DIETARY FIBRE-RICH OYSTER MUSHROOM (*PLEUROTUS SAJOR-CAJU*) POWDER AS FOOD INGREDIENT AND ITS APPLICATION IN DEVELOPING LOW-GLYCAEMIC BISCUIT

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by

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LIST OF SYMBOLS AND ABBREVIATIONS

µg	microgram
µl	microlitre
µm	micrometre
× *g*	times gravity
AACC	American Association of Cereal Chemist
ACN – H_2O	Acetonitril-deionised water
AF	Atta flour
ANOVA	analysis of variance
AOAC	Association of Official Analytical Chemists
ARASC	Animal Research and Service Centre
a_w	water activity
BA	barley flour
BG	blood glucose
BMI	body mass index
β	beta
CFU	colony forming unit
CHO	carbohydrate
CIELab	Commission International de l'Eclairge Lab
cal/g	calorie per gram
DF	dietary fibre
DBP	diastolic blood pressure
DM	diabetes mellitus
DSC	differential scanning calorimeter
EA	emulsifying activity
ELSD	Evaporating Light Scattering Detector
FAO	Food and Agriculture Organization
FBG	fasting blood glucose
FFC	Functional Food Center
FSG	free sugar glucose

GDRI	glucose dialysis retardation index
GI	glycaemic index
GOPOD	glucose oxidase/ peroxidase
g	gram
HDL	high-density lipoprotein
$HbA1_c$	glycosylated haemoglobin
HPLC	High Pressure Liquid Chromatography
hr	hour
ICC	International Association for Cereal Chemistry
IDF	insoluble dietary fibre
iAUC	incremental area under curve
kcal/100 g	kilocalorie per one hundred gram
kg	kilogram
LDL	low-density lipoprotein
M	molar
MRD	maximum recovery diluent
mM	millimolar
mg	milligram
min	minute
ml	millilitre
mmol/l	millimole per litre
mm/s	millimetre per second
nm	nanometre
OA	oat flour
OHC	oil holding capacity
PSC	*Pleurotus sajor-caju*
PSCE	*Pleurotus sajor-caju* aqueous extract
RAG	rapidly available glucose
RDS	rapidly digestible starch
RS	resistant starch
RVA	Rapid Visco Analyser

rpm	revolutions per minute
SAG	slowly available glucose
SBP	systolic blood pressure
SD	standard deviation
SDF	soluble dietary fibre
SDS	slowly digestible starch
SEM	scanning electron microscope
SPSS	Statistical Package for the Social Sciences
STZ	Streptozotocin
SWC	swelling capacity
TDF	total dietary fibre
TG	total glucose
TPA	texture profile analysis
TPC	total plate count
TS	total starch
USM	Universiti Sains Malaysia
UV/VIS	ultraviolet/visible
WHO	World Health Organization
WHC	water holding capacity
w/v	weight per volume
YMC	yeast and mould count

SERBUK CENDAWAN TIRAM *(PLEUROTUS SAJOR-CAJU*) YANG TINGGI SERAT DIETARI SEBAGAI RAMUAN MAKANAN DAN APLIKASINYA DALAM PENGHASILAN BISKUT RENDAH GLISEMIK

ABSTRAK

Permintaan pengguna bagi makanan berfungsi semakin meningkat disebabkan pravalens penyakit tidak berjangkit yang tinggi. Cendawan tiram kelabu (*Pleurotus sajor-caju*, PSC) yang ditanam secara meluas di Malaysia mempunyai pelbagai ciri perubatan tetapi kurang perhatian terhadap fungsi fisiologinya yang berkaitan dengan diabetes dan aplikasinya dalam penghasilan makanan berfungsi. Justeru itu, kajian ini bertujuan untuk menentukan nilai pemakanan, ciri berfungsi, kestabilan penyimpanan, kesan hipoglisemia *in vitro* dan *in vitro* serbuk PSC serta aplikasinya dalam penghasilan biskut indeks glisemik yang rendah (*Glycaemic Index*, GI). Kesan serbuk PSC sebagai pengganti tepung gandum (0, 4, 8 dan 12%) dalam biskut terhadap ciri pemakanan, fizikokimia, tekstur dan sensori serta GI telah dikaji. Hasil kajian menunjukkan bahawa serbuk PSC mengandungi jumlah protein (22.41%), abu (7.79%), serat dietari (*dietary fibre*, DF) (56.99%) dan β-glukan (3.32%) yang tinggi tetapi jumlah sukrosa (0.19%) dan lemak (2.30%) yang rendah. Ia juga mempunyai kapasiti memegang air (13.46 g/g), kapasiti memegang minyak (8.52 ml/g), kapasiti membengkak (19.49 ml/g) dan aktiviti mengemulsi (51.67%). Kajian penyimpanan menunjukkkan bahawa serbuk PSC mempamerkan nilai kolorimetri L* yang rendah secara signifikan sementara tiada perubahan dalam kandungan mikrob dengan peningkatan suhu dan tempoh penyimpanan. Mekanisme serbuk PSC untuk menyebabkan kesan hipoglisemia *in vitro* adalah melalui penjerapan glukosa, perencatan peresapan glukosa merentasi membran dialisis dan

kelewatan pelepasan glukosa daripada kanji dengan perencatan aktiviti α-amilase. Potensi hipoglisemia serbuk PSC adalah lebih tinggi daripada serbuk oat, barli dan atta. Selain itu, ekstrak akues PSC (*PSC aqueous extract*, PSCE) menunjukkan penurunan glukosa dalam darah (*blood glucose*, BG) dan penambahbaikan toleransi kepada glukosa dengan ketara dalam tikus biasa dan tikus diabetes yang diaruh oleh streptozotocin (STZ). PSCE pada 750 mg/kg telah dikenalpasti sebagai dos efektif yang optimum dan kesannya adalah setanding dengan metformin (150 mg/kg). Dalam kajian selama 21 hari, BG, berat badan dan glukosa dalam air kencing dalam tikus diabetes yang dirawat dengan PSCE telah dilaporkan menunjukkan penambahbaikan yang ketara berbanding dengan tikus diabetes kawalan. Penambahan serbuk PSC dalam biskut menyebabkan peningkatan nilai pemakanan terutamanya DF, gangguan struktur dan pengecilan diameter granul kanji, pengurangan kelikatan pes, pengurangan entalpi penggelatinan kanji, peningkatan nisbah kanji yang lambat dihadam dan akhirnya pengurangan GI biskut. Penambahan 8% serbuk PSC adalah formulasi yang terbaik dalam penghasilan biskut berfungsi yang rendah GI (GI=49), tinggi serat dietari (8.62%) dan diterima ramai. Oleh itu, serbuk PSC boleh digunakan sebagai ramuan makanan dan dalam penghasilan biskut rendah GI.

DIETARY FIBRE-RICH OYSTER MUSHROOM (*PLEUROTUS SAJOR-CAJU*) POWDER AS FOOD INGREDIENT AND ITS APPLICATION IN DEVELOPING LOW-GLYCAEMIC BISCUIT

ABSTRACT

Consumer's demand for functional food is increasing due to high prevalence of non communicable diseases. Grey oyster mushroom (*Pleurotus sajor-caju*, PSC) which cultivated widely in Malaysia possesses various medicinal properties but lack of attention on its diabetes-related physiological function and its application in functional food development. Hence, this study aimed to determine the nutritional values, functional properties, storage stability, *in vitro* and *in vivo* hypoglycaemic effects of PSC powder as well as its application in developing low-glycaemic index (low-GI) biscuit. The effects of PSC powder as wheat flour replacer (0, 4, 8 and 12%) in biscuit on nutritional, physicochemical, textural and sensorial properties as well as GI were examined. Results showed that PSC powder contained appreciable amounts of protein (22.41%), ash (7.79%), dietary fibre (DF) (56.99%) and β-glucan (3.32%) but negligible amounts of sucrose (0.19%) and fat (2.30%). It also featured water holding capacity (13.46 g/g), oil holding capacity (8.52 ml/g), swelling capacity (19.49 ml/g) and emulsifying activity (51.67%). Storage study revealed that PSC powder exhibited significant lower L* colorimetric value meanwhile microbial counts remained unchanged with increasing storage temperature and duration. The mechanisms of PSC powder to elicit the *in vitro* hypoglycaemic effects were through glucose adsorption, retardation of glucose diffusion across dialysis membrane and delayed glucose release from starch by inhibition of α-amylase activity. The hypoglycaemic potentials of PSC powder were higher than oat, barley and atta flour. In addition, PSC aqueous extract (PSCE) demonstrated significant blood glucose (BG) reduction and glucose tolerance improvement in normal and streptozotocin (STZ)-induced diabetic rats. The PSCE at 750 mg/kg was identified as the optimum effective dose and its effects were comparable to metformin (150 mg/kg). In 21-days study, BG, body weight and urine sugar in PSCE-treated diabetic rats were reported significant improvement compared to control diabetic rats. PSC powder incorporation in biscuit resulted in increased nutritional values particularly DF, disturbed structure and reduced diameter of starch granules, reduced pasting viscosity, reduced enthalpy of starch gelatinisation, increased proportion of slowly digestible starch and eventually reduced GI of biscuit. The addition of 8% PSC powder is the best formulation in developing low-GI (GI=49), high TDF (8.62%) and well-accepted functional biscuit. Therefore, PSC powder can be used as a food ingredient and in development of low-GI biscuit.

CHAPTER 1

INTRODUCTION

1.1 Background and Problem Statements

Presently, the incidences of chronic diseases are increasing at an alarming rate and becoming a major health issue in Malaysia and all over the world. Chronic diseases are diseases of slow progression and generally long duration (WHO, 2011). Chronic diseases such as stroke, heart disease, chronic respiratory diseases, cancer and diabetes mellitus (DM) are undoubtedly the leading cause of mortality in the world. Habib and Saha (2011) indicated that total deaths from the chronic diseases are forecasted to increase by 17% over the next ten years. Among all of the chronic diseases, DM is now a major global public health concern. As reported by International Diabetes Institute, Malaysia has been documented to have the fourth highest number of DM in Asia (Hasimah *et al*., 2014). The latest National Health and Morbidity Survey (NHMS, 2015) revealed that 3.5 million (17.5%) of Malaysians adult (18 years old and above) are suffering from DM.

Functional foods-based diet has been proposed as a comprehensive dietary approach in the prevention and control of DM in recent years. Over the last decade, the physiochemical properties of the dietary fibre (DF) as bioactive compound in functional foods are being paid attention in food research related to DM. DF is described as 'the consumable parts of plants or analogous carbohydrate (CHO) which resist to digestion and absorption in the small intestine of human with complete or partial fermentation in the large intestine' (AACC, 2001; Westernbrink *et al*., 2012). DF is of presently gaining significant importance owning to its close relationship with the reduced risk of many chronic diseases particularly type 2 DM by decreasing glycaemic response (Iwana, 2009; Kaczmarczyk *et al*., 2012).

Apart from that, foods containing high DF have been shown to have reduced glycaemic index (GI) (Marangoni and Poli, 2008). The GI is the ranking of different dietary CHO-rich foods depending on their ability to increase blood glucose (BG) levels in comparison to a reference food such as white bread and glucose (Atkinson *et al*., 2008). It is a measure of how high and how fast the BG rises, and how speedily the body responds by bringing back to normal after ingestion of food (Whitney *et al*., 1990). Researches have shown that diets with low-GI reduce the risk of developing DM, by improving the BG control (Rizkalla, 2004), increasing insulin sensitivity (Rizkalla, 2004) and controlling of body weight (McMillan, 2006).

The consumer demand for DF-enriched food products with low GI has increased as consumers seek to improve their health status and prevent DM. However, there is lack of GI information on food products and low-GI food which formulated with DF in the market. Therefore, it is necessary for food research and the food industry to work together for the mission of improving food product quality to meet consumer demands for diabetes-related functional foods (Ballali and Lanciai, 2012). Products used to elevate the DF content of foods traditionally come from cereals, legumes (McKee and Latner, 2000) and fruit processing by-products such as apple, grape and pineapple pomace (Sudha *et al*., 2007b; Yu and Ahmedna, 2013; Chareonthaikij *et al*., 2016). DF materials derived from vegetables and fruits have been gradually innovated in the world markets due to their better nutritional qualities (Chau and Huang, 2003).

Pleurotus sajor-caju (PSC) or universally known as grey oyster mushroom is acknowledged to be one of the great sources of DF (35.60% in oven-dried form) (Wan Rosli and Aishah, 2012; Kanagasabapathy *et al*., 2013). This prominent edible mushroom is featured by a gill attachment, white spore print, and often with an eccentric stip, or no stip at all (Miles and Chang, 1997). By incorporating locally-cultivated PSC as DF source into food products, it is believed to reduce nation's importation bill of DF items and reduce production cost of food products. The medicinal properties of PSC include lowering the blood pressure, strengthening the immune system against diseases including the viral ones, reducing the blood cholesterol level, combating the tumours and improving the liver function (Shah *et al*., 2007). Nevertheless, there is lack of scientific research evidenced on its hypoglycaemic and antidiabetic effects.

According to Tey *et al*. (2008) and FAOSTAT (2016), Malaysian's food consumption pattern has shifted towards wheat-based bakery products as replacer to the staple rice. Biscuit is one of the well-known wheat-based bakery products, widely consumed primarily due to their pleasant taste, affordable cost, high availability, ready to eat nature and longer shelf life (Sudha *et al*., 2007a). According to the findings from Malaysian Adult Nutrition Survey (MANS), biscuit is in the top 10 lists of daily consumed food among Malaysians (Norimah *et al*., 2008). Hence, biscuit could be an effective carrier of nutrients and utilised as a source for addition of various nutritionally rich ingredients for their diversification (Nandeesh *et al*., 2011). Nevertheless, biscuits in market are mostly high in fat and sugar content as well as lack of DF content.

Previously, researches have been conducted on the application of PSC powder as a source of DF in wheat-based products and meat-based products (Wan Rosli *et al*., 2011b; Wan Rosli and Aishah, 2012), but there is no data regarding the GI value on the food products. Therefore, the development of biscuits formulated with PSC powder (to partially replace wheat flour) with the intention of enhancing its DF content as well as lowering its GI was studied. Since wheat flour is the major ingredient in biscuit formulation, replacing it with other food component might affect the appearance, dimensions, colour, texture and palatibility of the finished products. Therefore, the textural, colour and sensory properties of finished products were also investigated in this research to determine the most accepted incorporation level of PSC powder. In addition, due to the fact that DF polysaccharides are complex and their physical properties and physiological functions might vary in the gastrointestinal tract, so the quality characteristics as well as the hypoglycaemic effects *in vitro* and *in vivo* of PSC powder were also determined.

1.2 Rationale and Significance of the Study

Diabetes has been a subject of expanded research; however the control and prevention of this disease have not been resolved. Diet has been demonstrated to play an essential role in the prevention and management of DM. Foods which are high in DF such as fruits and vegetables are shown to give the protective effects against DM. Nevertheless, populations in this competitive society tend to engage actively in their career until consuming fresh fruit and vegetables at optimal level becomes difficult to fulfil. On the contrary, they prefer to choose alternative DF source especially bakery products with DF enrichment. Therefore, development of functional food particularly DF-enriched bakery products is necessary in the food research and food industry to combat Malaysia's diabetes crisis.

Biscuit is a popular (top 10) daily consumed food among Malaysians because it is available, affordable and convenience to eat. However, in the market, there are full of processed biscuits which are unhealthy or lacking of natural nutrients such as DF that diminished during the refining process, resulted in low content of DF and high level of GI. Apart from that, biscuits are usually added with large amount of fat and sugar to produce smoother and tastier biscuits. There is a continuous worrying trend of developing food products which are appealing to the taste but neglecting the health issue. As a consequence, greater numbers of people are diagnosed with chronic illnesses. By incorporating DF-rich food ingredients into biscuit, consumers obtain greater chance to have healthy food items in their daily food choice.

There are certainly a number of high-DF biscuits formulated with wheat, oat and bran available in the market. However, these DF-rich food ingredients which are imported from other countries could increase the nation's importation bill and cause increment in the production cost as well as selling price of biscuits. Hence, it is needed to utilise locally available high-DF food ingredient to replace wheat and oat in the biscuit formulations, at the same time could increase variability of DF food ingredient.

Pleurotus sajor-caju (PSC) is an excellent grey oyster mushroom successfully cultivated and is gaining popularity in Malaysia due to the high relative humidity and climatic condition which are suitable for the growth of this mushroom. Due to the fact that oyster mushroom can be easily cultivated on decayed organic materials, its cultivation is a profitable agribusiness. In addition, it requires only a shorter growth time (within one to three days) (Patrabansh and Madan, 1997).

In addition, previous research has demonstrated that its dried form contains high DF and β-glucan (Wan Rosli and Aishah, 2012). Hence, it could be used to replace wheat flour as DF source in biscuit development to reduce nation's importation bill of DF ingredients and its production cost. PSC which contains high DF and β-glucan is believed to have anti-diabetic properties and have the potential to develop low-GI biscuits.

Pleurotus sajor-caju has been reported to have beneficial effects in immune function, hypertension, hypercholesterolemia and cancer (Shah *et al*., 2007). However, there is lack of research in determining its hypoglycaemic and antidiabetic effects. So, *in vitro* and *in vivo* hypoglycaemic effects of PSC are necessary to be done. In addition, quality characteristics of PSC powder such as nutritional values, functional properties and storage stability are also needed to report in this research to evaluate its potential in food application. In order to develop well-acceptance functional biscuit, GI value, nutritional values, physicochemical properties and sensorial properties of biscuit incorporated with PSC powder as partial replacement for wheat flour are essential to be determined. By knowing the low-GI value of the biscuit, diabetic individuals as well as general populations will be aware of the importance of low-GI concept and could use it as a tool to plan their diet appropriately.

1.3 Research Objectives

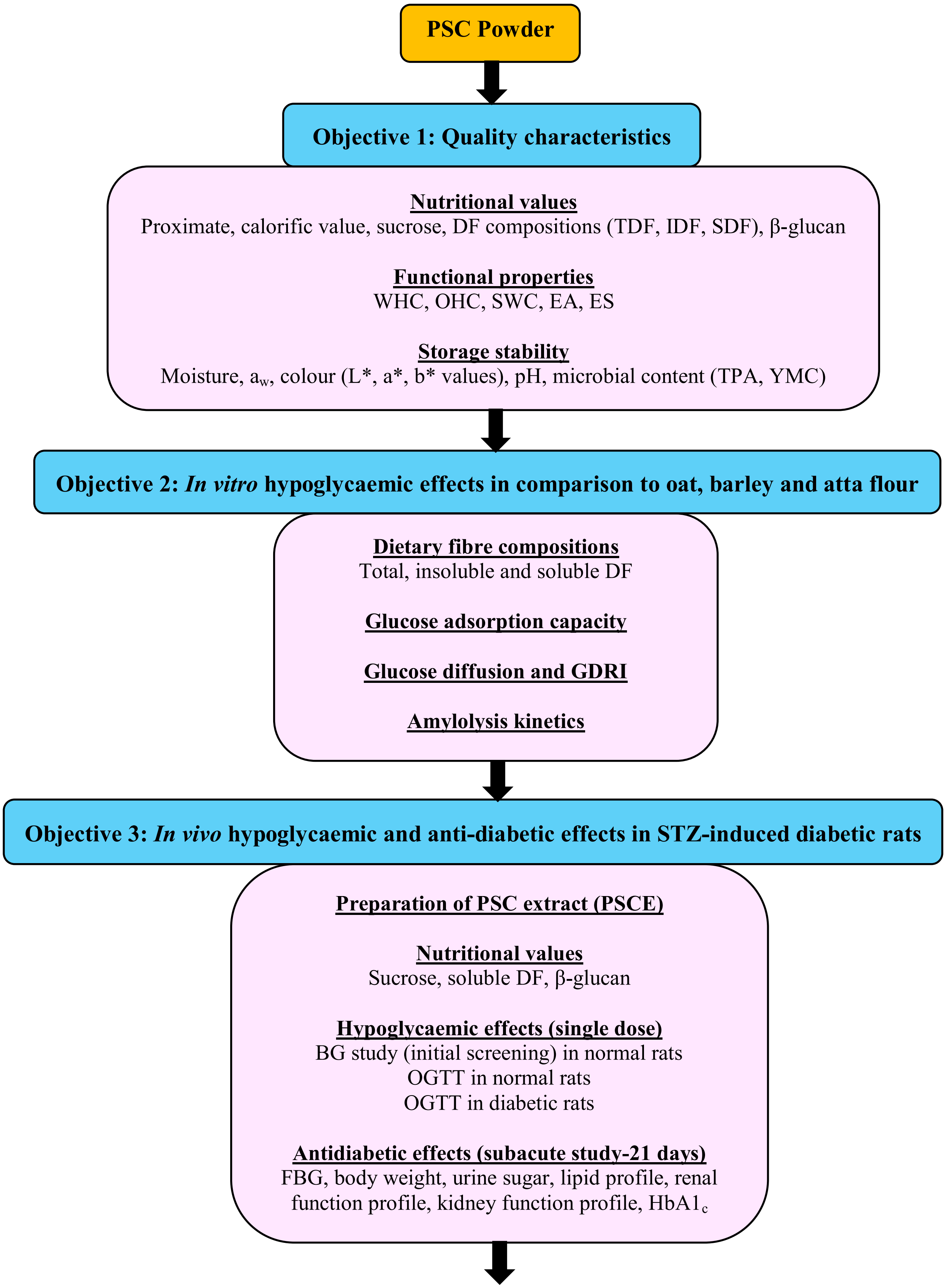
1.3.1 General Objectives

To analyse nutritional values and hypoglycaemic effects of PSC as well as its application in developing low-GI biscuit

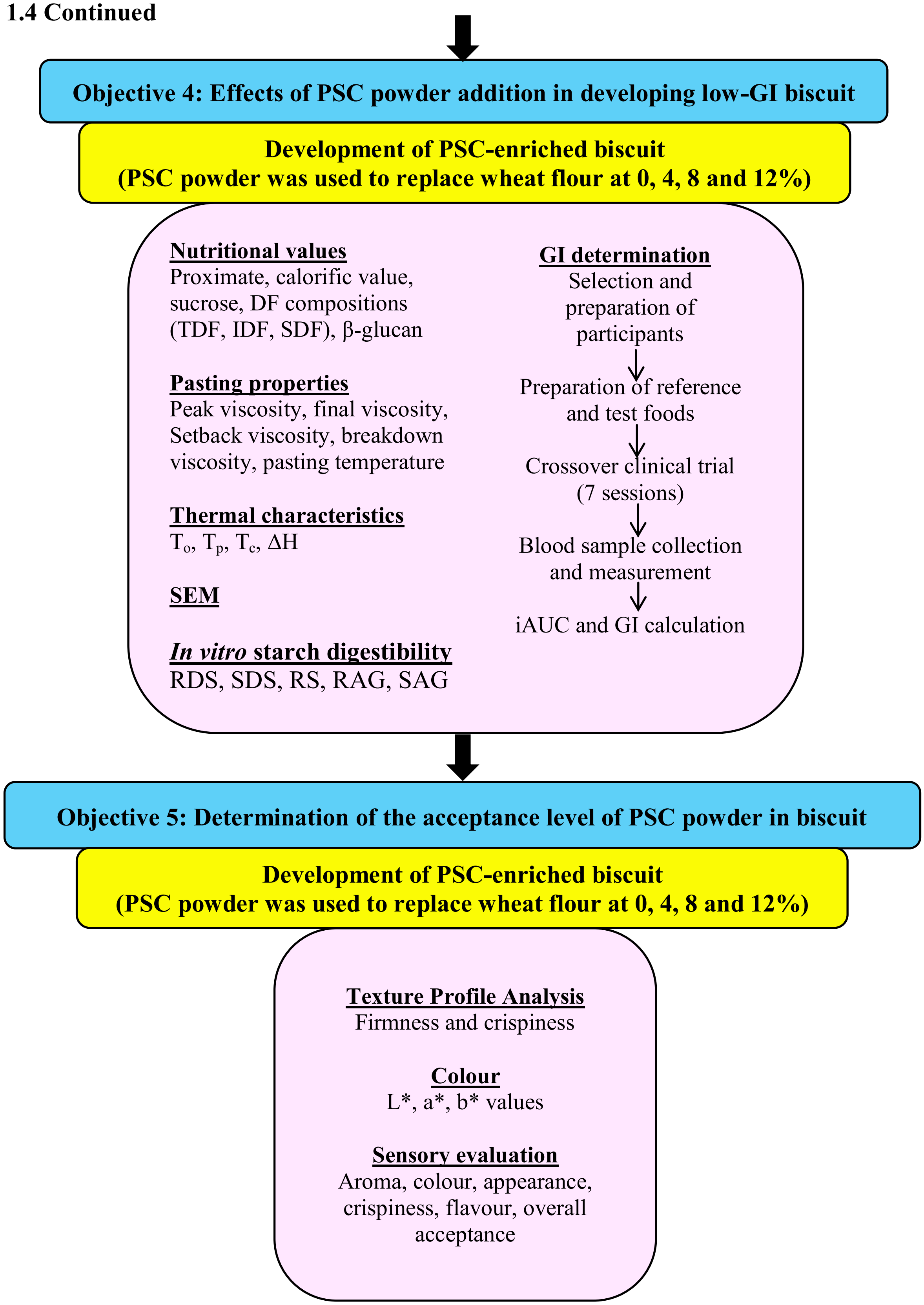
1.3.2 Specific Objectives

1. To measure quality characteristics including nutritional values, functional properties and storage stability of PSC powder.
2. To analyse the *in vitro* hypoglycaemic effects (glucose adsorption capacity, glucose diffusion and amylolysis kinetics) of PSC powder in comparison to oat, barley and atta flour.
3. To analyse the *in vivo* hypoglycaemic and antidiabetic effects of PSC aqueous extract (PSCE) in streptozotocin (STZ)-induced diabetic rats.
4. To examine the incorporation effects of different levels of PSC powder as partial replacement for wheat flour on nutritional values, pasting properties, thermal characteristics, starch granules morphology, *in vitro* starch digestibility and *in vivo* GI of biscuits.
5. To determine the most accepted incorporation level of PSC powder as partial replacement for wheat flour by evaluating the textural, colour and sensorial properties of biscuit.

1.4 Research Flow Chart



1.4 Continued



CHAPTER 2

LITERATURE REVIEW

2.1 Functional Food

2.1.1 Definition and Types of Functional Food

Conforming to decades of scientific inquiry, it is recognised that diet can maintain health and affect the risk of developing several chronic diseases (WHO, 2003). Adequate attention has been paid to the physiological functions of foods in accordance to the raising concerns for health. Due to the facts that health-conscious consumers tend to aware on what they eat and drink, they have turned to natural food sources as daily dietary enhancers rather than artificial substances (Mollet and Rowland, 2002). The consolidation of advancement in food technology, consumer demands and latest evidence-based science linking diet to disease have initiated an unprecedented opportunity to handle public health problems through diet. A better informed Malaysians and widespread interest in selected foods have stimulated emergence of various health-promoting products called functional foods (Stanton *et al*., 2011).

The term 'functional food' itself was initially introduced in Japan in the mid-1980s for food products, which are composed of specific physiologically-active components that influence the structure and/ or function of the body and are basically used to regulate or maintain specific health conditions (Siro *et al*., 2008). In 1991, the Japanese Ministry of Health and Welfare announced rules and regulations for approval of a specific health-related food category named FOSHU (Food for Specified Health Uses) (Arai, 2002). Ministry of Health Malaysia regulates the health claims established on foods and beverages through authority empowered in the Food Act of 1983 and the Malaysian Food Regulations of 1985; however there are no unique regulations for functional foods (Hassan and Mustapha, 2010).

There are several definitions for 'functional foods'. In Malaysia, functional food is generally described as 'a category of food which has health-enhancing effects. They are not chemicals, drugs or vitamins and also not prescribed by doctors or other formally qualified medical practitioners' (Hassan and Mustapha, 2010). In Europe, it is described as 'a food that is scientifically indicated to affect advantageously one or more target functions in the body, not only aimed to satisfy hunger and to supply essential nutrients necessary for normal maintenance, growth and development, but also relevant to either an improved health status and/or reduction of the risk of diseases. Functional foods are, or appears identical to a conventional food and not in the pill or capsule form. They must be a component of standard diet, which is consumed in normal quantities and on regular basis' (Roberfroid, 2000; Menrad, 2003).

However, there is not yet a universally accepted and official definition, possibly because it is a concept instead of a well-defined group of food products (Roberfroid, 2002). Therefore, in order to improve communication between the public, nutrition scientists and other parties as well as legitimise functional food science globally, functional food center (FFC) recently defines 'functional food' as natural or processed foods which contains known or unknown biologically-active compounds; the foods, in defined, effective, and non-toxic amounts, provide a clinically reported health benefit for the prevention, treatment or management of chronic diseases (Martirosyan and Singh, 2015).

The development of functional foods basically requires modern technology and different approaches. Siro *et al*. (2008) stated the prominent types of functional foods which include fortified products, enriched products, enhanced commodities and altered products (**Table 2.1**).

Table 2.1: Types of functional food

Types of functional food	Definition
Fortified products	A food fortified with additional nutrients
Enriched products	A food with added new nutrients or components not normally found in a particular food
Enhanced commodities	A food in which one of the components has been naturally enhanced through special growing conditions, new feed composition, genetic manipulation, or otherwise
Altered products	A food from which a deleterious component has been removed, reduced or replaced with another substance with beneficial effects

Source: Siro *et al*., 2008

2.1.2 Physiologically-Active Components

A quality of functional food mainly arises from contained a bioactive substance that stimulates metabolism (Jones, 2002). Advancement of science have allowed researchers to better describe the metabolism of food at the cellular level, feature the biological basis of disease states, discover the role of bioactive components in food and evaluate their impact on metabolic processes. Credible scientific research revealed that there are various potential and clinically reported health benefits of physiologically-active components. International Food Information Council (IFIC, 2011) revealed the physiologically-active food components and their potential health benefits (**Table 2.2)**.

Table 2.2: The physiologically-active food components, food sources and potential health benefits

Physiologically-active food components	Food sources	Health benefits
Carotenoids		
Beta-carotene	Carrot, pumpkin, tomato	Neutralises free radicals that may damage cells; strengthen cellular antioxidant defenses
Lutein, zeaxanthin	Broccoli, asparagus, eggs	Maintenance of healthy vision
Lycopene	Tomato, watermelon, red/pink grapefruit	Maintenance of prostate health
Fatty acids		
Monounsaturated fatty acids (MUFA)	Canola oil, olive oil, tree nuts	Reduces risk of coronary heart disease
Polyunsaturated fatty acids (PUFA): Omega-3 fatty acids-DHA/EPA	Fish oil, salmon, tuna	Reduce risk of coronary heart diseases; supports maintenance of eye health and mental function
Conjugated linoleic acid	Beef, lamb, some cheese	Maintenance of desired body composition and healthy immune function
Flavonoids		
Anthocyanins: cyanidin, malvidin	Berries, cherry, red grape	Strengthen cellular antioxidant defences; maintenance of healthy brain function
Flavanols: catechins, epicatechins	Apple, chocolate, tea	Maintenance of heart health

Table 2.2: Continued

Minerals		
Calcium	Sardines, spinach, milk	Reduce risk of osteoporosis
Potassium	Banana, bean, potato	Reduce risk of high blood pressure and stroke
Plant stanols/sterols		
Free stanols/sterols	Corn, soy, wheat	Reduces risk of coronary heart disease
Stanols/sterol esters	Fortified foods, beverages, table spread	Reduces risk of coronary heart disease
Prebiotics: inulin, fructo-oligosaccharides	Whole grains, garlic, honey	Support maintenance of digestive health and calcium absorption
Probiotics: yeast, *Lactobacilli*	Certain yogurts and cultured daily products	Support maintenance of digestive and immune health
Soy protein	Cheese, tofu, soybean	Reduce risk of coronary heart disease
Vitamins		
Folate	Bean, broccoli, lentils	Reduce risk of neural tube defects
Vitamin A	Organ meats, carrot, spinach	Support maintenance of eye, immune and bone health
Vitamin C	Citrus fruits, guava, kiwi,	Neutralises free radicals that may damage cells;

Source: International Food Information Council (IFIC, 2011)

Functional foods could be found virtually in all food categories. A variety of processed food products such as chocolate, infant milk formula, dairy products, health drinks and bakery products are effective carrier of physiologically-active components. Consumers can select from a wide spectrum of foods that match their dietary needs.

2.1.3 Functional Foods for Diabetes

Functional foods could be oftenly categorised according to the targeted populations or their health benefits (prevention of disease) (Wang and Li, 2014). For instance, there are functional foods for pregnancy, child growth, mental performance, cancer prevention, gastrointestinal health, body weight management, bone protection, cardiovascular disease prevention and DM prevention. In this context, functional foods for DM are focused.

Functional foods-based diet has been regarded as an effective dietary approach for prevention and control of DM in recent years. Researchers have paid attention on the characteristics of the bioactive components of functional foods in the management of various aspects of DM. Furthermore, certain protective effects of the food components and the food sources have been demonstrated *in vitro*, *in vivo* and in several clinical trials. The examples of the promising functional foods associated with DM prevention and management are presented in **Table 2.3**.

Table 2.3: The promising functional foods associated with DM prevention and management

Functional Food	Bioactive components	Beneficial effects	References
Water melon	Charantin, vicine	Insulin secretion; tissue glucose uptake; liver muscle glycogen synthesis	Yeh *et al*., 2003; Cheng *et al*., 2008
Fenugreek	Steroid saponin, soluble DF	Inhibit sodium-dependent intestinal glucose uptake; decrease intestinal disaccharidase activity and glucose absoprtion	Al-Habori *et al*, 2001; Hannan *et al*., 2007
Fish oil	Omega-3 fatty acids	Improve insulin sensitivity and reduce plasma glucose response; weight-loss improved HbA1c levels	Krebs *et al*., 2006; Waite *et al*., 2008
Ginseng	Ginsenosides (saponins)	Reduce glycaemic response; stimulate insulin biosynthesis	Ohnishi *et al*., 1996; Vuskan and Sievenpiper, 2005
Legumes and beans	α-amylase inhibitory peptide	Reduce digestion and absorption of dietary CHO; modulate postprandial glycaemic response	Helmstadter, 2010; Barrett and Udani, 2011

Table 2.3: Continued

Functional Food	Bioactive components	Beneficial effects	References
Mango	Carotenoids, gallic acid, quercetin	Inhibit α-amylase activity, increase glycogen synthesis, improve dyslipidemia, protect against diabetic nephropathy	Masibo and He, 2009; Lucas *et al*., 2011
Olive leaves	Oleuropein	Improve insulin secretion; reduce BG and cholesterol	Jemai *et al*., 2009; Cumaoglu *et al*., 2011
Stevia	Stevioside	Stimulate insulin secretion via direct action on β-cells; reduce postprandial BG	Jeppesen *et al*., 2000; Gregersen *et al*., 2004
Turmeric	Curcumin	Upregulation of adiponectin; activate pancreatic β-cell and enhance insulin release	Best *et al*., 2007; Aggarwal, 2010
Whole grains: oat, rye	Inulin, β-glucan	Improve glucose tolerance, increase insulin sensitivity and secretion; improve pancreatic β-cell function	Rosen *et al*., 2009; Shen *et al*., 2011

2.1.4 Consumer Acceptance of Functional Foods

The discovery, development and marketing of functional foods are presently the quickest expanding segments of the food industry. This trend is initiated by various factors, such as the growing interest of consumers in their health, the growing burden of pharmaceuticals and other health-care costs, the growing elderly population, the advances in biotechnology and the extremely competitive nature of the food market (Wang and Li, 2014). After all, it is crucial to understand the consumer acceptance towards functional foods.

The selection of food depends on the consumer's attitudes and beliefs (Roux *et al*., 2000; Biloukha and Utermohlen, 2000). Beliefs are the cognitive knowledge of consumers, benefits, objectives and linking attributes. Attitudes are the affective responses or feelings to product attributes. Consumers apply several product criteria to access whether a food product meets their requirements and expectations. Based on the diverse characteristics perceived in a food product, consumers endorse an attitude towards the food (Dewettinck, 2008). The human perception or subjectivity is determining consumers' choice, attitude and preference (Verbeke, 2002).

In functional food development, it is vital to notice that obtaining functional food quality does not merely entangle providing the bioactive ingredients at the suitable level for the physiological effectiveness, but also meets the consumer's expectations (Siro *et al*., 2008). Different surveys showed that acceptance of functional foods from consumers is far from being unconditional, pertaining to taste, product quality, price, convenience and trustworthiness of health claims. Patterson (2006) pointed out that the dominant role of taste is a factor which basically directs consumers' food selection. Other than that, monitoring consumer attitudes towards functional foods is essential. Several studies have focused on consumer trends (De Jong *et al*., 2003; Wadolowska *et al*., 2009), consumer attitudes towards functional foods (Siro *et al*., 2008) and their possible health effects (Niva and Makela, 2007; Mullie *et al*., 2009).

The socio-demographic factors such as gender (Saher *et al*., 2004), age (Wadolowska *et al*., 2009), education/income (Anttolainen *et al*., 2001) and health claim (Wadolowska *et al*., 2009) impacts their attitudes towards functional foods. Normally, females are more interested in understanding functional foods than males (Saher *et al*., 2004) and different food products can be attractive for one or the other gender (Ares and Gambaro, 2007). Age is another important element which impacts the consumers' choice for functional foods. Older generations (older than 55) prefer to consume functional foods attributed to the health beneficial effects because they suffer from disease more oftenly while younger generations prefer to seek for foods to regulate appetite and body weight (Wadolowska *et al*., 2009).

Education is another aspect contributing to healthy eating; functional food consumers generally have a higher education level compared to the non-users (Anttolainen *et al*., 2001). Groups with higher socio-economic level have higher ability or willingness to pay a price premium (Stanton *et al*., 2011). Furthermore, health claims of functional food are other important predictors which influence the cousumers' willingness to purchase functional food. Diet-related health problems such as high blood pressure, high blood cholesterol and DM cause an increment in the consumption of functional foods

(Landstrom *et al*., 2007). For instance, individuals with cardiovascular disease prefer to take cholesterol-lowering margarine to obtain a positive health effect (De Almeida *et al*., 2006).

Consumers' attitude and acceptance towards functional foods influence the success and markets size. In the beginning phases of the functional foods market, consumers have usually been suspicious regarding 'unnaturalness' of functional foods due to the production requires high technology to add, remove or modify bioactive components. This situation has led to the risk that functional foods are speculated as becoming less natural than conventional products and hence avoided by consumers who value naturalness in food selections (Frewer *et al*., 2003). Nevertheless, the responses of the consumers have shifted in a positive way after there is increased awareness towards functional foods among them (Poulsen, 1999). In this regard, consumers need to be better informed about ingredients, bioactive substances and benefits of functional foods.

2.2 Dietary Fibre as Physiologically-Active Component

2.2.1 Definition and Classification

Dietary fibre has a long history, its term created by Hipsley (1953) who suggested DF as a nondigestible component constructing the plant cell wall. After several revisions, DF was defined as 'a constituent consisting of remnants of plant cells which resists to digestion by the alimentary enzymes of man' (Trowell *et al*., 1985). It has been investigated since long time ago, from being described as a waste to being considered as a 'universal remedy' that can improve physiological condition in human organism (Asp, 2004; Rodriguez *et al*., 2006). Until last decade, the most consistent definition which is broadly accepted is from AACC (2001) and Westernbrink *et al*. (2013) who described DF as 'the consumable parts of plants or analogous CHO that resists to digestion and absorption in the small intestine of human with complete or partial fermentation in the large intestine'.

Dietary fibres are a category of compounds consisting of a variety of CHO polymers (oligosaccharides and polysaccharides). For examples, cellulose, hemicelluloses, β-glucan, gums, pectic substances, resistant starch, inulin and lignin are the major components of DF. DFs are non-starch polysaccharides that are indigestible (Rodríguez *et al*., 2006; Yangilar, 2013).

As reported by Webb *et al.* (2008), DFs can be further classified based on their solubility in aqueous solutions: soluble DF (SDF) and insoluble DF (IDF), which can be distinguished by their chemical, physical and functional properties. Fuentes-Zaragoza *et al*.

(2010) and Dhingra *et al*., (2012) classify DF components based on their water solubility. **Table 2.4** presented the classifications of DF components, their description and the main food sources.

Most foods that contain DF have approximately two-third insoluble and one-third soluble DF (Wong and Jenkins, 2007). Each category has different physiological effects. Lattimer and Haub (2010) interpreted that SDF dissolves in water forming viscous gels which bypass the digestion process in the small intestine and are readily fermented by the microflora in the large intestine. It has been documented to reduce the rate of starch digestion by limiting digestive enzyme accessibility due to its viscosity (Biliaderis and Marta, 2007). Meanwhile, in the human gastrointestinal tract, IDF are water-insoluble by which they do not form viscous gels attributed to their water insolubility and fermentation is strictly limited. It reduces postprandial serum glucose levels by retarding glucose diffusion from the intestinal membrane *in vitro* (Nishimune *et al*., 1991; Lopez *et al*., 1996). Due to the their characteristics, SDF has been related to the reduction of blood cholesterol level and the decrement of BG level in the small intestine, whereas IDF has the capability to increase fecal bulk and reduce intestinal transit (Jenkins *et al*., 2006; Ajila and Rao, 2013).