.8% w/ w XG atau Na CMC (masing-masing B10BPFXG atau B10BPFCMC) disediakan. Roti tersebut dikaji dari segi sifat-sifat fiziko-kimia, pemakanan dan sensori. BPF mempunyai kandungan proksimat (lemak, abu, gentian kasar dan karbohidrat), unsur-unsur makro dan mikro, jumlah gentian dietari (TDF), gentian dietari tak larut (IDF), gentian dietari larut (SDF), jumlah gula, *pentosan*s, jumlah fenolik, aktiviti antioksidan, pH, ^{0}*Brix*, keasidan boleh titrat, kapasiti penyerapan air dan minyak yang lebih tinggi secara signifikan ($p< 0.05$) berbanding CWF. BPF mempunyai ketumpatan pukal, aktiviti air (a_w) dan nilai kecerahan yang rendah. Penurunan hasil dan peningkatan nilai penghabluran diperolehi daripada selulosa terluntur telah dipastikan daripada keputusan spektrosopi inframerah jelmaan fourier dan pembelauan sinar-X. Kesemua tepung komposit campuran menunjukkan peningkatan secara signifikan ($p< 0.05$) pada nilai penyerapan air dan

indeks toleransi pergaulan dengan penurunan perubahan penggelatinan entalpi (ΔHg), darjah penguraian, kelikatan akhir dan nilai *setback*. Kesemua roti komposit menunjukkan lebih tinggi secara signifikan ($p < 0.05$) dalam kandungan lembapan, abu, gentian kasar, makro mineral yang penting, SDF (1.71-2.35%), IDF (6.78-7.35%), TDF (8.51-9.24%), jumlah gula (6.71-6.92%), jumlah *pentosans*, jumlah fenolik dan aktiviti antioksidan. Walau bagaimanapun, kandungan protein, lemak, karbohidrat dan nilai kalori didapati lebih rendah berbanding BCtr. Penambahan hidrokoloid (XG atau Na CMC) menyebabkan peningkatan kandungan kanji rintang dan memperlahankan kadar hidrolisis kanji dengan berikutnya merendahkan indeks hidrolisis dan anggaran indeks glisemik. Roti komposit menunjukkan warna krum yang gelap, isipadu rendah dan nilai kekerasan yang tinggi. Penambahan Na CMC memperbaiki isipadu dan kelembutan krum roti. Semasa dalam penyimpanan, lembapan dan a_w menunjukkan tren meningkat dan menurun masing-masing bagi krus dan krum roti. B10BPFCMC mempunyai krum yang paling lembut dikalangan semua roti. BCtr mempunyai nilai ΔHg yang lebih tinggi daripada roti komposit kecuali B10BPFCMC. Kesemua roti komposit menunjukkan tiada perbezaan signifikan ($p > 0.05$) dengan BCtr dari segi hitungan bakteria, kulat dan yis. Penilaian sensori menunjukkan roti B10BPFCMC mempunyai penerimaan keseluruhan yang paling tinggi.

CHARACTERIZATION OF BANANA (Musa acuminata × balbisiana cv. AWAK) PSEUDO-STEM FLOUR AND ITS POTENTIAL IN THE DEVELOPMENT OF NOVEL FIBRE-RICH BREAD

ABSTRACT

The physico-chemical and functional properties of banana pseudo-stem flour (BPF) was compared with the commercial wheat flour (CWF). Unbleached and bleached cellulose were prepared from BPF. Various flour blends were formulated; CWF (FCWF), FCWF was substituted with 10% BPF (F10BPF) and F10BPF with added 0.8% w/ w (flour weight basis) xanthan gum (XG) or sodium carboxymethyl cellulose (Na CMC) (F10BPFXG or F10BPFCMC, respectively). The formulated flour blends were subjected to the mixing, pasting, and thermal profiles analyses. Novel composite breads by partially substituting BPF for control CWF bread (BCtr) at 10% level (B10BPF) and B10BPF added with 0.8% w/ w of XG or Na CMC (B10BPFXG or B10BPFCMC, respectively) were prepared and evaluated for the physico-chemical, nutritional and sensory. The proximate contents (fat, ash, crude fibre and carbohydrate), macro and micro elements, total dietary fibre (TDF), insoluble dietary fibre (IDF), soluble dietary fibre (SDF), total sugars, pentosans, total phenolics, antioxidants activity, pH, °Brix, titratable acidity, water and oil holding capacities were significantly ($p< 0.05$) higher in BPF than in CWF. BPF had low bulk density, water activity (a_w) and lightness value. Low yield and high crystallinity were obtained from bleached cellulose as confirmed by the fourier transform infrared spectroscopy and x-ray diffraction results. All composite flour blends showed significantly ($p< 0.05$) high water absorption and mixing tolerance index with decreased in gelatinization enthalpy change (ΔHg), breakdown, final viscosity and setback values. All the composite breads indicated significantly (p<

0.05) higher moisture, ash, crude fibre, essential macro minerals, SDF (1.71-2.35%), IDF (6.78-7.35%), TDF (8.51-9.24%), total sugars (6.71-6.92%), total pentosans, total phenolics and antioxidant activities. However, protein, fat, carbohydrate and calorie values were lower than the BCtr. Addition of hydrocolloids (XG or Na CMC) resulted in an increased resistant starch content, and slow starch hydrolysis rate with subsequent reduction of hydrolysis index and estimated glycemic index. Composite breads showed dark crumb colour, low loaf volume and high hardness values. The addition of Na CMC improved the bread volume and crumb softness. During storage, moisture and a_w showed an increasing and decreasing trend in the bread crust and crumb, respectively. B10BPFCMC had the softest crumb among all the breads. BCtr had higher ΔHg value than composite breads (exception of B10BPFCMC). All composite breads were insignificantly ($p > 0.05$) different with the BCtr in terms of bacteria, mold and yeast count. Sensory evaluation indicated that the B10BPFCMC bread had the highest overall acceptability.

CHAPTER ONE

INTRODUCTION

1.1 Background

Banana, which belongs to the Musaceae family, is native to the Indonesian-Malaysian region of Asia. Bananas are produced in large quantities in the tropical and sub-tropical regions of the world especially in developing countries due to the special climatic conditions needed for growth (Zhang et al., 2005). The crop is of major importance to the people living in the areas in which it grows because it provides a major portion of their annual income and their primary source of food. Today, bananas are the fourth most widespread fruit crop in the world. World production of banana was reported to be approximately 102 million tonnes in year 2010 (FAOSTAT, 2012).

Bananas are unique fruit with unique properties. It consists of carbohydrate, protein, fibre, minerals, vitamins and other essential nutrients. The fruit is either consumed ripe, due to its high sugar content, or unripe as in several indigenous dishes which require high starch content (Tate, 1999; Rodriguez-Ambriz et al., 2008; Haslinda et al., 2009). According to Happi Emaga et al. (2007), potassium (K) was the most abundant element in the peel of banana followed by phosphorus (P), calcium (Ca), and magnesium (Mg).

1.2 Problem statements

The production of bananas has considerable economic importance due to its availability throughout the year (Habari, 2008). However, this agricultural activity generates a large amount of waste, because after harvesting, a large amount of pseudo-stems which composed of concentric layers of leaf sheaths, a by-product of banana is left behind in plantation soil to be used as organic material. This is because the fruit constitutes only 12% by weight of the plant. The remaining parts become agricultural waste, causing environmental problems in banana farming regions (Elanthikkal et al., 2010). The agricultural by-products can be divided into non-fibrous and fibrous materials. The fibrous wastes (stems, bunches and leaves) represented 54.3% of the plant total weight (Gañán et al., 2004).

Since, the banana cultivation generates a considerable amount of lignocellulosic wastes, hence, these crops could and should find a more rational way of utilization, namely as a source of cellulosic fibres (Elanthikkal et al., 2010). These crops have been utilized as a source of fibre in the pulping industry, and their decomposition generates energy (Cordeiro et al., 2004; Oliveira et al., 2009). According to Cordeiro et al. (2004), and Oliveira et al. (2009), banana waste materials are rich in minerals and nutrients. The potential application of these pseudo-stems depends on their chemical compositions. Nowadays, little information on the chemical compositions of the pseudo-stem has been reported. Most researchers are focusing on the pulp and peels (Zhang et al., 2005; Happi Emaga et al., 2007). Several studies have been conducted to determine the chemical and functional properties of banana flour, banana starches and fibre-rich powder from unripe banana flour (Bello-Perez et al., 1999; Mukhopadhyay et al., 2008; Rodriguez-Ambriz et al., 2008). There is a lack of information on the banana (*Musa acuminata* x *balbisiana* cv. Awak) pseudo-stem. The authors mostly focus on the chemical contents of the pseudo-stem such as: monosaccharides, fibre compositions, bioactive compounds and mineral contents (Cordeiro et al., 2004; Mukhopadhyay et al., 2008; Oliveira et al., 2009; Bhaskar et al., 2010; Bhaskar et al., 2011a, b, c; Saravanan and Aradhya, 2011).

There is an increasing problem in human health disease related to food intake such as high blood pressure, diabetes and cardiovascular (CVD) diseases. An estimated 17.5 million people died from CVDs in 2005 which represented 30% of all global deaths. WHO reported that by 2015 almost 20 million people will die from CVD (WHO, 2007). The CVD disease is associated with insufficient intake of dietary fibre in their diet or due to their unbalance lifestyle. The importance of functional ingredient (food fibres) has led to the development of large and potential market of fibre-rich products. Nowadays, there is a trend to find new sources of dietary fibre from agronomic by-products that was traditionally been undervalued. Several agriculture wastes such as rice straw, wheat bran, rice bran and sugarcane bagasse have been reported to have great potential to be utilized as a fibre ingredient in bakery products (Sidhu et al., 1999; Abdul-Hamid and Luan, 2000; Sangnark and Noomhorm, 2003; Sangnark and Noomhorm, 2004). However, further innovations in fibre food ingredient for designing new food systems are needed.

Dietary fibre is composed of edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fibre includes polysaccharides, oligosaccharides, lignin, and associated plant substances. It promotes beneficial physiological processes, including laxation, blood cholesterol and blood glucose attenuation (AACC, 2001). The dietary fibre is composed of total dietary fibre (TDF), which includes both soluble (SDF) and insoluble dietary fibre (IDF). A high dietary fibre intake has been widely reported to have beneficial effects for human health such as preventing constipation and reducing colonic cancer risk (Guillon and Champ, 2000; Drzikova et al., 2005). According to the American Dietetic Association (ADA), the recommended daily fibre intake for all group aged is 20 to 35 g/ day for optimal body health benefits (Harland and Narula, 2001). Furthermore, the indigestible properties of resistant starch can be classified as dietary fibre component (Frei et al., 2003). According to Borderias et al. (2005), the IDF/ SDF ratio should be 3:1 for well-balanced diet.

White bread is popularly consumed food but it is poor in nutritional quality. Therefore to meet the dietary fibre requirement, the development of enriched bread with a higher dietary fibre content is the best way to increase the fibre intake. Increasing awareness on the health benefits of fibre has led to increase in demands of fibre from various sources. Toward this goal, an increasing number of study on enhancing the nutritive value of bread has been developed from a variety of different sources to fulfill the increasing demands of modern dietary habits (nutritious and convenient) with consideration on the products' nutritional contents (protein, mineral, vitamin and fibre) (Škrbiç and Filipçev, 2008). Partial substitution of high fibre ingredient in food lacking in dietary fibre is necessary in order to increase the dietary fibre intake in the diet (Dreher, 2001). Many works were conducted on partial replacement of wheat flour by fibre rich sources such as rice straw, barley, oat, rye and whole wheat (Sangnark and Noomhorm, 2004; Sabanis et al., 2009; Rosell and Santos, 2010; Ragaee et al., 2011) for the production of composite breads.

1.3 Significance of study

Agricultural by-products with nutrient rich contents (fibre, ash and minerals) are utilized as value added food ingredient for development of healthy bakery food products (Sangnark and Noomhorm, 2004; Škrbić et al., 2009). The banana pseudo-stem could be considered as a new source of dietary fibre to be utilized into bakery products. Hence, the production of the banana pseudo-stem flour (BPF) is necessary in order to substitute wheat flour with BPF to value add the wheat-based bakery product in terms of dietary fibre, resistant starch and reduced glycemic index.

However, partial substitution of non-wheat flour for wheat flour is often associated with gluten dilution and hence modify the consistency (reduce tolerance to over-mixing) and rheological property (reduced extensibility) which resulted in the handling problems (viscosity and stickiness) during processing of product and subsequently influence the volume, texture and impair the sensory characteristics of the finished products (Gelroth and Ranhotra, 2001). Therefore, application of additive such as hydrocolloids is needed as gluten substitutes in composite bakery products (Urlacher and Dalbe, 1992; Friend et al., 1993; Guarda et al., 2004; Gambuś et al., 2007; Sim et al., 2009).

Xanthan gum (XG) and sodium carboxymethyl cellulose (Na CMC) are commonly used in food industry at low concentrations to provide good storage stability, water binding capacity and aesthetic appeal. The XG is known to be compatible with many food components, such as protein, salts and acids. It exhibits significant viscoelasticity property even at low concentrations (Gambuś et al., 2007). XG has pseudoplastic behaviour which is important in bakery products, especially during dough preparation, such as kneading and molding. It also prevents lump formation during kneading and improves dough homogeneity. The Na CMC increases dough viscosity, and improves extensibility and elasticity in flour doughs (Cota et al., 2004). It also increases loaf volume by promotes and uniformity air cells size in baked goods (Nussinovitch, 1997; Sworn, 2000; Mikuš et al., 2013). The Na CMC has high ability to hold water as moisture binder during baking and storage. This characteristic reduces staling and moisture loss during storage and resulted in positive effects on the crumb (Friend et al., 1993; Collar et al., 2001; Sciarini et al., 2012).

Banana pseudo-stem flour could be a potential source in providing a novel fibre in foods especially in bread. This is because the application of BPF in foods industries especially in bakery products has not been investigated. Hence, based on these, the present study was conducted to develop new composite breads incorporated with BPF. BPF was used as partial substitute for wheat flour at 10% level in breadmaking so as to improve the nutritive value of the bread which has health benefits to consumers. In addition, hydrocolloids (XG and Na CMC) were added in the bread formulation to improve the quality of the fresh bread.

Based on the facts as discussed above, the availability and the nutritional values of the banana pseudo-stem have potential to be utilized in food industry. However, limited information is available on the utilization of banana pesudo-stem in bakery products. Thus, this study was conducted with objectives as stated in the next section (section 1.4).

1.4 Objectives

The overall objective of this study was to develop a healthy bread by incorporating a novel fibre ingredient processed from banana pseudo-stem. The specific objectives include:

1. To study the physico-chemical and functional properties of banana pseudo-stem flour (BPF).
2. To compare the functional properties (mixing properties, pasting profiles and thermal characteristics) of different prepared flour blends.
3. To study the effects of breads incorporated with BPF (at 10% level) with addition of hydrocolloids (XG or Na CMC) in terms of the physico-chemical and sensory attributes of the fresh breads.
4. To study the quality attributes (moisture content, water activity, texture, thermal characteristics, microbiological and sensory evaluation) of breads during storage.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Botanical and Morphological Description of Banana

Banana with all the species, varieties or hybrids belong to the genus *Musa*, order Zingiberales, family Musaceae (Table 2.1) (Simmonds, 1962; Benítez et al., 2013). Banana plants are large, perennial, monocotyledonous herbs with subterranean rhizomes called a corm which is the true stem of the banana plant (Plate 2.1). The corm produces aerial shoots which is called a pseudo-stem without hard tissues and not a true stem. It is composed of large overlapping leaf stalk bases which are tightly rolled round each other forming a clustered, cylindrical structure with almost 48 cm in diameter, and tightly clasping and slightly swollen at the base (Samson, 1980; Mukhopadhyay et al., 2008; Benítez et al., 2013) (Plate 2.2 and Plate 2.3). The pseudo-stem grows to a height of 2-9 m depending on the variety and conditions. After the bunch of fruit has ripened, no more are produced and the stem is usually cut down. The suckers develop around the base of the old plant and these are used for propagation purpose (Allen, 1967; Pillay and Tripathi, 2007).

The leaves stand in a spiral and new leaves arise from an underground true stem or rhizome (Samson, 1980; Pillay and Tripathi, 2007). Each banana plant produces 35-50 leaves in its growth cycle. When the banana plant has formed an average of 40 leaves (within 8 to 18 months), the terminal bud of the corm develops directly into the inflorescence which is carried up on a long smooth unbranched stem through the centre of the pseudo-stem emerging at the top in the centre of the leaf cluster (UNCST, 2007). The inflorescence is a compound spike of female and male flowers arranged in groups. Groups of flowers are protected by bracts (red or purple bracts), which fall off as the flowers develop (Allen, 1967; Pillay and Tripathi, 2007) (Plate 2.4).

Table 2.1 Biological classification of the banana plant

Taxonomic hierarchy	
Kingdom	Plantae
Subkingdom	Tracheobionta
Superdivision	Spermatophyta
Division	Magnoliophyta
Class	Liliopsida
Subclass	Zingiberidae
Order	Zingiberales
Family	Musaceae
Genus	*Musa*
Botanical name	*Musa acuminata* x *balbisiana cv*. Awak
Local name (Bahasa Malaysia)	Pisang Awak

(Source: USDA, 2011)

Plate 2.1 Banana plant

Plate 2.2 Cylindrical structure of banana pseudo-stems

Plate 2.3 Cross-sectional view of banana pseudo-stem

Plate 2.4 Banana flower covered by bract

The female flowers, which develop into the fruits, are further back, towards the main stem. The female inflorescences develop into fingers that constitute the bunch. Banana bunches possess 4 to 12 groups on a thick stalk; each group is called a hand, each with at least 10 fingers or an individual fruits (Plate 2.5). The fruits differ from cultivar to cultivar in characteristics such as shape, size, colour of skin and flavour, each of which may have many local names. The cultivated bananas are divided into two groups: those producing fruits which are usually eaten raw, and those which are cooked before eating due to it having a poor or unpleasant flavour in their raw state (Allen, 1967; Samson, 1980; Pua, 2010).

Plate 2.5 Banana fruits bunch arise from banana flower

2.2 Nutritional Value and Uses of Banana Pseudo-stem

Banana pseudo-stem has been reported to contain 15.1% moisture, 2.5% protein, low fat (1.7%) content, and 28.8% of total dietary fibre. Furthermore, Cordeiro et al. (2004), and Mukhopadhyay et al. (2008) have reported banana pseudo-stem has a good amount of several important macro minerals [potassium (K), calcium (Ca), magnesium (Mg) and phosphorus (P)] which is important to maintain body health. Additionally, the pseudo-stem was reported to be rich in non-starch polysaccharides or commonly referred as dietary fibres, 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 pseudo-stem is mostly cellulosic material while core or pith is rich in non-starch polysaccharides but lower in lignin content. The carbohydrate composition of banana pseudo-stem was found to be rich in low molecular weight sugars; glucose (87.0%) is present as the predominant sugar followed by xylose (8.3%) and arabinose (4.5%) (Bhaskar et al., 2011a) (Table 2.2).

Banana pseudo-stem is a by-product of the banana plant has potential for providing profitable products such as food source for human consumption. Recent studies have been shown that it possesses a commercial importance as a dietary source in the diet especially after processing. The tender core of the banana pseudo-stem located in the centre (core) of the banana stem is an edible and consumed as vegetables in many countries especially in India and Malaysia (Mohapatra et al., 2010). In Malaysia, it is commonly boiled before cooking to soften the texture of the stem.

Table 2.2 The compositions of banana pseudo-stem

Nutritional value (%)	
Moisture	15.1
Protein	2.5
Fat	1.7
Total dietary fibre	28.8
Ash	14
Potassium	33.4
Calcium	7.5
Magnesium	4.3
phosphorus	2.2
Cellulose	31.27
Hemicellulose	14.98
Lignin	15.07
Starch	27.3
Total sugar	87.8
Glucose	87.0
Arabinose	4.5
Xylose	8.3

(Source: FAO, 1990; Cordeiro et al., 2004; Mukhopadhyay et al., 2008; Bhaskar et al., 2011a)

The banana plants (fruits, leaves, roots and stalks) have been in use for long time to treat many types of diseases. In Ayurveda medicine from India, different parts of the banana plant such as banana flower and banana pseudo-stem are known to be used in traditional medicine for reducing diabetic complications by ameliorate lysosomal enzyme activities of intestinal and renal disaccharides, thereby, regulates the reduction of blood glucose levels in diabetic patient (Pellai and Aashan, 1955; Sampath Kumar et al., 2012). Furthermore, according to available documents recorded in folkloric medicine, other parts of the banana plant such as fruits, leaves, stalks and roots have been used mostly to cure common illnesses such as fevers, diarrhea, wounds healing and to recover skin-related disease such as skin inflammation (Coe and Anderson, 1999; Pillay and Tripathi, 2007; Sampath Kumar et al., 2012). Several bioactive compounds, such as dopamine, *N*-acetyl-serotonin, noradrenaline, antihyperglycemic factors, and isochronal-4-one derivative have been identified in different parts of the banana plant (Waalkes et al., 1958; Qian et al., 2007; Bhaskar et al., 2011c). Bhaskar et al. (2011c) reported that the extracted bioactive compounds from banana plant have a potential as a phytochemical ingredient to be utilized in many areas of industries such as food, pharmaceuticals, and medicine.

Several studies have been shown that banana pseudo-stem is a good source of antioxidant compounds and also anti-diabetic properties (Bhaskar et al., 2010; Bhaskar et al., 2011b, c; Saravanan and Aradhya, 2011). Clinical study conducted by Bhaskar et al. (2010) showed that diabetic rats fed with banana pseudo-stem extracts at 5% level significantly reduced blood glucose levels and ameliorate the diabetic condition. The bioactive compounds of banana pseudo-stem extracts are able to promote glucose uptake into cells, which could be beneficial for consumers with diabetes (Bhaskar et al., 2010).

Recent research indicated that juice extracted from banana pseudo-stem (*Musa Cavendish*) has the potential to be process into isotonic drink due to the presence of high mineral content especially potassium (Feriotti and Iguti, 2011). Results on the compositions of pseudo-stem showed its potential in providing better nutrition and prevention of diseases.

Several researches; Noeline et al. (2005), Anirudhan et al. (2006), and Elanthikkal et al. (2010) reported that the banana pseudo-stem has high content of polysaccharide such as cellulose which could be extracted and produced several cellulose derivatives food gum: sodium carboxymethyl cellulose (Na CMC) and microcrystalline cellulose which can be used in food, cosmetic and medical industries and absorbents for waste water treatments. Isolation of cellulose from Cavendish banana pseudo-stem (*Musa cavendishii* LAMBERT) to produce cellulose derivatives (Na CMC) was conducted by Adinugraha et al. (2005). They found that approximately 98.63% purity of Na CMC can be produced from the banana pseudo-stem.

2.3 Minerals

Minerals are inorganic compounds that function in regulating body metabolisms. Minerals play an important role in maintaining proper function and good health in the human body (Bhat et al., 2010). According to Hendricks (1998), and Korstanje and Hoek (2001), approximately 98% of the Ca and 80% of the P in the human body are found in the skeleton. Inadequate intake of minerals in the diet is often associated with metabolic and physical disorder as well as increased susceptibility to infectious diseases due to the weakening of the immune system (Chaturvedi et al., 2004; UNCST, 2007). Plants (fruits, vegetables, cereals and grains) and drinking water are important sources of essential elements. Daily diets intake of fruits and vegetables in small quantity with balance consumptions can provide optimum essential minerals required to maintain body health (Chaturvedi et al., 2004).

Minerals can be divided into two basic groups based on their requirement; macro element and micro element (trace element). The macro elements such as Ca, Mg, sodium (Na), K and P are required in fairly substantial amounts for maintaining proper function and good health in the human body (Bhat et al., 2010). An average adult requires an intake of more than 100 mg/ day of macro minerals (Hendricks, 1998). Whereas, micro elements such as zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), selenium (Se), cobalt (Co), molybdenum (Mo) and iodine (I) are needed in a small amount with recommended daily intake within microgram range to maintain specific functions in the body (Hendricks, 1998).

Sodium is the main extracellular cation which has been confirmed to result in arterial pressure with excessive of consumption. In contrast, K which is the intracellular cation has been found to have capability in controlling pathogenesis of hypertension and cardiovascular disease (Adrogue and Madias, 1997). Good sources of K may help the body to maintain normal fluid and electrolyte balances in the cells (FDA, 2000). Study was performed by D'Elia et al. (2011) regarding the influence of regular K intake on incidence of stroke, coronary heart disease and cardiovascular disease. They had found that the participants who had consumed more than 1.64 g or 42 mmol/ day of K in their daily diet has potential to reduce the risk of stroke (21% reduction), with a trend towards lower risk of coronary heart disease and cardiovascular disease. This result suggests that higher consumption of potassium-rich foods is beneficial to prevent vascular disease.

Calcium plays a vital role in maintaining functions of heart, nerve and muscle. Calcium ions are important in vascular contraction, nerve transmission and blood coagulation. The calcium ions can be absorbed, excreted, secreted and stored in the bone where these mechanisms are regulated by hormones to maintain the concentration of ionized calcium in the plasma. Ca is secreted from the bone during insufficient intake from daily diet. Pregnant or lactating women needed greater intake of calcium (Korstanje and Hoek, 2001). Lacking of Ca in human body is associated with the disease of osteoporosis which is a condition of reduction in bone mass and later resulted to the brittle or fragile bones that are more susceptible to fracture. Study showed that dietary supplementation with Ca can increased the rate of gain in skeletal mineral (Ca) (increase the bone mineral density) of children whose dietary Ca intake is approximately 1000 mg/ day. Johnston et al. (1992)

recommended that persists gain in bone mineral would probably resulted in an increase in peak bone mass which will be lower the incidence of osteoporotic fractures in their future life (Korstanje and Hoek, 2001). Aggarwal et al. (2012) conducted a study on the correlation between Ca and the risk of rickets in children. The result showed that the low intake of dietary Ca (204 ± 129 mg/ day) had significantly developed rickets as compared to the control (healthy subject) with intake of dietary Ca at concentration 453 ± 234 mg/ day. According to Korstanje and Hoek (2001), the recommended intake of total Ca per day varies from 800 to 12,000 mg.

Chaturvedi et al. (2004) reported that the functions of Mg and Zn are to prevent muscle degeneration, cardiomyopathy, growth retardation, dermatitis, alopecia, immunologic dysfunction, bleeding disorders, gonadal atrophy, impaired spermatogenesis and congenital malformations. Mg is important in regulating active Ca transport and it influences both matrix and mineral metabolisms in bone. Lacking of Mg resulted in similar effects as reported in Ca such as decreased activities of osteoclastic and osteoblastic, osteopenia, bone fragility (osteoporosis) and retardation of growth (Korstanje and Hoek, 2001). Clinical study showed that dietary Mg intake was associated with reduced risk of sudden cardiac death in women (Chiuve et al., 2011). The suggested daily dietary intake of Mg is between 220 and 400 mg/ day (Korstanje and Hoek, 2001). Zn has antioxidant membrane stabilizer properties, which has the ability to scavenge harmful free radicals because of its antioxidant membrane (Korstanje and Hoek, 2001). Recent study showed that, Zn supplementation to food has beneficial effects to the patients with diabetes mellitus. Jayawardena et al., (2012) reported Zn treated subjects showed reduction in post-prandial blood sugar. They also found that, Zn was able to reduce the low-density lipoprotein cholesterol in the Zn treated group. The recommended dietary intake of Zn is average 9-12 mg/ day (Korstanje and Hoek, 2001).

Fe is an important intrinsic component of cytochrome, hemoglobin, and myoglobin (Hemalatha et al., 2007; Yaday and Chandra, 2011). The most common disease associated with Fe deficiency is anemia. Anemia is related with increased cell prophyrin, where it inhibits ferrochelatase enzyme; this can then further inhibit synthesis of heme. The decreased in hemoglobin synthesis which resulted from Fe deficiency is susceptible to the anemia disease (Yaday and Chandra, 2011). Study demonstrated that the daily supplementation of Fe led to significant improvement in the hemoglobin, serum ferritin, and free erythrocyte protoporphyrin in the Fe treated group (Beasley et al., 2000; Zavaleta et al., 2000). Thus, this can prevent or lower the risk of anemia. Korstanje and Hoek (2001) reported that the general recommended intake of Fe is 15 ± 5 mg/ day. However, a pregnant woman requires higher amount than the recommended amount.

2.4 Dietary Fibre

Carbohydrates are composed of the elements carbon, hydrogen and oxygen with form a hierarchy of structures begin with the simple sugars, monosaccharides (e.g. glucose and fructose), these units can be joined together in pairs to form disaccharides (e.g. sucrose and maltose), followed by oligosaccharides (e.g. cyclodextrin) which contain up to nine monosaccharide units and polysaccharides may contain up to several hundred thousand (e.g. starch and cellulose) (Annison et al., 1993; Gurr and Asp, 1994). They are classified into water soluble and water insoluble carbohydrates and some carbohydrates are digestible while others are not. The digestible polysaccharides such as starch are a major source of physiological energy (Annison et al., 1993).

According to AACC (2001), dietary fibre is defined as the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Fibre is not a nutritionally, chemically, or physically uniform material, which adds another dimension of complexity (Van Soest et al., 1991). Dietary fibre is generally recognized as the low-calorie bulking ingredients (Annison et al., 1993).

Dietary fibre components consist mainly of polysaccharides (complex polymers of sugar units). The main components of dietary fibre are non-starch polysaccharides (NSP). NSP include cellulose, hemicelluloses (arabinoxylans and arabinogalactans), pectins, modified celluloses, fructans (oligomers and polymers of fructose: inulin), gums, and mucilages. Oligosaccharides, such as oligofructan is a low molecular weight analogue of the digestion-resistant polysaccharide (AACC, 2001). The constituents of dietary fibre are summarized in Table 2.3.

Dietary fibre can be found in the human diet through a wide variety of plant-based food sources, such as vegetables, fruits, legumes and both raw and processed cereals. However, the different compositions of dietary fibre (SDF, IDF and TDF) vary with the types of plant variety (Dhingra et al., 2012). For example, bran and whole grain cereals are rich in hemicelluloses, cereal and vegetables have good source of cellulose. Whereas, fruits with edible seeds (strawberries) and mature vegetables (root vegetables or carrots) were reported to be high in lignin. Dried bean and oats have high content of SDF and fruits such as oranges and apples contain a good source of pectin. Furthermore, the amount (%) of the different dietary fibre constituents is dependent on the growing stages of the plants. For example, in the plant cell walls, the amount of ash, cellulose and lignin tend to be higher in mature than immature plants. In contrast, the percentage of non-cellulosic polysaccharides (hemicellulose, polyfructoses, galactooligosaccharide, pectin, gums and mucilages) tend to be lower in mature than in immature plants. Other than the maturity of plants, the ripening and the portion of the plant consumed as well as storage of plant foods may also influence the compositions of dietary fibre (Dreher, 2001; Elleuch et al., 2011).

Table 2.3 Constituents of dietary fibre

Non-starch polysaccharides and resistant oligosaccharides
Cellulose
Non-cellulosic polysaccharides
Hemicellulose
- Arabinoxylans
- Arabinogalactans
Polyfructoses
- Inulin
- Oligofructans
Galactooligosaccharides
Gums
Mucilages
Pectins
Analogous Carbohydrates
Indigestible dextrins
- Resistant maltodextrins (from corn and other source)
- Resistant potato dextrins
Synthesized carbohydrate compounds
- Polydextrose
- Methyl cellulose
- Hydroxypropylmethyl cellulose
Indigestible (resistant) starches
Lignin
Substances associated with the non-starch polysaccharide and lignin complex in plants
Waxes
Phytate
Cutin
Saponins
Suberin
Tannins

(Source: AACC, 2001)

Total dietary fibre is the analytical term for dietary fibre that includes both SDF and IDF. SDF consists of non-cellulosic polysaccharides (pectin, mucilages, and gums) which can be found in fruits, barley, legumes and oats, whereas IDF consists mainly of cell wall components such as hemicelluloses, cellulose and lignin which present mainly in wheat, vegetables and most grain products. Approximately 75% of the dietary fibre in foods is found in insoluble fraction (Dreher, 2001; Elleuch et al., 2011; Dhingra et al., 2012).

2.4.1 Soluble dietary fibre (SDF)

SDF is soluble in aqueous enzyme systems and can be precipitated upon addition of 4 parts alcohol to the aqueous mixture. Examples of SDF are pectin, β-glucan, gum and inulin (Ang, 2005; Elleuch et al., 2011). The SDF plays a vital role in the digestive and absorptive processes. SDF is indigestible fibre, hence it can help to control blood glucose levels and slowing the glucose absorption process in patient who has diabetes mellitus disease. Some studies showed that subject with food intake rich in SDF diet (low-cholesterol and low-fat) helped lower blood cholesterol in those individuals with elevated blood cholesterol levels (Dreher, 2001; Dhingra et al., 2012; Schoenaker et al., 2012).