EFFECT OF SWEETENER AND RESIDUE OF OVERRIPE BANANA INCORPORATION ON PHYSICOCHEMICAL PROPERTIES, SENSORY ACCEPTABILITY AND GLYCAEMIC INDEX OF CHOCOLATE COOKIES

NG YEE VERN

UNIVERSITI SAINS MALAYSIA

2020

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by

NG YEE VERN

Thesis submitted in fulfilment of the requirements for the degree of Master of Science

July 2020

ACKNOWLEDGEMENT

First and foremost, I would like to take this opportunity to express my deepest gratitude and appreciation to my dedicated main supervisor Prof. Dr. Wan Rosli Wan Ishak and co-supervisor Dr. Tengku Alina Tengku Ismail for their supervision, enlightened guidance, invaluable time, patience, advices and suggestions throughout the course of this research project. In addition, my sincere appreciations to all the staffs in Nutrition and Dietetics Laboratory, Cultural Laboratory, Analytical Laboratory and Food Preparation Laboratory in the School of Health Sciences, USM for their generous cooperation, helps especially supplying all the apparatus and chemicals needed and willing to share their experience in operating the sophisticated instrument. Furthermore, I am thankful to all my colleagues especially Nurraihana, Saffa Azid and YenYee for their assistances, advices and supports during the studying period. My special thanks to all the volunteers involved in the research studies for their interest, commitment and time. Last but not least, I acknowledge my beloved family members: father (Ng Check Chiam), mother (Ng Shee Shee) and also my siblings for their strong support and patience during the completion of my research.

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LIST OF SYMBOLS

m	Meter
cm	Centimeter
mm	Millimetre
µm	Micrometre
nm	Nanometre
>	Greater than
<	Lower than
≥	Greater than or equal to
≤	Lower than or equal to
L	Litre
mL	Millilitre
µL	Microlitre
g	Gram
mg	Milligram
kg	Kilogram
%	Percentage
°C	Degree Celsius
p	p-value
mmol/l	Millimole per litre
N	Normality
°Brix	Degree brix
w/v	Weight per volume
M	Molar
s	Second

LIST OF ABBREVIATIONS

AACC	American Association of Cereal Chemist
ADA	American Diabetes Association
ANOVA	Analysis of variance
BMI	Body mass index
CVD	Cardiovascular diseases
DBP	Diastolic blood pressure
DM	Diabetes mellitus
et al.	And others
FAO	Food and Agricultural Organization
FDA	Food and Drug Administration
GI	Glycaemic index
GL	Glycaemic load
HbA1c	Glycated hemoglobin
HCL	Hydrochloric acid
HPLC	High-performance liquid chromatography
iAUC	Incremental area under curve
IGF	Insulin-like growth factor
IOM	International Organization for Migration
LDL	Low-density lipoprotein
MANS	Malaysian Adults Nutrition Survey
MDG	Malaysian Dietary Guidelines
Min	Minute(s)
MOH	Ministry of Health
NaOH	Sodium hydroxide
OBR	Overripe banana residue
OBS	Overripe banana sweetener
QC	Quality control
RDA	Recommended Daily Allowance
RNI	Recommended Nutrients Intake
SACN	Scientific Advisory Committee on Nutrition
SBP	Systolic blood pressure

SD	Standard deviation
SEM	Standard error of mean
SEM	Scanning electron microscopy
SPSS	Statistical Package for Social Science
TDF	Total dietary fibre
TPA	Texture profile analysis
TSS	Total soluble solid
UHT	Ultra-heat treatment
USDA	United State Department of Agricultural
WHO	World Health Organization

KESAN PENAMBAHAN PEMANIS DAN SISA PISANG RANUM KE ATAS CIRI-CIRI FIZIKOKIMIA, PENERIMAAN SENSORI DAN INDEKS GLISEMIK BISKUT COKLAT

ABSTRAK

Permintaan untuk produk bakeri yang diperkaya serat dan rendah gula semakin meningkat kerana prevalens diabetis yang tinggi. Pisang adalah salah satu buah yang disukai ramai dan memberikan faedah kesihatan pemakanan yang sangat baik. Sementara itu, banyak pisang ranum telah dibuang kerana kualiti dan penampilannya yang rendah. Namun begitu, pisang ranum menunjukkan sumber yang kaya dengan pemanis semulajadi dan serat dietari yang berpotensi digunakan sebagai ramuan makanan baru untuk menggantikan gula dan tepung gandum dalam produk bakeri. Oleh itu, kajian ini bertujuan untuk menentukan komposisi pemakanan, profil tekstur, penerimaan sensori dan nilai indeks glisemik (GI) biskut coklat yang ditambah dengan pemanis pisang ranum (OBS) sebagai pengganti separa (0, 5, 10, 15 dan 20%) untuk gula dan penggunaan residu pisang ranum (OBR) sebagai pengganti separa (8%) untuk tepung gandum. Keputusan telah menunjukkan bahawa penambahan OBR dan OBS meningkatkan nilai pemakanan biskut coklat. Biskut coklat yang ditambah dengan 8% OBR + 20% OBS mencatat kandungan serat dietari (7.80%) dan abu (1.47%) tertinggi. Kedua-duanya kandungan karbohidrat dan sukrosa biskut coklat dikurangkan dengan peningkatan tahap OBS. Analisis profil tekstur menunjukkan peningkatan bagi nisbah sebaran dan menurun bagi kekerasan dengan peningkatan tahap OBS dalam biskut coklat. Skor sensori untuk 0% dan 8% OBR biskut coklat tidak menunjukkan perbezaan yang signifikan. Selain itu, penambahan OBS dalam biskut coklat sehingga 15% menghasilkan skor tertinggi dari segi aroma, rasa dan penerimaan keseluruhan. Berdasarkan keputusan yang didapati dari ujian penerimaan sensori, tiga formulasi biskut coklat (0%, 8% OBR dan 8% OBR + 15% OBS) dipilih untuk ujian GI. Keputusan didapati bahawa nilai GI untuk 0%-biskut coklat, 8% OBR-biskut coklat dan 8%OBR + 15%OBS-biskut coklat masing-masing adalah 63, 56 dan 50. Hasil kajian ini menunjukkan bahawa pisang ranum boleh digunakan sebagai ramuan makanan dalam penghasilan biskut coklat yang berkhasiat dan rendah GI.

EFFECT OF SWEETENER AND RESIDUE OF OVERRIPE BANANA INCORPORATION ON PHYSICOCHEMICAL PROPERTIES, SENSORY ACCEPTABILITY AND GLYCAEMIC INDEX OF CHOCOLATE COOKIES

ABSTRACT

Demand for dietary fibre-enriched and low sugar bakery products is increasing rapidly due to current high incidence of Type 2 diabetes mellitus. Banana is one of the most consumed fruit which provide excellent nutritional health benefits. Meanwhile, overripe banana has been discarded due to its low quality and appearance. Despite its appearance, overripe banana exhibits rich sources of natural sweetener and dietary fibre which could potentially be used as a novel food ingredient to replace added sugar and wheat flour in bakery product. Thus, the study aims to determine the nutritional values, physical properties, sensory acceptability and glycaemic index (GI) value of chocolate cookies formulated with overripe banana sweetener (OBS) as partial replacement (0, 5, 10, 15 and 20%) for table sugar and utilization of overripe banana residue (OBR) as partial replacement (8%) for wheat flour. Results have shown that incorporation of OBR and OBS significantly ($p<0.05$) increased nutritional values of chocolate cookies. Chocolate cookies formulated with 8% OBR+20% OBS recorded the highest TDF (7.80%) and ash (1.47%) content. Both carbohydrate and sucrose content of chocolate cookies were reduced significantly with increasing level of OBS. In texture profile analyses, an increment in spread ratio as well as a decrease in firmness were shown with increasing levels of OBS in chocolate cookies. Sensory scores for control and 8% OBR-incorporated cookie were not significant difference for all the sensory attributes. Moreover, incorporation of OBS up to 15% produced the highest scores in term of aroma, flavour and overall acceptance. Based on the sensory acceptability results, Three formulations of chocolate cookies (0%, 8% OBR and 8% OBR+15% OBS) were selected for GI testing. It was found that the GI values for 0%-cookie, 8% OBR-cookie and 8%OBR+15%OBS-cookie were 63, 56 and 50, respectively. The results of this study showed that overripe banana can be used as a food ingredient in developing low-GI chocolate cookie.

CHAPTER 1

INTRODUCTION

1.1 Background and problem statements

In recent decades, the incidence of chronic diseases is increasing at an alarming rate. Chronic diseases include cardiovascular diseases (CVD), cancers, chronic respiratory diseases and diabetes mellitus (DM) are the major cause of mortality in the world (Ramli and Taher, 2008). The prevalence of chronic diseases is rising rapidly and is forecasted to exceed as the common causes of death by 2030 (WHO, 2011). Among the chronic diseases, DM is currently a global public health concern and reported to have led to 1.6 million death globally in 2016 (WHO, 2016). The prevalence of DM has doubled in the past three decades, ranging from 4.7% in 1980 to 8.8% in 2017 and it is expected to increase to almost 10% by the year 2045, equalling to 9.9% of the population (Cho *et al*., 2018). Furthermore, Malaysia was reported to probably have the distinction of having the highest prevalence of DM among all the countries in ASEAN region (Chan, 2015). The Ministry of Health (MOH, 2015) reported that DM in Malaysia increased in line with age which starting from 0.7% within the age group of 20 – 24 years old, arriving a peak of 27.9% at age group 70 – 74 years. The incidence of DM is due to many factors, for example rapid urbanization, eating habit and increasing rates of obesity and sedentary lifestyle (Hu, 2011). Even there are plenty of efforts and anti – diabetic agents provided, DM is still a major cause of morbidity and mortality worldwide (Erejuwa *et al.*, 2012).

The increasing trend of DM has led to high demand of diabetes-related functional food with the purpose of improving their blood glucose control. One of the approaches is by assessing the physiological effects of food using the concept of glycaemic index (GI) which is a value given to carbohydrate-rich foods based on their effect on post-meal glycaemia (Esfahani *et al*., 2009). The GI of a food depends on the rate of digestion and absorption of carbohydrates in the small intestine (Arvidsson-Lenner *et al*., 2004). As a result, low-GI foods are able to produce a gradual rise in blood glucose level and are therefore, more favourable in terms of health, especially for the management of diabetes. There are several food components that can be used to reduce the GI of a food. These include the presence of dietary fibre and types of sugar added in the food.

Dietary Fibre (DF) is the edible part of plant which is resistant to enzymatic digestion and absorption in human small intestines with complete or partial fermentation in the large intestine (Dhingra *et al*., 2012; AACC 2001). DF is an important component in our daily diet and naturally present in cereals, vegetables, fruits and nuts (Dhingra *et al*., 2012). DF plays an important role in human health and body function (Dreher, 2001). High consumption of DF has been proven to reduce the risk of certain types of diseases such as obesity, diabetes, cancer and cardiovascular diseases (Cho *et al*., 2013; Lattimer *et al*., 2010). DF particularly soluble fibre is mostly found in fruits and vegetables and has been shown to have a direct effect on the GI of a food (Weickert and Pfeiffer, 2018). The viscous, gel-forming and more readily fermented properties of these fibres increase viscosity of food which leads to prolonged carbohydrate digestion and absorption as well as improved satiety. Thus, lowering postprandial blood glucose level (Post *et al*., 2012). The recommended DF intake for adults is 20-35 g/day (ADA, 2001). Nevertheless, the intake of DF among populations is low, ranging from only 3 – 16 g/day (Lee and Wan Muda, 2019).

Sugars are one of the major components in our diet and are normally added into foods and beverages to enhance the colour, texture and flavour development (Goldfein and Slavin, 2015). The most common of which is sucrose or table sugar which is widely used in the food industry for the production of commercialised food products such as bakery products, ice cream and carbonated beverages (Zargaraan *et al*., 2016). However, over consumption of sucrose-rich product may lead to weight gain, cardiovascular diseases and type 2 diabetes (Goldfein and Slavin, 2015). As a consequence, artificial sweeteners (non-nutritive sweetener) such as aspartame, sucralose, neotame and saccharin have received great attention to replace added sugar as these sugars generally have little to no calories and provide low glycaemic response (Mattes and Popkin, 2008). Nevertheless, the effect of artificial sweeteners on human health is still a controversial topic. There are previous studies that found the links between artificial sweeteners and adverse health effects, such as weight gain, cancer, nausea, diarrhea and metabolic disorders (Harpaz *et al*., 2018; Hampton, 2008; Whitehouse *et al*., 2008). Moreover, there was a study which reported that artificial sweeteners induce glucose intolerance by altering the gut microbiota (Suez *et al*., 2014). Hence, there is an increasing interest in searching for a more natural and nutrient-rich sweetener. Alternative sweeteners that are believed to be healthier are natural sweeteners from high sugar tropical fruits such as banana, pineapple, mangoes and pomegranate. Interestingly, these are safer to be consumed due to no toxicity claimed (Song *et al.*, 2006).

Banana (Musa sp.) is one of the most widely consumed fruit and main international trade fruit in the world (Castelo-Branco *et al*., 2017). Today, banana is the world second largest fruit crop with an estimated gross production exceeds 117 million tonnes (FAO, 2017). Banana has long been recognised as a great source of nutrients and beneficial effects on human health, for instance lower risk of high blood pressure and stroke, improve bowel movement, maintain blood sugar level and help in weight loss (Sidhu and Zafar, 2018; Kumar *et al.*, 2012). However, banana is a perishable fruit that has a short lifespan from harvest until the onset of deterioration (Karim *et al.*, 2018). Previous studies have claimed that the purchase intention for overripe banana was significantly low due to low quality, appearance of brown spots as well as decrease in firmness of the pulp (Rohm *et al.*, 2017; Symmank *et al.*, 2018). As a result, banana has been shown to be one of the most-wasted products as most retailers ask for fruit in yellow colour which associated with ripe banana (Mattsson *et al.*, 2017; Shahir and Visvanathan, 2014). Despite that, overripe banana provides an excellent source of vitamins (A, B_6, C and D), minerals (potassium and magnesium), DF and natural sweetener (Kumar *et al.*, 2012). The sugar content, which is mainly composed of sucrose, fructose and glucose is increased tenfold from unripe banana to overripe banana, rising from 1.26 to 12.28% (Yap *et al.*, 2017). A previous study by Chaipai *et al.* (2018) revealed that the DF in banana pulp does not vary with maturity although most of the starch will be converted into sugar in overripe banana. There have been a few studies that utlized overripe banana or second grade banana to produce banana puree films (Martelli *et al.*, 2012) and biodegradable starch laminates (Alanís-López *et al.*, 2011). However, overripe banana is still underutilized and very little effort has been made to identify its functionality in terms of application to food (Padam *et al.*, 2014). Hence, the utilization of overripe banana will not only help in increasing the value of food products but also indirectly reduce food waste.

Presently, bakery products such as breads, cakes, cookies, and pastries have a great demand as one of integral part in our daily life. Most of people eat baked goods to reduce the consumption of staple food such as rice (Sheng *et al*., 2008). Cookies are small, flat and sweet bakery product that are widely consumed due to their ready-to-eat, convenient, affordable cost, high availability and longer shelf life (Adeyeye and Akingbala, 2015). According to Malaysian Adults Nutrition Survey (MANS, 2014), cookies is in the top 10 lists of daily consumed food among Malaysians (Kasim *et al*., 2018). Hence, cookies could be an alternative carrier of nutrients and utilised as a source for addition of various nutritionally rich ingredients for their diversification (Nandeesh *et al*., 2011). Nevertheless, cookies in the market are mostly high in fat and sugar content as well as lack of DF content. Currently, research has been conducted on the use of banana pulp powder as a source of DF in noodle (Ritthiruangdej *et al*., 2011), ice cream (Yangılar, 2015) and wheat-based product (Loong and Wong, 2018; Adubofuor *et al*., 2016). However, there is a lack of overripe banana application in bakery product such as cookie. In this context, the objective of this study was to determine the nutritional properties, sensory acceptability and glycaemic index (GI) value of chocolate cookies formulated with overripe banana sweetener (OBS) as partial replacement for table sugar and utilization of overripe banana residue (OBR) as partial replacement for wheat flour. OBS is the sugar extracted from overripe banana pulp whereas OBR is the remaining residue of the banana pulp after the removal of sugar.

1.2 Rational and significance of the study

Eating chocolate cookies can be associated with a range of emotions. Aside from the emotional comfort that chocolate cookies may provide, there are scientific explanations for why people salivate for them. Some research suggests that the ingredients in chocolate cookies may have addictive properties with sugar has the most profound effect. Evidence has shown that sugars can induce rewards and cravings in magnitude to those induced by addictive drugs (Ahmed et al., 2013). Besides, chocolate contains small amounts of a compound known as anandamide which is also a brain chemical that is responsible for mood-altering effects (Benton and Nehlig, 2004). According to Wenk (2019), chocolate which in addition to sugar and fat may raise further the level of anandamide in our brains making chocolate cookies so universally craved that most people find them irresistible.

However, most of commercialized chocolate cookies are often high-fat and sugar-rich which resulted in low nutrient content and high level of GI. Hence, chocolate cookies are often been identified as unhealthy food or snack. There is a continous worrying trend of developing food products which are focusing on the taste but neglecting the health issue. As a consequence, greater numbers of people are diagnosed with chronic illness. By incorporating natural ingredients into chocolate cookie, consumers have greater chance to have healthy food items in their daily food choice as well as making chocolate cookie part of a healthy diet.

Due to the fact that overripe banana are often treated as waste, its immense nutritional content is believed to have the potential to develop DF-rich and low-GI chocolate cookie. Furthermore, by utilizing locally available natural ingredients can avoid increment in the production cost as well as selling price of the chocolate cookies, at the same time could reduce the wastage of food.

1.3 Objectives of the study

1.3.1 General objective

To investigate the physicochemical properties, sensory acceptability and glycaemic index (GI) value of chocolate cookies incorporated with overripe banana sweetener (OBS) and overripe banana residue (OBR).

1.3.2 Specific objectives

1. To determine the nutritional compositions of chocolate cookies incorporated with different percentage of OBS and OBR.
2. To examine the texture profiles and microstucture characteristics of chocolate cookies incorporated with different percentage of OBS and OBR.
3. To evaluate the sensory acceptibility of chocolate cookies incorporated with different percentages of OBS and OBR
4. To determine the GI of chocolate cookies incorporated with OBS and OBR.

CHAPTER 2

LITERATURE REVIEW

2.1 Banana (*Musa sp.*)

Figure 2.1 shows a taxonomy background of banana. The taxonomy group of banana was first identified and described by Carl Linnaeus in 1753 (Hyam and Pankhurst, 1995).

Scientific classification

Kingdom	: Plantae
Division	: Magnoliophyta
Class	: Liliopsida
Order	: Zingiberales
Family	: Musaceae
Genus	: *Musa*
Species	: *Musa accuminata*
	: *Musa balbisiana*

Common names

Dessert banana, forbidden fruit, banana, nana

Figure 2.1 Taxonomy background of banana (The Plant List, 2013)

Banana (*Musa sp.*) is an edible fruit produced by a plant belonging to the genus of Musa from the family of Musaceae, which is a large monocotyledonous herb (Marikkar *et al*., 2016). It can grow from 2 to 9 meters in height at maturity (Marikkar *et al*., 2016; Nelson *et al*., 2006). As banana plants (Figure 2.2(a)) are normally tall and sturdy, they are often mistaken for trees, but the trunk is actually a "false stem" or pseudostem. A pseudostem composed of leaf sheaths and a terminal crown of leaves through which an inflorescence (flower spike) emerges carrying a bunch of banana (consists of 50 – 150 bananas) as shown in Figure 2.2(b) (Stevens and Ware, 2018).

Figure 2.2(a) Banana plant (Petruzzello et al., 2019)

Figure 2.2(b) Bananas growing in a bunch (Petruzzello *et al*., 2019)

Bananas are plants of the tropical humid lowlands and are mostly grown between 40° north and south of the equator. According to Sulaiman *et al*. (2011), there are more than 20 edible banana cultivar types and most of them are derived from two wild species, known as *Musa acuminate* (A-genome) and *Musa balbisiana* (B-genome). *Musa acuminate* is the most widespread of the species and have their centre of diversity in the Malaysian (Simmonds, 1962) and Indonesia (Horry *et al*., 1997). As a result, this species is focused in this study. Meanwhile, the distribution of *Musa balbisiana* is reported from East India to South China, Philippines, Moluccas and New Guinea (Smartt, 1976; Tucker, 1993). Some examples of cultivated varieties of *Musa* are listed in Table 2.1.

Banana fruit is a very popular fruit in terms of its importance as a food crop in the world market (Singh *et al*., 2016). The fruit is variable in size, colour but is usually elongated-cylindrical and curved (Nelson *et al*., 2006). Furthermore, the fruit can vary in taste from starchy to sweet, and texture from firm to mushy depends on the ripeness of the banana (Stevens and Ware, 2018). Ripen banana is mainly eaten raw as a dessert or sweet fruit, whereas unripen banana is utilised in cooking (fried banana, banana chips etc) (Singh *et al*., 2018; Singh *et al*., 2016). Moreover, banana also can be processed into a number of food products, for example ripe banana can be made into puree form, which can further used in variety of products such as yogurt, ice cream, bakery products and baby food (Singh *et al*., 2016; Aurore *et al*., 2009); unripe green banana can be dried and ground into flour so that it can be stored for longer periods and utilized for other purposes (Cheok *et al*., 2018).

Table 2.1 Example of some cultivated varieties of *Musa*

Crossed species	**Main distribution**	**Genome group**	**Subgroup (Cultivar)**	**Common cultivar names**
M. acuminate × M. acuminate	Malaysia, India, Indonesia, Philippines, Sri Lanka, Thailand, Vietnam, Australia	AA	Inarnibal	Pisang lemak
			Lakatan	Pisang berangan, Phayan
			Pisang Lilin	Lidi, Pisang Lidi
			Sucrier	Lady's Finger, Amas, Caramelo
		AAA	Cavendish	Mons Mari, Williams
M. acuminate × M. balbisana	Philippines, Bhutan, China, India, Vietnam, Papua New Guinea, Sri Lanka	AB	Kamarangasenge	Sukali Ndizi
			Ney Poovan	Lady's Finger
		AAB	Maoli-Popoulu	Pacific Plantain, Comino, Pompo
			Pisang Raja	Pisang Raja, Larip, Houdir

Adopted from Ploetz *et al.*, 2007

2.1.1 The production of banana

Bananas are the fourth most important food crop after wheat, rice and maize in terms of production and are the world's favourite fruit in terms of consumption quantity. It is an important staple food and contributes to the food security of millions of people in the developing world (Tripathi *et al.*, 2014). With the global population surpassing 7 billion people, the main driver of fast production expansion has been the increasing consumption requirements of rising population in developing countries. The bulk of the global production increase has come from top producers who are also top consumers such as Brazil, Philippine, India and China. Furthermore, increasing health awareness in Western markets has contributed to the rising demand, with banana consumption having substantially gained in popularity among European and North American consumers.

As shown in Figure 2.3(a) and Figure 2.3(b), bananas are predominantly produced in Asia with Asia-Pacific leads the banana market with 61% share of global consumption. Within Asia-Pacific, India is the largest producer of bananas in the world, with a production of 29.7 million metric tons per years on average between 2010 and 2017, from an area of 0.84 million hectares (FAO, 2019). Other major banana-producing countries are China (11.58 million tons), Indonesia (7.26 million tons), Philippine (6.14 million tons) and Brazil (6.75 million tons) (FAO, 2020a; Shahbandeh, 2020).

The global banana exports were estimated at 19.2 million metric ton in 2018 and set a new record high of 20.2 million tonnes in 2019, an estimated increase of 5% as compared to 2018. Two leading exporters, Philippine and Ecuador is accountable for the rise (FAO, 2020b). Moreover, most of the bananas are consumed in the countries where they are grown and only 20% are exported to other countries (Singh *et al*., 2016). India's exports of banana represent only 0.3% of the world exports since most of the banana grown in India are for the domestic market. Due to the structure of landholdings in India, there are certain limits on land usage. Thus, the contract-farming model is used, which allows the agribusiness producers to produce bananas in larger areas than the legal constraints. In India, production and productivity have increased significantly with the expansion of area under cultivation.

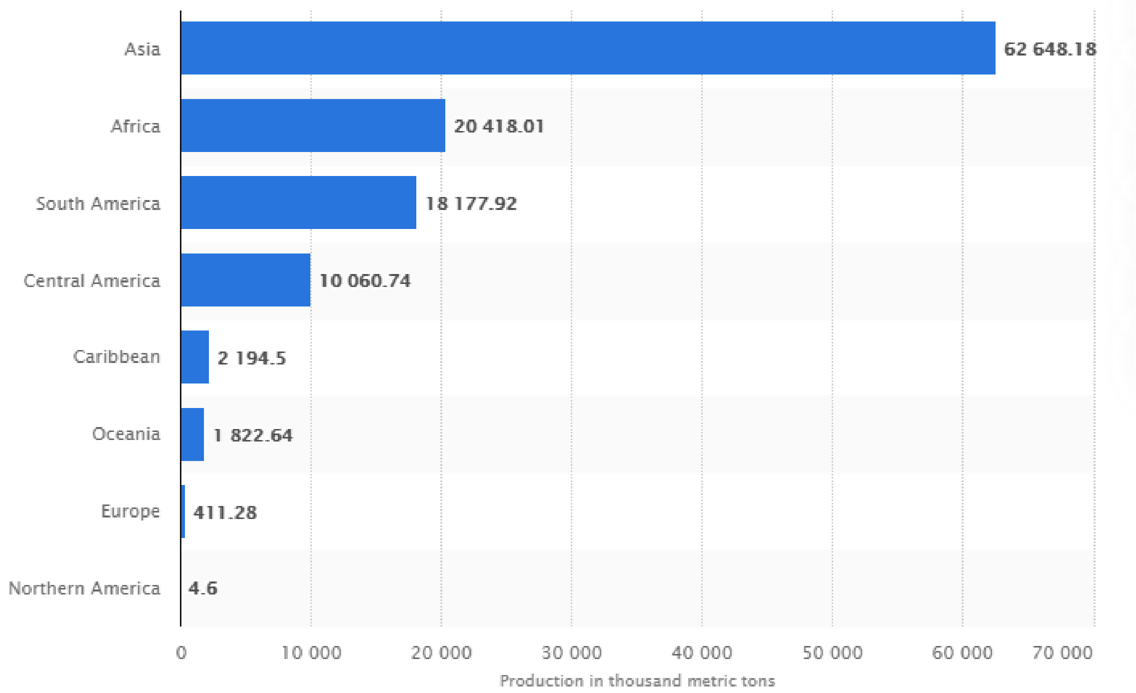

Figure 2.3(a)　　World production of bananas in 2018 (Shahbandeh, 2020)

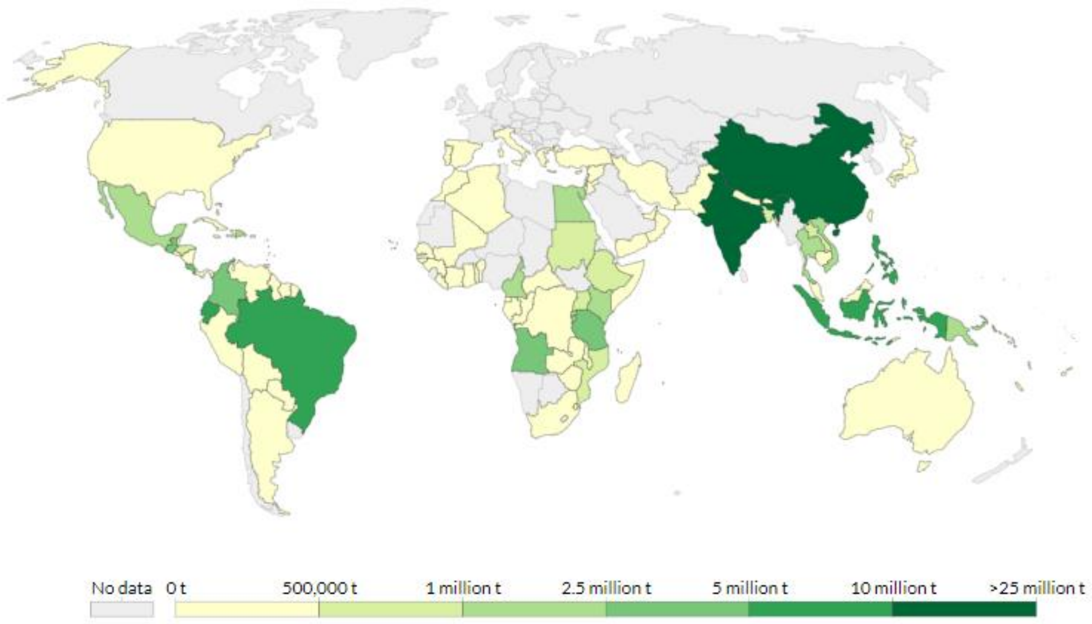

Figure 2.3(b)　　Bananas production in 2018 (FAO, 2020a)

In Malaysia, banana is also one of the important fruit crops cultivated with ranked second in terms of production area and fourth in export revenue (Kayat *et al*., 2016). In Figure 2.4, the production trend shows that banana has increased continually from 2.8 million tons in 2013 to 3.5 million tons in 2017, an increase about 21.4% in 5 years (Abu Dardak, 2019). Most of the bananas grown commercially are found in Johor, Perak, Kelantan, Pahang, Kedah and Selangor (MOA, 2019). About 50% of the bananas cultivated are *Pisang Berangan* and the Cavendish type, and the remaining popular cultivars *are Pisang Mas, Pisang Rastali, Pisang Raja*, *Pisang Awak, Pisang Nangka* and *Pisang Tanduk* (Kayat *et al*., 2016). Bananas are mostly cultivated for local consumption as banana is the most-consumed fruits (10 kg/year) as compared with other fruits as reported by Department of Statistic Malaysia (2018) presented in Table 2.2. The consumption trend will determine the supply and demand of fruits in Malaysia as higher demand from domestic market will lead to higher income. Meanwhile about 12% of the total production (mostly the Cavendish variety) is exported, mainly to Singapore, Brunei, Hong Kong and the Middle East (MOA, 2015). Considering the importance of banana in domestic and export markets, the government has banana as one of the fruits to be prioritised for development under the National Agricultural Policy (Mohamad Roff *et al*., 2012).

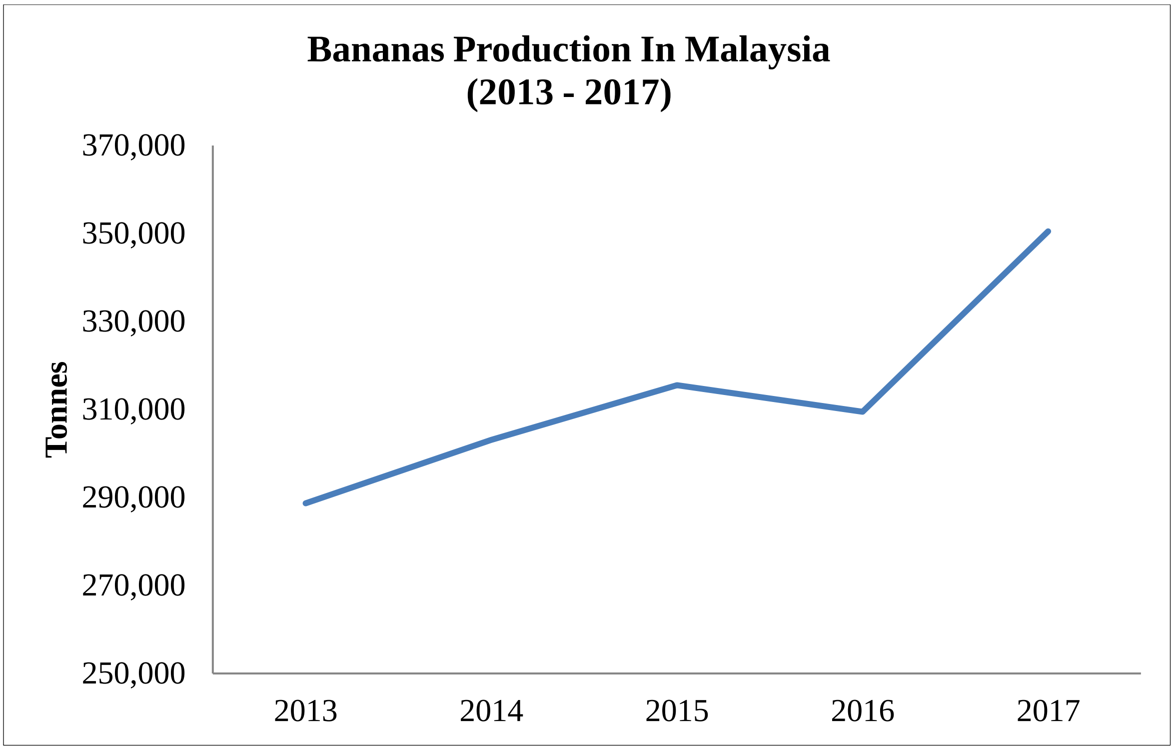

Figure 2.4 Bananas production in Malaysia (Abu Dardak, 2019)

Table 2.2 Tropical fruit consumption per capita in Malaysia, 2018

No.	Type of fruits	Consumption (kg/year)
1.	Banana	10.0
2.	Pineapple	7.6
3.	Durian	6.4
4.	Watermelon	3.3
5.	Guava	2.5
6.	Mango	2.0
7.	Jackfruit	1.9
8.	Papaya	1.7
9.	Rambutan	1.1
10.	Mangosteen	0.4

Source: Department of Statistic Malaysia (2018)

2.1.2 Ripening of banana

Fruit ripening is a genetically programmed, highly coordinated process of organ transformation from unripe to ripe stage, in order to yield an attractive edible fruit with an optimum blend of colour, taste, aroma and texture (Maduwanthi and Marapana, 2017; Perotti *et al*., 2014). Bananas are climacteric fruits which are artificially ripened regularly. Ripening process of banana can be divided into three stages: pre-climacteric stage, climacteric/ ripening stage and lastly ripe and senescence stage (Maduwanthi and Marapana, 2017; Robinson and Saúco, 2010). During ripening process of banana, bananas undergo a set of biochemical and physical changes that lead to a soft and edible ripe fruit.

2.1.2(a) Changes in physical properties of banana

Textural change is very important and a major event in fruit ripening. According to few studies, there are dramatic changes occur in banana peel colour and pulp texture during the rise in respiration during storage of climacteric fruit as shown in Table 2.3 and Figure 2.5. Skin colour changes from green to yellow, firmness is decreased and fruit gets softened (Adi *et al*., 2019; Karim *et al*., 2018; Mba *et al*., 2013; Tapre and Jain, 2012). Banana normally exhibit fruit softening mainly due to depolymerisation and solubilisation of cell wall components and loss of cell structure. Change in turgor pressure and degradation of cell wall polysaccharides and enzymatic degradation of starch are determinant mechanisms of fruit ripening (Adane *et al*., 2015; Li *et al*., 2010). According to Maduwanthi and Marapana (2017), the compounds responsible for the changes in peel colour are chlorophyll and carotenoids. As banana ripens, chlorophyll content decreases and become absent in ripe fruit (Moser *et al*., 2012). At the same time, the level of total carotenoids decrease to half the level at the colour break and subsequently again reached a level similar to that in green banana (Aquino *et al*., 2018). Mainly colour changes in banana during ripening are based on the peel colour rather than the pulp colour. Hence, colour of banana peel has been used in the assessment of the stages of ripeness of banana (Karim *et al*., 2018; Sogo-Temi *et al*., 2014).

The physical and mechanical properties of banana fruit and changes in these parameters during different ripening stages is important attributes to design handling, sorting, peeling, processing and packaging system. Knowing these properties of agricultural products would help engineers to prepare the machine's unit properly to protect fruits from bruises, injuries and other defects that emanate as results of post-harvest processing treatments.

Table 2.3 Description of banana ripening stages

Maturity index	**Storage day**	**Ripening stage**	**Peel colour**	**Observation**
I	1	Mature	All peels are green	Hard, rigid
II	3	Early ripening	Green peel with a trace of yellow	Slightly bend, ripening started
III	6	Intermediate ripening	More green area than yellow	
IV	8		Yellow with green hint	
V	9	Ripe	All yellow colour	Peel readily, pulp firm, aromatic
VI	11	Fully ripe	All yellow with brown speckles	
VII	13	Overripe	Yellow with increasing brown areas	Pulp soft and darkening, highly aromatic

Modified from Mba *et al*. (2013) and Karim *et al*. (2018)

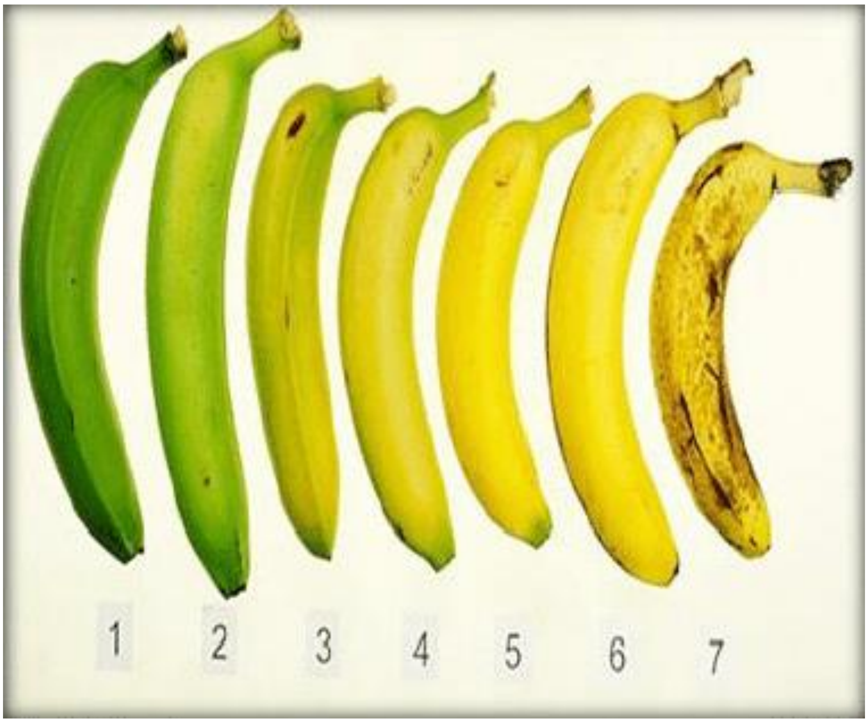

Figure 2.5 Ripening stages of banana (Madan *et al*., 2014)

2.1.2(b) Changes in chemical compositions of banana

The effects ripening on the chemical composition of banana at different levels of ripening stages have been studied by various researchers. The results showed that the chemical composition of banana pulp was diversely affected by ripening as shown in Table 2.4. Moisture content is an important characteristic as it affects the consumers' acceptability of the fruit. The moisture content of banana was reported to increase significantly during ripening (Yap *et al*., 2017; Tapre and Jain, 2012). The increment of moisture content is mainly due to breakdown of carbohydrate within the fruit and moisture migrated from peel to pulp which also explains the softening of banana pulp as ripening proceeds (Mohapatra *et al*., 2010; Sakyi-Dawson *et al*., 2008).

A few studies reported a significant decrease in ash content with increase in banana maturity (Yap *et al*., 2017; Khawas *et al*., 2014; Adeyemi and Oladiji, 2009).

The variation in ash content may be due to differential absorption capacity of minerals at different stages of development (Adeyemi and Oladiji, 2009). Changes in mineral composition varied and were not consistent with the stages of ripeness. Study by Adeyemi and Oladiji (2009) reported an increase in zinc and manganese content until they reached a peak at the ripe stage and decreased afterward meanwhile a constant decline was shown in magnesium content as banana ripen. The decrease in magnesium level could be due to the conversion of chlorophyll (green pigment) in unripe banana to carotenoids (yellow colour characteristic) in ripe banana. It forms a non-enzymatic covalent bonding with chlorophyll thus its conversion to carotenoids (Toma *et al*., 2018). Magnesium is an important component of chlorophyll thus is higher in unripe banana (Adeyemi and Oladiji, 2009). In contrast, the concentration of magnesium and potassium was shown to increase as ripening occurred by Yap *et al*., (2017). Such variations could be because of different varieties of banana used and its growing condition (Yap *et al*., 2017).

Fat content was very low in unripe banana but appeared subsequently in ripe banana. Meanwhile, protein content of banana was also quite low with only 3% detected and did not markedly change during ripening (Chaipai *et al*., 2018; Robinson and Sauco, 2011).

The most prominent chemical change that occurs during ripening of banana is the hydrolysis of starch and the accumulation of sugars (glucose, fructose and sucrose) which are responsible for the sweetening of the fruit as the ripening progress has been reported by various studies. As banana ripen, starch content was shown to reduce gradually while total sugar content was observed to increase tenfold from stage 1 to stage 7 (Chaipai *et al*., 2018; Toma *et al*., 2018; Maduwanthi *et al*., 2017;

Yap *et al*., 2017; Zulkifli *et al*., 2016). Fructose content was found to be the lowest in unripe banana but was the dominant sugar in overripe banana followed by glucose and lastly sucrose (Yap *et al*., 2017). According to Xiao *et al* (2018), the conversion of starch-to-sugars during banana ripening is associated with the transformation of inedible-to-edible. The decline of starch content is explained by the degradation of starch and the formation of free sugars through enzymatic breakdown process. A study by Chaipai *et al*., (2018) found that the starch in unripe stage is resistant to enzymes. This is because the starch granule in unripe banana is generally tightly packed in a radial pattern and is dehydrated thus limits the accessibility of digestive enzymes. As ripening proceed, the starch granule is rehydrated by the increment of moisture content which loosens the compact structure of starch and therefore became less resistant.

Increase in solubility of pectin polysaccharides is also one of the major changes happens during banana ripening. Several studies have claimed that the total dietary fibre (TDF) was shown to increase significantly with the progress of maturity (Chaipai *et al*., 2018; Maduwanthi and Marapana, 2017; Khawas *et al*., 2014). The increase in DF content at ripe stage over unripe stage is most possibly due to increase in soluble fibre pectin which responsible for the softening of banana pulp. The increase of soluble pectin along with softening of banana pulp is related with pectin degradation of insoluble protopectin to soluble pectin by pectic enzymes (Maduwanthi and Marapana, 2017; Emaga *et al*., 2008). According to Chaipai *et al*. (2018), the cell wall of the unripe banana is more compact due to the pectin molecules being tightly bound in the cell wall, which contribute to the firmness of the fruit.

There are variations in pH and total soluble solids (TSS) at the different ripening stages of banana. Most of the studies indicated pH value of banana is inversely proportional to the banana ripeness (Adi *et al*., 2019; Toma *et al*., 2018; Zulkifli *et al*., 2016). The high pH at unripe stage which then reduced as banana ripens was a result of high organic acid contents in the fruit (Adi *et al*., 2018).The changes in banana acidity are mainly caused by the changes in malic acid, citric acid and oxalic acid during ripening process (Etienne *et al*., 2014). Besides that, a significant different of banana pH was observed by Mohapatra *et al*., (2016) and result showed that pH value could also be affected due to the conversion of starch to sugar in banana. Meanwhile, TSS reflects the sugar concentration in banana fruit, the changes in TSS content in ripe banana were found to be significant (Adi *et al*., 2019; Toma *et al*., 2018; Yap *et al*., 2017; Zulkifli *et al*., 2016). Moreover, the increment of TSS can be used as an indicator to relate the conversion of starch into sugar for banana (Tapre and Jain, 2012).

The stages of ripening of banana play an important role in physical, chemical and functional properties of the fruit. By understanding the physicochemical changes of banana ripening can forms the basis for expanding the utilization of bananas.

Table 2.4 Chemical compositions of banana at different ripening stages

Parameter (g/100g)	Ripeness stage 1	2	3	4	5	6	7
Energy	388.64 ±0.13		387.02 ±0.06	386.79 ±0.06	388.46 ±0.63	387.92 ±0.49	388.80 ±0.19
Moisture	76.13 ±0.06	76.72 ±0.16	77.3 ±0.13	78.3 ±0.17	79.28 ±0.09	82.61 ±0.08	86.22 ±0.08
Protein	3.08 ±0.04		3.04 ±0.08	3.07 ±0.06	3.37 ±0.13	3.27 ±0.05	3.28 ±0.12
Fat	n/a	n/a	0.27 ±0.11	0.15 ±0.07		0.22 ±0.01	
TDF	6.47 ±0.03		7.47 ±0.16	6.38 ±0.07	7.75 ±0.04	7.83 ±0.05	8.80 ±0.12
Starch	2.80 ±0.20	1.50 ±0.91	1.64 ±0.55	1.59 ±0.28	1.76 ±0.51	1.66 ±0.14	0.91 ±0.05
Total sugar	1.26 ±0.31	2.69 ±0.55	4.01 ±0.68	3.99 ±0.73	5.17 ±5.37	5.37 ±0.37	12.28 ±2.03
Glucose	0.59 ±0.19	1.16 ±0.42	1.54 ±0.25	2.04 ±0.44	2.26 ±0.30	2.24 ±0.14	3.33 ±0.53
Fructose	0.23 ±0.13	0.79 ±0.21	1.03 ±0.17	1.16 ±0.06	1.44 ±0.20	1.48 ±0.05	7.10 ±0.85
Sucrose	0.44 ±0.12	0.75 ±0.12	0.80 ±0.36	1.44 ±1.04	1.47 ±0.48	1.66 ±0.44	1.86 ±0.71
Ash	4.198 ±0.24	4.081 ±0.06	4.071 ±0.08	3.831 ±0.08	3.404 ±0.01	3.307 ±0.14	3.173 ±0.11
Potassium (mg/100g)	421.81 ±75.1	501.88 ±21.9	528.36 ±8.15	565.15 ±53.4	583.74 ±70.7	630.04 ±94.2	708.81 ±56.9
Magnesium (mg/100g)	36.26 ±2.94	40.32 ±7.1	40.90 ±9.43	48.78 ±3.96	57.66 ±4.02	58.75 ±2.16	59.45 ±8.58
pH	6.18 ±0.06	6.03 ±0.04	5.97 ±0.05	5.14 ±0.01	5.14 ±0.02	5.07 ±0.04	4.82 ±0.08
TSS	12.9 ±0.5	14.1 ±0.4	17.3 ±0.2	18.4 ±0.1	19.2 ±0.3	20.0 ±0.4	21.6 ±0.8
Titratable acidity							
Citric acid	2.34 ±0.02	2.27 ±0.13	2.19 ±0.04	2.24 ±0.03	2.01 ±0.04	1.65 ±0.08	1.48 ±0.04
Malic acid	2.24 ±0.02	2.17 ±0.13	2.10 ±0.04	2.14 ±0.03	1.92 ±0.03	1.57 ±0.07	1.41 ±0.04

Adopted from Adi *et al*. (2019), Chaipai *et al*. (2018) and Yap *et al*. (2017)

2.1.3 The potential health effects of banana

Banana is a ready-to-eat and affordable fruit for human consumption, which works to build good health due to its immense nutritional and medicinal value. Table 2.5 shows the list of potential health effects of banana.

Table 2.5 Potential health effects of banana

Health effect	Explanation	References
Reduce risk of high blood pressure	Banana contains high amount of potassium which is an essential mineral for maintaining normal blood pressure and heart function. Furthermore, potassium also helps to maintain normal fluid and electrolyte balances in the cell.	Olvera-Hernández *et al*. (2018); Dayanand *et al*. (2015); D'Elia *et al*. (2014);
Cardiovascular protection	Potassium-rich fruit like banana was found to able to lower the risk of stroke. A number of studies have demonstrated the ability of banana to maintain normal blood pressure and heart function.	Hjartåker *et al*. (2015); Cressey *et al*. (2014)
Restore normal bowel activity	Banana is rich in DF (insoluble and soluble fibre) which can help to restore normal bowel activity and help to prevent both constipation and diarrhea. The soluble fibre especially pectin can normalize the colon's function by absorbing large amount of water and provide bulk producing ability. Banana is also a rich source of prebiotic (fructooligosaccharide). The beneficial bacteria do not just nourish probiotic bacteria in the colon but also produce vitamins and digestive enzymes that improve body's ability to absorb nutrients.	Cassettari *et al*. (2019); Bae (2014); Wang *et al*. (2014)
Protection from ulcers and heartburn	The antacid effects of bananas have been recognized to protect against stomach ulcers damage. Leucocyanidin, a flavonoid in banana, has been reported to increase the thickness of the mucous membrane layer of the stomach. Banana can help to neutralize acidity thus able to prevent heartburn. A simple mixture of banana and milk was found to significantly supressed acid secretion in an animal study.	Ali *et al*. (2018); Rafa Zubair *et al*. (2018);

Protection against neurodegenerative diseases (Alzheimer's disease)	The effect of banana extracts on neuron cells was investigated and found that the phenolic phytochemicals prevented neurotoxicity on the cells. The results indicated banana in our daily diet may protect neuron cells against oxidative stress-induced neurotoxicity and have the potential to reduce the risk of neurodegenerative disorders such as Alzheimer's disease. Moreover, ripe banana contains carotenoid which has been shown to have beneficial effects on neurodegenerative diseases. Several results obtained from animal and cell culture model studies have linked the consumption of carotenoid-rich food with decreased risk of neurodegenerative diseases.	Honarvar *et al*. (2017); Kesse-Guyot *et al*. (2014); Heo *et al*. (2008)
Lower cholesterol	The effect of DF and polyphenol properties of banana on serum cholesterol in rats fed with cholesterol enriched diet was studied. The results reported a decline in body weight and serum total cholesterol. Banana is also rich in unsaturated fatty acid, vitamin E, total saponin and flavonoids which may regulate the lipid metabolism.	Dikshit *et al*. (2016); Liyanage *et al*. (2016); Liyanage *et al*. (2015)
Regulate blood glucose level	Banana contains high amount of DF and amylase-resistant starch which slow down carbohydrate absorption in the body and prolong feeling of fullness thus prevent sharp increase of blood glucose level. A few studies compared few varieties of banana and found that most banana exhibit low glycaemic index value and suggested that banana may be a snack for both healthy or diabetic patient who are under dietary management.	Olvera-Hernández *et al*. (2018); Adedayo *et al*. (2016); Cressey *et al*. (2014)
Kidney health	The high potassium content in banana can improve overall functional efficiency of kidneys. Potassium intake can suppress excretion of calcium in the urine and reduce the risk of kidney stones. A prospective study on Swedish population showed that the population consume more than 75 servings of fruits and vegetables per month minimize their risk of kidney cancer by 40%. Among the fruits, banana was shown to be the most protective. Furthermore, eating bananas four	Silva *et al*. (2016); Mosa and Khalil (2015); Rashidkhani *et al*. (2005)