Effect of Konjac Glucomannan on Metabolic Responses and Appetite Regulation in Healthy Adults

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Effect of Konjac Glucomannan on Metabolic Responses and Appetite Regulation in Healthy Adults

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List of Abbreviations

$^{12}CO_2$	Carbon 12 carbon dioxide
^{13}C	Carbon 13
$^{13}CO_2$	Carbon 13 carbon dioxide
AOAC	Association of Official Analytical Chemists
AUC	Area under the curve
BM	Body mass
BMI	Doby mass index
CHD	Coronary heart disease
CFU	Colony-forming units
CCK	Cholecystokinin
CNS	Central nervous system
CVD	Cardiovascular disease
DF	Dietary fibre
DM	Diabetes mellitus
DOB	Delta over baseline
DPP-IV	Dipeptidyl peptidase IV
EE	Energy expenditure
EFSA	European Food Safety Authority
EI	Energy intake
FAO	Food and Agriculture Organization
FDA	Food and drug administration
FJJDS	Fruit juices, juice drinks and smoothies
FPG	Fasting plasma glucose
GH	Growth hormone
GHS-R	Growth hormones secretagogue receptor
GI	Gastrointestinal
GIP	Glucose-dependent insulinotropic polypeptide
GLP-1	Glucagon-like peptide-1
GLP-1R	Glucagon-like peptide-1 receptor
GLU	Glucose
GLUTs	Glucose transporters
GRAS	Generally Recognised as Safe
HbA1c	Glycated Haemoglobin
HDL	High-density lipoprotein
ISDF	Insoluble dietary fibre
KGM	Konjac glucomannan
LDL	Low-density lipoprotein
min	Minute
MJ	Megajoule
mm	Millimetre
mmol/L	Millimoles per litre

MMU	Manchester Metropolitan University
MW	Molecular weight
NEFA	Non-esterified fatty acid
NHS	National Health Service
NPY	Neuropeptide Y
NSP	Non-starch polysaccharides
OGTT	Oral glucose tolerance test
PP	Pancreatic polypeptide
PPG	Post-prandial plasma glucose
PYY	Peptide tyrosine tyrosine
RCTs	Randomized controlled trials
SACN	Scientific Advisory Committee on Nutrition
SBTT	Small bowel transit time
SCFA	Short-chain fatty acids
SD	Standard deviation
SDF	Soluble dietary fibre
SEM	Standard error of the mean
SGLTs	Sodium-dependent glucose cotransporters
SPSS	Statistical Package for Social Sciences
TC	Total cholesterol
TAG	Triacylglycerol
T_{lag}	Time of maximal emptying rate
T_{half}	Half emptying time
T1DM	Type 1 diabetes mellitus
T2DM	Type 2 diabetes mellitus
USA	United States of America
VAS	Visual Analogue Scale
VDF	Viscous dietary fibre
VLDL	Very-low-density lipoprotein
w/w	Percent weight in weight
WHO	World Health Organisation

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Abstract

Background: The rapid rise in the prevalence of obesity and type 2 diabetes (T2DM) has caused major health concerns worldwide. There is evidence that increased dietary fibre (DF) intake may protect against T2DM in adults. Furthermore, several studies underscore the effectiveness of viscous soluble DFs, including konjac glucomannan (KGM), in reducing body weight and blood cholesterol levels. Recent market research indicates the public awareness of the health benefits of DF and their preference for more convenient ways to improve DF consumption, including drinking fruit juice and smoothies. Nevertheless, there are concerns about their high sugar content, which may adversely affect metabolic homeostasis.

Aim and objectives: This research aims to determine the impact of KGM preloading on the acute metabolic and appetite response to meal consumption. To achieve this goal, fives studies were conducted: A survey to elucidate the attitudes and perceptions of smoothie consumers in a university cohort; an experiment to examine the effect of KGM powder fortification on the rheological properties of commercial fruit smoothies; a survey of UK adults to explore their knowledge and awareness of DF consumption; a randomised crossover trial of healthy adults to evaluate the effectiveness of KGM capsule consumption at improving 2hr metabolic and appetite response to the ingestion of sugar-rich smoothies; a systematic review to assess the metabolic benefits of KGM capsules in healthy adults and adults with obesity and/or T2DM.

Results: This research demonstrated that smoothie consumption was above the national UK average in the university cohort (92% vs 40%), and the majority of respondents described health benefits (65.5%) as their motivation for drinking smoothies but raised concerns about their sugar content (%). In addition, the majority of UK respondents to a second survey who consumed DF regularly believed that whole fruit contained more fibre and enhanced satiety and glycaemic control more so than fruit beverages. However, the addition of 0.5g,1g and 2g KGM powder to commercial fruit smoothies to improve their DF content, significantly increased viscosity ($p<0.001$), firmness ($p<0.001$), cohesiveness ($p<0.001$) and consistency ($p<0.001$) of smoothie samples, both immediately and after overnight storage causing rheological and sensory issues. To overcome this issue, KGM capsules were used in the subsequent human intervention. The consumption of KGM capsules before smoothie ingestion was associated with a significant ($p=0.01$) decrease in 2hr postprandial serum insulin concentration compared to 1g KGM and placebo. The effects of KGM on other measures (blood glucose and lipids, gastric emptying rate, subjective appetite, and circulating gut hormone (ghrelin, GLP-1, PYY and PP) concentrations were nonsignificant. In contrast to these non-significant acute effects, the systematic review found some evidence from RCTs on the effectiveness of KGM capsule supplementation (1g to 3g daily) for 4 to 8 weeks at reducing body weight, blood glucose, as well as total and LDL cholesterol in adults.

Conclusion: This research demonstrated the awareness of health benefits of DF but limited knowledge about the fibre content of food products in the study population. It also showed that smoothies were popular, but there were concerns about their sugar content. However, the fortification of fruit smoothies with KGM powder was challenging and caused undesirable rheological changes in smoothies. Importantly, KGM capsule consumption had a modest effect of on acute (2hr) improvements in appetite and metabolic response to sugar-rich smoothie ingestion. Additionally, the systematic review found some evidence on the beneficial chronic effect of supplementation with KGM capsules on body weight, glycaemic control, and lipid profile (total and LDL cholesterol).

Declaration and Copyright Statements

Declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or institute of learning.

Signed: **Ohaad Fahad Awlya** (candidate) Date **07/03/2022**

Statement 1

This thesis is being submitted in partial fulfilment of the requirements for the degree of PhD.

Signed **Ohaad Fahad Awlya** (candidate) Date **07/03/2022**

Statement 2

This thesis is the result of my own independent work/investigation, except where otherwise stated. Other sources are acknowledged by explicit references.

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Statement 3

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available to outside organisations.

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Chapter 1 : Introduction

1.1 Obesity

Obesity is defined as an excessive adipose tissue accumulation that can lead to serious health issues (Zbiciak-Nylec et al., 2018). The World Health Organisation (WHO) identifies obesity according to the body mass index (BMI), obtained by dividing the body mass over the square of the body height. If the BMI is between 25 and 30, the individual is classified as overweight. If the BMI is more than 30, the person is considered to have obesity (Bernard et al., 2022). Obesity is a global health issue associated with increased morbidity and mortality. Currently, obesity is considered ‘‘the 21st Century Pandemic’’ (Ryan et al., 2020).

The prevalence of obesity has increased dramatically since 1980. In 2015, 107.7 million children and 603.7 million adults internationally were overweight or had obesity (Collaborators, 2017). Almost 3 million deaths and 35.8 million disability-adjusted life years are lost each year from obesity-related disease (Fox et al., 2019; Bernard et al., 2022). In addition, data from Health Survey England in 2018 showed that 28.7% of the adult population in England are living with obesity, and 35.6% are considered overweight (Conolly et al., 2019). This worldwide prevalence of obesity was due to urbanization, economic growth, inactive lifestyle, and high-calorie diets (Figure 1.1) (Bernard et al., 2022).

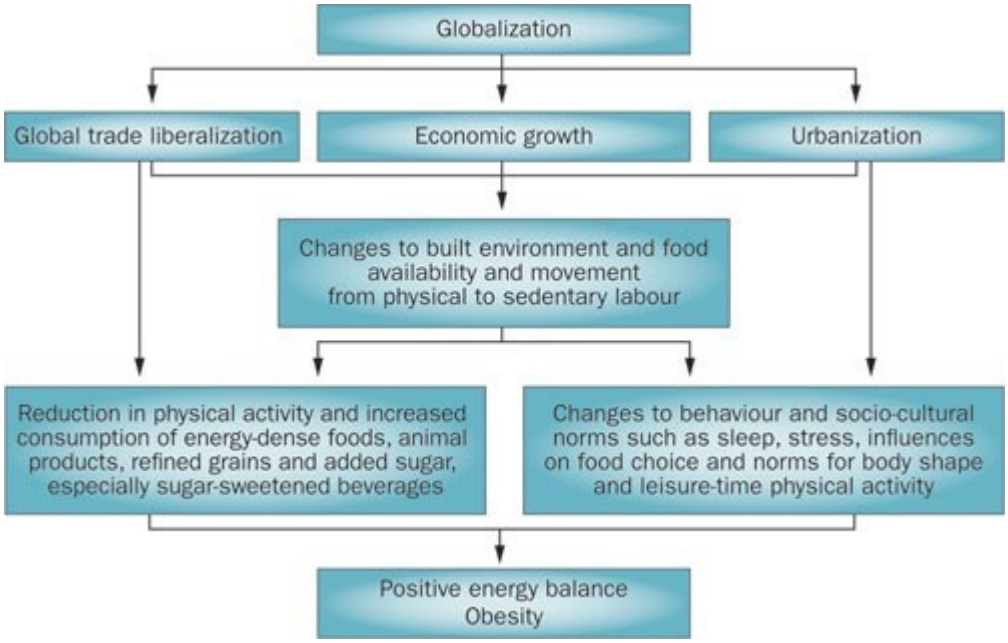


Figure 1-1 Environmental underpinnings of global obesity prevalence.

Adapted from (Malik et al., 2013).

The progression of the obesity epidemic worldwide is alarming as global predictions suggest that by 2025, 18% of men and more than 21% of women will be living with obesity (Tantengco, 2022). It is also predicted that by 2050, over 50% of the UK adult population will be living with obesity (McPherson et al., 2007; El-Sayed et al., 2012). These figures make obesity a significant challenge for healthcare organisations and a research topic that needs attention. It is estimated that overweight and obesity-related conditions across the UK cost the NHS £6.1 billion each year (Public Health England, 2017). Obesity is ranked among the leading health issues that cause death worldwide. In addition, it is associated with higher risks of developing common chronic diseases, including cardiovascular diseases (CVD) (Mokdad et al., 2003), various types of cancer, diabetes mellitus (DM) (Barlow and Dietz, 1998), primarily type 2 diabetes mellitus (T2DM) and insulin resistance (Kahn et al., 2006).

The accumulation of fat during obesity results from the imbalance between energy intake and energy expenditure (Little et al., 2007). The drivers of obesity are complex, including genetic and biological factors, obesogenic environment, and socioeconomic, cultural and physiological factors (Castiglione et al., 2002; Cheung and Mao, 2012). Obesity has been recognised as an independent risk factor for chronic conditions such as insulin resistance and diabetes (Seidell, 2000). It has been well documented that obesity promotes insulin resistance by reducing peripheral response to insulin, leading to increased glucose production by the liver and reduced glucose uptake by the skeletal muscles (Kahn et al., 2000). Excessively accumulated adipose tissue in people with obesity releases non-esterified fatty acids (NEFAs), glycerol, hormones and pro-inflammatory cytokines, which are involved in the development of insulin resistance and β cell dysfunction (Kahn et al., 2006). Furthermore, obesity is positively associated increased intrahepatic fat, and increased fasting very-low-density lipoprotein (VLDL) and triacylglycerol (TAG), (Tappy and Lê, 2010). It is well established that both high NEFAs and high plasma TAG concentrations are linked to insulin resistance (Shulman, 2000). In addition to lipotoxicity, chronic low grade inflammation caused by adipocyte hypoxia and subsequent endothelial reticulum stress, adiponectin reduction, leptin elevation, and macrophage infiltration contributes to insulin resistance by inhibiting insulin receptor substrate 1 and peroxisome proliferator- activated receptor gamma (PPARγ), together with stimulating lipolytic activity and FFA release (Ye and Jianping, 2013). Thus, obesity is the most crucial risk factor for insulin resistance and T2DM (Leitner et al., 2017). In this regard, the term 'Diabesity' describes the concomitant rise in the prevalence of obesity and diabetes across the world (Ng et al., 2021).

Furthermore, diabesity denotes the pathophysiological interlink between T2DM and obesity, mediated by insulin resistance and hyperinsulinemia (Astrup and Finer, 2000; Klein et al., 2022).

1.2 Diabetes Mellitus

Diabetes mellitus (DM) is a common chronic condition worldwide with an enormous financial and social burden (Banegas et al., 2003; Fingeret et al., 2018). According to the International Diabetes Federation (IDF), in 2021 10.5% of men and women aged 20 to 79 year were living with diabetes across the globe, and this figure is expected to rise to approximately 12.2% by 2045 (Sun et al., 2022). The highest predicted increases in diabetes are believed to occur in middle-income countries (21.1%) compared to significantly lower levels in higher-income nations (11.9%). The prevalence of diabetes put a significant strain on healthcare around the world, with estimates suggesting that 966 billion dollars were spent on diabetes care in 2021; and this figure is projected to rise up to 1054 billion dollars by 2045 (Sun et al., 2022). Also, the number of people with diabetes has substantially increased in the UK, reaching approximately 5 million people in 2021 (Lee, 2022).

There are two main types of DM, type 1 diabetes mellitus (T1DM) and type 2 diabetes mellitus (T2DM). T2DM is associated with gradual damage of β cell functions mainly due to but not exclusively caused by insulin resistance (Scheen, 2003). Importantly, T2DM is generally preventable and represents 90% of the diabetic population (NICE, 2015). Clinically, DM is characterised by increased blood glucose levels (hyperglycaemia) resulting from a deficiency in insulin secretion by pancreatic β cells, ineffective insulin action, or both (Ozougwu et al., 2013). In addition, chronic

hyperglycaemia in DM is associated with the subsequent dysfunction of several organs, such as the heart, eyes, kidneys and blood vessels (Soumya and Srilatha, 2011; WHO, 2016).

It is well documented that a high intake of low-nutrient-dense foods such as sugar is associated with weight gain, obesity, and T2DM. Consequently, the Scientific Advisory Committee on Nutrition (SACN) has reported that the current dietary recommendations for free sugar intake should be reduced from 10% to less than 5% of the daily total energy intake. These recommendations apply to all age groups from 2 years upwards (Scientific Advisory Committee on Health, 2015). This new recommendation aims to regulate high free sugar consumption to beneficially reduce the risk of weight gain, obesity and T2DM. However, the UK's average sugar consumption is two to three times higher than the current recommendations (Newens and Walton, 2016).

Dietary food linked with the risk of developing T2DM can be divided into two different groups; groups positively related to the risk of developing T2DM, such as low dietary fibres cereal products, snacks, fries, soft drinks and beverages, and unrelated groups such as chicken, fish, raw vegetables and fruits (van Dam et al., 2002).

Given the compelling evidence on the association between high sugar intake and inadequate consumption of dietary fibres with obesity and T2DM (Lê et al., 2016), it is essential to review the biological effects of fibre intake on metabolic and appetite responses to the ingestion of meals with high sugar content.

Although efforts are continuously being made to increase public knowledge of the detrimental effects of high sugar intake and its association with the risk of developing T2DM, dietary or nutritional interventions through the development or production of foods on the market may play a role in countering public sugar consumption behaviours (Lê et al., 2016).

1.3 Regulation of appetite, food intake and gastric emptying

The excessive intake of energy and macronutrients, mainly carbohydrates and fats, is linked to weight gain and obesity via central and peripheral dysregulation of appetite and food intake. Satiety and appetite are terms commonly used to describe the feelings of being full or hungry, respectively (Smith and Ferguson, 2008). Satiety is defined as the feeling of fullness after eating and prevents people from beginning eating. However, the term “satiation” refers to the process that causes people to stop eating (Benelam, 2009). In contrast, the term “appetite” describes the hunger and desire to eat (Douglas et al., 2017).

The regulation of food intake and hunger is regulated through multi-factorial biological and physiological factors. As originally described by Blundell et al. (1987) and modified later by Mela (2006), satiety and satiation following food intake are regulated by a cascade of biological mechanisms that link the internal properties of food macronutrient composition, energy density, physical structure and sensory qualities of food to peripheral physiology, metabolism, and central processing circuits (Figure 1.2).

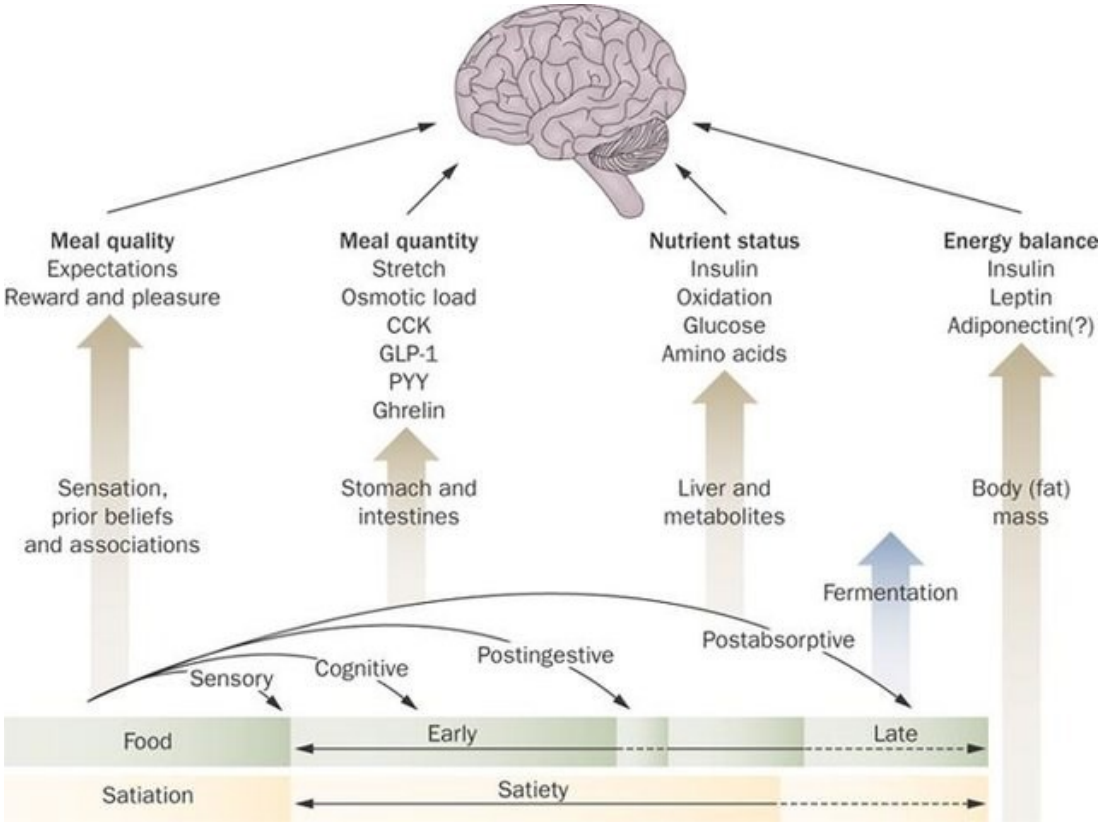


Figure 1-2 Blundell's satiety cascade. Sensory, cognitive, postingestive and postabsorptive influences on feelings of satiation and satiety over time. Shortly after meal ingestion, perceived quality of a meal (in terms of expectations, reward and pleasure) plays an important role in the development of satiation feeling. When consumed food reaches the stomach, postingestive and postabsorptive processes dominate and meal quantity gains importance. The increase in gastric volume triggers the release of satiety hormones, combined with cognitive perceptions of the food and drink, stimulate satiation. On the long term, nutrient sensing neurons in the hypothalamus detect energy imbalance and control food intake.

Source: Bilman et al. (2017).

The feelings of hunger or satiety control and daily eating behaviour can be influenced by information about the availability or absence of food (Rui, 2013). This information is transmitted to the brain by visual or olfactory signals via polymodal sensory mechanisms (Rui, 2013).

Physical properties of the meal influence food intake and appetite depending on their related oro-sensory exposure time. Longer sensory exposure times are consistently associated with lower food intakes (Forde et al., 2013). This observation may be

linked to the role of cephalic phase responses to foods. Cephalic phase responses are a set of physiological responses conceived to prepare the digestive system for the incoming flow of nutrients after ingestion to maintain homeostasis. Numerous studies propose that cephalic phase responses are much smaller for liquids than solids (Brunstrom et al., 2010; Brunstrom, 2011).

Furthermore, liquids have been shown to have low satiating efficiency. It is hypothesised that the absence of cephalic phase responses to liquid foods may be one of the causes why the energy content of drinks enter the body undetected and lead to an inadequate adaptive response to energy intake (de Graaf and Cees, 2011). This idea fits with the concept of a nutrient-sensing system that informs the brain and the gastrointestinal tract of what is coming into the human body. With liquids, this system is bypassed. Therefore, the consumption of liquid rather than solid foods faster could impair this association and lead to overconsumption of energy and eventually to weight gain. Slower eating, in contrast, may help the human body associate the sensory signals from food with their metabolic consequences (de Graaf and Cees, 2011).

When consumed nutrients gain entrance to the stomach, they mediate the release of polypeptide hormones from the GI enteroendocrine cells, influencing the sensations of satiety and hunger (Druce and Bloom, 2006; Rui, 2013). The GI tract comprises fundamental neural plexuses connected to the central nervous system (CNS), allowing functional autonomy. CNS plays a vital role in regulating GI functions, including motility, the control of energy balance and sensations of satiety and hunger (Klok et al., 2007; Browning and Travagli, 2014). Peripherally, hormones and

cytokines released from the gastrointestinal tract, pancreas and adipose tissue affect hunger, satiety and feeding behaviour. In addition, gastric emptying and other physical factors may also affect these parameters (Benelam, 2009).

1.3.1 Hormones involved in the regulation of appetite, food intake and gastric emptying

A wide range of peptide hormones are produced and released inside the GI tract (Horner and Lee, 2015). They target the brain and are crucial for the regulation of appetite by influencing the feelings of hunger or satiety as well as the principle of the rate of gastric emptying (Druce and Bloom, 2006; Rui, 2013). The main gut hormones that are known to regulate appetite and food intake are discussed below.

1.3.1.1 Ghrelin

Ghrelin, known as “the hunger hormone”, is a 28 amino-acid peptide released mainly from the P/D-1 endocrine cells in the fundus (Sakata and Sakai, 2010; Delporte, 2013). Ghrelin is also produced, to a lower extent, in many tissue locations, including the duodenum, small intestine, colon, pituitary, hypothalamus and pancreas (Masuda et al., 2000; Date, 2012; Delporte, 2013).

Ghrelin is a major regulator of appetite, adiposity and gastric emptying (Hellström et al., 2006; Delporte, 2013). The orexigenic effects of active ghrelin are attributed to the activation of neuropeptide Y (NPY) and Agouti-related protein (AGRP) neurons in the hypothalamus, centrally increasing food intake (Shintani et al., 2001). Several human and animal research studies indicate that circulating levels of ghrelin increase significantly during fasting and pre-prandial periods and decline dramatically following food consumption in a dose-dependent manner (Tschöp et al., 2000;

Cummings et al., 2001; Cummings et al., 2004). This indicates that high-energy meals induce a greater ghrelin reduction than low-energy meals (Callahan et al., 2004). Postprandial ghrelin release also depends on the macronutrient composition of the ingested meal. The effect of carbohydrate-rich meals on ghrelin secretion appears to be biphasic, characterised by an initial decrease and a delayed rebound in the later postabsorptive period (Erdmann et al., 2006; Hafiz et al., 2022). Protein has the most satiating capacity among macronutrients and induces ghrelin suppression for a more extended period. Dietary fat exerts minor suppressing effects on ghrelin secretion (Koliaki et al., 2010). Other studies suggest that exogenous ghrelin administration increases appetite and energy consumption in healthy individuals and people with obesity (Wren et al., 2001). In addition, ghrelin has been shown to increase the rate of gastric emptying in healthy and diabetes participants (Hellström et al., 2006). Ghrelin exists in two molecular forms; 1) acyl ghrelin, also known as the "biologically active ghrelin", which exerts orexigenic activity (Nakai et al., 2003; Delporte, 2013), and 2) des-acyl ghrelin which may exert biological actions the arcuate nucleus and impair the orexigenic effects of circulating ghrelin in a ghrelin receptors independent manner (Fernandez et al., 2016).

1.3.1.2 Leptin

Leptin is a 167 amino acid predominantly synthesised and released from the white adipose tissue (Zhang et al., 1994) and, to a lesser extent, from the gastric epithelium (Bado et al., 1998). Leptin contributes to the regulation of energy homeostasis and immune functions (Liu et al., 2013). The secretion of leptin from adipose tissue is influenced by various factors, including age, gender, glucose consumption and

exercise (Park and Ahima, 2015). It has been shown that the circulating levels of leptin in the blood are strongly associated with the mass of adipose tissue (Maffei et al., 1995) but not with energy intake (Stanley et al., 2005). Experimental studies have shown that both peripheral and intravenous administration of leptin diminish food intake instinctively after fasting (Ahima et al., 1998). Leptin is thus believed to have a long-term regulatory impact on appetite and food consumption (Hellström et al., 2004).

1.3.1.3 Glucagon-like peptide-1 (GLP-1)

Glucagon-like peptide-1 (GLP-1) is a 30 amino-acid peptide hormone produced and released from L-cells in the duodenum and the intestinal mucosa, including the small and large intestine (Lim and Brubaker, 2006). Two biologically active forms of GLP-1, GLP-17-37 amide and GLP-17-36 amide, are predominantly synthesised after cleavage at the N-terminus of two biologically inactive GLP-1 molecules (GLP-11-37 amide and GLP-11-36 amide) (Ørskov et al., 1994). GLP-17-36 amide is usually degraded by dipeptidyl peptidase IV (DPP-IV) less than two minutes after its release into the biologically inactive form GLP-19-36 amide (Delzenne et al., 2010). The main function of GLP-1 is to act as an incretin hormone stimulating a decrease in blood glucose levels via the increase in insulin secretion when glucose levels in the plasma are high (De Graaf et al., 2016). GLP-1 binds to GLP-1 receptors (GLP-1R), which are naturally expressed through the (CNS) central nervous system and in peripheral tissues (Bullock et al., 1996). Feinle et al. (2002) reported that almost 50% of the glucose-induced increase in postprandial insulin levels is attributed to GLP-1. In addition, GLP-1 reduces appetite and hunger (Moran et al., 2005), decreases the

release of glucagon, promotes neogenesis of β cells (Zheng et al., 2019), delays the apoptosis of β cells and augments the release of insulin (Meloni et al., 2013).

Several research studies have demonstrated that GLP-1 decreases the rate of gastric emptying in healthy individuals (Delgado-Aros et al., 2002) and those with obesity (Näslund, 2000) or T2DM (Meier, 2012). Furthermore, the production and secretion of GLP-1 depend on the macronutrient content of consumed meals (Parvaresh Rizi et al., 2018). For instance, the increase in circulating GLP-1 levels is more noticeable with meals rich in protein and/or fat in comparison to low-protein and low-fat meals (Parvaresh Rizi et al., 2018).

1.3.1.4 Peptide tyrosine tyrosine (PYY)

Peptide tyrosine tyrosine (PYY) is a 36 amino-acid peptide that is produced and released in the small intestine by gastrointestinal L-cells. PYY exists in two endogenous forms; PYY1-36 and its truncated bioactive 34 amino-acid peptide PYY3-36, which is the main circulating form during both hunger and satiety (Batterham et al., 2006). PYY3-36 acts through binding to the neuropeptide Y2 receptor (NPY2R) (Batterham et al., 2002), which is predominantly expressed in the CNS, hypothalamus, liver, spleen, liver and adipose tissue (Cummings and Overduin, 2007).

Circulating levels of PYY are normally low during fasting and start to rise within 15-30 minutes after food consumption, typically reaching a peak after 1 to 2 hours postprandially, which is maintained for a few hours before decreasing within 6 hours from reaching the maximum value (Koegler et al., 2005). The secretion of PYY following food consumption occurs in a dose- and energy-dependent manner and

differs by the type of macronutrients consumed (Huda et al., 2006). For instance, meals rich in fat stimulate a greater release of PYY in comparison with meals rich in carbohydrates and proteins of the same energy content (Adrian et al., 1985). Experimental studies have demonstrated that the peripheral infusion of PYY3-36 reduces food intake in both humans and rodents (Batterham and Bloom, 2003; Chelikani et al., 2004; Batterham et al., 2007).

Batterham et al. (2002) found that peripheral administration of PYY to healthy lean individuals resulted in a 33% decrease in energy intake, a decrease in the time of food consumption and a reduction in appetite levels that persisted for 12 hours post-administration. These researchers also found that intracerebral administration of PYY in rodents reduced food consumption (Batterham et al., 2002). Other researchers found that intravenous infusion of PYY decreased food consumption and increased the duration between consumed meals (Chelikani et al., 2005; Moran et al., 2005).

1.3.1.5 Pancreatic Polypeptide (PP)

Pancreatic Polypeptide (PP) is a 36 amino acid mainly released by F-cells predominantly located in the Islets of Langerhans (Ekblad and Sundler, 2002). PP acts via binding to the Y4 and Y5 receptors (Larhammar, 1996), which are widely expressed in the brain and hypothalamus (Huda et al., 2006; Karra and Batterham, 2010). Similar to GLP-1, the levels of PP in the blood are low during fasting. However, levels of PP rise significantly following meals in a biphasic mode proportionate to the energy content and stay elevated for 4 to 6 hours postprandially (Track et al., 1980). PP has been shown to influence metabolism, energy intake and the rate of gastric

emptying (Strömmer et al., 2005). Interestingly, PP appears to have orexigenic and anorexigenic effects depending on the route of administration (Katsuura et al., 2002).

Intracerebroventricular PP infusion increases appetite and food consumption in rodents (Asakawa et al., 2003). In contrast, there are reports from rodent and human studies that peripheral treatments with PP may decrease food consumption in subjects with or without obesity (Batterham and Bloom, 2003; Asakawa et al., 2006).

Asakawa et al. (2003) found that intraperitoneal PP administration led to the increased expression of urocortin, a hypothalamic anorexigenic peptide, and simultaneously decreased expression of orexigenic ghrelin in gastric cells. This is supported by more recent research that indicates release of PP is significantly reduced in individuals with obesity or anorexia nervosa (Shi et al., 2015; Guida et al., 2017). Thus, PP may be involved in the regulation of energy balance and obesity in humans (Asakawa et al., 2003).

1.3.1.6 Cholecystokinin (CCK)

Cholecystokinin was the first gut hormone found to exhibit effects on appetite, particularly the suppression of hunger (Gibbs et al., 1973; Chaudhri et al., 2006). CCK regulates a range of physiological processes, including the distribution of nutrients to the intestines and the release of gastric and pancreatic acids (Dockray, 2014). The two most frequently investigated forms of CCK are CCK-8 and CCK-33 (Delzenne et al., 2010). CCK is released from intestinal I-cells in the duodenum and small intestine (Rehfeld et al., 2007) in response to dietary lipid (particularly long chain FFAs) and proteins (Camilleri, 2019). CCK exerts its functions via binding to both CCK-1 and CCK-2 receptors, which are widely expressed in the brain, leading to the relaxation of the

proximal stomach and enhancement of contractions in the distal stomach (Okonkwo and Adeyinka, 2018). Circulating concentrations of CCK generally increase 15 to 30 minutes post food consumption (Chearskul et al., 2008; Moehlecke et al., 2016) and decrease progressively to baseline levels within 3 to 5 hours (Liddle et al., 1985). Intravenous administration of small quantities of CCK can reduce hunger and energy intake in rodents and humans with or without obesity (Stacher et al., 1982; Huda et al., 2006). Similar to GLP-1 and PYY, CCK also reduces the rate of gastric emptying (Hellström et al., 2006; Dockray, 2012) through activation of vagal afferent fibres. CCK causes relaxation of the proximal stomach and slowing of gastric emptying by inhibition of antral contractility and stimulation of pyloric contractions (Camilleri, 2019).

1.3.1.7 Insulin

Insulin is a peptide hormone produced and released by pancreatic β cells (Da Silva et al., 2018). Insulin is a key regulator of blood glucose concentrations (Roberts et al., 2009) and affects the metabolism of carbohydrates, proteins, and fat (Qaid and Abdelrahman, 2016). However, the impact of insulin on the regulation of appetite in humans is incompletely understood. When glucose is absorbed in the bloodstream following meal ingestion, insulin is subsequently released to exert well-characterised hypoglycaemic effects (Polonsky et al., 1988; Dimitriadis et al., 2011). Several animal studies have reported that hyperglycaemia decreases meals intake (Nicolaidis and Rowland, 1976; Woods et al., 1984). The insulin response to a meal is further modified by the insulinotropic incretin hormones GLP-1 and GIP. In comparison, the role of insulin in the regulation of appetite and energy homeostasis is complex

(Chapman et al., 1998). There is evidence that, in individuals without obesity, endogenous insulin exerts central anorexigenic effects via insulin receptor substrates (IRS) in the arcuate nucleus, with an inverse relationship between insulin concentrations, subjective appetite and subsequent food intake (Austin and Marks, 2008). This effect may be partially driven by the accompanying glucose intake. However, absolute glucose concentrations are not strongly correlated with appetite. Thus, the observed appetite-suppressing actions of endogenous insulin may be attributed to the postprandial release of incretin hormones (De Graaf et al., 2004). This is further supported by previous studies which have not reported a significant association between the exogenous insulin concentrations and energy intake (Woo et al., 1984; Lavin et al., 1996).

1.3.1.8 Amylin

Amylin is a 37 amino-acid peptide produced by pancreatic β cells in response to food consumption (Neary and Batterham, 2009). It is co-released with insulin at a molar ratio of 1:100 (amylin: insulin) (Neary and Batterham, 2009). Circulating levels of amylin increase significantly after food ingestion before reaching a peak at 1-hour postprandially. The peak concentration remains high for up to 4 hours (Huang et al., 1992). Peripheral administration of amylin in rodents has been shown to generate anorexic effects leading to weight loss (Lutz and Rand, 1995).

In addition, amylin has been shown to reduce ad libitum food intake in diabetic and non-diabetic individuals with obesity (Chapman et al., 2005). Amylin exerts its effects through binding to amylin receptors, which are present in the CNS, including the

hypothalamus and area postrema, a paired structure in the medulla oblongata of the brainstem (Kim et al., 2001).

1.3.2 Gastric emptying

Gastric emptying is a complex process by which the stomach discharges its content into the small intestine leading to the absorption and distribution of aliments to the body. Gastric emptying is mediated by the proximal stomach, antrum, pylorus, and duodenum (Varón and Zuleta, 2010). The complex regulation of gastric emptying involves variations in intragastric pressure, which encourage food movement from the stomach into the duodenum (Hellström et al., 2006). The procedure of gastric emptying is controlled by several hormonal and neural signals. These signals aid a balanced transfer of nutrients from the stomach into the duodenum for absorption in the small intestine (Hellström et al., 2006; Tambascia et al., 2014). When the stomach is full of nutrients, the neural and hormonal stimulations (ghrelin and motilin) increase significantly and act via autonomic motor nerves to augment motility and gastric secretion after food consumption and reduce them as the stomach empties (Hellström et al., 2006). The distribution of aliments in the duodenum relies on the power and incidence of antral contractions; therefore, the delivery of nutrients from the stomach to the duodenum depends upon the opening of the pyloric sphincter (Indireshkumar et al., 2000). Gastric emptying occurs at an exponential frequency linked with the quantity of food in the stomach, so gastric emptying progresses quickly and effectively when the stomach is full. Vagal excitatory reflexes, stimulated by gastric distension, mediate this procedure (Travagli et al., 2003).

1.3.2.1 Factors that affect gastric emptying

Several complex factors have been shown to influence the rate of gastric emptying in the stomach. The gastric emptying of solids is a much slower process than liquid ingestion (Achour et al., 2001; Leiper, 2015). This is mainly because emptying of liquids does not necessitate trituration (Maurer, 2015). In contrast, the gastric emptying of solids requires an initial relaxation of the proximal stomach, followed by an increase in tonic contractions, with calorie density being a key regulator of the process (Houghton et al., 1988; Sachdeva et al., 2013).

The speed of liquid emptying is regulated by both calorie density and osmosis. For example, when liquids are more concentrated, calorie-dense and intense in osmotic terms, gastric emptying becomes slower (Vist and Maughan, 1995); hence, the ingested water is driven along the stomach to the duodenum only by the propulsive force of peristaltic waves without any controlling actions of the pylorus. However, when sugars such as dextrose are added to the liquid solution, there is a reduction in the propagated pressure waves with an increase in pyloric closure in the stomach, resulting in a slower rate of gastric emptying (Hunt et al., 1985; Leiper, 2015).

Additionally, the rate of nutrient transfer from the stomach to the duodenum is proportional to the intragastric volume. Several studies indicated that increasing intragastric volume exacerbate the rate of gastric emptying with both liquids and solids meal (Hunt et al., 1985; Leiper, 2015).

The rate of gastric emptying is also affected by the physical and chemical characteristics of the meal. It is well documented that carbohydrates and proteins empty quicker than fats (Gall and Payne-James, 2016). Carbohydrates in the form of

liquids are usually the most frequently used macronutrients to investigate the impact of calorie content on the gastric emptying rate. Several research studies have reported that liquids that contain less than 2.5% carbohydrates are emptied from the stomach at the same quantity and rate as water. However, emptying liquids with more than 6% carbohydrates is significantly slower (Leiper, 2015). Thus, increasing the energy content of nutrients slows down the rate of gastric emptying (Maughan et al., 2004).

Blood glucose concentrations have also been shown to affect the rate of gastric emptying in humans (Rayner et al., 2001; Chang et al., 2010). Recent literature has indicated that acute variations in blood glucose concentrations have a substantial effect on the rate of gastric emptying and gastric motor function (Rayner et al., 2001). Several studies have shown that hypoglycaemia accelerates the gastric emptying rate in healthy individuals and patients with T1DM (Schvarcz et al., 1997). In contrast, a delay in gastric emptying rate has been observed in patients with acute hyperglycaemia (Øster-Jørgensen et al., 1990; Russo et al., 2005).

Factors such as pH and temperature of meals, body posture and position, exercise, and the GI tract's endocrine function also influence the gastric emptying rate (Calbet and MacLean, 1997). However, these factors are beyond the scope of this research.

1.3.2.2 Measurement of gastric emptying

Several methods have been developed and utilised to assess gastric emptying rates in clinical and research studies. However, the selection of the method depends on various factors, including the physical and chemical characteristics of meals, the

invasiveness, precision, availability of resources and ethical considerations (Szarka and Camilleri, 2009).

The measurement of gastric emptying rate is possible via imaging studies and indirect techniques.

1.3.2.3 Indirect techniques

A popular indirect technique to measure gastric emptying rate is breath testing. This technique was first described in 1993 (Ghoos et al., 1993) and uses the Carbon-13 (^{13}C) as a label for standardised meals. It is a safe non-radioactive test that utilises the stable isotope ^{13}C (Szarka and Camilleri, 2009). It is fundamentally based on the fast intestinal absorption and rapid oxidation of the combined marker to $^{13}CO_2$ in the liver, which is consequently detected within the breath, and the assumption that the processes of absorption, oxidation and exhalation happen at a constant frequency (Barbara, 2009). Breath samples are analysed using non-dispersive infra-red spectroscopy and isotope ratio mass spectrometry, and the rate of isotopic development in the breath is measured to assess the rate of gastric emptying (Ghoos et al., 1993; Barbara, 2009; Sanaka and Nakada, 2010). Breath testing is a safe, effective, non-invasive and relativity inexpensive technique that allows the measurement of gastric emptying for both solids and liquids. It can also be utilised to assess emptying during exercise (Ghoos et al., 1993; Barbara, 2009; Sanaka and Nakada, 2010; Camps et al., 2018). Therefore, breath testing is widely applied in clinical and research settings. However, it is worth pointing out that a sampling duration of at least four hours is required to enable precise emptying measurements

using the breath testing technique (Sanaka and Nakada, 2010). Therefore, this limitation represents the main drawback of this indirect testing technique.

Another indirect technique is the paracetamol absorption test. This technique is based on the absorption of a pharmaceutical or isotopic tracer in blood samples. The change in the tracer's concentration indicates absorption, which allows the assessment of gastric emptying. The paracetamol absorption test involves the ingestion of paracetamol with meals at a concentration ranging from 20 mg/kg body weight to 1.5 g (Willems et al., 2001). Normally, the absorption of paracetamol in the stomach is negligible. Therefore, variations in paracetamol concentration in the blood are used to measure the rate of gastric emptying. (Medhus et al., 2001). The paracetamol absorption test is relatively inexpensive and easy to perform. However, it is an invasive method that can only be used to assess solid meal emptying (Näslund, 2000).

Scintigraphy first described in 1966 (Griffith et al., 1966), is known as the 'gold standard' technique in evaluating the gastric emptying rate of both solid and liquid meals (Hellström et al., 2006; Szarka and Camilleri, 2009). It is a safe, non-invasive, quantitative, and straightforward procedure that uses an external gamma camera to capture two-dimensional images of the gastric area after the ingestion of meals tagged with radioisotopes (Szarka and Camilleri, 2009). As shown in figure 3, captured images are used to identify the areas of interest, allowing the quantification of radioactivity (Szarka and Camilleri, 2009).

One of the main advantages of scintigraphy is its ability to assess both solid and liquid gastric emptying using distinct radioisotope markers. However, scintigraphy has an evident drawback, which is radiation exposure. Therefore, this technique is inadvisable for children, pregnant women, and researchers conducting multiple scintigraphic studies (Jackson et al., 2004). In addition, scintigraphy is an expensive and time-consuming technique (Al-Saffar et al., 2019).

Magnetic resonance imaging (MRI) and real-time ultrasonography are additional methods that have been extensively used to assess gastric emptying in recent years. MRI allows the measurement of gastric emptying through visualisation of the ingested meals, which enables the measurement of volume and distribution of meals in addition to gastric secretion (Maughan et al., 1996; Schwizer et al., 2006; Sauter et al., 2012). Similar to scintigraphy, MRI is a validated technique used to assess liquids and mixed solid-liquid meals (Feinle et al., 1999). MRI scans are presented in 3D images to calculate the volume and concentration of ingested meals and gastric contents (Feinle et al., 1999). For MRI assessment, the labelling of consumed meals is achieved using gadolinium tetraazacyclododecane tetraacetic acid (Gd-DOTA). Gd-DOTA is the most stable contrast agent within the gastric environment, with optimum adherence to both solids and liquids (de Zwart and de Roos, 2010). The use of MRI negates the drawbacks of exposure to radiation and the invasiveness of the previously mentioned techniques. However, due to the lack of availability of seated MRI instruments, the assessment of gastric emptying is usually performed at a right-sided semi-supine position. This represents one of the main disadvantages of MRI imaging (de Zwart and de Roos, 2010). Compared to MRI, real-time ultrasound imaging is an easy, safe and non-invasive method used to assess gastric emptying

(Bateman and Whittingham, 1982). Real-time ultrasound imaging was first described in 1982 (Bateman and Whittingham, 1982). It allows the measurement of gastric emptying by capturing cross-sectional images at consistent intervals and producing a three-dimensional illustration of the stomach (Fenster et al., 2011). Real-time ultrasound imaging is an effective and relatively cheap procedure that strongly correlates with scintigraphy (Gentilcore et al., 2006; Szarka and Camilleri, 2009). It is, however, a time-consuming procedure that requires skilled operators. In addition, the quality of images is reduced in patients with increased body fat (Szarka and Camilleri, 2009). Moreover, it does not allow the measurement of emptying with solid meals.

1.3.2.4 Direct techniques

A commonly used direct technique is the double sampling gastric aspiration. This method was first described in 1968 (George, 1968) and modified in the late 1980s (Beckers et al., 1988). It necessitates intubation of the stomach and the use of phenol red, which is a non-absorbable dye frequently used in research. This method allows the measurement of gastric emptying, the volume and components of gastric secretion based on identifying red phenol concentration in gastric samples aspirated before and following a known concentration of dye to the gastric content (George, 1968; Beckers et al., 1988). The double sampling gastric aspiration is a consistent, relatively cheap, and accurate technique widely used in clinical settings (George, 1968). In addition, it can be utilised to measure gastric emptying features even during physical activity (Gant et al., 2007; Jeukendrup and Moseley, 2010). However, this

method is invasive and can only be used to assess the emptying of the liquid meals (Maughan et al., 1996; Feinle et al., 1999).

1.4 Anatomy and function of the gastrointestinal system

The GI system is anatomically and physiologically attached to the endocrine, nervous, cardiovascular and lymphoid systems. It comprises the GI tract, including the mouth, pharynx, oesophagus, stomach, duodenum, small intestine, large intestine, and rectum, combined with other distinct accessory organs, including the salivary glands, liver, pancreas, and gallbladder (Peate, 2018). The GI tract achieves its main functions via four distinct processes; digestion, secretion, absorption and motility (Chen et al., 2010). The main processes involved in food digestion and nutrient absorption occur in the stomach and the small intestine. Therefore, these organs play a crucial role in regulating food intake and nutrient absorption.

1.4.1 Stomach

The stomach is a J-shaped muscular organ located in the upper part of the abdomen (O'Malley and Bordoni, 2019). The stomach is divided into five anatomical sections; cardia, fundus, corpus (body), antrum and pylorus (Hunt et al., 2015) (Figure 1.3). The stomach has five key functions: 1) Acting as a provisional reservoir for consumed food. 2) Executing mechanical actions, known as peristaltic contractions, which contribute to food fractional breakdown. 3) Executing chemical actions via the release of enzymes and acid, which allow partial food digestion and aid food peristalsis (Ramsay and Carr, 2011). The secretion of acid also represents an important non-immunological mechanism against pathogen invasions (Hellström et al., 2006; Hunt et al., 2015). 4) Controlling the proportion and frequency of food

delivery, in the form of fluid chyme, to the small intestine for further digestion and absorption. 5) Producing a glycoprotein, known as the intrinsic factor, necessary for vitamin B12 absorption in the small intestine (Hellström et al., 2006; Rizzo, 2015).

Motility is one of the main features of the stomach, involving both the proximal and the distal regions. It is a process controlled by complex neural and hormonal signals (Hunt et al., 2015). The proximal region, which includes the cardia, fundus, and proximal one-third of the corpus, represents a reservoir for the stomach. As a result, the proximal region delivers low frequency, and continuous contractions generate basal pressure inside the abdomen (Soybel, 2005).

The distal region, which includes two-thirds of the corpus, antrum and pylorus, is responsible for mixing the stomach content before delivery to the duodenum (Hellström et al., 2006; Hunt et al., 2015). The stomach also secretes peptide hormones, such as gastrin and ghrelin, that are crucial for food digestion (Hellström et al., 2006; Hunt et al., 2015).

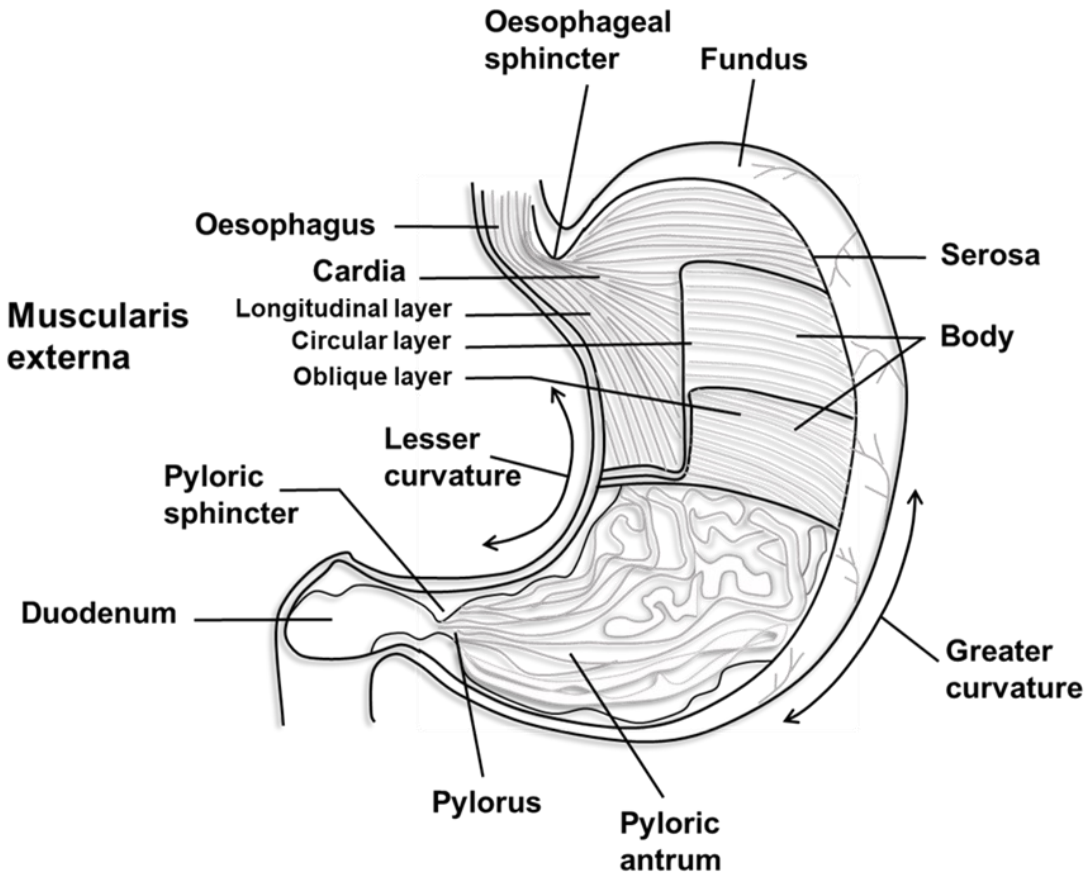


Figure 1-3 Anatomic structure of the stomach.

Figure drawn by the author based on information adapted from (Hunt et al., 2015).

1.5 Carbohydrates

Carbohydrates are a vital constituent of our diet, representing the majority of daily energy intake. They cover around 56% of the usable energy in a diet of 12,500 (kJ) kilojoules daily. Several forms of carbohydrates exist in the human diet (Paulev and Zubieta-Calleja, 2004). They are categorised based on the number of monosaccharides they contain. Carbohydrates can be divided into simple sugars, also named monosaccharides, such as glucose, fructose and galactose, which are the least complex forms of carbohydrates, and complex sugars, including disaccharides. Carbohydrates also include oligosaccharides consisting of 3 to 9 units and polysaccharides with more than 9 units (Gropper and Smith, 2012).

Glucose and fructose are the primary forms of carbohydrates (sugars) found naturally in food (Dennison et al., 1997). They are rapidly absorbable, leading to increased glucose levels in the blood (Abayomi and Charnley, 2012a), with their digestion and absorption differing in several ways (Elliott et al., 2002). Therefore, glucose transporters are fundamental in controlling glucose distribution processes (Sala-Rabanal et al., 2016).

Glucose transporters (GLUTs) 1-5 and sodium-dependent glucose cotransporter (SGLTs) 1-2 are the main transporters for the whole-body metabolism (Table 1.1). The GLUTs family is vital for glucose delivery to the liver and brain, while the SGLTs family has a significant role in glucose retention in the kidney (Sala-Rabanal et al., 2016). SGLT1 proteins are the principal transporters of glucose and galactose, while fructose is mainly transported via GLUT5 proteins. Fructose is absorbed by a separate carrier that is not sodium-dependent and works by facilitated diffusion rather than active transport (Figure 1.4) (Wood et al., 2003).

Table 1-1 Metabolically important active and passive glucose transporters.

Isoform	Main tissue localisation	Insulin sensitive	Functions
GLUT1	Red blood cells Brain barrier Heart (minimum amount)	Insulin-independent	Transports glucose
GLUT2	Liver Small intestine Pancreas (β cells)	Insulin-independent	Transports glucose and fructose (low affinity)
GLUT3	Neurons Brain	Insulin-independent	Transports glucose (high affinity)
GLUT4	Heart (high amount) Skeletal muscle Adipose tissue	Insulin-dependent	Transports glucose (high affinity)
GLUT5	Enterocyte of intestinal epithelium	Insulin-independent Fructose transporter	Transports fructose (very low affinity)
SGLTs1	Enterocyte of intestinal epithelium	Insulin-independent Na^+ and ATP- dependent	Glucose absorption
SGLTs2	Kidney	Insulin-independent Na^+ and ATP- dependent	Glucose retention

Adapted from (Wood et al., 2003).

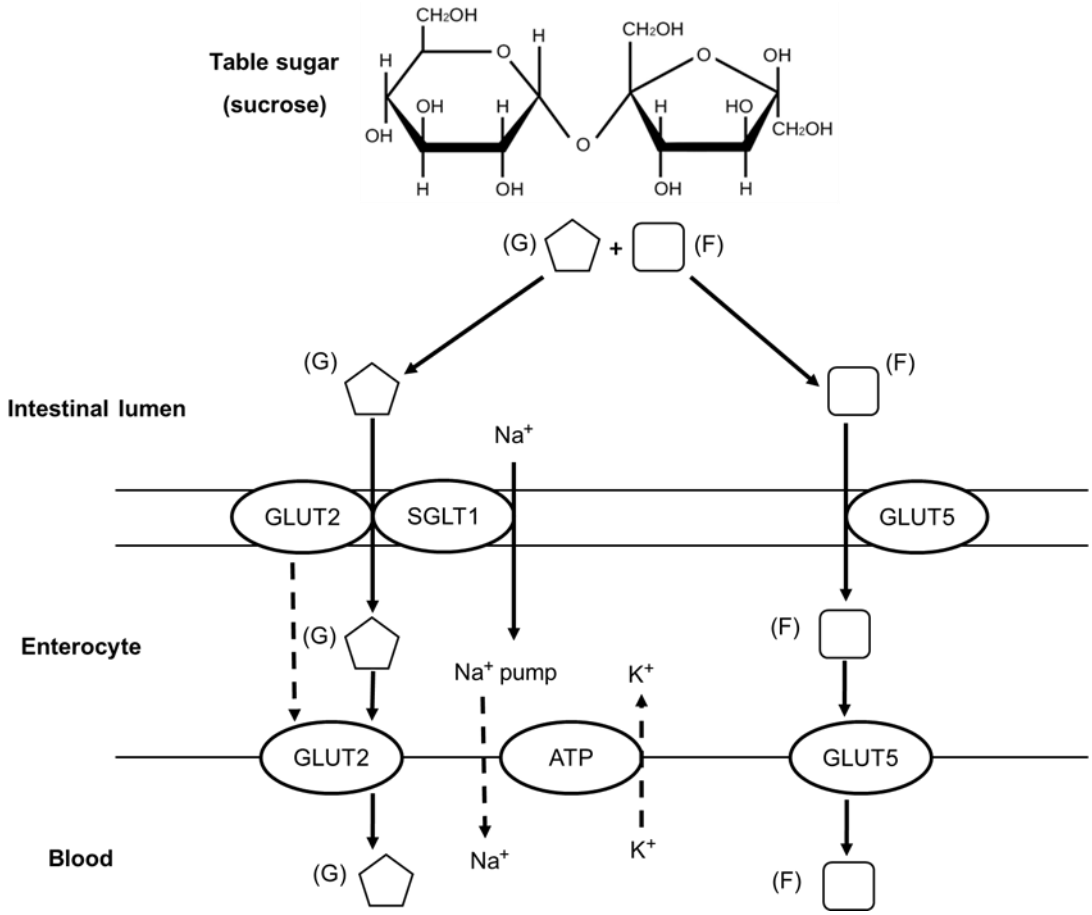


Figure 1-4 Monosaccharide transport from the small intestine to the blood.

By 1) active transport through binding to the sodium-dependent glucose transporter (SGLT1) and 2) the sodium-independent transport through binding to the glucose transporter (GLUT2). (G) = Glucose, (F) = Fructose. Figure drawn by the author based on information adapted from (Goodman, 2010).

Following the absorption of sugars into the circulation, postprandial glucose levels significantly increase in the blood, leading to the stimulation of pancreatic β cells, which release insulin in significant quantities to normalise glucose concentration in the blood (Zheng et al., 2008).

The Scientific Advisory Committee on Nutrition (SACN) reported that there is no difference found in the molecular structure between sugars no matter where they come from, whether naturally occurring in food or added to food, but the body processes them differently (Hess et al., 2012; Scientific Advisory Committee on

Health, 2015). 'Free sugars' are defined as all monosaccharides and disaccharides added to foods by the manufacturer or consumer, in addition to the sugars naturally existent in unsweetened fruit juice and honey (Agostoni et al., 2010; Scientific Advisory Committee on Health, 2015). 'Added sugars' are defined, by the SACN, as sugars that are added to food through the preparation process and syrups but do not include the sugars present in unsweetened fruit juice or honey (Hess et al., 2012; Scientific Advisory Committee on Health, 2015). 'Intrinsic sugars' are mainly intakes from the cellular structure of fruit, vegetables and milk. It has been shown that 'Intrinsic sugars' provide up to 13% of total energy intake (Scientific Advisory Committee on Health, 2015). Legal definitions of sugars can give rise to misconceptions about the 'healthiness' of food products (Drichoutis et al., 2005). For example, the ingredient 'sugar' was associated with a symbolic meaning of healthiness when labelled as 'fruit sugar' (Sütterlin and Siegrist, 2015).

Smoothies are popularly considered "Superfruits" and promoted as a health-conscious beverage option for "Wellness" due to their claimed rich nutritional profile (Medina, 2011). Smoothie consumption has also increased due to the assumption that drinking smoothies may help to meet the recommended 5-a-day of fruit and vegetables (Di Cagno et al., 2011; Keenan et al., 2012; Liu et al., 2014; Nowicka et al., 2016). In addition, Bates and Price (2015) reported that drinking smoothies are a convenient way to increase fruit and vegetable intake in younger individuals.

Smoothies are often labelled as "No Sugars Added" and are usually marketed as a healthy substitute to fizzy soft drinks and other sugar-sweetened beverages (Taylor et al., 2005; Keenan et al., 2012). However, a large proportion of commercially

available fruit smoothies may contain 13g of natural sugars per 100 ml (Boulton et al., 2016). In addition, fruit smoothies contain comparable sugar contents to Pepsi-soda and Coca-Cola drinks. Every 100 ml of the above beverages contains 10g, 10.6g and 10.8g of sugars, respectively (Public Health England, 2015). This is believed to be high as the recommended daily amount of sugar by the National Health Service is found to be 24g for children and 30g for adults (NHS, 2020). Furthermore, some concerns have been raised over the rapidly absorbable simple sugars in fruit smoothies that would quickly increase blood glucose levels (Ali and Tahmassebi, 2014; Boulton et al., 2016). Thus, potentially leading to or contributing to conditions such as T2DM.

Consequently, excessive consumption of fruit smoothies may lead to impaired glucose regulation and increase the risk of obesity and type 2 diabetes mellitus (T2DM) (Boulton et al., 2016). Moreover, removing the peel during the processing of fruit smoothies reduce their dietary fibre (DF) content. The Scientific Advisory Committee on Nutrition (SACN) defines dietary fibre as “all carbohydrates that are neither digested nor absorbed in the small intestine and have a degree of polymerisation of three or more monomeric units, plus lignin” (Scientific Advisory Committee on Health, 2015).

Although, previous studies have not focused on the appetitive responses to smoothies, some studies suggested that liquids may be less satiating than nutritionally-comparable solid and semi-solid foods, possibly due to several physiological factors (e.g. increased rate of ingestion, reduced mastication, and increased rate of gastric emptying) (McCrickerd and Forde, 2016). The gastric

emptying of solids is a much slower process than that of liquid ingestion (Fisher et al., 1982; Achour et al., 2001). This is mainly because emptying of liquids does not necessitate trituration (Houghton et al., 1988). Hence, providing an explanation behind the differences reported in the studies above.

The short sensory exposure time during liquid ingestion limits the connection between sensory attributes of liquids with their satiating effects and subsequent learning (Mars et al., 2009). Indeed, one benefit of fruit and vegetable consumption is that it induces satiety through exposure time due to being solid in nature (Chambers et al., 2015). This effect may be attenuated when solid ingredients are reduced to a liquid state. Smoothies provide a medium in which they combine solid ingredients into a semiliquid form that can be consumed in a short timeframe (Chambers et al., 2015). Therefore, excess intake of fruit smoothies would increase energy intake due to liquid and semi-liquid foods being unable to satisfy hunger and appetite for a similar timeframe to that of solids (Qian, 2006; Slavin and Green, 2007; Bertenshaw et al., 2008; Abayomi and Charnley, 2012b).

In light of these concerns, Public Health England (PHE) has reported that unsweetened 100% fruit juice, vegetable juice, and smoothies are counted as a maximum of one portion towards the five-a-day consumption of fruit and vegetables (Baker et al., 2001). In addition, the Eat Well guide developed by PHE stated that the total consumption of fruit juice and smoothies should not exceed 150 ml per day (Baker et al., 2001; Frantsve-Hawley et al., 2017; Heyman et al., 2017). Interestingly, the average size of commercially available smoothies is 250ml, exceeding that

recommended by PHE and thus justifying the need for further research into the nutritional contents.

Carbohydrates can also be classed into digestible and non-digestible carbohydrates based on their digestion mode. Digestible carbohydrates such as starch and sucrose are digested and absorbed in the upper gastrointestinal tract. The digestible carbohydrates most commonly found in food are disaccharides, oligosaccharides and polysaccharides. These carbohydrates are fragmented into monosaccharides due to mechanical, chemical, and enzymatic reactions in the oral cavity and continue in the stomach and the small intestine (Gropper and Smith, 2012). In contrast, indigestible carbohydrates such as cellulose, pectin, and inulin cannot be broken to monosaccharides in the upper GI (Gropper and Smith, 2012). This is mainly because the human digestive system does not possess enzymes capable of digesting them (Alexander et al., 2019). Thus, they enter the large intestine where they are fermented by bacteria residing in colon, producing short-chain fatty acids (SCFAs) which control the glycaemic response, enhance mineral absorption, stimulate satiety leading to weight loss, diminish inflammation biomarkers, and enhance intestinal integrity and well-being. Non-digestible carbohydrates differ in their physicochemical characteristics, mainly fermentability. While non-digestible carbohydrates repel digestion by mammalian enzymes, many are used as substrates for bacterial fermentation inside the GI (Thompson et al., 2017).

It has been well documented that the consumption of non-digestible carbohydrates such as dietary fibre causes a reduction in any subsequent food ingestion via mechanisms that include the secretion of gut hormones and acute variations in the

glucose concentration in the blood (Lockyer et al., 2017) . It has also been reported that several types of carbohydrates or sugars could differ in their effects on food ingestion (Feinle et al., 2002).

1.6 Dietary fibres

The SACN defined dietary fibres (DFs) as all carbohydrates that are neither digested nor absorbed in the small intestine and have a degree of polymerisation of three or more monomeric units, plus lignin. Non-digestible carbohydrates DFs are resistant to hydrolysis in the small intestine and are fermented by colon bacteria (Scientific Advisory Committee on Health, 2015).

Intakes of DF in Europe have varied over time and across the countries. Many countries have high fibre intakes, but high-income countries generally tend to have lower than optimal intakes (Stephen et al., 2017). According to WHO recommendations, a healthy diet should contain more than 25 g DF (European Commission, 2017). Most European countries recommend consuming 25 to 30 g of fibre per day (Stephen et al., 2017). Some countries have different recommendations for men and women, e.g. Australia and New Zealand recommend 25 g or more for women and 30 g or more for men (Stephen et al., 2017). Many of these recommendations are based on the estimated intake of 3 to 4 g fibre per megajoule (MJ) of energy intake, which is why men, who generally have higher energy intakes, sometimes have a higher fibre recommendation than women (Stephen et al., 2017).

In the UK, the reference nutrient intake for adults is 30 g daily based on the Association of Official Agricultural Chemists (AOAC) method, which replaced the non-starch polysaccharides (NSP) method in 2002. The new recommendation is to

increase fibre intake by approximately 25%, from 24g (18g NSP) to 30g was based on the latest available data from the meta-analyses of prospective cohort studies on cardiovascular disease, coronary heart disease, stroke, type 2 diabetes mellitus and colorectal cancer (Aune et al., 2011; Threapleton et al., 2013a; Threapleton et al., 2013b; Threapleton et al., 2013c). However, few adults in the UK meet this recommendation, and actual intakes are two-thirds of the recommended levels. Mean daily intakes for men and women are 21 g and 17 g, respectively, with only 13% of men and 4% of women consuming 30 g or more dietary fibre daily (Evans, 2020). Some countries, such as the USA, have intake levels as low as 50% of the recommended values (Canene-Adams et al., 2022).

The primary sources of dietary fibre vary by country. Northern European countries, including Germany, Sweden and Denmark (but not the UK), typically have high intakes of cereals. In contrast, Southern European countries consume more fruit (Bingham et al., 2003). In the UK, vegetable consumption is generally higher than fruit. From the same analysis, legume intake was low in all the European countries except for Spain (Evans, 2020).

1.6.1 Dietary fibre classification

There are several systems to categorise the components of DF. The most widely accepted classification for DF is based on its viscosity and solubility in a buffer at defined pH and their fermentability in an in *vitro* system using an aqueous enzyme solution representative of human alimentary enzymes (Chiu and Stewart, 2012). Thus DF is classified into two main categories: water-insoluble/less fermented fibres such

as cellulose, hemicellulose, lignin and water-soluble/well-fermented fibres such as pectin and gums (Macagnan et al., 2016).

1.6.1.1 Solubility

Soluble dietary fibres (SDFs) dissolve in water, forming viscous gels and are fermented by the microflora of the large intestine (Oakenfull, 2001). Non-cellulosic polysaccharides such as gums, mucilages and pectin are examples of SDFs (Oakenfull, 2001). There is a correlation between high consumption of SDF and increased bacterial populations in the large intestine (Koh et al., 2016). SDF forms a viscous solution that delays digestion and absorption of nutrients (Kristensen and Jensen, 2011). In contrast, insoluble dietary fibres (ISDFs), such as hemicellulose, cellulose, and lignin, do not form gels and are unlikely to be fermented in large quantities due to their water insolubility (Wong and Jenkins, 2007). ISDFs are commonly found in grain products such as rye and wheat, whereas legumes, fruits and vegetables are rich sources of SDF (Lunn and Buttriss, 2007). ISDFs lower energy digestibility because they improve the rate of transit time and increase laxation via water attraction over the GI tract. This results in reduced digestion and absorption of nutrients (Ötles and Ozgoz, 2014). Both SDFs and ISDFs could contribute to controlling body weight, gastric emptying rate, glucose and lipid concentrations in the blood (Ötles and Ozgoz, 2014).

1.6.1.2 Fermentability

SDFs are resistant to digestion and are not absorbed in the small intestine (Alimentarius, 2008). Therefore, SDFs are anaerobically fermented by colonic bacteria upon entering the colon. The Food and Agriculture Organization (FAO)

reported that 70% of SDFs are fermented in the colon and provide estimated energy of 8 kilojoules per gram (kJ/g). However, the energy produced during the fermentation process may be lost in several forms, such as gas and faeces (Alimentarius, 2008). In addition, this estimated energy depends on several factors, including the type of SDFs, microflora characteristics and the fermentation process (Alimentarius, 2008).

Fermentation of SDFs is associated with the formation of carbon dioxide (CO_2) and short-chain fatty acids (SCFAs) such as butyrate and acetate (Topping and Clifton, 2001). Consequently, contribute to the regulation of food intake by increasing energy digestibility, slowing the gastrointestinal transit time and promoting gut peptide synthesis (Koh et al., 2016). In addition, it has been proposed that propionate and butyrate may enter the bloodstream through the portal blood system and stimulate PYY and GLP-1 production (Sleeth et al., 2010).

1.6.1.3 Viscosity

SDFs viscosity is described as the physical interaction of polysaccharides in solution. Viscous dietary fibres (VDFs) are mainly SDFs such as β-glucans, gums, seaweed alginates and pectin, forming thicker solutions when mixed with liquids. The level of viscosity is based on fibre concentration, structure, chemical composition, the rate of hydration and molecular weight (MW) (Oakenfull, 2001).

VDFs exert beneficial health effects by increasing the viscosity of the small intestine, which delays gastric emptying and enhances satiety levels, contributing to reducing body weight (Lunn and Buttriss, 2007). VDFs also shorten colonic transit time, thereby reducing the risk of colorectal cancer and cardiovascular disease (Vermorken

et al., 2016), and diminish rises of postprandial glucose and lipids (Lunn and Buttriss, 2007).

1.6.2 Dietary fibre and appetite regulation

As a major part of the consumed food, DF has a potential effect on satiety and hunger regulation (Kirkmeyer and Mattes, 2000). Several proposed mechanisms describe the influence of DF on satiety (Slavin et al., 2007). Firstly, the ingestion of foods rich in DF prolongs the chewing time, increasing sensory exposure to food in the oral cavity and satiation level (Pentikäinen et al., 2017). Secondly, SDFs increase the viscosity of the intestinal lumen and water holding capacity of the ingested foods, possibly increasing the intestinal volume and inducing a feeling of fullness (Higgs, 2008). Furthermore, DF may reduce the rate of nutrient absorption and enhance satiety (Kristensen and Jensen, 2011).

DFs also stimulate intestinal satiety signals to reduce the gastric emptying rate (Powley and Phillips, 2004; Ritter, 2004). The most well-studied intestinal satiety hormones are PYY, ghrelin, CCK, and GLP-1 (Delzenne et al., 2010; Mars et al., 2012). Thus, the intake of DF slows down the gastric emptying rate by prolonging the release of gastrointestinal peptides and promotes a persistent satiety sensation (Kristensen and Jensen, 2011). Importantly, DF ingestion suppresses the production of ghrelin, the only gut hormone that induces hunger and accelerates gastric emptying (Hartvigsen et al., 2014; Gonzalez-Anton et al., 2017). It has been reported that plasma ghrelin concentrations decrease after the intake of DF-rich bread, whilst the highest ghrelin levels are found after consuming commercial bread (Hartvigsen et al., 2014; Gonzalez-Anton et al., 2017).

1.6.3 Dietary fibre and weight management

It has been reported that the regular consumption of the recommended amounts of DFs has not only regulated satiety and controlled appetite (Kristensen and Jensen, 2011) but also prevented weight gain and obesity (Onakpoya et al., 2014).

Howarth et al. (2001) reviewed 50 intervention trials on the associations between DF intake, body weight and energy intake. The researchers found that increasing DF intake by 14 g/day for a period longer than 2 days was associated with a 1.9 kg weight loss and a 10% decrease in energy intake over 3.8 months (Howarth et al., 2001).

In addition, a prospective cohort study of 252 middle-aged women demonstrated increased SDF consumption was associated with slightly beneficial changes in body weight, and body fat (0.25 kg and 0.25% decrease per 1g increase in fibre intake, respectively) DFs can protect against weight gain via several mechanisms. First, DFs reduce food and energy intake (Tucker and Thomas, 2009), particularly metabolisable energy (ME), which is the amount of energy consumed minus the energy lost in the faeces, combustible gases and urine (Jovanovski et al., 2020). Second, the fermentation of SDFs by gut microbiota stimulates the production of PYY and GLP-1. These hormones play a critical role in body weight regulation inducing satiety (Keenan et al., 2006; Parvaresh Rizi et al., 2018).

1.6.4 Dietary fibre and metabolic response

The consumption of SDFs appears to improve glycaemic control by increasing the intraluminal intestinal viscosity and small bowel transit time (SBTT), contributing to reduced glucose absorption. VDFs bind to glucose molecules in the intestinal lumen, limiting their absorption in the small intestine (Lattimer and Haub, 2010).

Additionally, DFs reduce the digestive actions of gastrointestinal enzymes such as α-glucosidase and α-amylase, decreasing the degradation of carbohydrates into glucose and preventing a postprandial rise in blood glucose levels. DFs also affect the secretion of gut hormones such as CCK and GLP-1, further contributing to glucose homeostasis (Adam et al., 2014; Zaremba et al., 2018).

Moreover, the ingestion of DFs stimulates the secretion of the glucose-dependent insulinotropic gastric inhibitory polypeptide (GIP), an incretin hormone that stimulates postprandial insulin release (Sandberg et al., 2017). These physiological actions decrease daily insulin surge, leading to a postprandial reduction in counter-regulatory hormone release, and improved insulin sensitivity. Further, SDFs promote the production of SCFAs, particularly acetate and butyrate, by the bacteria in the colon. SCFAs protect the intestinal mucosa against oxidative stress, decrease inflammation, improve insulin sensitivity and reduce postprandial blood glucose levels by lowering circulating free fatty acids (Alexander et al., 2019).

DF intake also benefits cholesterol homeostasis in adults (Vuksan et al., 2000; Lattimer and Haub, 2010). Postulated mechanisms for these cholesterol-lowering effects include alterations in cholesterol absorption (Gallaher et al., 2002). Moreover, enhanced production of bile acids in the liver, reduced bile acid re-absorption, increased faecal sterol or bile acid output and alterations in hepatic metabolism and plasma clearance of lipoproteins (Wu et al., 2011). The mechanisms responsible for the cholesterol-lowering effects of DFs may include reduced gastric emptying rate, decreased nutrient absorption rate, and increased bile acids excretion. Consequently, contribute to a reduction in total cholesterol (TC) and low-density

lipoprotein (LDL) levels. Additionally, SDFs stimulate SCFA production, particularly propionate by gut microbiota, reducing cholesterol synthesis (Vuksan et al., 2008; Alexander et al., 2019).

1.6.5 Konjac glucomannan as a proposed dietary fibre

KGM has superior hydration ability, with 1 g of KGM absorbing up to 200 mL of water and forming a voluminous mucilage. Its viscosity is also the highest among common hydrocolloids. As a result, it can promote gastric satiation through a gel-like viscous mass created in the stomach (Guo et al., 2021). The viscosity of 1% KGM solutions is approximately 10 times more than 1% guar gum solutions and 100 times more than other SDFs like pectin (Doi, 1995). Such a high viscosity allows KGM to be clinically effective in lower concentrations (as low as 3g per day) compared to other types of DF (McCarty, 2002). This superior thickening ability delays nutrient absorption and extends the release of appetite-related gut hormones that, prolonging the sense of satiety (Guo et al., 2021). KGM is also well-tolerated with only mild gastrointestinal effects and is stable under varying pH conditions (Lu et al., 2018; Zhao et al., 2020).

Some of the DFs, such as β-glucan and arabinoxylan, have limited use in beverages; for instance, β-glucan and arabinoxylan have a noticeable cereal flavour (Inglett and Newman, 1994; Jòzef, 2007), and they need mixing with hot water (Rieder and Samuelsen, 2012). Other DFs such as KGM do not have such claims. Also, they are flavourless, scentless and colourless (Chua et al., 2010; Xu et al., 2014; Kuczora et al., 2015). Moreover, KGM can dissolve in cold water and not break down under low pH conditions. These properties make KGM novel DF optimal for incorporation in beverages to improve their nutritional profile and shelf-life (Mudgil et al., 2014).

Konjac glucomannan (KGM) is a soluble viscous dietary fibre extracted from brown konjac root tubers. KGM is considered one of the most VDFs, with viscosity that is five times higher than that of guar gum, xanthan gum and b-glucans in concentrations of 1 to 7% (Vuksan et al., 2000). KGM is a major hydrocolloid polysaccharide that belongs to the *Amorphophallus* Konjac group of the *Araceae* family (Kohyama et al., 1992; Pereira et al., 2010; Behera and Ray, 2016).

The Konjac plant is among the main vegetable (tuber) crops grown in Africa and Southeast Asia (Chua et al., 2010; Pereira et al., 2010; Behera and Ray, 2017). There are more than 170 species that belong to this genus. However, only fewer than 10 are often used for nutritional aspects (Herranz et al., 2012). Commonly, the external appearance of the plant consists of an underground stem that extends into a corm. It has an extensively dissected umbrella-shaped leaf blade extended to the other end of the stem overhead the ground (Figure 1.5) (Chua et al., 2010).

Figure 1-5 Amorphophallus konjac k. Koch plant.

The upper stem and leaf (left) and harvested corm contains the KGM (right). Adapted from (Au-Yeung, 2016).

KGM plants are typically ground immediately after harvesting to produce raw flour; otherwise, they are refined for other uses. During the refining process, KGM material is produced by either dry or wet processing to obtain different grades of KGM for various uses (Chua et al., 2012).

1.6.5.1 History, use, and safety of konjac glucomannan

KGM plants have a long history of use back to 206 BC "before Christ" in China, when the genus Amorphophallus was discovered and used as Chinese medicine and food source. KGM was made known to the general public in Japan in 950 AD "Anno Domini". Then, KGM eventually became popular as a vegetarian foodstuff (Xu et al., 2001). In the 19th century, the production and consumption of KGM significantly increased. Currently, KGM is consumed in most areas in Japan and China. KGM-gel has been widely used to treat cough and asthma. In addition, KGM-gel has also been consumed as a functional food in Japanese cuisine in the form of noodles, known as "konnyaku", and cake known as "shirataki" (Wootton et al., 1993; Bown, 2000).

Apart from starch, lipid and minerals, glucomannan is the main component of the konjac corm which accounts for ∼70% of the dry weight of refined flour (Behera and Ray, 2017). KGM is considered one of the most viscous dietary fibres (VDFs), with viscosity that is five times higher than that of guar gum, xanthan gum and β -glucans in concentrations of 1 to 7% (Vuksan et al., 2000). VDFs increase the viscosity of the intraluminal space while decreasing nutrient absorption and the rate of gastric emptying, which leads to increased satiety and energy regulation (J. L. Slavin, 2005). In fact, there has been a growing demand for products that contain nutrients with the above health benefits (Mintel, 2021). KGM was approved as a food additive by

the US Food and Drug Administration (FDA) in 1997 and received the 'Generally Recognised as Safe' (GRAS) status. In the US, KGM was approved due to its exceptional gelling and rheological properties, which allowed it to be applied as a binding agent and texture enhancer in the food industry for meat and seafood (Jiménez-Colmenero et al., 2012; Salcedo-Sandoval et al., 2015; Zhang et al., 2016). Then, it was approved in Europe and Canada in 1998. KGM was given an E425 agreement code by European Food Safety Authority (EFSA) EFSA (2010). The EFSA panel has approved two health claims for the use of KGM powder. The expert panel confirmed that there was sufficient evidence to support a cause-effect relationship between KGM powder with cholesterol reduction and body weight regulation (EFSA Panel on Dietetic Products and Allergies, 2010). Therefore, providing a further rationale for the inclusion of KGM in fruit beverages; however, further research is required to fully elucidate this role in translational studies. Moreover, the World Health Organization (WHO) included KGM as one of the ten greatest healthy foods (Yao-ling et al., 2013; Behera and Ray, 2016).

KGM has been extensively utilised in controlled medication delivery systems and as a food supplement (Sood et al., 2008; Onakpoya et al., 2014). KGM-gel has attracted widespread attention among European and North American consumers. This is because most commercial KGM-gel food products indicate the high fibre and low energy content of KGM-gel, which enhances its benefits in terms of weight regulation (Karl et al., 2016; Au-Yeung et al., 2018). There are many available forms and variations of KGM-gel, such as rice, imitation meats (pork, chicken, and sausages), imitation seafood (shrimps and scallops), imitation pasta of various shapes (shells, penne, and fettuccine), and vegetables (peas, corn, and carrots). KGM-gel has also

frequently been used as an additive to soy, tofu, or oat to enhance their oro-sensory properties. These forms of KGM-gel food can be used as an alternative to high-energy content foods (Jiménez-Colmenero et al., 2012).

Despite the widespread consumption of KGM in Asia, there is a limitation to its use. Some concerns have been established regarding the KGM-gel, including oesophagal and GI obstruction due to the fast hydration of KGM gel (Fung, 1984; Gaudry, 1985).

Furthermore, the United States, Europe, and Canada reported choking risk and oesophageal obstruction in children and the elderly after consuming flavoured fruit snacks made of KGM-gel. These observed effects might be due to the method of use (Vanderbeek et al., 2007; Sood et al., 2008). In addition, other studies observed gastrointestinal mild side effects related to the consumption of KGM as an SDF (Sood et al., 2008). KGM contains around 5-14% protein, which causes a fishy smell, requiring a de-odourisation process. These functional limitations can be solved by partially hydrolysing the polymers. However, this potential process may decrease its effectiveness. As a result, KGM use received a safety warning from EFSA. This was due to choking effects upon ingestion with an insufficient amount of water and for people with swallowing difficulties. Thus, users were advised to drink plenty of water to ensure that the material reached the stomach (EFSA, 2010). Furthermore, it has been reported that the KGM viscosity is about 36,500 millipascal per second (mPa.s). This property might restrict its use in fruit juice because VDF is only suitable for semi-liquid beverages (Lopez-Rubio et al., 2016).

Despite all of the above, most randomised controlled trials (RCTs) confirmed that KGM is well tolerated and can be safely used in human trials and research studies (Sood et al., 2008; Guo et al., 2021; Nagasawa et al., 2021).

1.6.5.2 Physicochemical properties of konjac glucomannan

Amorphophallus konjac K. Koch is considered the most well-known crop containing one of the primary yields of KGM (Parry, 2009; Tester et al., 2017). The molecular weight of KGM is between 200 to 2000 kilodalton (KDa) (Ma et al., 2019). KGM side chains contain 5 to 10% acetyl groups that occur every 10-19 units on the KGM backbone in β-1, 6 linkages, making KGM soluble in water (Maekaji, 1978; Zhang et al., 2005) and cannot be hydrolysed by salivary and pancreatic amylase (Doi, 1995). (Figure 1.6) shows the structure of KGM.

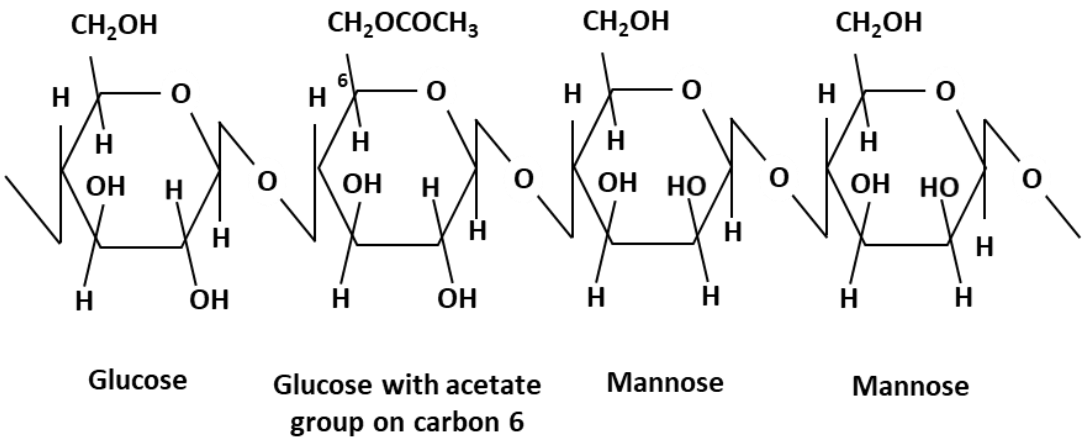


Figure 1-6 Chemical structure of KGM.

It shows a linear backbone of beta-1 (β-1), 4 linkages of D-mannopyranose and D-glucopyranose sugars organised in a random order in a ratio of 1.6:1, with repeats of three to five blocks of prevalent mannopyranose sugars. Figure adapted from (Keithley et al., 2013).

The corms of KGM include 49-60% glucomannan, 2-5% fibre, 3-5% soluble sugars, 10-30% starch, 3.4-5.3% ash, 5-14% crude protein and 3-7% minerals, including calcium,

aluminium, iron, magnesium, chromium, potassium, zinc, cobalt, selenium, manganese, phosphorus, potassium, silicon, sodium, and zinc (Li et al., 2005) and a small number of alkaloids and saponins in addition to the hint elements of organic compounds zinc (Akesowan, 2002; Li et al., 2005; Chua et al., 2010).

KGM is found in two forms, powder and gel. The powder form has a high water-holding capacity (up to 50-150 times its weight), producing a highly viscous solution (Parry, 2009). When KGM powder is dissolved in an aqueous solution at concentrations less than 7 to 8% weight by weight (w/w), it produces pseudoplastic or non-Newtonian conduct. This is because of the formation of junction zones from the hyperentanglement of the KGM backbone (Kohyama et al., 1992; Dave et al., 1998). In contrast, KGM solutions show Newtonian flow and the inability to form a viscous gel at concentrations less than 0.55%. The rheological properties of KGM powder rely on its source, concentration, and purity. KGM milled to fine particles achieves faster viscosity when added to aqueous solutions (Li et al., 2005). Gel is the other form of KGM. The rheological characteristics of the KGM gel have been studied widely in pharmacological and industrial applications (Alonso-Sande et al., 2009; Jiménez-Colmenero et al., 2012).

1.6.5.3 Macronutrient and sensory properties of konjac glucomannan

Although KGM in powder or gel form displays different physicochemical characteristics, both forms present similar nutrient content consisting of dietary fibre and minor quantities of protein and carbohydrates (Table 1.2). For equal fibre content, the energy value of both KGM forms is similar. Due to the gelation process

and the ability of KGM-gel to trap water, the energy density (ED) varies between the two KGM forms.

Table 1-2 Nutrient composition of KGM and powder and gel.

Nutrient composition	KGM powder (g)	KGM gel (3% KGM gel)
Energy Content (kcal)	12	12
Carbohydrate (g)	0	0
Protein and fat (g)	0	0
Dietary Fibre (g) *	3	3
Weight (g)	3	100
Energy Density (kcal/g)	4	0.12

*Energy contribution of fibre was calculated as 4 kcal/g.

Adapted from (Au-Yeung, 2016).

The sensory properties of KGM are mainly affected by the grade of purity investigated the main differences between refined and unrefined KGM (Chua et al., 2010). Refined KGM samples, with refining higher than 95% KGM, for both forms, produced odourless and tasteless properties and the formation of white semi-translucent gels. These gels have a firm and elastic texture. Unrefined KGM powder ranges from yellow to grey and produces a dark grey or light-brown gel (Chua et al., 2010).

1.6.5.4 Health benefits of konjac glucomannan

A large number of studies on KGM have indicated that KGM supplementation is associated with a variety of health benefits, including the reduction in cholesterol

levels (Sood et al., 2008), triglyceride concentration in blood (Martino et al., 2013), improve laxation (Chen et al., 2006), enhancement of immune functions and intestinal activities (Chiu and Stewart, 2012; Onitake et al., 2015), reduction of body weight (Zalewski et al., 2015), prevention of diabetes (Chen et al., 2006) and the resolution of inflammation (Onishi et al., 2007). In addition, FDA has recognised KGM as a safe biomaterial (Xu et al., 2007) and WHO included KGM as one of the ten most incredible healthy foods (Yao-ling et al., 2013; Behera and Ray, 2016).

A meta-analysis of 14 randomised controlled trials using KGM reported that KGM consumption was associated with a significant reduction in fasting blood glucose (0.41 mmol/L), total cholesterol (0.50 mmol/L), LDL cholesterol (0.41 mmol/L), triglycerides (0.13 mmol/L) and body weight (0.79 kg) (Sood et al., 2008). The meta-analysis emphasised the importance of increasing the length and quality of the randomised controlled trials of KGM powder.

Subsequently, EFSA approved two health claims for using KGM powder for health improvement. In addition, the expert panel confirmed that there was sufficient evidence to support a cause-effect relationship between KGM powder and cholesterol reduction and body weight regulation (EFSA, 2010). Due to insufficient evidence, the panel did not approve claims for improvements in triglycerides and fasting blood glucose. In contrast, no health claims have been approved for the use of KGM in the United States and Canada.

The gelatinous nature of KGM in the body provides a sense of satiety and fullness and promotes peristalsis, thus regularising bowel movements. Thus, KGM induces sensory satiation by increasing oral cavity exposure time, reducing meal palatability

and energy density (Au-Yeung, 2016). Furthermore, during digestion, KGM merges with the food bolus and forms a nondigestible bolus, leading to sugar and fat retention in the bolus, thereby reducing assimilation and metabolism (Chen et al., 2003).

KGM absorbs digested body waste in the stomach and intestine by entrapping it into a gelatinous mass, which is eliminated from the body without being absorbed. KGM is also highly fermented by host bacteria, as it passes relatively unchanged into the colon because human salivary and pancreatic amylase cannot split the β-1, 4 linkages. The increased production of SCFAs by colonic bacteria subsequent to the fermentation of KGM stimulate mucus production and secretion in the large intestine which acts as a barrier against insulting agents and prevent infections. Increased SCFA also promotes generation of colonic regulatory T cells, maintaining a normal function of the innate and adaptive immune system. This immunoregulatory effect may reduce the risk of inflammatory bowel disease and colorectal cancer (Makki et al., 2018).

Further, it acts as a barrier to the absorption of sugars and nutrients due to its viscosity produced in the gastrointestinal compartments (Devaraj et al., 2019). These characteristics make the KGM an attractive DF for the food industry and a potentially helpful dietary supplement in the clinical setting. (Figure 1.7) illustrates the proposed mechanisms of action of KGM.

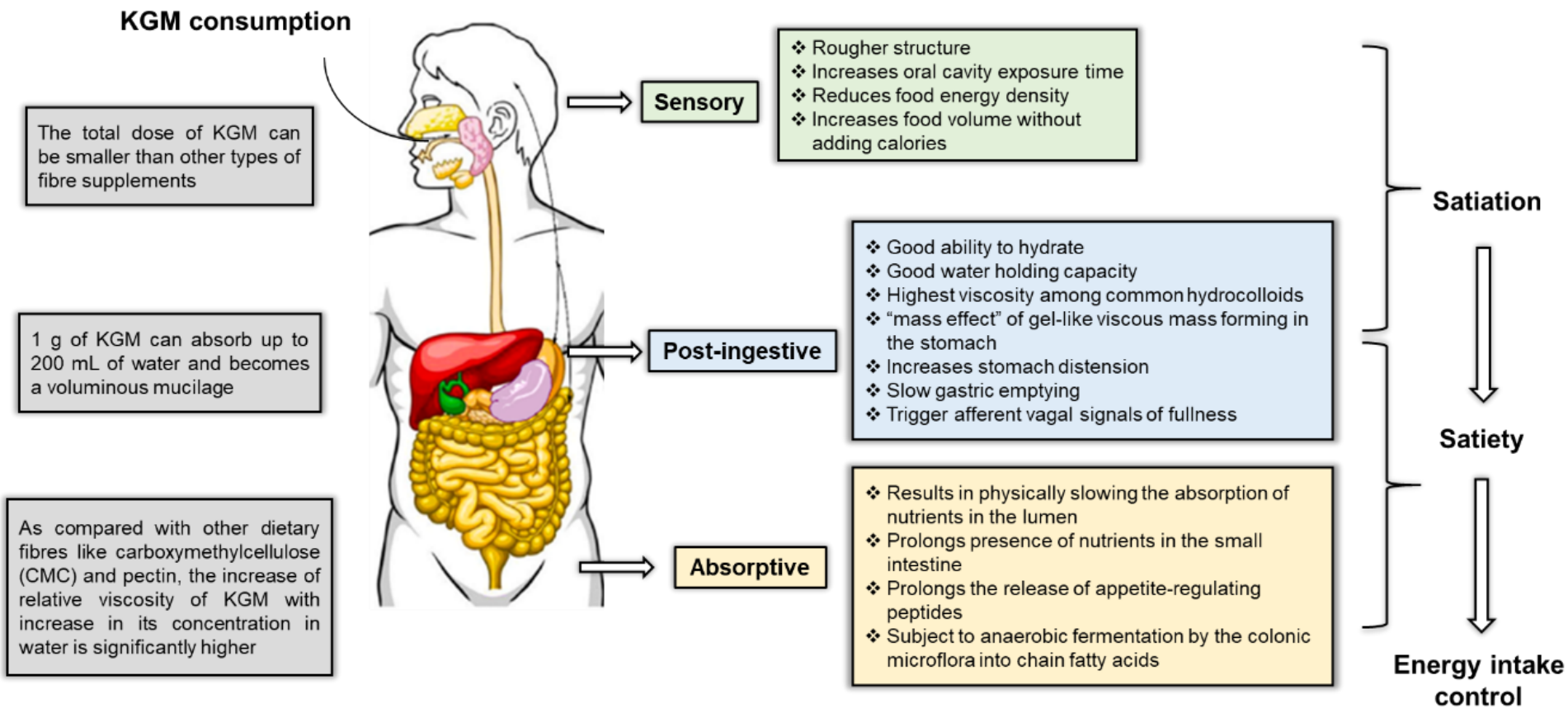


Figure 1-7 The proposed modes of action of KGM leading to the regulation of appetite control and management of weight loss.

Figure drawn by the author based on information adapted from (Guo et al., 2021).

1.7 Aim and Objectives

The aim of this research was to determine the impact of KGM supplementation on the acute metabolic and appetite response to meal consumption. To achieve this goal, fives studies were conducted to:

1. Elucidate the attitudes and perceptions of smoothie consumers in a university cohort.
2. Examine the effect of KGM powder fortification on the rheological properties of commercial fruit smoothies.
3. Explore the knowledge and awareness of UK adults regarding DF consumption.
4. Evaluate the effectiveness of KGM capsule consumption at improving 2hr metabolic and appetite response to the ingestion of sugar-rich smoothies.
5. Assess the metabolic benefits of KGM capsules in healthy adults and adults with obesity and/or T2DM.

Chapter 2: Attitudes, beliefs, and behaviours in a UK university cohort regarding the consumption and nutritional characteristics of smoothies

2.1 Introduction

The World Health Organisation (WHO) has recommended daily consumption of at least 400 g of fruit and vegetables (WHO, 2003). Although the WHO stated that increasing fruit and vegetable consumption is one of the most critical health behaviours, only 28% of UK adults consumed the recommended amount of fruit and vegetables daily in 2018 (Department of Health, 2018). Hence smoothies offer an opportunity to increase fruit and vegetable consumption (Boulton et al., 2016).

Smoothies are considered healthy and popular beverages that may increase fruit and vegetable intake at the individual level (Derbyshire, 2017). The term “Smoothie” was introduced first in 1960 in the US and, after 40 years, the market for smoothies re-emerged in 2000 (Qian, 2006). Fruit smoothies are blended beverages using the whole fruit (pitted and peeled). Smoothies can be consumed either as a meal replacement or as a nutritious between-meal snack depending on the serving size, gaining increasing market influence in the UK market (Mintel, 2018). Over five years (2016 to 2021), both smoothies and juice bars industry in the UK had revenue growth of £56.3 million at a compound annual rate of 5% (Mintel, 2021). All of which highlights the increased popularity of the beverage, emphasising the need for further research.

Although published scientific data on smoothie consumption is limited, the availability and accessibility of smoothies appear to have increased (Mintel, 2021). Ready-to-drink beverages (i.e. pre-packaged), made-to-order smoothie bars, and kitchen appliances that facilitate the production of freshly made smoothies are now widespread in the market. Commercial reports suggest that the smoothie industry

has experienced considerable financial growth in many countries (e.g. the UK, USA, Australia and New Zealand) (Gehtman, 2008). For example, the British Soft Drinks Association indicated that in 2011, 51 million litres of commercial smoothies were consumed in the UK (Mintel, 2016). The most recent market analysis by Mintel (2021) showed that 71% of respondents had consumed smoothies between August and October 2020, with 14% of the respondents drinking smoothies daily. The recent uptake in smoothie beverage consumption results from a variety of variables. A recent study indicated that 60% of people agreed that smoothies increased nutrient intake(Mintel, 2021). In addition, daily consumption was higher in households with children, reflecting the family appeal of smoothies (Mintel, 2021). This is believed to be due to a shift towards healthier eating patterns and ensuring recommended daily intake is achieved in younger children. In line with the above trend, a study by Bates and Price (2015) reported that offering fruit smoothies (as a substitute for a whole fruit) as part of a school breakfast programme over (10 weeks) led to an increase in the number of adolescents students eating ≥1 serving of whole fruit/day increased from (4.3% to 45.1%). Thus, including smoothies as part of a school breakfast can improve fruit consumption among students as smoothies are more accessible than whole fruit (e.g. no peeling or chewing required). Smoothies are also more appealing to students as they resembling popular dessert drinks such as milkshakes (Myers et al., 2021).

A recent study found that smoothies are rich in nutrients such as antioxidants, vitamins and polyphenols as opposed to other beverages available (Nowicka et al., 2016). That interest in immunity is expected to continue, which may also boost smoothies appeal in the future (Mintel, 2021). It has been found by Mintel (2016)

that university students and employed people are among the groups with the highest smoothie consumption. This finding is in line with that of the literature, which suggests the level of education is positively correlated with that of fruit and vegetable intake (Rothpletz-Puglia et al., 2022). This is likely due to a better understanding and knowledge of dietary requirements and nutrient contents of specific food groups. Therefore, it is important to explore the contribution of smoothies to the dietary intake of this population groups, with a particular focus on their interest in drinking smoothies as a healthy and convenient way to increase fruit consumption and protect against health conditions.

2.2 Aim and Objectives

This study aimed to explore a UK university cohort's attitudes, beliefs, and behaviours toward these popular drinks.This was achieved through the following research study objectives: 1) describe patterns of smoothie consumption among a UK university cohort of smoothie consumers; 2) investigate the rationale behind smoothie consumption; 3) awareness and perception of the study participants regarding the sugar content of smoothies; 4) explore study participants views on the nutritional profile for a healthy smoothie; and 5) identify the factors contributing to the preference for freshly made smoothies or available commercial smoothies.

2.3 Materials and Methods

2.3.1 Ethical approval

A cross-sectional online survey was conducted between March and June 2017 (120 days). This study was approved by the MMU Manchester Metropolitan (MMU)'s

Ethics Committee, Faculty of Health, Psychology & Social Care (Ethics checklists Ref No: 1458) (Appendix 1).

2.3.2 Participants, eligibility criteria and recruitment

Participants included in the study were adults (older than 18 years), UK university students or staff, and consumers of fruit smoothies (n=59). The study only enrolled smoothie's consumers as identified via participant baseline survey distribution. This was conducted to maximise the chance of identifying the frequency of consumption, favourite smoothie flavours and brands commonly consumed by the study participants.

Participants were recruited by advertisement posters placed on the University of campus. The project was also advertised on social media. In addition, in collaboration with the MMU Faculty of Health, Psychology & Social Care, the information about the project was distributed via email to MMU students and staff. The recruitment process also included snowballing, whereby the interested volunteers were asked to pass on details of the study to others via spoken word or email.

The distributed emails contained a link to the online survey containing an initial study overview and a consent form. The informed consent form was signed electronically by all subjects before participation. In addition, the information sheet was provided to the potential participants (Appendix 2).

2.3.3 Sample size

The sample size for this survey was calculated from an estimated consumption rate of 40% in the general population (Mintel, 2016) using the following formula: Study sample was calculated = 57. Sample size = $Z_{1-\alpha/2}^2 p (1 – p) / d^2$

Where $Z_{1-\alpha/2}$ corresponds to a $p < 0.05$, p is the estimated prevalence from previous studies, and d is the precision appropriate for the estimated prevalence (for a common prevalence, the precision of 0.05 is suggested).

2.3.4 Survey overview

This survey was developed and administered to the university cohort population. The survey explored smoothie consumption among university students and staff, including their perceptions, preferences, and attitudes. Questions in relation to preferences and attitudes were adapted and modified from Solah et al. (2015) and Mintel (2016).

A web-based research survey platform (Qualtrics®) was used to create the questionnaire and to collect participants' responses. Survey questions were piloted on five volunteers, who were not members of the research team, to determine the face validity (content, structure and wording) of the questionnaire. This pilot study was conducted to inform the researcher about the overall structure of the questionnaire and to help with the amendment of the individual questions. This process resulted in the formulation of new questions and minor changes to structure and wording. The final version contained nominally- and ordinally- rated questions. (~5 min duration) to allow for increased participation in the online survey.

2.3.5 Survey design

The survey was divided into 6 sections. Section 1 included demographic information, such as age, gender and occupation (undergraduate, postgraduate, academic staff, technical/support staff). Section 2 investigated smoothie consumption frequency per month in the last three months. In section 3, smoothie consumers were asked to provide rationale for consuming smoothies (i.e., smoothies being tasty or healthy, as a meal replacement, to meet 5-a-day or other reasons). In section 4, participants were asked to choose their favourite smoothie brands and flavours from a list of the products available in the UK market. Section 5 was used to explore attitudes towards the nutritional profile of smoothies, including the importance of low fat, low sugar, high protein, high fibre, or high mineral and vitamin content. Section 6 was used to identify the factors contributing to the preference for freshly made smoothies or available commercial smoothies (Appendix 3) (McCartney et al., 2018).

2.3.6 Data analysis

SPSS statistical software version 23 was used to analyse the data. Ordinally rated variables were described as median and interquartile range (IQR), while nominal data were described by frequency and percentage. Cross-tabulation with the Chi-square test was used to explore the association of the ordinally-rated responses. If the assumptions for Chi-square tests were violated, the likelihood ratio test was used as the alternative. Spearman's correlation was employed to explore the relationship between age and smoothie consumption.

As the study participants' questions of interest (attitudes, perceptions and consumption habits) were based on ranking, the data were considered

nonparametric. Therefore, non-parametric comparative tests, i.e., the Kruskal-Wallis tests, were used depending on the number of categories per group. Significant findings were followed up with Bonferroni adjust pairwise comparisons. The statistical significance was defined as a p-value<0.05. It is worth mentioning that there was an outlier in the smoothie consumption data from the study participants (Baharun, 2008).

2.4 Results

Overall, 66 participants took part in the study, but 57 participants (15 males, 43 females, one unknown) completed the survey. The study participants were students and university staff (13 undergraduates, 27 postgraduates, 4 support and technical staff and 15 academic staff) aged 18 to 57 (33±9) years (Table 2.1).

Table 2-1 Characteristics of the study participants (n=59).

Variable	Participants n (%)
Age groups (y)	
18-24	12 (21.8)
25-34	28 (50.9)
35-44	9 (16.4)
45-54	4 (7.3)
55-64	2 (3.6)
Gender	
Male	15 (25.9)
Female	43 (74.1)
Occupation status	
Undergraduate	13 (22.0)
Postgraduate	27 (45.8)
Technical and Support Staff	4 (6.8)
Academic Staff	15 (25.4)

2.4.1 Smoothie consumption frequency (per month) by demographic characteristics

Overall, a large proportion of the study participants with available data on smoothie consumption had drunk smoothies over the last three months (92.2%) between March and June 2017. On average, the study participants had consumed smoothie drinks at least 3 times over the previous three months (Median=3, IQR=3).

The relationship between smoothie consumption per month and the age groups of the study participants was analysed using Spearman's correlation test. As shown in (Figure 2.1), there was a significant inverse correlation (r_s=-0.33, *p*=0.038), with younger participants (20-30) years old drinking a larger number of smoothies per month.

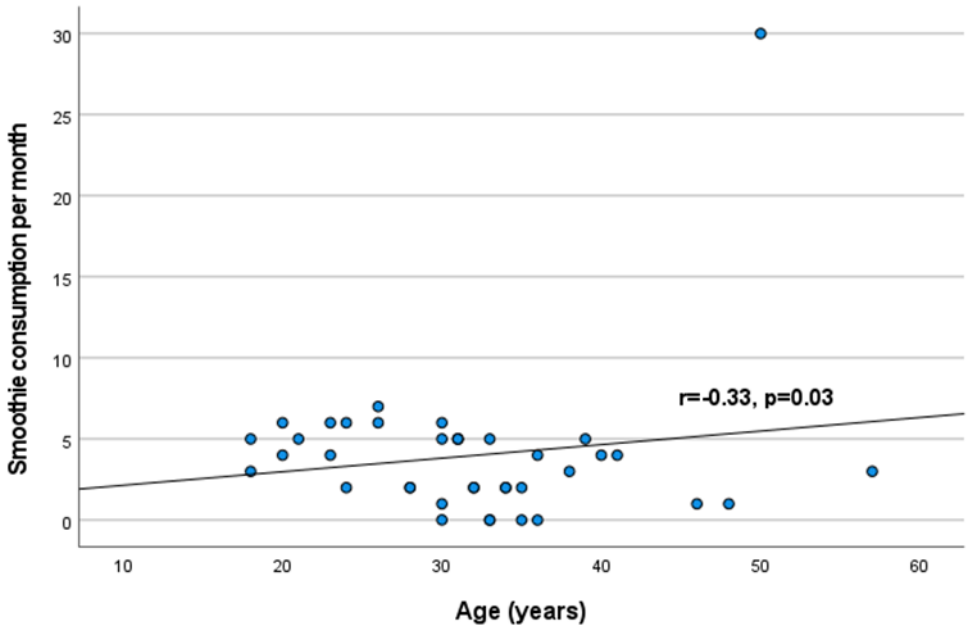


Figure 2-1 The correlation between the age of the study participants and smoothie consumption per month in the last three months between March and June 2017.

Kruskal-Wallis test indicated that the consumption of smoothies varied significantly across occupation groups (X^2=9.5, p=0.023). As shown in (Figure 2.2), the median consumption was higher in undergraduate students (5 times per month) and technical/support staff (approximately 4 times per month) than in postgraduate students and academic staff each (nearly 2 times per month).

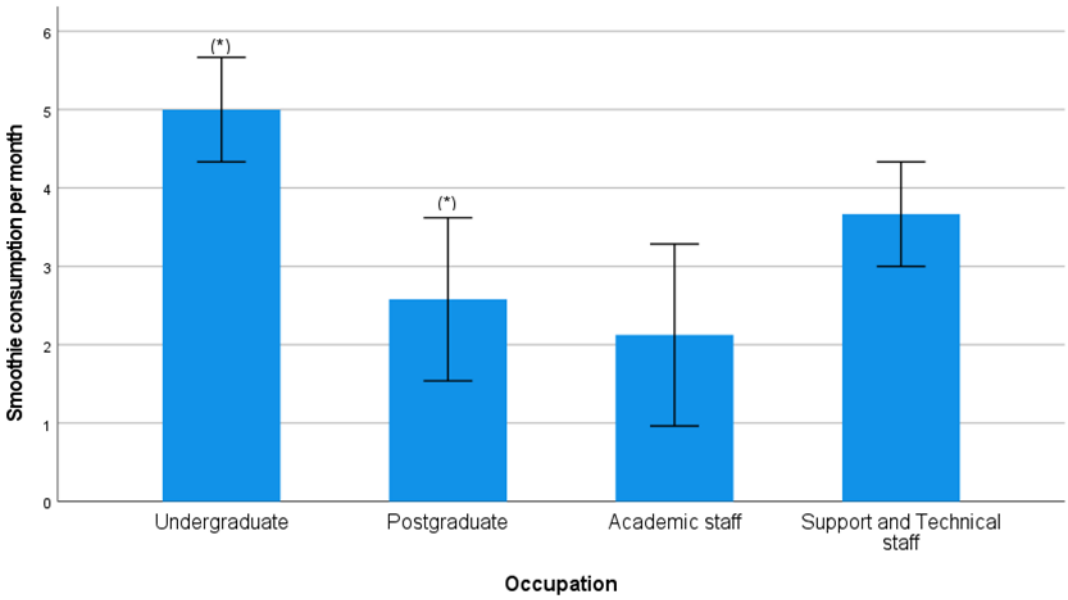


Figure 2-2 The difference in smoothie consumption per month in the last three months between March and June 2017 across the occupation groups of the study participants. (*) indicates the groups with a significantly different smoothie consumption per month.

The above significant finding (X^2=9.5, p=0.023) was followed by a post-hoc analysis with Bonferroni correction to identify the occupation groups with a significant difference in smoothie consumption per month. Following pairwise comparisons of the occupation groups, the only significant difference was observed between undergraduate and postgraduate students (median difference=3, Bonferroni adjusted p=0.02). The difference in smoothie consumption between other study population groups was non-significant.

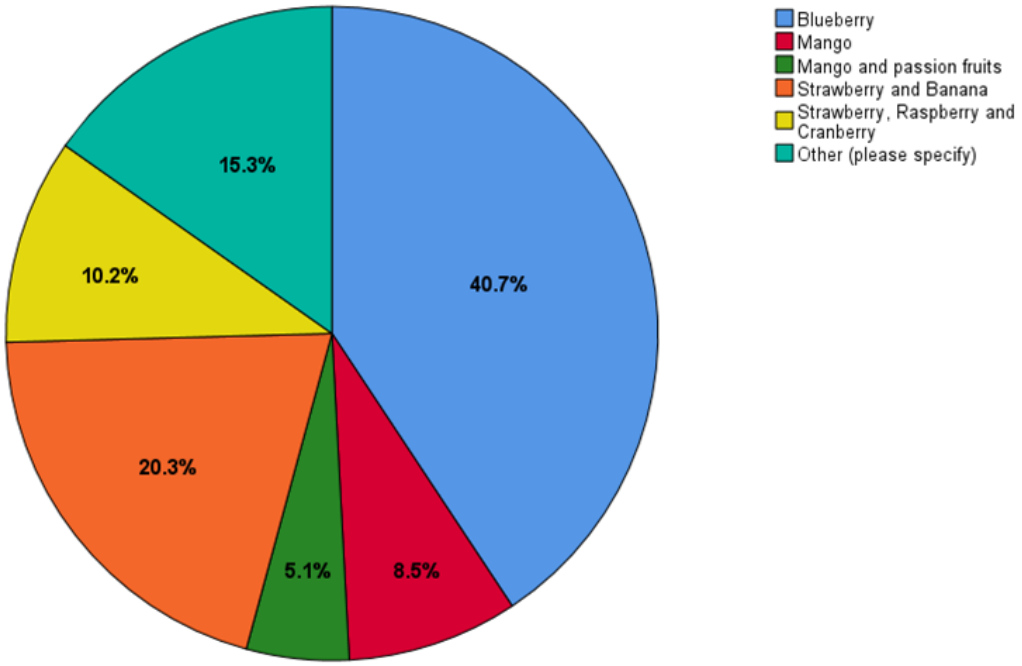
2.4.2 Reasons for drinking smoothies

The majority of the participants reported taste (72.4%) and health benefits (65.5%) as their reasons for drinking smoothies. In addition, 31% of the study participants stated that they consumed smoothies to meet the 5-a-day recommendation. Notably, meal replacement was the least frequently reported reason for drinking smoothies (10.3%).

The likelihood ratio test showed that the reasons for drinking smoothies were not significantly different between occupation groups: being tasty (LR=0.20, p=0.97) or healthy (LR=3.38, p=0.33), consuming for a meal replacement (LR=4.27, p=0.23), meeting the 5-a-day (LR=2.36, p=0.50) or consuming for other reasons (LR=7.14, p=0.06).

2.4.3 Favourite smoothie flavours and brands available in the UK market

The percentage responses to favourite smoothie brands and flavours are illustrated in (Figure 2.3). The current study results showed that blueberry was the favourite smoothie flavour (40.7%) and Naked was the preferred smoothie brand (41.1%) among study participants.



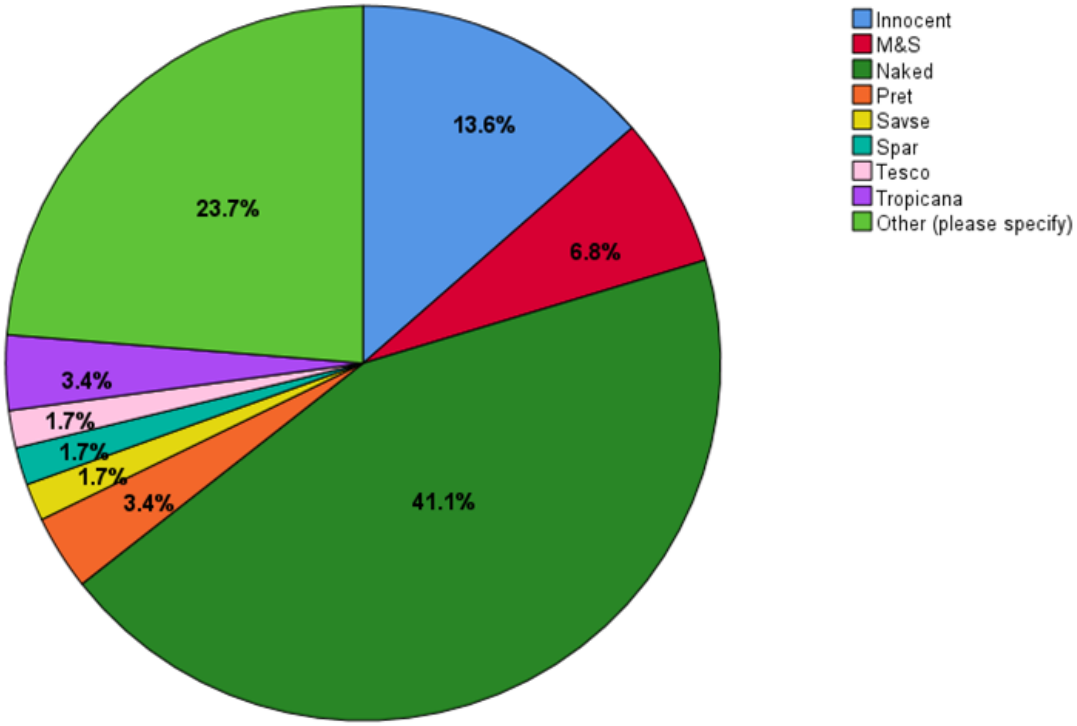


Figure 2-3 Favourite smoothie brands and flavours available in the UK market among the study participants.

2.4.4 Perceived importance of nutritional profile of a healthy smoothie

Overall, the participants rated low sugar (median=2), followed by high fibre (median=3) and low fat (median=3), as the most important nutrient profiles for a healthy smoothie (Figure 2.4).

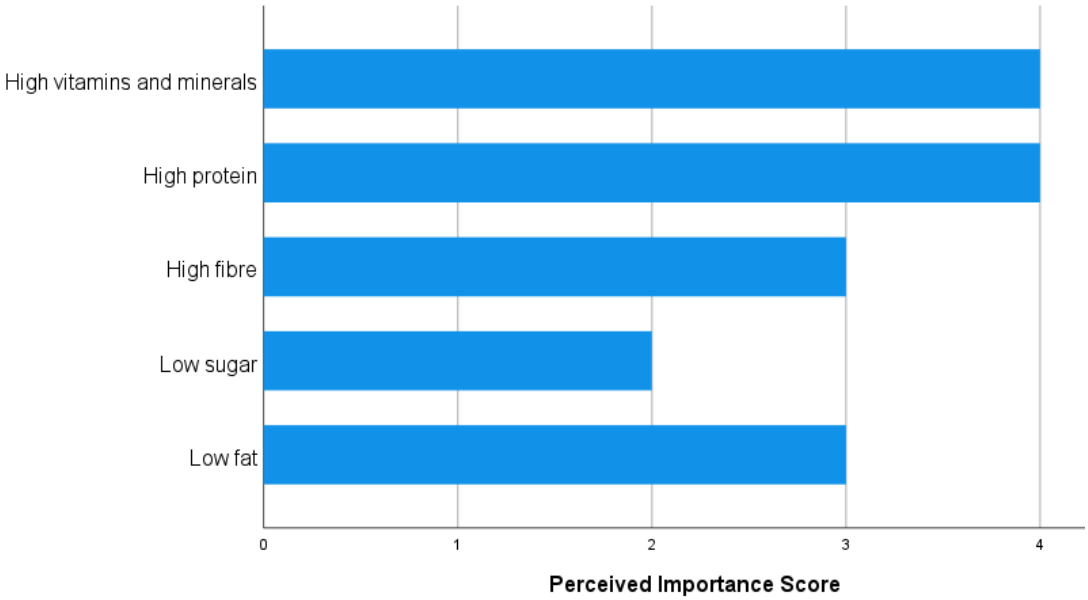


Figure 2-4 Perceived importance of various nutrient profiles for a healthy smoothie among the study participants. Higher scores indicate less perceived importance.

Based on the Kruskal Wallis test, the perceived importance of high fibre content (X^2=7.6, *p*=0.02) and high mineral and vitamin content (X^2=6.8, p=0.03) differed significantly between occupations groups of the study participants. The perceived importance of high fibre content was highest among undergraduate students (median=2). Conversely, the perceived importance of high minerals and vitamins was lowest in undergraduate students (median=5). Postgraduate students had the

highest importance rate for the high mineral and vitamin content (median=3) (Figure 2.5).

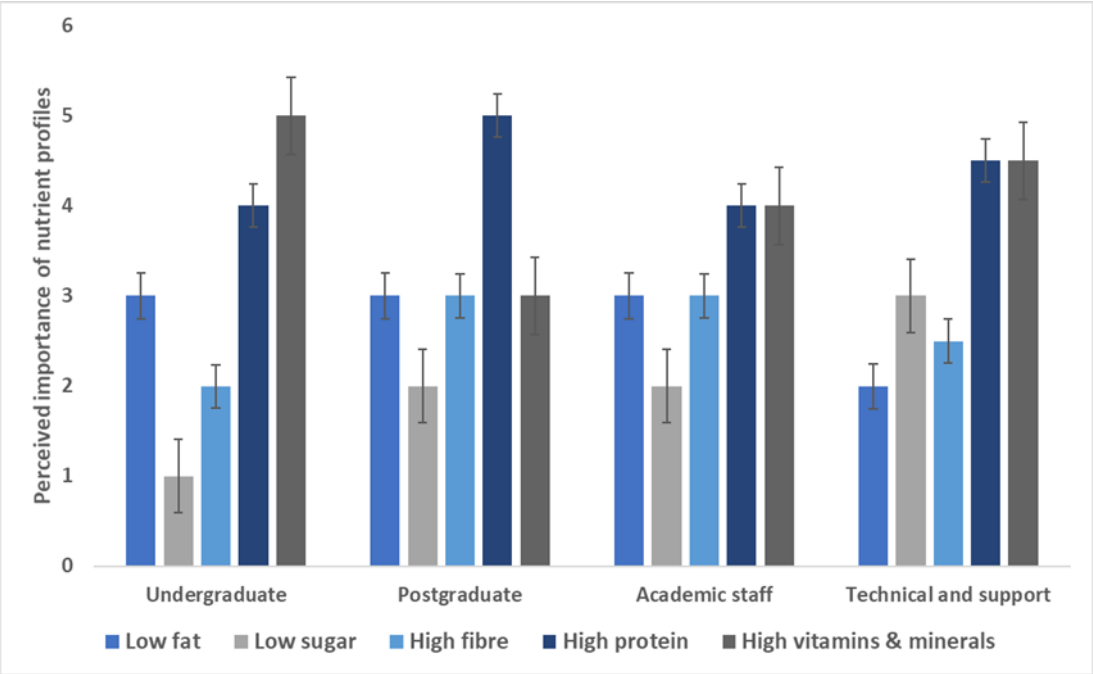


Figure 2-5 Perceived importance of various nutrient profiles for a healthy smoothie by occupation groups. (*) indicates the nutrient profiles that had significantly different ratings across occupation groups.

In comparison, the perceived importance of low fat (X^2=3.02, *p*=0.22), low sugar (X^2=2.45, *p*=0.29), high fibre (X^2=3.76, *p*=0.15), high protein (X^2=1.71, *p*=0.42), and

high vitamin and mineral profiles (X^2=4.80, p=0.09) did not differ significantly between age groups (Figure 2.6).

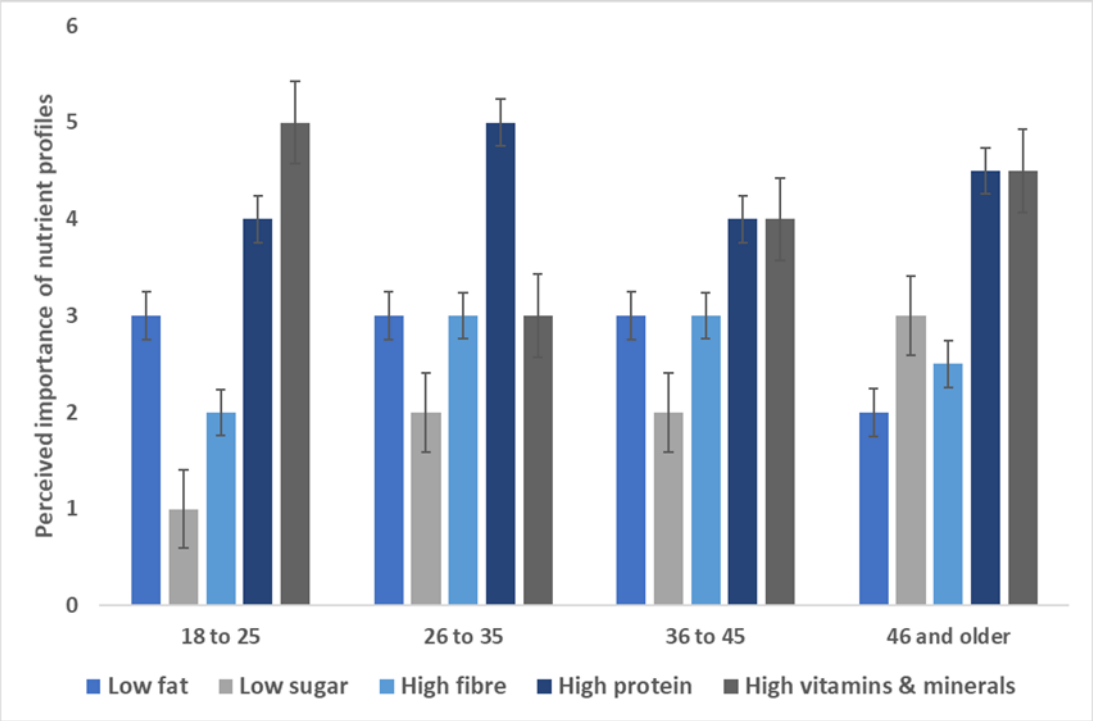


Figure 2-6 Perceived importance of various nutrient profiles for a healthy smoothie by age groups.

Table 2-2 Perceived importance of nutrient profile of healthier smoothies between a group of occupation. Values are presented as median scores.

Importance of nutrients in a healthy smoothie	Undergraduate	Postgraduate	Academic staff	Support and Technical staff	*P*-value
Low sugar	1	2	2	3	0.18
High fibre	2	3	3	2.5	0.02
Low fat	3	3	3	2	0.39
High protein	4	5	4	4.5	0.52
High vitamin and mineral	5	3	4	4.5	0.03

2.4.5 The rationale for preferring freshly made smoothies over available commercial smoothies

In terms of the rationale contributing to the preference for freshly made smoothies or available commercial smoothies, 41.4% of participants reported that making their

own fresh smoothies was less expensive than available commercial smoothies. In addition, 25.9% of the study participants stated that freshly made smoothies are healthier than commercial smoothies. However, 17.2% thought freshly made smoothies might be less tasty than commercial smoothies, and 15.5% had other reasons not specified.

Based on the likelihood ratio test, the above factors differed significantly across occupation groups (LR=21.02, p=0.01). The higher price of commercial smoothies was expressed mainly by postgraduate students (51.9%) and academic staff (50%). At the same time, none of the support and technical staff described the high price as their reason contributing to the preference for freshly made smoothies rather than available commercial smoothies. Among the participants, undergraduate students expressed that freshly made smoothies were healthier than commercial smoothies more frequently than other occupation groups (46.2%). The less desirable taste of freshly made smoothies was described as a reason by variable percentages of undergraduate (30.8%) or postgraduate students (18.5%) and support/technical staff (25%). However, academic staff did not describe the taste as a reason for preferring available commercial smoothies over freshly made smoothies (Table 2.3).

The majority of support and technical staff (50%) reported other reasons than price, taste or health profile for their preference for freshly made smoothies or available commercial smoothies.

The reasons contributing to the preference for freshly made smoothies rather than available commercial smoothies did not vary significantly across age groups (LR=16.47, p=0.058). However, the higher price for commercial smoothies was the

factor reported by most participants aged 26 to 35 (46.4%) and those aged 46 years and older (83%). In comparison, a large proportion of the youngest participants aged 18 to 25 years chose the less desirable taste of freshly made smoothies as their reason for preferring commercial smoothies (41.7%), and participants aged 35 to 46 years mostly believed that freshly made smoothies were healthier than commercial smoothies (44.4%).

Table 2-3 The reasons for preferring freshly made or available commercial smoothies by age and occupation groups.

Variable	Commercial smoothies are too expensive	Freshly made smoothies are healthier	Freshly made smoothies do not taste as good	Other
18 to 25 years	16.70%	33.30%	41.70%	8.30%
26 to 35 years	46.40%	25.00%	10.70%	17.90%
36 to 45 years	22.20%	44.40%	11.10%	22.20%
46 years & older	83.30%	0.00%	0.00%	16.70%
Undergraduate	23.10%	46.20%	30.80%	0.00%
Postgraduate	51.90%	14.80%	18.50%	14.80%
Academic staff	50.00%	28.60%	0.00%	21.40%
Support and Technical staff	0.00%	25.00%	25.00%	50.00%

2.5 Discussion

This study explored patterns of smoothie consumption, individual motives for consuming smoothies, favourite smoothie flavours and brands, perceived importance of nutritional characteristics of a healthy smoothie and factors contributing to the preference for freshly made smoothies or available commercial smoothies among the UK university cohort.

The present study found that the majority of the study participants (92.2%) had ingested smoothies over the last three months between March and June 2017 (3 times per month). This is consistent with a study by McCartney et al. (2018) found that 94% of the participants had consumed smoothies at least once per month. The higher rate of smoothie consumption in the present research may be related to the study design, which included only smoothie consumers and used a questionnaire specifically designed to gain more insight into the motives, behaviours and attitudes regarding smoothie consumption. Nevertheless, it may indicate the smoothie drinking trends among the wider population, particularly the university cohort. Although, the smoothie consumption in the current survey appears to be higher than the 40% consumption rate reported by the world's leading Market intelligence agency (Mintel, 2016). However, this discrepancy could also be due to the difference in the study population of these surveys. For example, the current study recruited participants from a university cohort, while the Mintel report survey was conducted on a general population (Mintel, 2016). Furthermore, Sijtsema et al. (2012) reported that the general population might have lower consumption of smoothies because they gain less income and prefer eating fresh fruit.

Furthermore, researchers have consistently shown that frequent eating out and time constraints are the main factors that influence the attitudes and dietary habits of university students (Shive and Morris, 2006). Moreover, an additional study evaluated the frequent consumption of fruit smoothies among university students and the availability of fruit smoothies on campus. The results (62.3%) indicated that fruit smoothies are available on campus and consumed by university students (Idumah et al., 2020). The above finding offers a rationale behind the level of

smoothie consumption given the increased availability of the product to consumers and thus may have overinflated the results in relation to other demographics.

Recent data from a Brazilian survey (Yassin et al., 2020) found that young individuals with higher incomes had a higher smoothie consumption per month than other groups. In contrast, the present study found that the academic staff and postgraduate students mainly highlighted that they preferred freshly made smoothies over commercial smoothies because the price was the main prohibitive. The price was also the key factor in the lower smoothie consumption among the general population Sijtsema et al. (2012). These findings are comparable with Mintel's report that over half of the smoothie consumers believe that smoothies are too expensive. Only a quarter feel they are reasonable value for money (Mintel, 2018). However, it should be noted that the current study was conducted in a university cohort, while being consistent in age, do tend to be on the lower end of the income range which may provide a rationale for differences in results.

Despite the high consumption rate in the entire population of the present study, there was an inverse relationship between the level of education and smoothie consumption. The median consumption was higher in undergraduate students (5 times per month), followed by technical/support staff (4 times per month) compared to postgraduates and academic staff (nearly 2 times per month). The Mintel survey found comparable results, where 39% of undergraduate university students and 24% of master's degrees students and 19% of employed participants had consumed smoothies in the past three months (Mintel, 2016). This may imply that among the university cohort, individuals with higher education are more conscious of the

nutritional profile, including the high sugar content of the available commercial smoothies, than undergraduate students and technical/support staff. This finding supports that of earlier research which demonstrates a positive correlation between the level of education and nutritional awareness (Rothpletz-Puglia et al., 2022).

Another factor could be the age of participants with higher education or academic positions. In this regard, smoothie consumption frequency was significantly higher among younger participants (undergraduate students), drinking a larger number of smoothies per month (5 times) than their older counterparts. These results aligned with a recent market analysis by Mintel (2021) showed that between August and October 2020, smoothie ingestion was substantially higher in younger adults (18-34-year-olds) compared to older groups. One explanation for why younger participants drink smoothies more frequently than the older participants is the accessibility and availability of smoothies as a convenient way to increase fruit intake for young individuals who do not want to peel or chew fruit (Bates and Price, 2015). Smoothies are similar in texture to popular dessert drinks such as milkshakes, and this similarity may be appealing to young individuals (Bates and Price, 2015). In addition, smoothies appeal to younger people because of their novelty and the younger generation's interest in trying new foods and drinks (Chen et al., 2013; Bates and Price, 2015; Yassin et al., 2020).

In the current study, taste (72.4%) and health benefits (65.5%) were the most frequently reported reasons for drinking smoothies among the university cohort. This finding aligns with the Mintel report, where most respondents described smoothies as a good source of vitamins (38%) or an excellent way to get a portion of fruit and

vegetables (41%). This figure is comparable to the percentage of the study participants (31%) who described meeting the 5-a-day recommendation as a motive for drinking smoothies. Moreover, 54% of the participants in the Mintel report agreed that smoothies are healthier alternatives to other drinks (Mintel, 2016). Health benefits and flavour were also important motives for smoothie consumption in Brazilian adults (Yassin et al., 2020). In that survey, 62.4% of the participants indicated that the health factor was the main reason they would consume smoothies, followed by 60% who highlighted the importance of flavour. Thus, further research is required to elucidate the factors behind smoothie choice fully.

A previous Mintel report also stated that 52% of the consumers in the UK drank smoothies during busy times as a meal replacement (Mintel, 2018). In contrast, meal replacement was the least frequently reported reason (10.3%) for drinking smoothies in the current study. This may indicate that university students and staff would not prefer smoothies over other options to replace proper meals during their busy times. A further explanation could be that available smoothies may not induce the feeling of satiety because of their low dietary fibre content following the removal of the fruit peel (Slavin and Green, 2007).

Naked was identified as the favourite smoothie brand (41.1%) among the study samples. Interestingly, this contrasts with (Mintel) the world's leading market intelligence agency, which found Innocent the dominant smoothie brand in the UK market (Mintel, 2016). The predominance of the Naked brand among the study samples could be due to the wider availability of this brand in the university cafeteria or canteen and the lower price compared to the Innocent brand. This may have

implications for market research on the variability of smoothie brand consumption across different population groups. Thus, further research is required to determine whether or not this finding is valid. Moreover, the study should look at employing interviews alongside questionnaires to gain a greater understanding of the rationale behind the answers presented to allow for a more conclusive finding.

The finding of blueberry (40%) followed by strawberry and banana (20.7%) flavours as the most favourite smoothie flavours in the present study differed from the predominant flavour in three smoothie studies (Mintel, 2016; Ribeiro et al., 2017; Yassin et al., 2020) which showed that strawberry and banana flavours were more popular among the respondents. This might interest the market analysis, informing the targeted provision of favourable smoothie flavours among the university cohorts.

Regarding the perceived importance of the nutritional characteristics of a healthy smoothie, the study participants rated low sugar followed by high fibre and low-fat profiles as the most crucial demand for a healthy smoothie. This highlighted a better understanding of the healthy nutrient among the university cohort compared to the general population. In Mintel (2016), 73% of the respondents agreed that pack labelling should present information about the sugar content of commercial smoothies. However, only 28% of consumers thought that smoothies were unhealthy because they contained too much sugar, whilst 27% of consumers neither agreed nor disagreed that smoothies had high sugar content. Nevertheless, according to the most recent Mintel survey (2021), 36% of smoothie consumers reported increasing their intake (the quantity not reported) because of concerns about immunity against

COVID-19 infection and the perceived high vitamin content of smoothies, which could improve immunity.

In terms of the factors contributing to the preference for freshly made smoothies or commercial smoothies, 41.4% of the participants in the current study thought that commercial smoothies were too expensive; these findings are comparable to the UK juice drinks and smoothies market report, which found 51% of respondents believed that smoothies were costly and just 14% assumed that smoothies offered value of money (Mintel, 2016). Moreover, 25.9% of the study samples thought that freshly made smoothies were healthier than commercial smoothies, which may reflect the adequate knowledge of the study participants about the nutritional profiles of smoothies, and 17.2% said freshly made smoothies might be less tasty than commercially available smoothies. Nevertheless, the survey did not explore the participant views about the benefits of eating raw fruit.

2.5.1 Strengths and limitations

This study used a survey adapted from Mintel, Global New Products Database (GNPD), an online database that provides intensive details of the past, present and future of key markets. Mintel's market research covered UK-specific titles across all key categories and industries. It is considered the most comprehensive online source of rigorously collected sales data, consumer opinions and market information that offers valuable insights into the British business sector and how UK consumers think (Mintel, 2021). Further, the current research adds to the previous studies by focusing on smoothie consumption in the higher education setting, which provides a novel aspect as previous research has focussed on a general population. The findings are

also stratified by age and occupation (student and staff), providing more detailed information about the perceptions and attitudes of these groups regarding the use of smoothies.

Moreover, the online survey also tends to be a reliable and versatile method of inquiry. This is because surveys are standardized. The low cost and overall convenience of online surveys increased the response rate and design flexibility. However, as with all data collection methods, online surveys include limitations. This study was restricted to the consumers of fruit beverages which would affect the inferences about the overall smoothie consumption among the university cohort. The survey did not specify the range of smoothie consumption which may have affected the precision of self-reported consumption frequencies. It was also suggested to differentiate between consumers and non-consumers in the survey. The comparison of consumption behaviours between occupational groups was also limited by the unequal samples across the groups. Finally, the participants' consumption behaviour, perceptions, and attitudes could have been explored more extensively by covering a more comprehensive range of closed and open-ended questions. For example, 1) examine the effect of eating habits and socioeconomic status on smoothie consumption in the university cohort, 2) explore energy and sugar content awareness and expected satiety value. The other limitations of this study included the use of a convenience sampling method, samples were selected from the population only because there were conveniently available to the researcher, a non-representative study population, and the study's cross-sectional design, which limited the generalisability of the findings. This survey aimed to explore smoothie consumption and attitudes towards the sugar content of smoothies among the

university cohort to inform the researcher of the most appropriate smoothie in terms of acceptability and availability for experimental studies on the benefits of fibre-fortified smoothies for the study population. Therefore, further market analysis with a broader coverage area and more participants is recommended to compare consumers and non-consumers by age, gender and socioeconomic status.

2.6 Conclusion

This research demonstrated that the consumption of smoothies amongst the university cohort was above the national level in the UK. The consumption was higher in younger participants and undergraduate students. Furthermore, the majority of the participants believed that smoothies were tasty and considered smoothies as healthier alternatives to other drinks such as soft drinks and fruit juice. Interestingly, the current survey showed that sugar content was the most critical concern among smoothie consumers at the study participants. This probably reflects the awareness of the study population regarding the nutritional characteristics of the smoothies currently available in the UK market and their interest in consuming products with a healthier nutritional profile. The findings from this survey will inform the planning and development of the subsequent experimental studies regarding the benefits of fibre-enriched fruit smoothies to interfere with the sugar naturally exist in the fruit smoothies without removing or substituting their sugar content. Furthermore, the outcomes reflected that smoothie are preferable and popular beverages that indicate any changes in their ingredients would significantly impact overall health and acceptance.

Chapter 3 : Effect of konjac glucomannan powder on the rheological properties of commercial fruit smoothies

3.1 Introduction

Fruit and vegetables are essential for a healthy diet. There is also clear evidence that an adequate daily intake of fruit and vegetables (> 200 g/d) is associated with a significantly lower risk of cardiovascular disease (CVD), stroke, total cancer incidence and all-cause mortality (Aune et al., 2017).

The data from Health Survey England indicate a majority of people in the UK people do not meet their recommended fruit and vegetable intake. In 2018, only 28% of the UK adults consumed five daily portions of fruit and vegetables, with a mean intake of 3.7 portions per day. Similarly, only 18% of the UK children aged 5 to 15 had five daily portions of fruit and vegetables (Osborne and Cooper, 2018).

Inadequate intake of fruit and vegetables could be due to several factors, including limited knowledge of a healthy diet, busy lifestyle, limited accessibility, availability, costs and shelf-life, together with the higher price of fresh fruit and vegetables (Benton and Young, 2019). To overcome these barriers and to increase fruit and vegetable consumption, it has been suggested to use fruit and vegetable-based beverages, such as smoothies (Medina, 2011).

The addition of DF to fruit smoothies may improve their glycaemic effects and satiating properties, with potentially beneficial cardiometabolic outcomes. Fibre viscosity appears to be an essential contributor to satiety (Lyly et al., 2009). In an experimental study by Vuksan et al. (2009), the consumption of a 350mL strawberry flavoured drink containing 5g of a high viscosity fibre (novel viscous polysaccharide; NVP) over 3 weeks led to significant reductions in subsequent calories intake and weight in healthy adolescents compared to the consumption of similar drinks

containing low viscosity fibre (cellulose; CE) or medium viscosity (glucomannan; GM) fibres (Vuksan et al., 2009). Similarly, Juvonen et al. (2009) found that ingesting high viscosity oat bran β -glucan 30g/300-mL beverages improved postprandial glucose, lipid metabolism and gut hormone responses and gastric emptying rate. Similarly, the addition of barely β glucan (3g/250mL) or (2.5g/250mL) dietary fibre from fruit to a 100% fruit beverage increased fullness, reduced energy intake at lunch, decreased ghrelin concentration and increased PP over 3 hours after breakfast (Lumaga et al., 2012). Thus, providing evidence to support the DF fortification of fruit beverages. However, two systematic reviews have demonstrated inconsistent and relatively small effects of fibre consumption on satiety (Clark and Slavin, 2013) and body weight (Wanders et al., 2011) possibly due to diversity in fibre type, function and related sensory characteristics (Chambers et al., 2017).

KGM was approved as a food additive by the US Food and Drug Administration (FDA) in 1997 and received the Generally Recognised as Safe (GRAS) status due to its exceptional gelling and rheological properties, which allowed it to be applied as a binding agent and texture enhancer in the food industry (Jiménez-Colmenero et al., 2012; Salcedo-Sandoval et al., 2015; T. Zhang et al., 2016). Moreover, the World Health Organization (WHO) included KGM as one of the ten greatest healthy foods (Yao-ling et al., 2013; Behera and Ray, 2016). The EFSA panel has approved two health claims for the use of KGM powder, providing a further rationale for the inclusion of KGM in fruit beverages; however, further research is required to fully elucidate this role in translational studies. Studies have highlighted that liquids are the more suitable medium for the delivery of dietary fibres as opposed to solids, as

this allows fibres to be ingested In their fully hydrolysed form, which has ultimately been shown to have a greater effect on satiety (El Khoury et al., 2015).

DF-fortified products have increased in popularity as health-conscious consumers try to find convenient ways to increase fibre intake (Chakraborty et al., 2019). So far, several DFs have been used to fortify fruit-based beverages, including wheat bran, oat β -glucan, guar gum, and xanthan gum (Lyly et al., 2009; Lumaga et al., 2012; Paquet et al., 2014). The food industry suggests that the addition of DF to these products is performed without removing or substituting their sugar content (Jenkins et al., 2011; Kristensen and Jensen, 2011; Cassidy et al., 2018). This is the preferred procedure in the food industry because removing sugars from fruit juice is technologically demanding and expensive. The other issue is that such products may not be appealing to the consumers' taste (Bhaskaran and Hardley, 2002; Tuorila, 2007). The incorporation of DFs into popular beverages such as smoothies present certain challenges related to the rheological properties of the finished products (Sun-Waterhouse et al., 2014). For example, the addition of guar gum to a fruit beverage (10g/400mL) increased beverage viscosity to the point that it became undrinkable (Lyly et al., 2004). DFs, especially insoluble dietary fibres (ISDFs), when added in high concentrations to beverages, not only cause some processing and sensory problems such as bitterness, astringency and grittiness but also present technical challenges related to stability during and after production (Sun-Waterhouse et al., 2014). Thus, it is difficult to enrich such products with DFs to the level that meets the dietary requirements, which allows “source of fibre” and “high fibre” claims to be made for the products if they respectively provide at least 3 g of fibre per 100 g (1.5 g of fibre

per 100 kcal) and at least 6 g of fibre per 100 g (3 g of fibre per 100 kcal) (Europa, 2006).

Therefore, it is important to consider the rheological properties of KGM enriched products, including their viscosity and texture, as they could influence the sensory acceptability and overall quality of such products from the consumer perspective.

3.2 Aim and objectives

3.2.1 Aim

The aim of this chapter was to evaluate the rheological properties of KGM fortification of a commercial fruit smoothie.

3.2.2 Objectives

1- To incorporate different concentrations of KGM powder into a commercial fruit smoothie.

2- To measure the rheological characteristics of the KGM-fortified commercial fruit smoothie, including viscosity and texture, using a Brookfield Viscometer and Texture Analyser.

3.3 Materials and Methods

To observe Health and Safety regulations, COSHH risk assessment forms were completed and approved by Manchester Metropolitan University's Faculty of Health, Psychology and Social Care. (COSHH risk assessment Ref No: Awlya210318COSHHC) (Appendix 4). In order to evaluate the rheological properties of smoothies post KGM fortification, the experiment consisted of a smoothie sample selection, preparation of KGM fibre by milling, sieving and measuring the powder particle size, preparation

of 300 ml samples of smoothies, addition of KGM powder to smoothies, mixing the powder with the smoothie, homogenisation of the mixture and analysis of the samples at two time points: once immediately after post-processing and again following overnight storage (12 hours) at a cool temperature (4°C) in the food laboratory refrigerator to evaluate the gel-forming capacity of KGM.

KGM powder was obtained from the e-commerce company Myprotein™, UK. The samples of commercial strawberry and banana-flavoured fruit smoothies from Innocent® brand were purchased from local suppliers. Nutritional information for Innocent® strawberry and banana smoothie is provided (Appendix 5).

Although the previous survey of the university cohort found that Naked was the favourite smoothie brand, this experimental study used samples of "Innocent®" smoothie because this brand is the UK leader in the smoothie market. Innocent's top-selling smoothie flavours are strawberry and banana (Mintel, 2016). They were also the second preferred choice by the study subjects as surveyed in the current research (see chapter 2). Therefore, Innocent® strawberry and banana smoothies were chosen as the test product for this research.

3.3.1 Preparation of KGM powder

3.3.1.1 Milling and sieving process

In order to have powders with a fine particle size (with particle size less than 147 microns) to be suitable for smoothie fortification, KGM powder was milled and sieved as explained in (Sun and Guanggu, 2003). These techniques greatly improve the quality of KGM flour (Sun and Guanggu, 2003). Approximately 200g of KGM powder was milled in several rounds with different particle sizes using a small-scale ultra-

centrifugal mill (RETSCH MILL ZM200, United States). In line with the standard procedures, the particle sizes of 250 µm, 150 µm and 75 µm were then chosen for sieving (Sun and Guanggu, 2003). The powder was sieved at 18000 RPM for three minutes using a RETSCH Analytical Sieve Shaker type AS200. Then, sieved KGM powders were measured at weights of 0.5g, 1g and 2g (Sun and Guanggu, 2003; Li et al., 2005; Majid, 2018).

3.3.2 Fortification of commercial fruit smoothies

Smoothie samples were produced in the food technology laboratory at MMU, Department of Health Professions. The tested products were the KGM-fortified fruit smoothies. A smoothie without KGM (control) was used as the internal reference sample.

Based on the available literature to insure the efficacy in human interventions, KGM powders with three different amounts (0.5g, 1g, and 2g) were gradually added to 300 ml of fruit smoothie (Sun-Waterhouse et al., 2010; Sun-Waterhouse et al., 2014). Previous studies suggested that concentrations of DF such as apple fibre (0.5 g per 300 mL smoothie) are the sufficient amount to increase fibre content whilst maintaining the palatability of smoothies to participants (Vuksan et al., 2000; Sun-Waterhouse et al., 2014; Tiwari, 2018). Therefore, the current experiment used 0.5g KGM concentration as the initial concentration to enable subsequent measurement of sugar absorption and gastrointestinal secretions (Vuksan et al., 2000). Research has also suggested metabolic improvements in blood glucose and total cholesterol levels using 3g/d KGM supplementation (1g KGM per meal) (Chearskul et al., 2007; Chearskul et al., 2009). Thus, 2g KGM fibre was used as the maximum concentration

to avoid sensory issues such as thickness, separation, precipitation and unpleasant taste and increase the fibre content of the smoothies to interfere with the sugar content (Vuksan et al., 1999; Sun-Waterhouse et al., 2014; Poonam, 2016). The production process illustrated in (Figure 3.1) included three main technological stages: (i) KGM powder was milled, sieved and weighed as mentioned previously. (ii) Smoothies were fortified separately with three different concentrations of KGM (0.5, 1 and 2 g per 300 ml), representing 0.17, 0.33 and 0.68g per 100 ml, respectively. (iii) Smoothies were homogenised using a Silverson Mixer with a high shear screen (8,000 rpm L5T, Silverson Machines Inc., East Longemeadow, MA, USA) for 4 minutes (Sun-Waterhouse et al., 2014). Finally, smoothie samples were stored overnight (12 hours) at a cool temperature (4°C) in the food laboratory refrigerator to evaluate the gel-forming capacity of KGM. All fortified and control smoothie samples were produced under the same processing conditions (Chambers et al., 2017; Tiwari, 2018).

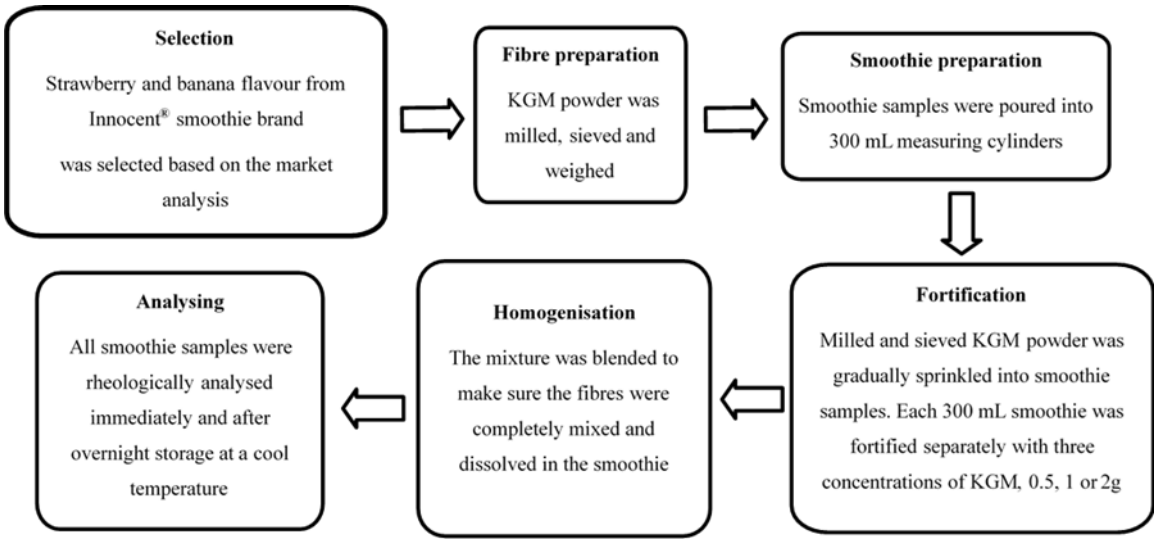


Figure 3-1 Summary of the processing steps involved in the fortification of commercial fruit smoothies.

3.3.3 Rheological measurements of smoothie samples

The rheological measurements of fortified and control smoothie samples were conducted at two-time points: once immediately after processing and then following overnight storage at a cool temperature. This involved the analyses of viscosity and texture parameters (Nowicka et al., 2016; Markowski et al., 2017).

3.3.3.1 Viscosity

The viscosity was measured at room temperature for (i) control smoothies, (ii) smoothies fortified with 0.5 g KGM, (iii) smoothies fortified with 1 g KGM and (iv) smoothies fortified with 2 g KGM (Rahimi et al., 2017).

The viscosity of each sample was measured over 120 seconds using a calibrated Brookfield Viscometer Model (BROOKFIELD DVII PRO, Brookfield Technical Centre, Harlow, UK) with Spindle No. RV4 and equipped with a controlled temperature device at a rotation of 20 revolutions per minutes (rpm). Each sample was analysed in triplicate both immediately after production and overnight (Bourne, 2002; Buriti et al., 2014).

3.3.3.2 Texture

The texture was measured at room temperature for (i) control smoothies, (ii) smoothies fortified with 0.5 g KGM, (iii) smoothies fortified with 1 g KGM and (iv) smoothies fortified with 2 g KGM. Texture analysis was conducted in triplicate for control and fortified smoothies. Texture properties were measured on each batch (control samples and samples fortified with 0.5g, 1g and 2g of KGM powder) both immediately and after overnight storage at a cool temperature (4°C).

A TA-XT plus Texture Analyser (Stable Micro Systems, Surrey, UK) was utilised to analyse smoothie texture using the back extrusion test (Buriti et al., 2014). Texture parameters consisted of firmness, consistency, cohesiveness, and work of cohesion. According to standard procedures, these parameters were obtained by using the Exponent© 2014 software, version 6.1.7.0 (Stable Micro Systems) (Buriti et al., 2014; de Souza Pereira et al., 2018; Bembem and Agrahar-Murugkar, 2020). Firmness (hardness) was measured as the 'peak' or maximum force (g) of the probe required to compress the liquid sample of smoothie within the container, with higher values representing greater firmness of the sample. The area of work under the curve of the maximum force (g/s) during the first compression was taken as a measurement of consistency, with higher values indicating thicker consistency of the sample. The maximum negative force (g) required to pull out a fraction of the sample upon the return of the probe to the original position was taken as a measure of the cohesiveness of the sample, with more negative values representing more cohesiveness. The area of the work under the curve (g/s) for the cohesive force was defined as the 'work of cohesion', with higher values indicating more resistance to withdrawal of the sample and indirectly greater cohesiveness, consistency and viscosity of the samples.

3.4 Data analysis

The statistical analysis of viscosity and texture data was conducted using SPSS version 23. The distribution of data was checked using the Shapiro Wilk test. Because all variables were non-normally distributed, the values for viscosity and texture parameters were presented as the median and (IQR). The statistical significance was defined as a p-value < 0.05. To accommodate the skewness of dependent variables

(Doncaster and Davey, 2007), a general linear model (GLM) analysis using factorial ANOVA with Bonferroni corrected pairwise comparisons were performed to compare the viscosity and texture of smoothie samples between different concentrations of KGM and between days of measurement.

3.5 Results

The viscosity and texture parameters of the control and fortified smoothie samples measured immediately after fortification and after overnight storage at a cool temperature (4°C) are presented in (Table 3.1).

Table 3-1 Viscosity and texture (firmness, cohesion, work of cohesion and consistency) of control smoothies and smoothie samples fortified with 0.5g, 1g and 2g KGM powder.

Viscosity and Texture properties	Immediate				After overnight storage 4°C			
	Control	0.5g KGM	1g KGM	2g KGM	Control	0.5g KGM	1g KGM	2g KGM
Viscosity (cP)	883.6±17.0	922.5±18.8	1104.1±48.6	1517.5±52.8	892.5±17.6	1517.5±28.3	2652.5±28.1	6849.7±135.2
Firmness (1 g force)	18.89±0.12	19.92±.12	21.44±.28	26.94±1.07	19.23±.05	19.99±.17	22.04±.52	30.68±1.26
Cohesiveness (2 g force)	-8.69±.06	-9.52±.17	-10.77±.83	-17.93±2.35	-8.58±.08	-10.37±.14	-13.48±.73	-27.30±.22
Work of Cohesion (g/s)	-2.71±.13	-3.61±.35	-5.77±1.73	-35.47±8.42	-2.62±.18	-4.97±.46	-14.98±3.62	-73.68±1.04
Consistency (g/s)	409.85±1.35	431.24±.89	463.66±3.10	590.04±26.89	419.73±.86	428.73±1.37	474.42±12.84	689.99±36.64

3.5.1 Viscosity

The average viscosity of the fortified smoothie samples was significantly higher than that of control samples both immediately after fortification and after overnight storage at a cool temperature, implying the interaction effect of KGM concentration and the day of measurement (F=2643.42, *p*<0.001). As shown in (Table 3.2), the difference between the viscosity of fortified and control smoothie samples was more significant on Day 1 (after overnight storage in a cool temperature) than on Day 0 (immediately after fortification).

Table 3-2 Viscosity of fortified and control smoothie samples by day and KGM concentrations.

Viscosity difference between control and fortified smoothie samples (cP)	Day 0		Day 1	
	MD	p value	MD	p value
0.5g KGM vs control	38.88	0.41	625	<0.001
1g KGM vs control	220.55	<0.001	1760	<0.001
2g KGM vs control	633.88	<0.001	5957.22	<0.001
1g KGM vs 0.5g KGM	181.66	0.001	1135	<0.001
2g KGM vs 0.5g KGM	595	<0.001	5332.22	<0.001
2g KGM vs 1g KGM	413.33	<0.001	4197.22	<0.001

3.5.2 Texture

Texture analysis was performed on firmness, cohesiveness, work of cohesion and consistency of the smoothie samples.

3.5.2.1 Firmness

The mean firmness (hardness) of the fortified smoothie samples was significantly higher than that of control samples both immediately after fortification and after overnight storage at a cool temperature, implying the interaction effect of KGM concentration and the day of measurement (F=11.25, $p<0.001$). As illustrated in (Table 3.3), the difference between the firmness of fortified smoothie samples and control samples was greater on Day 1 (after overnight storage in a cool temperature) than on Day 0 (immediately after fortification). It was found that immediately after fortification (Day 0), samples fortified with 1g (MD=2.54g, $p=0.003$) and 2g (MD=8.04g, $p<0.001$) of KGM had significantly greater firmness than the control samples. A similar pattern was observed after overnight storage at a cool temperature. Again, smoothie samples fortified with 1g (MD=2.81g, $p=0.006$) and 2g (MD=11.45g, $p<0.001$) of KGM had significantly greater firmness than the control samples. The firmness of samples fortified with 0.5g of KGM and control samples was comparable on Day 0 (MD=1.02g, $p=0.33$) and Day 1 (MD=0.76g, $p=1.00$).

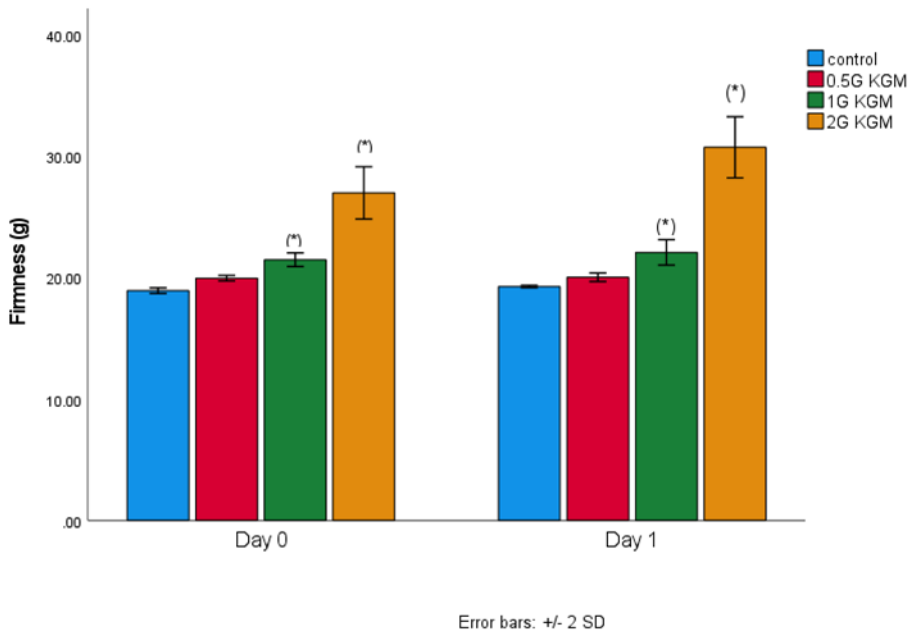


Figure 3-2 Differences in smoothie firmness between fortified and control samples immediately after fortification (Day 0) and after overnight storage at a cool temperature (Day 1). KGM concentrations with significantly higher firmness than control is represented by (*).

Furthermore, on Day 0 and Day 1, there were significant differences between the firmness of samples fortified with 0.5g, 1g and 2g of KGM (Table 3.3).

Table 3-3 Firmness of smoothie samples by day and KGM concentrations.

Firmness difference between control and fortified smoothie samples (g)	Day 0		Day 1	
	MD	p value	MD	p value
0.5g KGM vs control	1.02	0.06	0.76	0.15
1g KGM vs control	2.54	<0.001	2.81	<0.001
2g KGM vs control	8.04	<0.001	11.45	<0.001
1g KGM vs 0.5g KGM	1.51	0.009	2.04	0.001
2g KGM vs 0.5g KGM	7.01	<0.001	10.69	<0.001
2g KGM vs 1g KGM	5.5	<0.001	8.64	<0.001

3.5.2.2 Cohesiveness

The average cohesiveness (solidity) of the fortified smoothie samples was significantly higher than that of control samples both immediately after fortification and after overnight storage at a cool temperature, implying an interaction effect of KGM concentration and the day of measurement (F=31.94, $p<0.001$). As shown in (Table 3.4), the difference between the cohesiveness of fortified smoothie samples and control samples was greater on Day 1 (after overnight storage in a cool temperature) than on Day 0 (immediately after fortification). It was found that immediately after fortification (Day 0), samples fortified with 1g (MD=-2.09 g, $p=0.014$) and 2g KGM (MD=-9.24 g, $p<0.001$) had significantly greater cohesiveness than the control sample. A similar pattern was observed after overnight storage at a cool temperature. Again, smoothie samples fortified with 1g (MD=-4.90 g, $p<0.001$) and 2g KGM (MD=-81.71 g, $p<0.001$) had significantly higher cohesiveness than the control sample. Cohesiveness of samples fortified with 0.5g of KGM was comparable to control samples on day 0 (MD=- 0.83 g, $p=0.28$) but significantly higher than control samples on day 1 (MD=-1.79 g, $p=0.03$).

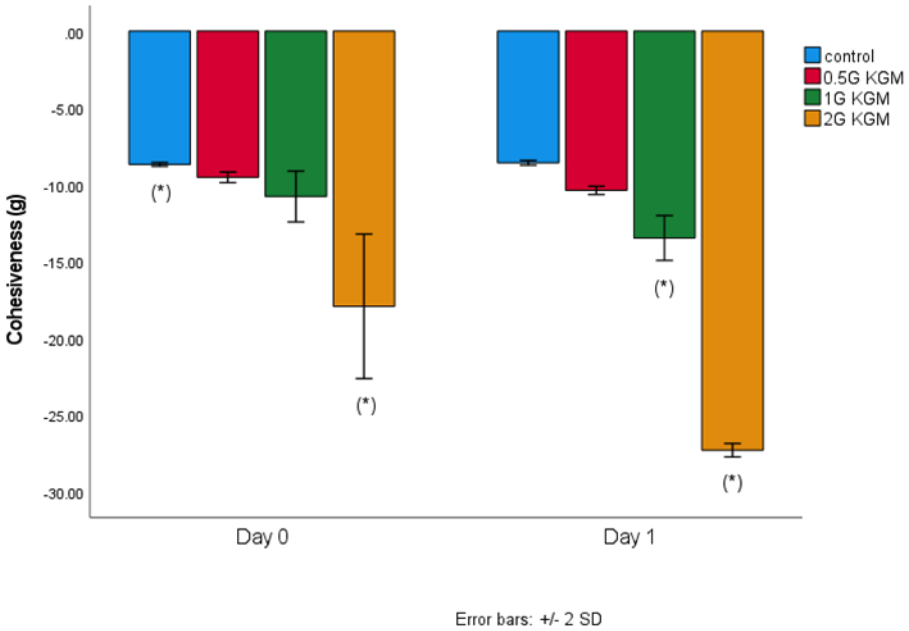


Figure 3-3 Differences in smoothie cohesiveness between fortified and control samples immediately after fortification (Day 0) and after overnight storage at a cool temperature (Day 1). KGM concentrations with significantly greater cohesiveness are represented by (*).

As presented in (Table 3.4), there were significant differences between the cohesiveness of samples fortified with 0.5g, 1g and 2g of KGM on Day 0 and Day 1, with greater cohesiveness being observed on Day 1.

Table 3-4 Cohesiveness of smoothie samples by day and KGM concentrations.

Difference in cohesiveness between control and fortified smoothie samples (g)	Day 0		Day 1	
	MD	p value	MD	p value
0.5g KGM vs control	-0.83	0.28	-1.79	0.03
1g KGM vs control	-2.08	0.01	-4.89	<0.001
2g KGM vs control	-9.24	<0.001	-18.71	<0.001
1g KGM vs 0.5g KGM	-1.25	0.11	-3.1	0.001
2g KGM vs 0.5g KGM	-8.4	<0.001	-16.92	<0.001
2g KGM vs 1g KGM	-7.15	<0.001	-13.82	<0.001

3.5.2.3 Work of Cohesion

The mean work of cohesion (force applied to the liquid) of the fortified smoothie samples was significantly higher than that of control samples both immediately after fortification and after overnight storage at a cool temperature, implying an interaction effect of KGM concentration and the day of measurement ($F=43.12$, $p<0.001$). The difference between the work of cohesion of fortified smoothie samples and control samples was greater on Day 1 (after overnight storage in a cool temperature) than Day 0 (immediately after fortification) (Figure 3.4). Immediately

after fortification (Day 0), the work of cohesion for the samples fortified with 1g KGM was not significantly different from control samples (MD=-3.05 g/s, *p*=0.27). However, samples fortified with 2g KGM exhibited a significantly greater work of cohesion than control samples (MD=-32.75g/s, *p*<0.001). In contrast, smoothie samples fortified with 1g (MD=-12.35 g/s, *p*<0.001) and 2g KGM (MD=-71.06 g/s, *p*<0.001) both displayed significantly greater work of cohesion than control samples after overnight storage at a cool temperature. The work of cohesion for the samples fortified with 0.5g KGM and control samples was comparable on day 0 (MD=-0.90 g/s, *p*=0.74 and day 1 (MD=-2.34g/s, *p*=0.40).

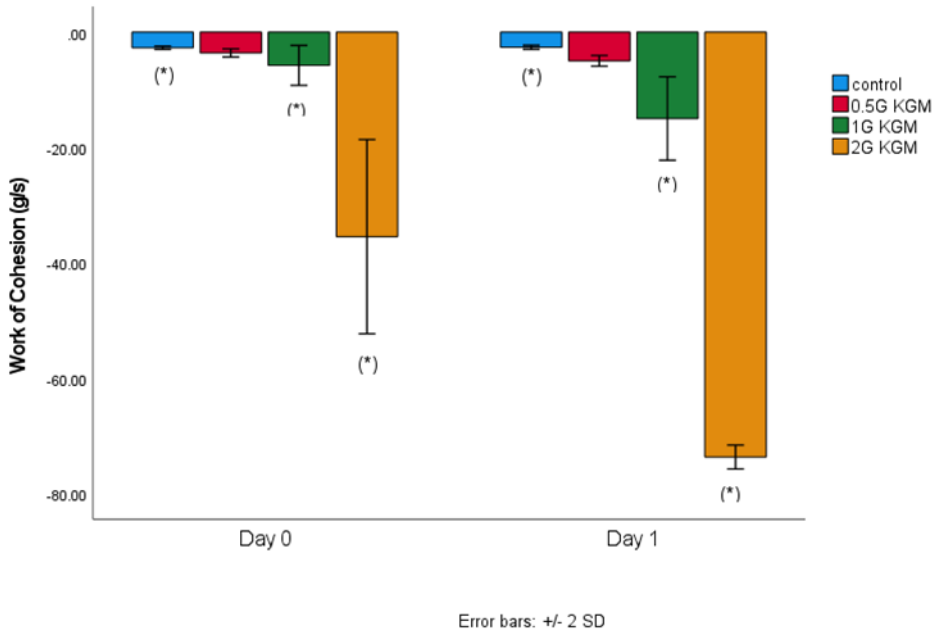


Figure 3-4 Differences in the work of cohesion between fortified and control smoothie samples immediately after fortification (Day 0) and after overnight storage at a cool temperature (Day 1). KGM concentrations with significantly greater work of cohesion are represented by (*).

In addition, there were significant differences between the work of cohesion of samples fortified with 0.5g, 1g and 2g of KGM both immediately after fortification and again after overnight storage, as shown in (Table 3.5).

Table 3-5 Work of cohesion of smoothie samples by day and KGM concentrations.

Difference in work of cohesion between control and fortified smoothie samples (g/s)	Day 0		Day 1	
	MD	p value	MD	p value
0.5g KGM vs control	-0.90	0.74	-2.34	0.40
1g KGM vs control	-3.05	0.27	-12.35	<0.001
2g KGM vs control	-32.75	<0.001	-71.05	<0.001
1g KGM vs 0.5g KGM	-2.15	0.43	-10.01	0.002
2g KGM vs 0.5g KGM	-31.85	<0.001	-68.70	<0.001
2g KGM vs 1g KGM	-29.70	<0.001	-58.69	<0.001

3.5.2.4 Consistency

The average consistency (thickness) of the fortified smoothie samples was significantly higher than that of control samples both immediately after fortification and after overnight storage at a cool temperature, implying an interaction effect of KGM concentration and the day of measurement (F=11.98, p<0.001). It was found that immediately after fortification (day 0), samples fortified with 1g (MD=53.81 g/s,

p=0.001) and 2g (MD=180.18 g/s, *p*<0.001) of KGM had significantly greater consistency than the control sample. A similar pattern was observed after overnight storage at a cool temperature. Again, smoothie samples fortified with 1g (MD=54.69 g/s, *p*=0.001) and 2g (MD=270.26 g/s, *p*<0.001) of KGM had significantly greater consistency than the control sample. The thickness of samples fortified with 0.5g of KGM and control samples was comparable in Day 0 (MD=21.39 g/s, *p*=0.14 and Day 1 (MD=8.99 g/s, *p*=0.52) (Figure 3.5).

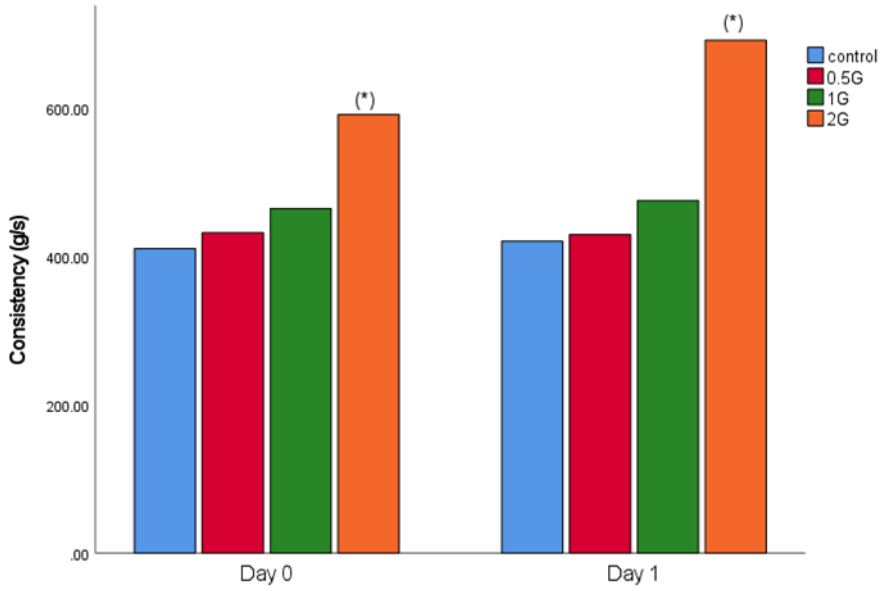


Figure 3-5 Differences in the consistency of smoothies between fortified and control smoothie samples immediately after fortification (Day 0) and after overnight storage at a cool temperature (Day 1). KGM concentrations with significantly greater consistency are represented by (*).

As shown in (Table 3.6), the consistency of fortified smoothie samples and control samples was greater on Day 1 (after overnight storage in a cool temperature) than on Day 0 (immediately after fortification).

Table 3-6 Consistency of smoothie samples by day and KGM concentrations.

Difference in consistency between control and fortified smoothie samples (g/s)	Day 0		Day 1	
	MD	p value	MD	p value
0.5g KGM vs control	21.39	0.14	8.99	0.52
1g KGM vs control	53.81	0.001	54.69	0.001
2g KGM vs control	180.18	<0.001	270.26	<0.001
1g KGM vs 0.5g KGM	32.41	0.03	45.69	0.004
2g KGM vs 0.5g KGM	158.79	<0.001	261.26	<0.001
2g KGM vs 1g KGM	126.37	<0.001	215.57	<0.001

3.6 Discussion

This study used a food processing experiment to evaluate the feasibility of adding KGM powder as a soluble DF to a popular commercial fruit smoothie brand in order to evaluate the differing rheological properties. To the best of the author's knowledge, this is the first experiment that explores the influence of the addition of KGM fibres to fruit smoothies on their rheological properties.

The present study showed that adding 1g and 2g of KGM powder to fruit smoothies (0.33g/100ml and 0.66g/100ml concentrations, respectively) significantly increased their viscosity, firmness, solidity, and thickness compared to the control samples on

Day 0 and Day 1. Interestingly, these alterations were dependent on the concentration and storage duration. Smoothies that were fortified with high KGM weight (2g) and stored for a longer period (overnight) had a less desirable viscosity and texture than other samples, causing gel formation, separation and precipitation of the smoothie samples. Due to these altered rheological properties of the fortified smoothie samples were unlikely to be suitable for sensory analysis as earlier studies by Powrie et al. (2002) have indicated that consumers dislike thicker smoothies. Nevertheless, these observations were consistent with previous experiments and were considered influential while introducing SDF supplement into fruit juices. A study with either guar gum, xanthan gum or catboxymethylcellulose 2g/ 227.30 mL as a dietary fibre component added to apple juice indicated that all of the gums introduced an undesirable consistency and mouthfeel (Powrie et al., 2002). Thus, the addition of 2g fibre to the fruit juice may affect the rheological properties and the consumer preference for fibre enriched drinks. Theoretically, VDFs thicken when mixed with fluids, depending on the chemical composition and concentration of the VDF (Schneeman, 1998).

It has been reported that the KGM viscosity is about 36,500 mPa·s. This might restrict KGM incorporation into liquid beverages such as fruit juice and fruit drinks (Morgan et al., 1990; Powrie et al., 2002). Instead, VDFs are more suitable for semiliquid beverages such fruit smoothies (Lopez-Rubio et al., 2016). This is supported by more recent studies, which have underscored the limitations of adding VDFs to drinks (Aggarwal et al., 2020; Atzler et al., 2021), including instability issues of phase separation and precipitation and altered palatability of beverages (Lyly et al., 2009; Sun-Waterhouse et al., 2014; Poonam, 2016).

The present study demonstrated that adding higher concentrations of KGM powder to fruit smoothies was not feasible, causing rheological and technical challenges that render the fortified product inappropriate for use in human studies. However, the above changes in viscosity and texture of smoothies were not significant when samples were fortified with a low concentration of KGM (0.5g), particularly immediately after fortification. Using lower concentrations of KGM powder may be more suitable for including in beverages, particularly smoothies. However, low concentrations of KGM may not be physiologically effective to improve glucose absorption and satiety following the consumption of fruit smoothies. According to EFSA, in order to obtain claimed effects, at least 3 g of glucomannan per day should be administered (EFSA, 2010).

3.7 Conclusion

This experiment showed that the addition of concentrated glucomannan powder as a soluble dietary fibre to commercially available fruit smoothies could significantly increase their viscosity and change their texture, including firmness, cohesiveness, work of cohesion and consistency in a dose-dependent fashion. Also, the overnight storage at a cool temperature of smoothies fortified with KGM would accentuate their altered rheological characteristics. These effects would cause sensory problems in smoothies, including separation and precipitation issues during food processing, with substantial influence on the textural and visual features of these products. Therefore, KGM powder may not be the appropriate form of DF for the fortification of smoothies because of its high viscosity and other physical properties.

Although the fortification with a low concentration of 0.5g KGM powder did not disturb the immediate rheological properties of smoothie samples, it affected the viscosity and texture over time. Furthermore, this concentration would not be sufficient to exert significant metabolic benefits to the human intervention study. Thus, the use of KGM in the form of a powder was excluded in this project, and supplementation with KGM capsules was considered for the human intervention phase of this project.

Chapter 4: Knowledge, perception, attitude, and awareness regarding the consumption of dietary fibre among UK adults

4.1 Introduction

Dietary fibre (DF) is a key component in healthy diets. The consumption of DF is vital in preventing and controlling several chronic diseases, including cancer, type 2 diabetes (T2DM), hypertension, hyperlipidaemia, hypercholesterolemia and other health issues (Kendall et al., 2010). Increasing intake of nutrients rich in DF, such as whole grains, fruit and vegetables, is therefore crucial in reducing the rates of obesity in developed countries (Slavin and Joanne, 2003). In this regard, the American Dietetic Association (ADA) suggested that DFs are consumed from various sources (Marlett et al., 2002). The Scientific Advisory Committee on Nutrition (SACN) has recommended increasing the dietary reference value (DRV) for DF in UK adults to 30g/day. The SACN also recommended an average DF intake of 15 g/day for children aged 2 to 5 years, 20 g/ day for children aged 5 to 11 years, 25 g/day for children aged 11 to 16 years and 30g /day for adolescents aged 16 to 18 years (Scientific Advisory Committee on Health, 2015). However, the average daily DF intakes in the UK are well below the recommended values. Currently, the mean intake for UK adults is 21 g for men and 17 g for women (Evans, 2020), with only 13 % of men and 4 % of women meeting the recommended DF intake of 30g/day. Furthermore, according to National Diet and Nutrition Survey (2018), the total DF intake in UK children is below the DRVs for their specific age groups, 10.4 g/day in children 1.5 to 3 years, 14.3 g/day in children aged 4 to 10 years, and 16 g/day in those aged 11 to 18 years (Roberts et al., 2018). This is because the dietary patterns have shifted towards lower consumption of foods with high fibre content, such as whole-grain products or fruits and vegetables, and higher consumption of meat and rapidly digestible carbohydrates (such as processed grains and free sugar). These significant changes

in the dietary pattern have been considered as the factors underlying the increase in the prevalence of non-communicable chronic diseases (Kendall et al., 2010).

Increasing the intake of DF necessitate several strategies and actions from stakeholders. Currently, more focus is on reducing the consumption of sugars than improving fibre intake (Evans, 2020). It is, however, necessary to raise public awareness towards the adequate consumption of DFs by enhancing their knowledge of healthy eating and health benefits of DFs by public health campaigns and community-based nutrition education programmes (Evans, 2020).

In order to improve dietary choices and include different varieties of food, consumers are required to know more about the nutritional recommendations and standard food-based guidelines. They should also be supported to use this knowledge to improve their food choices, diets, and eating preferences (Guiné et al., 2016). The lack of general knowledge about DFs as a key component in healthy diets represents a barrier to increased intake in adults (Mihai et al., 2019). Currently, there is insufficient data on the knowledge, awareness, and attitude of the general population towards the health benefits of DF consumption (Amirabdollahian et al., 2016).

Thus, assessing consumers' knowledge of DF could potentially lead to identifying the relevant gaps in the public understanding and their misperceptions about DFs to inform the development of effective nutrition education programmes.

4.2 Aim and Objectives

This survey aimed to explore the knowledge, perception, and attitude regarding the consumption of dietary fibre among UK adults. This was achieved by investigating the current views and perceptions of UK adults about the health benefits of DFs.

4.3 Materials and Methods

This study was approved by the Ethical Advisory Committee of Manchester Metropolitan University, Faculty of Science and Engineering (Ref No: 34196) (Appendix 6).

4.3.1 Participants, eligibility criteria and recruitment

Adults 18 years and older living in the UK were eligible to participate in the survey. In addition, a basic knowledge of English was required to complete the survey. Participants younger than 18 years and participants with inflammatory bowel disease (IBD) or coeliac disease were not allowed to participate in this study. Based on the previous surveys that explored the knowledge and attitudes regarding DF, an initial sample size of 182 was considered for this survey based on previous study (Guiné et al., 2016).

Participants were recruited via electronic e-mail invitations as well as the survey links shared on social media or sent to the interested volunteers both internally and externally. The link to the online survey provided the participants with an initial overview of the study and an information sheet. The participants were required to accept the informed consent statement before starting the survey (Appendix 7).

The platform used to collect participants' responses used in this study was JISC. Participants identifying information was anonymised, and the data were stored confidentially in JISC online database.

4.3.2 Survey overview

This online survey was conducted between January and February 2022. The current online survey was developed and administered to UK adults. Participants' knowledge, attitudes and perceptions regarding DFs were explored using an online questionnaire. Survey questions were adapted from published questionnaires investigating other aspects of DF knowledge worldwide (Guiné et al., 2016; S. Lockyer et al., 2016; Alfawaz et al., 2020).

Survey questions were piloted on five volunteers to determine the face validity (content, structure and wording) of the questionnaire. This pilot study was conducted to inform the researcher about the overall structure of the questionnaire and to help with the amendment of the individual questions. This process resulted in new questions and minor changes to structure and wording (McCartney et al., 2018). The final version contained ordinally-rated questions and open-ended qualitative questions to increase the response rate while capturing more detailed answers (~10 minutes duration).

4.3.3 Survey design

The survey was designed according to the current dietary advice and the literature linking DF and health. It consisted of 20 questions and five sections.

Section 1 included questions about socio-demographic information, such as age, gender, place of living (England, Northern Ireland, Scotland, Wales), highest academic qualification (GCSEs, A level, Bachelors degree, Masters degree, PhD or other Doctorate) and employment status employed full-time, employed part-time, unemployed, retired, prefer not to say).

Section 2 explored the knowledge of dietary fibre. This section consisted of 3 subsections: i) questions on the perceived importance of changes towards a healthy diet such as consumption of more vegetables and fruits, less sugar, less fat and more whole grain products. The answers were rated on a scale of 1 to 4, with 1 indicating the highest importance; ii) a multiple-choice question about the foods with a high fibre content (vegetables, cereals fibre, fruit and berries and whole-grain products, or others; iii) a multiple-choice question about the health benefits of DFs (reducing the risk of T2DM high blood cholesterol, and cardiovascular diseases, supporting weight loss, improving digestion and bowel health).

Section 3 investigated the participants' behaviours related to dietary fibre consumption, including the frequency of DF consumption (i.e. at least once a day, at least once a week and once a month or less), strategies to increase daily fibre intake (eating whole fruits instead of drinking fruit juices, snacking on raw vegetables instead of chips or crackers and adding fruits or vegetables to daily meals), and main source of DF (i.e. diet, supplements and both diet and supplements). In addition, participants were asked to state the barriers against the consumption of fibre-rich food and beverages (taste, cost, availability, and the lack of information about the content and health benefits of the fibre in the nutritional label).

Section 4 focused on the participants' perceptions of DF content in whole fruit compared with fruit beverages. It used 3-point Likert scale statements (agree, neither agree nor disagree and disagree) about 1) DF content in whole fruit vs fruit beverages, 2) effect of peel removal on DF content of fruit beverages, 3) satiety after consuming whole fruit vs fruit juice, and 4) health benefits of whole fruits vs fruit juice for improving blood glucose levels.

Section 5 evaluated participants' awareness regarding daily DF intake. Two questions were rated on a 3-point scale to measure the perceived importance of adequate daily DF consumption (important, neutral, not important) and the presence of clear information about fibre content on the back of the pack label (very important, somewhat important, not important at all). There was also a question about the side effects of overconsuming DFs (i.e., feeling gassy, bloated, causes constipation, causes diarrhoea, or other) (Appendix 8).

4.3.4 Data analysis

SPSS statistical software version 23 was used to analyse the data. The analysis of the survey data was mostly exploratory. Nominal data were described by frequency and percentage, while ordinal variables were expressed as the median and interquartile range (IQR).

4.4 Results

A total of 308 (89 male, 217 female) respondents completed the survey. The majority of respondents were between 26 to 35 years old (48.5%), lived in England (82.6%), had a postgraduate degree (43 % master's, 22% PhD or other doctorates), and were

employed full-time (43.7%). The socio-demographic characteristics of the respondents are presented in (Table 4.1).

Table 4-1 Characteristics of the study participants (n=308).

Variable	Frequency	Participants n (%)
Gender		
Female	217	70.5
Male	89	28.9
Prefer not to say	2	0.6
Age		
18-25 years old	64	21.4
26-35 years old	145	48.5
36-45 years old	72	24.1
46-55 years old	15	5.0
Over 55 years old	3	1.0
Location		
England	242	82.6
Northern Ireland	23	7.8
Scotland	15	5.1
Wales	13	4.4
Qualification		
A level	23	7.7
Bachelor's degree	67	22.3
GCSEs	15	5.0
Master's degree	129	43.0
PhD or other Doctorate	66	22.0
Employment		
Employed Full-Time	131	43.7
Employed Part-Time	55	18.3
Prefer not to say	30	10.0
Retired	10	3.3
Unemployed	74	24.7

4.4.1 Knowledge about dietary fibre in study participants

The respondents rated the consumption of whole grain products as a more important change (median score: 2±1) towards a healthy diet, followed by vegetables and fruits (median score: 3±1), less sugar (median score: 3±1) and less fat (median score: 3±1), respectively.

Notably, 33.7% of the participants described vegetables as fibre rich foods, while 24.0% and 23.5% of the respondents considered fruit and berries followed by whole-grain products were high in fibre, respectively. On the other hand, only 18.8% of respondents believed that cereals were high fibre content. The proportion of respondents who stated that DF supports weight loss (26.7%) or improves digestion and bowel health (26.4%) was more prominent than those who stressed the protective role of DF against T2DM (19.3%) or high blood cholesterol (15.5%) and cardiovascular diseases (12.1%). (Table 4.2) summarises the perceived importance of changes towards a healthy diet among the respondents and their attitudes towards fibre consumption.

Table 4-2 The perceived importance of changes towards a healthy diet among the respondents and their attitudes towards fibre consumption.

Variable	Frequency	Participants n (%)
Ways to increase daily fibre intake		
Eat whole fruits instead of drinking fruit juices	176	57.1
Snack on raw vegetables instead of chips or crackers	154	50
Add fruits or vegetables to your meals	190	61.7
Dietary fibre consumption		
At least once a day	154	50
At least once a week	140	45.5
Once a month or less	20	6.5%
Foods high in fibre		
Vegetables	215	69.8
Cereals	120	39
Fruits and berries	153	49.7
Whole grain products	150	48.7
Health benefits of dietary fibres		
Reduces the risk of type 2 diabetes	125	40.6
Reduces blood cholesterol	100	32.5
Lowers the risk of cardiovascular diseases	78	25.3
Supports weight loss	173	56.2
improves digestion and bowel health	171	55.5

4.4.2 Dietary fibre consumption behaviour and attitude

Half of the respondents (50%) indicated that they consumed fibre at least once a day. A further (44.6%) ate fibre at least once a week. In addition, the study participants indicated that they would add fruits or vegetables to their meals to increase their daily DF intake (36.5%). In comparison, 33.8% and 29.6% considered eating whole fruits instead of drinking fruit juices and snacking on raw vegetables instead of chips or crackers as an excellent way to increase DF intake. Notably, the majority (48.3%) stated that diet was the primary source of their fibre intake. However, 24.8% and 26.8% of the respondents indicated that they consume fibre from supplements or both supplements and diet, respectively. Respondents underscored different reasons for not consuming fibre rich food and beverages, including tasteful (21.9%), higher cost (17.9%), rapid spoilage (24.5%), limited availability (12.3%) and unclear information about the content and health benefits of DFs in the nutritional label (23.3%).

4.4.3 Awareness of dietary fibre intake

The perceived importance of adequate daily DF consumption. More than half of the participants (55.3%) indicated that sufficient daily fibre consumption is essential, while (39.7%) were neutral about this statement. Also, (66.1%) of the participants stressed that it is crucial to provide information about fibre content on the back-of-pack label, while (30.2%) regarded it as somewhat necessary. In addition, the participants described different side effects for the overconsumption of DFs, including flatulence (26.5%), bloating (31.6%), constipation (19.3%) and diarrhoea (22.5%).

4.4.4 Attitudes towards the consumption of whole fruit compared to fruit beverages

Participants' perceptions of DF content in whole fruit compared with fruit beverages showed that they mostly agreed (58.6%) that peel removal during fruit beverages reduces their dietary fibre content compared with whole fruits, whereas (35.4%) were neutral towards this view. Furthermore, they mostly (64.9%) agreed that satiety sensation is greater after consuming whole fruit than fruit juice, although (26.8%) of respondents were neutral on this notion. Similarly, (63.3%) of the participants believed that whole fruits are healthier than fruit juice because their ingestion leads to a minor increase in blood sugar. However, again (32.3%) were neutral on this belief. Participants' perceptions of DF content in whole fruit vs fruit beverages are presented in (Table 4.3).

Table 4-3 Perceptions of dietary fibre content in whole fruit vs fruit beverages.

Perceptions of DF content in whole fruit vs fruit beverages	Agree		Disagree		Neither agree nor disagree	
	Frequency	%	Frequency	%	Frequency	%
Removal of the peel during processing may lead to reduced dietary fibre content after fruit beverage consumption compared with whole fruit	177	58.6	18	6	107	35.4
Satiety sensation is greater after consuming whole fruit compared to fruit juice	196	64.9	25	8.3	81	26.8
Whole fruits are healthier than fruit juice because their ingestion leads to less increase in blood sugar	190	63.3	13	4.3	97	32.3

4.5 Discussion

The present survey provided insights into the knowledge, attitude and awareness regarding the consumption of foods rich in DF and their health benefits among the UK adult population.

In this survey, most respondents described vegetables as the main fibre rich foods while 50.3% and 49.3% of the respondents respectively considered fruit and berries as well as whole-grain products to be high in fibre. In previous studies, the participants described whole-grain products, vegetables, fruit and berries as the primary sources of dietary fibre (Cashel et al., 2001; Lyly et al., 2004). However, in the present survey, only 18% of respondents considered cereals as a good source of fibre, which may indicate their limited knowledge about the nutrient content of cereals which are the primary source of complex carbohydrates in the UK. This is consistent with the respondents' understanding of fibre-rich foods as they considered vegetables, fruit, and berries good DF sources (Alfawaz et al., 2020).

In the present survey, the respondents also stated that they were willing to increase their daily intake of DF. They would add fruits or vegetables to their meals, eat whole fruits instead of drinking fruit juices, snack on raw vegetables instead of chips or crackers as a good way to increase DF intake, which highlights their preference for fresh fruit and vegetables rather than fruit beverages.

Interestingly, in the present study, higher consumption of whole grain products was perceived as the most critical change to maintain a healthier diet compared to the higher intake of vegetables and fruits or lower consumption of sugar and fat. This may reflect the gap in the general population's knowledge about the proportional

importance of eating adequate portions of fruit and vegetable intake and reduced consumption of foods high in sugar and fat. This contrasts with the findings of a survey in Finland (Lyly et al., 2004). In that survey, only 5% of the respondents considered more whole-grain products as important changes towards a healthier diet. In comparison (43%) of respondents who thought the consumption of more vegetables and less sweet delicacies (26%) was larger than those who perceived consumption of less fat (18%), more fruit (14%) and more fish (10%) as an important change to maintain a healthier diet (Lyly et al., 2004). Similarly, in another survey (Margetts et al., 1997), 80% of EU participants stressed the need to consume more fruits and vegetables and less fat when asked to describe their perception of a healthy diet. Nevertheless, research suggested that adult consumers in Europe have a good awareness of healthy diets. For instance, a survey conducted in 1997 reported that 80% of EU participants stated the need to consume more fruits and vegetables and less fat when asked to describe their perception of a healthy diet (Margetts et al., 1997), however this may be related to the characteristics of a healthy diet in general rather than a particular interest in the fibre content of fruits and vegetables

This survey also found that the proportion of respondents who stated that DF supports weight loss (26.7%) or improves digestion and bowel health (26.4%) was more prominent than those who stressed the protective role of DF against T2DM (19.3%), elevated blood cholesterol (15.5%) or cardiovascular diseases (12.1%). This is different from a recent survey of Saudi adults (Alfawaz et al., 2020), where the majority of the respondents were aware of the protective effects of fibre-rich foods against obesity (70.5%), cardiovascular diseases (68.9%), and hyperglycaemia (68.9%). This may indicate the better nutritional knowledge of Saudi Arabian people

than those in the UK (Alfawaz et al., 2020). However, it is not translated to a higher intake of DF as, similar to the UK, their average daily fibre intake of 10 g/d in Saudi Arabia is below the recommended daily consumption of 25 – 30g/d (Alfawaz et al., 2019). This is in contrast with previous studies where nutrition knowledge was associated with actual food choices (Barzegari et al., 2011). However, it might be in line with other studies that observed external reasons might affect food choices, such as consumers' perceptions, food labelling, and sensory evaluation (Hoppert et al., 2012).

Approximately half of the study population indicated that they consumed DF daily. This is consistent with a survey of Finnish adults (Lyly et al., 2004) that demonstrated 51% of male and female participants had an adequate intake of DF. Also, a study in Saudi Arabia showed that the majority of respondents regularly (≥3 times a week) consumed fibre-rich foods, including fruit and vegetables, nuts and pulses (Alfawaz et al., 2020). This may indicate public awareness of the importance of DF consumption in these regions. However, other perceived benefits of fruit and vegetables can be other important factors.

The majority of respondents in the present survey stated that diet was the primary source of their fibre intake as well as they use fibre supplements. This is in line with Anderson et al. (2009) reported that 48% of the respondents described diet as the only source of their DF intake, although 52% reported that they also used supplements. This suggests that adults may commonly use fibre supplements. Generally, it has been shown that 10 g to 15 g of the recommended 30 g daily fibre intake are supplied from dietary sources. This may be due to the inadequate

consumption of fruits and vegetables and the higher consumption of refined carbohydrates rather than whole-grain foods. Thus, the public may use fibre supplements as an alternative to fibre rich but challenging to eat food items to increase their DF intake (Anderson et al., 2009).

In addition, the respondents described various barriers against the consumption of DF, including tastefulness, price, food waste, availability, and the lack of information about fibre content on food labels. Notably, the lack of knowledge (23.3%), rapid spoilage (24.5%) and less desirable taste of foods with high fibre content (21.9%) were described by a larger proportion of the respondents. Consistent with this observation, in a recent survey by Alfawaz et al. (2020), the respondents stated that foods rich in DF were expensive (72.1%), not readily available (51.6%), and not tasteful (52.8%). These barriers may explain the lower average intake of fibers from the diet and the wider use of fibre supplements by the respondents.

This finding has important implications for the food industry as it indicates the need for improved labelling, reformulation of fibre rich food products and the market research for the alternative ways to increase fibre consumption in people who are concerned about the short shelf life of fresh fibre rich foods.

The respondents of the present survey also showed an awareness of consuming the required amount of DF as they mostly emphasised the importance of adequate DF intake (55.3%) and underscored the need for nutritional labelling on the fibre content of food products (66.1%). The importance of clear nutritional information was also reflected in the responses to a previous survey (AC Martinho et al., 2013) which showed that most participants (77%) consulted the food labels before purchasing

food products, and 43% were particularly interested in the fibre content. This highlights the public interest in the nutritional quality of food products and the need for standard and nutritionally informative food labelling.

In the current survey, most respondents believed that fruit beverages had a lower content of DF than whole fruits because the peel is removed during the processing of these drinks. However, the higher DF content of whole fruits was also stated as the reason for their favourable effect on satiety and blood sugar regulation compared to fruit juice. This is supported by a previous survey (AC Martinho et al., 2013) where most respondents (67%) were aware that whole foods had more fibres than non-integral foods. In addition, 74% of respondents affirmed that the fruit with the peel was richer in fibre compared to the peeled fruit (Lyly et al., 2004). The above finding indicates that the study population had clear perceptions of the health benefits that eating whole fruits could offer.

4.6 Conclusion

The present study observed an awareness regarding the importance and health benefits of adequate fibre intake among a sample of UK adults. Most participants regularly consumed DF, and fibre supplements were common. Interestingly, the study participants were aware of the benefits of DF for weight management and obesity prevention, but they did not show clear awareness about the protective role of DF intake against T2DM and cardiovascular disease. Further, the study population had some knowledge of how to improve DF intake by consuming whole fruit and vegetables as they were aware of their higher fibre content that would improve satiety and glucose control.

There were, however, specific barriers against higher intake of fibre from the diet, particularly taste, price, food waste and nutritional information on the food labels. However, there were limitations in the knowledge and perception of the study population about the fibre content of various food products. There was also a discrepancy between knowledge and consumption of DF in this group of UK adults. These findings should be interpreted with caution because the respondents were mostly well-educated and did not represent the general population. Furthermore, the responses were not stratified by sociodemographic characteristics of the study participants.

Nevertheless, nutritional education focusing on changing the perception towards foods rich in DF should be preferred to disseminate DF intake information to improve a healthy lifestyle. The survey findings will aid in developing an idea about the general knowledge of adults regarding a healthy diet. In addition, the findings will be the basis of further research studies that will assess the effect of DF on the rate of glucose absorption, gastric emptying, and appetite.

Chapter 5 : The effect of konjac glucomannan capsules on metabolic and appetite responses to smoothie ingestion in healthy adults: A randomised controlled trial

5.1 Introduction

There is compelling evidence of the favourable metabolic effects of soluble dietary fibres (SDFs), either naturally occurring in food or in the form of extracts and supplements (Evans, 2020). Consequently, many national and international health and medical organisations recommend increasing dietary fibre (DF) intake for adults and children.

As reviewed in chapter 1, clinical and epidemiological studies show that SDF intake is inversely related to appetite (Guo et al., 2022), weight gain and obesity (Wanders et al., 2011; Canene-Adams et al., 2022). Furthermore, SDF consumption reduces postprandial rise in blood glucose levels after carbohydrate-rich meals and improves total cholesterol (TC) and low-density lipoprotein cholesterol (LDL-C) levels (Vuksan et al., 2011). These beneficial effects are mainly ascribed to the viscous and gel-forming properties of SDFs.

Among SDFs, konjac glucomannan (KGM) has drawn particular attention as a highly viscous dietary fibre with good tolerability and mild gastrointestinal side effects. KGM has excellent biocompatibility and non-toxic and harmless characteristics, and it can be used in food, medicine and biological fields (Du et al., 2021).

5.1.1 Konjac glucomannan and glycaemic control

The role of KGM in reducing hyperglycaemia, improving insulin secretion and potentially exerting anti-diabetic effects has generated significant research interest. However, the findings from clinical interventions have been inconsistent.

Several studies have supported the benefits of KGM consumption for glycaemic control in different groups of populations. The post prandial glucose (PBG) lowering effect of 4g KGM was comparable to a larger dose (6g) of another VDF, i.e., guar gum (Boers et al., 2017). Recently, Yoshida et al. (2020) found dose-dependent improvements in PBG and insulin levels undergoing a 75-g oral glucose tolerance test (OGTT) in healthy adults who consumed rice gruel containing 0.4 or 0.8% KGM compared to the control group. Furthermore, the addition of 2 g and 4 g KGM powder into flatbread flour slightly reduced PBG response compared to a similar product enriched with bran fibre. In this study, only the highest level of 4 g KGM had a substantial effect (Boers et al., 2017). However, Chearskul et al. (2009) observed a non-significant effect of KGM capsules on postprandial glycaemia in adults with T2DM. Thus, KGM may be more effective in individuals without impaired glucose homeostasis (Honsek et al., 2018), although this requires studies comparing KGM effects on glycaemic response in adults with diabetes and healthy individuals.

In comparison, KGM supplementation has effectively improved FBG in healthy adults and those with diabetes. A recent experimental study demonstrated that in patients with T2DM, HbA1c and fasting plasma glucose levels also significantly decreased from 8.3% to 8.0% and from 173.2 to 152.8 mg/dL, respectively, over 12 weeks of consuming foods that were enriched with at least 100g KGM (Ueno et al., 2021). In contrast, using KGM gel (noodles) for four weeks did not improve glycosylated haemoglobin (HbA1c) (Li and Sing-Chung, 2016). The inferior effectiveness of KGM incorporated into the meals may be attributed to the solid matrix of the foods that prevent the full hydration of KGM (Boers et al., 2017).

5.1.2 Konjac glucomannan, appetite and body weight regulation

Konjac glucomannan, is widely chosen by many researchers in designing satiety-enhanced foods due to the highest viscosity that could be imparted to food amongst polysaccharides (Ho et al., 2017). The evidence on the effectiveness of KGM in reducing appetite and food intake is mixed. Early studies demonstrated a significant effect of KGM supplements on appetite. However, only some of these studies were randomised placebo-controlled trials, and all were short-term and performed in small study populations (Walsh et al., 1984; Vita et al., 1992; Cairella and Marchini, 1995).

In individuals with metabolic syndrome, eating KGM noodles (400 g/day) was associated with a significant reduction in body weight (-0.79 kg) after 4 weeks compared to the placebo noodles (-0.58 kg) (Cheang et al., 2017). There were also significant decreases in body weight (-0.55 kg) of overweight adults receiving a 3g KGM supplement plus 300 mg calcium carbonate compared to the placebo group (+1.21 kg) (Kaats et al., 2015). In another study, sedentary and overweight participants who ingested 1.5 g hard gelatine KGM capsules with approximately 237 mL of water about 5 minutes before each of the 2 largest meals of the day a total of (3 g) of KGM per day over 8 weeks. KGM supplementation successfully reduced daily caloric intake from pre-intervention to the end of the study (Kraemer et al., 2007). On the contrary, a systematic review (Onakpoya et al., 2014) of the RCTs on the efficacy of KGM supplementation in overweight and obesity did not find a significant association between KGM intake and body weight reduction. Therefore, the role of KGM in the regulation of food intake, appetite and body weight is unclear.

5.1.3 Konjac glucomannan and lipid control

Konjac glucomannan can be beneficial for lipid metabolism, lowering TC and LDL-C levels (Gallaher et al., 2000; Kraemer et al., 2007). In addition, KGM fermentation in the large intestine leads to the formation of propionate predominantly, which may decrease cholesterol synthesis (Connolly et al., 2010). However, there is some inconsistency in the clinical studies.

In a study of people with obesity who were not on diet restrictions, daily consumption of 1g KGM over 8 weeks caused a significant reduction in serum TC and LDL-C levels; mean decreases were 21.7 mg/dL and 15.0 mg/ dL, respectively (Walsh et al., 1984). Similarly, Arvill and Bodin (1995) found that following 4 weeks of KGM consumption (3.9 g/day), serum TC levels fell by 10% and LDL-C levels by 7.2%. Also, a study of adults with elevated TC (6.69 mmol/L) and TAG levels (2.88 mmol/L) at baseline showed that the consumption of drinks containing 3g KGM powder for 14 days reduced TC, LDL-C and TAG levels by 3.74%, 3% and 11.5%, respectively (Suwannaporn et al., 2015). Furthermore, over 12 weeks of supplementation with KGM (1.5 g) plus Garcinia (2.4 g) before main meals in healthy participants was associated with significant reductions in TC (−32.0 mg/dL) and LDL-C levels (−28.7 mg/dL) compared to placebo (Vasques et al., 2008). These effects on TC and LDL-C are consistent with a previous meta-analysis by Sood et al. (2008), which suggested the cholesterol-lowering effect of KGM. These findings support the modest cholesterol-lowering effect of KGM supplementation in healthy adults and those with obesity or elevated blood cholesterol.

5.2 Research rationale

The above review provided some evidence on the beneficial metabolic effects of KGM. However, the dose-response relationship between KGM intake and metabolic parameters is limited. Furthermore, there is insufficient data regarding the impact of KGM on metabolic outcomes after consuming a drink with high sugar content. In addition, the information on the effect of KGM supplementation on the appetite-regulating hormones is scarce and mainly on ghrelin and leptin fluctuations.

The present research is the first study to explore the metabolic effect of KGM supplementation in two different concentrations (1g and 2g). Further, this study adds to the available literature by examining the acute (2-hour) changes in a wide range of objective appetite-related measures, including a comprehensive gut hormone profile (ghrelin, GLP-1, PYY and PP) and gastric emptying rate. It also provides novel insights into the role of KGM supplementation in improving metabolic response to the ingestion of sugar-rich fruit smoothies.

5.3 Aim and Objectives

5.3.1 Aim

This study aimed to assess the acute effect of konjac glucomannan capsules on metabolic and appetite responses to fruit smoothies in healthy adults.

5.3.2 Objectives

- To conduct a crossover placebo-controlled trial to measure the acute (2- hour) effect of KGM supplementation on blood glycaemic and lipid responses, appetite-regulating hormones, gastric emptying rate and subjective measures

of appetite in healthy adults after drinking commercial fruit smoothies high in sugar content.

- To determine whether there is a dose-dependent response relationship between the amount of KGM supplementation (1 and 2g) and the changes in the metabolic markers (blood glucose, insulin, total cholesterol, triglyceride, non-esterified free fatty acids, ghrelin, GLP1, PPY and PP), gastric emptying rate, subjective appetite (hunger, fullness, satisfaction, prospective food consumption) and gastrointestinal discomfort (bloating) after the ingestion of a commercial fruit smoothie drink with high sugar content in healthy adults.

5.4 Study hypotheses

1. The consumption of KGM capsules does not significantly change 2hr metabolic response, including blood glucose and insulin concentration, gastric emptying rate and circulating gut hormones (ghrelin, GLP-1, PYY, and PP) to the ingestion of sugar-rich fruit smoothie drinks.
2. The pre-ingestion of KGM capsules does not significantly affect the subjective appetite (hunger, fullness, satisfaction and prospective food consumption) within 2 hours after drinking sugar-rich fruit smoothies.

5.5 Materials and Methods

5.5.1 Study design and ethical approval

This was a randomised, single-blind placebo-controlled trial with a crossover design. This intervention was undertaken over 12 months from 2019 to 2020. The study was conducted in the department of Life Science laboratories in John Dalton Building, Manchester Metropolitan University (MMU). This study was approved by the Ethical

Advisory Committee of MMU's Faculty of Science and Engineering (Ref No: 0480-1201) (Appendix 8).

5.5.2 Inclusion and exclusion criteria

Adults aged 18 to 45 years with a body mass index (BMI) between 20 to 25 kg/m^2 were eligible to participate in this experimental study.

Individuals with eating disorders or special diets, known food allergy or intolerance, constipation or diarrhoea, recent participation in nutritional interventions, previous history of gastrointestinal problems (malabsorption syndrome, autoimmune disease, inflammatory bowel syndrome, hepatobiliary disease, peptic ulcer), recent history of bariatric surgery or other operations affecting the gastrointestinal tract were excluded from the trials. Also, individuals who used supplements or medications with metabolic effects (including drugs for weight management), individuals with a history of psychiatric disorders, substance abuse, learning difficulties and pregnant or lactating women were not eligible to participate in this study.

5.5.3 Recruitment and study participants

The recruitment was for two months. Healthy participants were recruited into the study via poster advertisements placed on the MMU campus and advertisements on social media. In addition, information about the project was distributed via email to MMU students and staff. Promotion of the study was also undertaken externally in the health and fitness centres. Furthermore, the recruitment process used snowballing, whereby the interested volunteers were asked to pass on details of the study to others via email or social networks.

Individuals who responded to the advertisements were invited to a 60-minute familiarisation session. During this session, the project was described to the volunteers, and they received a copy of the participant information sheet (Appendix 11). Participants were encouraged to seek further clarification from the researcher before participating in the study. The interested participants were made fully aware of all the experimental procedures and their right to withdraw from the study at any time. Then, a written consent form (Appendix 10) was obtained from each participant. They were also asked to complete a medical screening questionnaire.

Overall, 8 participants (3 females and 5 males), healthy non-smoker adults aged 18 to 45 years with a body mass index (BMI) between 20 to 25 kg/m^2 were included in this experimental study after the initial screening.

5.5.4 Sample size

The sample size was calculated in G*Power version 3 using the *a priori* power analysis procedure for a repeated-measures between-factor ANOVA with a 90% power and a 2-sided significance level of $p<0.05$ ($\alpha=0.05$). To detect a mean difference of 9.5mmol/L in the 2-hour changes of blood glucose concentration from baseline and a within-subject SD difference of 1.75mmol/L between glucomannan supplementation and placebo groups, 8 participants were required for this crossover study (Rothwell, 2018). This estimation was based on the studies which measured 2-hour glucose concentration during OGTT (with standard ingestion of 75g glucose) (Chearskul et al., 2007).

5.5.5 Preliminary trial

All participants conducted a preliminary visit prior to their first experimental trial. This session involved anthropometric measurements (height and weight) and familiarisation with the breath sampling procedures. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer, and body mass was measured to the nearest 0.01 kg using an electronic scale (GFK 150; Adam Equipment Co. Ltd., Milton Keynes).

5.5.6 Pre-trial standardisation

Participants were requested to refrain from alcohol and caffeine ingestion 24 hours before each experimental laboratory visit. Participants were asked to attend the laboratory in the morning following an overnight fast (12 hours) from 9.00 pm. In addition, participants were advised to drink 500 mL of water 90 minutes before arrival to ensure they would be hydrated during the experiment.

All experimental trials commenced in the morning between 09:00 and 09:30 am. There was a two-week interval between each experimental trial to allow for the washout of ^{13}C from the breath and to minimise the carryover effects between trials (Cheang et al., 2017).

5.5.7 Materials

KGM capsules (500 mg) were purchased from Holland & Barrett Retailer (Nuneaton, Warwickshire, CV10 7RH B29387). White rice flour was purchased from local suppliers. Then, 500 mg of white rice was included in capsules with similar weight to those filled with KGM. Capsules had a similar appearance to blind the participants

against the actual dose and type of the supplements. White rice flour is identical in colour and appearance to KGM. Therefore, to achieve the purpose of blinding, white rice was chosen as the placebo in line with previous studies on KGM supplementation and metabolic changes (Chearskul et al., 2007; Chearskul et al., 2009; K Fai et al., 2011).

Commercial fruit smoothies were also purchased from local suppliers. The commercial smoothie used in these trials had a 'Strawberry and Banana' flavour from the Innocent® smoothie brand (see chapter 2). Nutritional information for Innocent® strawberries and bananas smoothie (250 mL) is presented in (Appendix 5). The smoothie samples used for each experiment were identical in taste, texture, appearance, calorie and macronutrient content, and the only difference in the experiment was the concentrations of the KGM capsules (1g and 2g). The serving size of the 500 mL commercial fruit smoothie was in line with previous studies (Reshef et al., 2005; Brunstrom et al., 2010; Morand et al., 2011; Bell et al., 2017; Moazzen and Alizadeh, 2017) to provide sufficient quantities of ingested glucose for the subsequent measurement of sugar absorption (Yu et al., 2014) and appetite (Melson et al., 2019).

5.5.8 Experimental trials

Initially, participants were randomly assigned to one of three sequences of trials. The sequence of trials was determined by an allocation schedule generated in Microsoft Excel (Kim et al., 2014) using a simple randomisation method. The trials involved the ingestion of 1 g KGM, 2 g KGM or placebo (white rice flour) capsules.

To ensure uniformity within each sequence and period, the crossover study had 3 sequences, 3 periods, and 3 trials designs (Prescott, 1999). They are presented in (Table 5.1). Within each experimental sequence, there was a 2-week washout interval to control, reduce the carryover effect and help the researchers to determine whether the outcome of the study was due to the study drug (Cleophas, 1993).

Table 5-1 Sequences and periods in the crossover study.

Sequence	Number of trials		
	1	**2**	**3**
1	KGM 1g	KGM 2g	Placebo
2	KGM 2g	Placebo	KGM 1g
3	Placebo	KGM 1g	KGM 2g

In all trials, participants have received four 500 mg capsules with 250 mL water and waited for 30 minutes as per the manufacturer's instructions to ensure that KGM was fully hydrated and according to standard protocols (EFSA, 2010). After 30 minutes, each participant drank 500 mL of commercial fruit smoothies. The blood samples were then collected 15 minutes intervals after smoothie ingestion during the first hour, then every 30 minutes post-ingestion during the second hour of the experiment (O'Connor and Campbell, 2016; Stote et al., 2019; Guo et al., 2022).

The basal end-expiratory breath samples were initially collected at baseline, then collected 30 minutes after KGM or placebo capsule intake and then at 15 minutes intervals post-smoothie ingestion for a total of 2-hour (Stote et al., 2019; Guo et al., 2022). During all trials, blood collections, gastric emptying rate (GER), and appetite

assessment measurements were conducted repeatedly at different time points over 120 minutes post-ingestion.

As presented in (Table 5.1), participants assigned to the first sequence received two 500 mg capsules containing (1 g KGM) and two 500 mg capsules containing (1 g white rice flour) placebo.; participants assigned to the second sequence received four 500 mg capsules containing (2 g KGM), and participants from the third sequence received four 500 mg placebo capsules containing (2 g white rice flour).

Measurements were taken at prespecified time points during the first trial of the experiment. This was followed by a two-week washout interval. Then, participants switched the capsules, as shown in (Table 5.1). After the completion of the second trial, there was another two-week washout interval. Then, participants crossed over to the third trial as described in the table.

5.5.9 Primary outcomes

Postprandial glucose concentration (mmol/L) and the area under the curve (AUC) for the 2-hours changes in blood glucose concentration after smoothie ingestion (mmol/L x 120 minutes).

Serum insulin concentration (pmol/L) and the AUC for insulin concentration over 120 minutes after smoothie ingestion.

5.5.10 Secondary outcomes

Gastric emptying rate, delta over baseline (DOB) of $^{13}CO_2$: $^{12}CO_2$ in the end-expiratory breath samples, half-emptying time (T_{half}) (minute) and the time of maximum emptying rate (T_{lag}) (minute) of $^{13}CO_2$.

Appetite regulating hormones, acylated ghrelin (pmol/L), active Glucagon-like peptide-1 (GLP-1) (pmol/L), Pancreatic Polypeptide (PP) (pmol/L), Peptide tyrosine tyrosine (PYY) (pmol/L).

Appetite sensation: hunger, fullness, prospective food consumption and satisfaction. Scores on a visual analogue scale (VAS) (100 mm). As well as gastrointestinal discomfort (bloating). Blood lipid concentration: Total cholesterol (TC, mmol/L), Non-esterified fatty acid (NEFA, mmol/L), and Triglyceride (TAG, mmol/L).

5.5.11 Blood analysis

Venous blood samples were collected repeatedly from each participant for over 120 minutes post-ingestion by inserting an intravenous cannula (BD Venflon, 20G, Becton Dickinson Infusion Therapy, Helsingborg, Sweden) into an antecubital vein which remained in place for the duration of the experiment. All blood samples were collected from the participant in a semi-supine position. After collecting each blood sample, cannulas were kept patent by flushing with non-heparinised saline (0.9% sodium chloride; Becton Dickinson, New Jersey, USA) to prevent occlusion. Volumes of 50µl of DPP-IV inhibitor (Merck Millipore Limited, UK) and 50µl of Pefabloc (Roche Diagnostics Limited, UK) were immediately added to prevent the degradation of active GLP-1 by DPP-IV and acylated ghrelin by protease (10µl/mL of whole blood of both inhibitors as recommended by the manufacturers). Using Hormone Core Sample Collection Procedures.

Blood samples were collected initially at baseline. Then participants were requested to ingest KGM or placebo capsules with 250mL water and waited for 30 minutes as per the manufacturer’s instructions to ensure that KGM was fully hydrated and

according to standard protocols (EFSA, 2010). Afterwards, participants were asked to consume the commercial fruit smoothie drink (500mL). The blood samples were then collected 15 minutes intervals after smoothie ingestion during the first hour, then every 30 minutes post-ingestion during the second hour of the experiment (O'Connor and Campbell, 2016; Stote et al., 2019; Guo et al., 2022).

All blood samples were kept on ice until all samples were collected. Blood samples were centrifuged (Z400K, HermLe, Germany) at 1500 x g for 15 minutes at 4° C. The serum was aliquoted and stored at -80° C until further biochemical analysis (Kraemer et al., 2007).

Collected blood samples were used to determine glucose, TC, TAG and NEFA concentrations. Blood samples were analysed in triplicate on a clinical chemistry analyser (Randox Daytona, Crumlin, UK).

In addition, circulating levels of acylated ghrelin concentration, insulin, active GLP-1, total PP, PYY were measured. Blood samples were analysed in triplicates to validate empirical data using multiplex analysis (Luminex 200, Luminex Corporation, Austin, TX, USA) with kits purchased from Merck-Millipore (HMHMAG-34K, Milliplex MAP, Merck Millipore Ltd., Feltham, UK).

5.5.12 Gastric emptying rate

Gastric emptying rate was measured using the ^{13}C breath test method (Pletsch et al., 2022). This method is a valid, reproducible, and non-invasive method for GER assessment. The ^{13}C sodium acetate breath test method is reliable to measure GER with liquids and semi-solid test meals (Braden et al., 2007). 100 mg of ^{13}C-sodium

acetate (Cambridge Isotope Laboratories, Inc) was added to the 500 mL of commercial fruit smoothie for GER measurement.

Measurements were taken in the following manner: the basal end-expiratory breath samples were initially collected at baseline, then collected 30 minutes after KGM or placebo capsule intake, and then at 15 minutes intervals post-smoothie ingestion for a total of 2-hour (Stote et al., 2019; Guo et al., 2022). On each occasion, breath samples were collected into a 100 mL foil bag by exhalation through a one-way valve mouthpiece (Wagner Analyzen-Technik, Bremen, Germany). Bags were then sealed with a plastic stopper and stored safely for later analysis.

The ratio of $^{13}CO_2$:$^{12}CO_2$ in the end-expiratory breath samples was measured by Nondispersive Isotope-Selective Infrared Spectroscopy (NDIRS) (IRIS Dynamic, Kibion, Germany). The difference in the ratio of $^{13}CO_2$:$^{12}CO_2$ from baseline breath samples to post-ingestion breath samples was expressed as delta over baseline (DOB) as a measure of GER. In addition, the half-emptying time (T_{half}) and time of maximum emptying rate (T_{lag}) of $^{13}CO_2$ from the stomach were also calculated based on equations integrated into the software.

5.5.13 Assessment of subjective appetite

Appetite was subjectively rated by the participants on a 100 mm visual analogue scale (VAS) as described by Douglas et al. (2017) and Flint et al. (2000). Subjective assessment of the appetite was conducted at baseline, 30 minutes after KGM or placebo capsule intake, 30 minutes after smoothie ingestion and then every 30 minutes over 2-hour (Freeland et al., 2009; Guo et al., 2022). During the experiment, participants were asked to rate their feelings of fullness, hunger, satisfaction

(positive physical and psychological responses relevant to perceived stomach feelings) and prospective food consumption based on a questionnaire. Along with the assessment of the gastrointestinal discomfort (bloating) (Flint et al., 2000) (Appendix 12).

5.6 Data analysis

Statistical analyses were carried out using IBM SPSS statistics (v25.0 for Windows; SPSS, Chicago, IL). Data distribution was checked using the Shapiro Wilk test. Normally distributed data were descriptively presented as mean and standard deviation (SD). Depending on the outcome measure, either one way (treatment) or two way (treatment x time) repeated measures ANOVAs were used to analyse the changes in the concentration and AUC of blood glucose, insulin and gut hormones between three experimental groups over 120 minutes. Separate repeated measure ANOVA models were designed for gastric emptying measures DOB and VAS ratings on appetite measures. The assumption of sphericity for repeated measures was assessed by Mauchly's test. Where appropriate, Greenhouse–Geisser corrections were applied for epsilon < 0.75, and the Huynh–Feldt correction was adopted for less-severe asphericity. Significant F tests for within-subject and between-group differences were followed by Bonferroni adjusted pairwise comparisons as appropriate. A p-value < 0.05 was considered statistically significant. The longitudinal changes in the repeatedly measured variables were visually presented as mean plots (with 95% confidence intervals). Also, the effect of experiment sequence on the outcomes was also tested using univariate ANOVA to ensure the findings were not different across three randomly assigned sequences.

5.7 Results

5.7.1 Anthropometric characteristics of the study participants

In total, 8 adults (5 male, 3 female) aged 20 to 40 years (mean age: 26±6 years) were randomly enrolled on this experimental study with these anthropometric characteristics, weight (71.33±6.56) kg, height (174±5.89) cm, and BMI (23.5±1.06) kg/m^2. The baseline measurements of the study participants were measured to display whether any significant differences exist between groups at bassline (Table 5.2).

Table 5-2 Baseline anthropometry and fasting plasma biochemistry of study subjects.

Variable	2g KGM		1g KGM		Placebo		
	Mean	SD	Mean	SD	Mean	SD	p value
Fasting blood glucose (mmol/L)	5.05	0.4	4.96	0.61	4.96	0.47	0.75
Insulin (pmol/L)	4034.3	2205.26	3650.11	1810.27	4025.01	2265.15	0.22
TC (mmol/L)	4.92	0.8	4.7	0.96	4.44	0.77	0.06
TG (mmol/L)	0.73	0.24	0.78	0.32	0.78	0.33	0.71
NEFA (mmol/L)	0.52	0.16	0.62	0.26	0.57	0.37	0.58
Ghrelin (pmol/L)	169.41	55.41	134.22	46.03	136.24	67.32	0.21
GLP1 (pmol/L)	9.25	6.11	11.47	6.91	9.73	9.14	0.006
PYY (pmol/L)	191.19	82.99	193	84.58	194.84	130.1	0.75
PP (pmol/L)	77.56	56.19	76.29	58.19	93.85	61.78	0.51
Hunger (mm)	48.5	26.55	49.88	17.77	50.25	29.13	0.98
Fullness (mm)	39.17	23.1	30.56	8.26	39.33	11.57	0.56
Satisfaction (mm)	27.17	16.08	24	10.47	24.17	19.2	0.89
Prospective food consumption (mm)	53.33	8.33	58.17	19.09	55	21.48	0.86
Bloating (mm)	3.86	8.57	5.43	8.44	1.57	2.15	0.06

5.7.2 Primary outcomes

5.7.2.1 Glucose concentration

The choice of treatment sequence did not have a significant effect on the observed changes in glucose concentration (F=3.73, *p*=0.11). Based on the two-way repeated-measures ANOVA, the main effect of treatment on blood glucose concentration was non-significant (F=1.27, *p*=0.32). In general, glucose levels were lower after supplementation with 2g KGM (5.64±0.27mmol/L) compared to 1g KGM (5.71±0.30mmol/L) and placebo (6.03±0.24mmol/L), although this difference was non-significant. However, there was a significant effect of time on the changes in the blood glucose levels from baseline to 120 minutes after fruit smoothie ingestion (F=15.69, *p*<0.001). Overall glucose levels increased slightly over 120 minutes compared to bassline (4.99±0.16mmol/L). Glucose levels were significantly higher in the placebo group at 30 minutes (7.14±0.39mmol/L) and 45 minutes (6.76±0.29mmol/L) after fruit smoothie ingestion (*p*=0.001, *p*<0.001, respectively) than baseline and before smoothie ingestion (*p*=0.009, *p*=0.015, respectively). In contrast, glucose levels gradually decelerated from 60 minutes to 120 minutes after smoothie ingestion when the lowest concentration was measured (4.81±0.28mmol/L) (Figure 5.1). The interaction effect of treatment*time on blood glucose concentration was non-significant (F=1.13, *p*=0.34).

AUC for glucose concentrations was greater in placebo experiment (162.56±127.8mmol/L x 120 minutes) compared to experiments with 2g KGM (108.57±70.1 mmol/L x 120 minutes) and 1g KGM (114.1±131.6 mmol/L x 120 minutes), although the differences were nonsignificant (F=1.28, *p*=0.31).

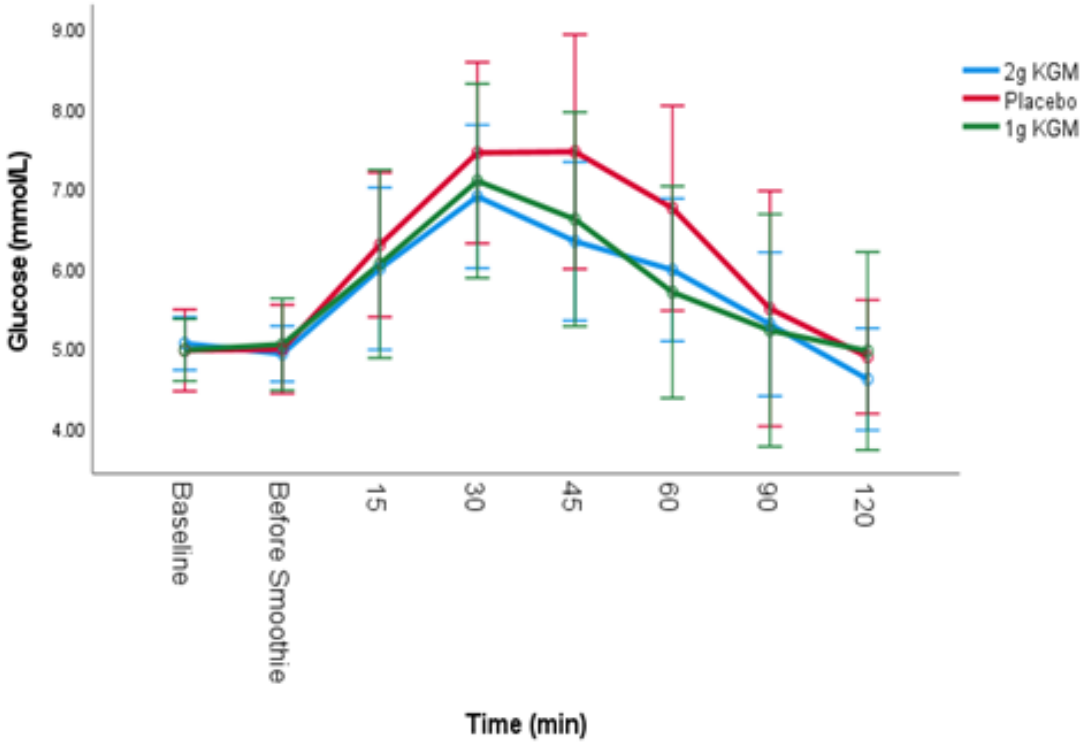


Figure 5-1 Changes in the glycaemic responses. Serum glucose concentrations glucose across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking 500 mL of a commercial fruit smoothie. Values represent mean ±95% CI.

5.7.2.2 Insulin concentration

The effect of treatment sequence on the observed changes in serum insulin concentration was non-significant (F=0.48, *p*=0.63). The two-way repeated-measures ANOVA demonstrated a significant effect of KGM supplementation (1g and 2g) on insulin concentration (F=5.98, *p*=0.01) over 120 minutes post-ingestion. Overall insulin levels were lower after smoothie ingestion in the 2g KGM group (2950.29±719.8pmol/L) compared to 1g KGM (3071.10±659.5 pmol/L) and placebo groups (3537.58±527.3pmol/L) (Figure 5.2). Notably, the difference in insulin AUC between the three experiments was nearly significant (F=5.05, *p*=0.051), indicating

that a higher dose (2g) of KGM capsule may improve insulin response (AUC= 332206± 269325 pmol/L x 120 minutes) to a sugar-rich semi-liquid meal compared to a lower dose (1g) of KGM (AUC= 357732± 251404pmol/L x 120 minutes) or placebo (AUC= 410756± 203793pmol/L x 120 minutes).

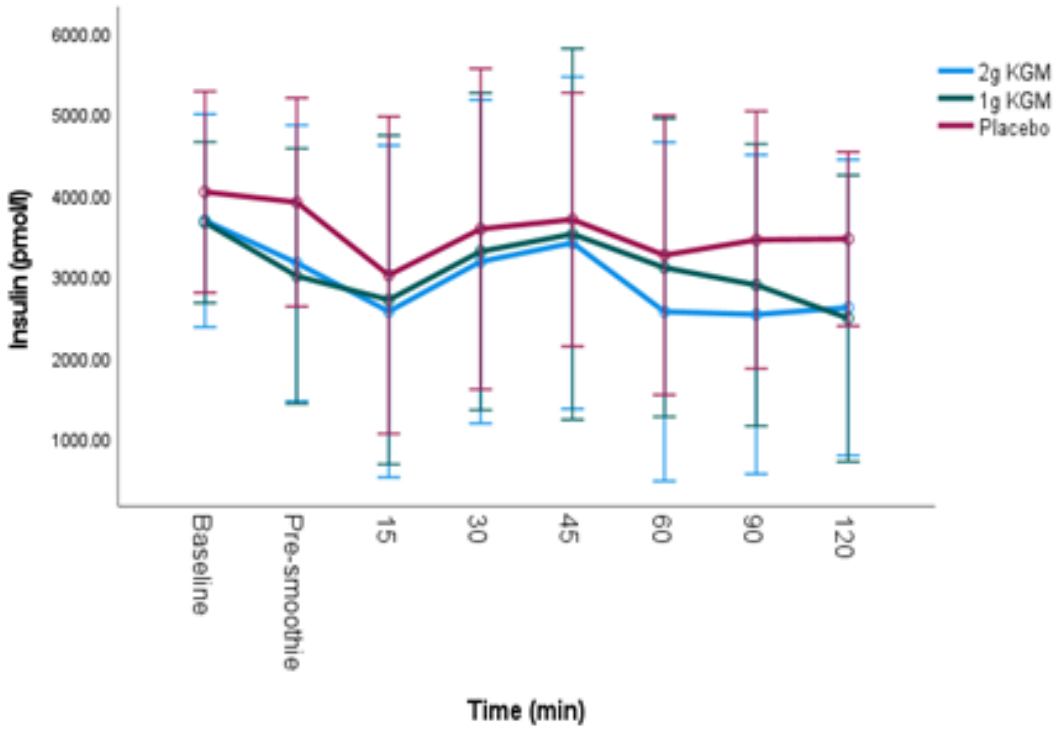


Figure 5-2 Changes in the glycaemic responses. Serum concentrations of insulin across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking 500 mL of a commercial fruit smoothie. Values represent mean ±95% CI.

5.7.3 Secondary outcomes

5.7.3.1 Gastric emptying rate

The effect of treatment sequence on the measures of gastric emptying rate was non-significant for DOB ($^{13}CO_2$:$^{12}CO_2$) (F=0.37, *p*=0.70), T_{half} (F=0.95, *p*=0.45), and T_{lag} (F=2.14, *p*=0.21). As presented in (Figure 5.3), the two-way repeated-measures ANOVA showed that the effect of the experiment on DOB ($^{13}CO_2$:$^{12}CO_2$) values was

small but non-significant (F=4.2, *p*=0.09). In contrast, the main impact of time on DOB was significant (F=18.11, *p*=0.008). Across three experiments, DOB values steadily increased from baseline to 45 minutes (26.14 ±2.3) and 60 minutes (26.02 ±2.7) post-ingestion when the highest DOB values were recorded. Subsequently, DOB values decreased from 75 minutes after smoothie ingestion until 12 minutes post-ingestion. However, the interaction of time and treatment on changes in DOB values was not significant (F =0.14, *p*=0.72). At any given time, point, DOB values were lower in the 2g KGM experiment (19.12±2.3) than 1g KGM (19.98±2.1) and placebo (21.76±1.87).

One-way repeated-measures ANOVA showed that the time taken to empty half of the smoothie from the stomach after supplementation (T_{half}) was comparable across three experiments (F=3.12, *p*=0.14). (T_{half}) on 2g KGM was (95.09 ± 18.01 minutes) while (T_{half}) on 1g KGM (88.66 ± 22.76 minutes) and placebo (85.80 ± 19.9 minutes) were shorter minutes. Likewise, the time of maximal emptying rate (T_{lag}) was comparable (F=3.03, *p*=0.14) on 2g KGM (59.91 ± 16.2 minutes), 1g KGM (56.57 ± 16.1 minutes), and placebo (46.51 ± 20.9 minutes) with less minutes as well. The difference in AUC across for DOB values three experiments was non-significant (F=3.30, *p*=0.06).

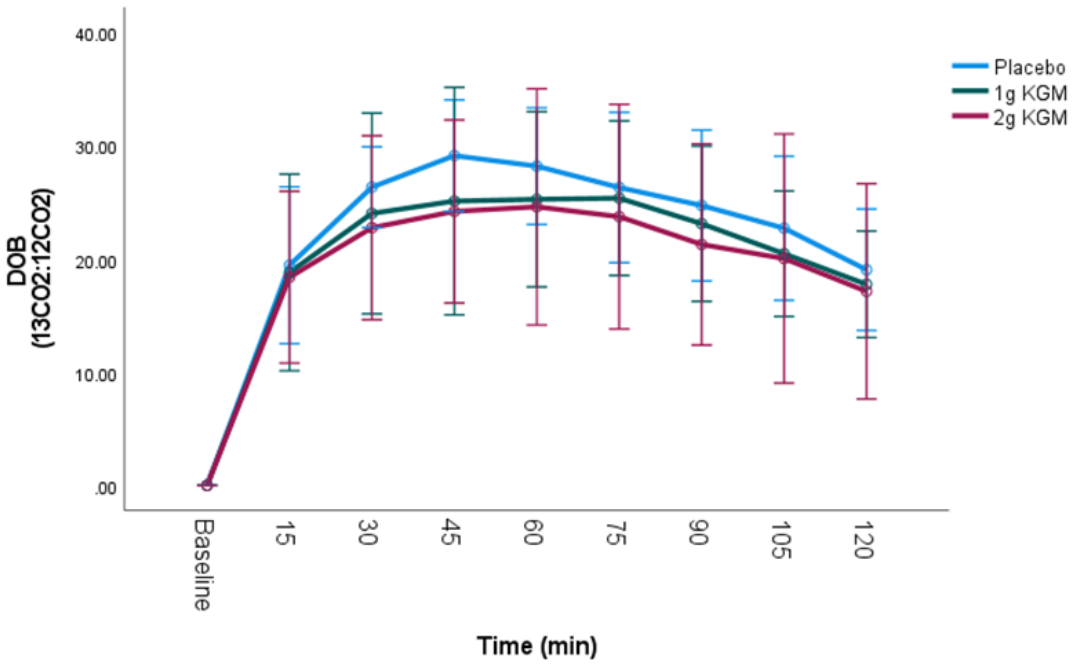


Figure 5-3 Changes in gastric emptying rate. The ratio of the delta over baseline (DOB) across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking 500 mL of a commercial fruit smoothie. Values are mean ±95%CI.

5.7.3.2 Appetite regulating hormones

The effect of treatment sequence on the observed changes in appetite regulating hormones was non-significant for ghrelin (F=2.15, *p*=0.21), GLP-1 (F=1.39, *p*=0.33), PYY (F=0.45, *p*=0.65) and PP (F=2.14, *p*=0.21).

5.7.3.3 Ghrelin

Based on the two-way repeated-measures ANOVA, the main effect of treatment on ghrelin concentration was non-significant (F=3.78, *p*=0.06). However, ghrelin levels were lower on 2g KGM (119.67±26.2pmol/L) compared to 1g KGM (140.64±33.6pmol/L) and placebo (150.87±38.4pmol/L). Ghrelin concentration changed significantly from baseline to 120 minutes after smoothie ingestion (F=13.99, *p*=0.01). Ghrelin concentration decreased at 30 minutes after drinking the smoothie, with the lowest level at 60 minutes. Then, ghrelin release increased

gradually; the highest was measured at 120 minutes after smoothie ingestion (Figure 5.4). However, the interaction effect of time and treatment was non-significant (F=2.66, *p*=0.14). The difference in ghrelin AUC between the three experiments was significant (F=8.08, *p*=0.02). The lowest ghrelin AUC was observed after supplementation with 2g KGM (115.9±59.1 pmol/L x 120 minutes) compared to 1g KGM (317.1±237.9 pmol/L x 120 minutes) or placebo (405.5±238.8 pmol/L x 120 minutes).

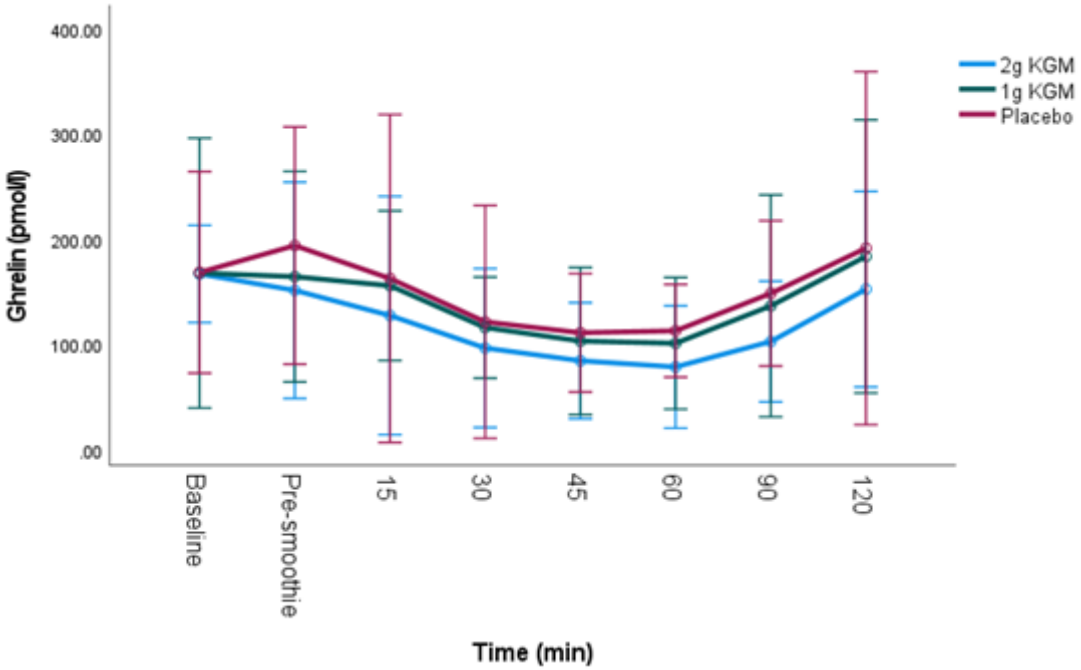


Figure 5-4 Changes in the appetite-regulating hormone Ghrelin. Serum concentrations of ghrelin across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

5.7.3.4 Glucagon-like peptide-1 (GLP-1)

The two-way repeated-measures ANOVA showed the effect of treatment on the observed changes in GLP-1 hormone was non-significant (F=2.69, *p*=0.10). Similarly, the effect of time (F=3.54, *p*= 0.06) and Treatment*Time interaction (F=0.99, *p*=0.46)

did not have a significant effect on GLP-1 levels (Figure 5.5). However, GLP-1 concentration was lower on placebo (9.3±2.5pmol/L) than 1g KGM (12.7±1.3pmol/L) and 2g KGM (12.8±2.5pmol/L). Treatment had a significant effect on the AUC for serum GLP-1 (F=4.93, *p*=0.02).

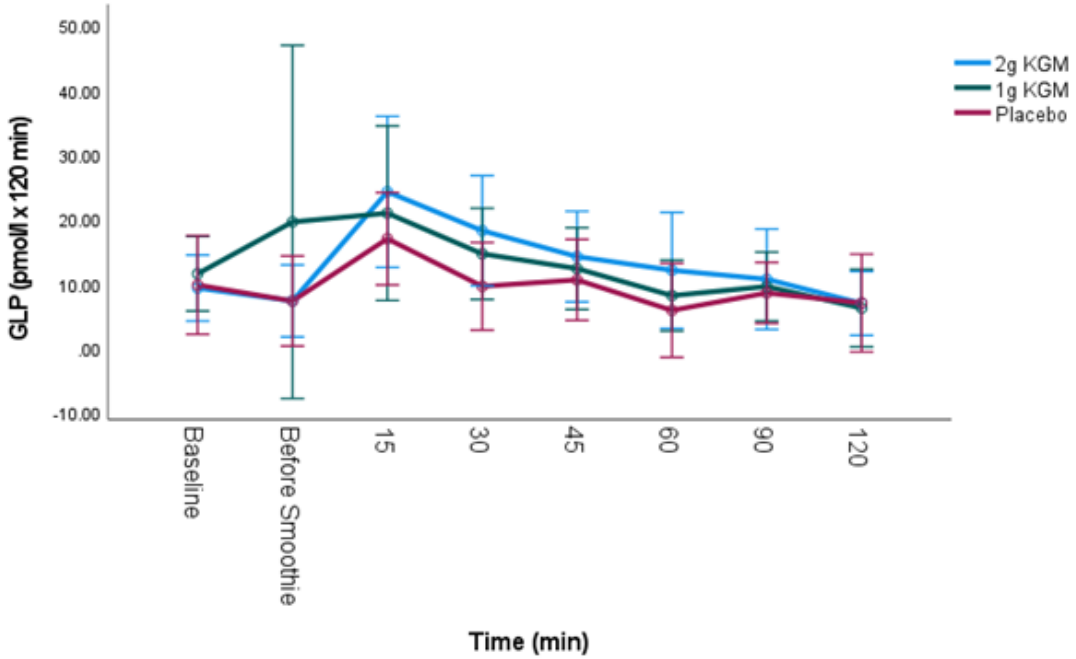


Figure 5-5 Changes in the appetite-regulating hormone GLP-1. Serum concentrations of GLP-1 across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

5.7.3.5 Peptide tyrosine tyrosine (PYY)

Based on the two-way repeated-measures ANOVA, the main effect of treatment on PYY concentration was statistically non-significant (F=2.24, *p*=0.14). Likewise, the effect of Treatment*Time interaction (F=0.13, *p*=0.92) did not have a significant effect on PYY levels (Figure 5.6). PYY concentration was higher in 2g KGM (151.9±27.1pmol/L) than 1g KGM (148.8±26.4pmol/L) and placebo

(139.2±29.9pmol/L). AUC for PYY was comparable across three experiments (F=1.82, *p*=0.19).

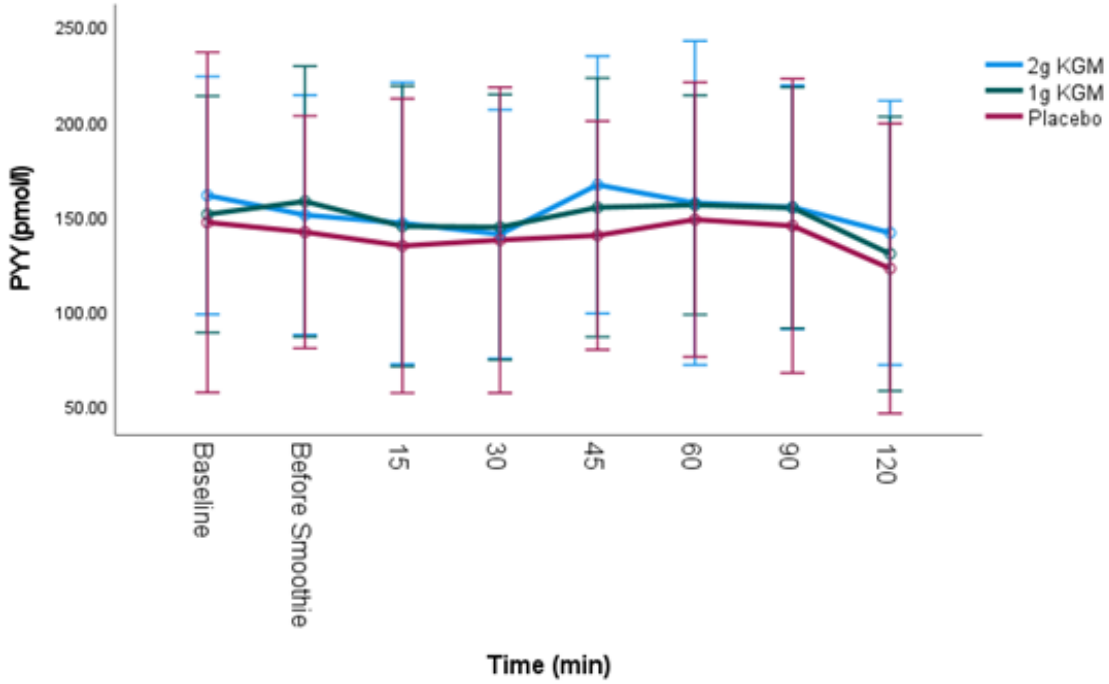


Figure 5-6 Changes in the appetite-regulating hormone PYY. Serum concentrations of PYY across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

5.7.3.6 Pancreatic polypeptide (PP)

The two-way repeated-measures ANOVA demonstrated a non-significant effect of the treatment (F=0.41, *p*=0.67) on PP concentration. Similarly, Treatment*Time interaction (F=0.73, *p*=0.73) did not significantly affect PP levels. PP concentration was slightly higher on 2g KGM (124.6±29.6pmol/L) than 1g KGM (119.1±27.2pmol/L) and placebo (118.3±26.1pmol/L). However, the effect of time on PP concentration was significant (F=4.72, *p*< 0.001). Overall, PP concentration steadily increased from baseline to 45 minutes after smoothie ingestion (147.1±36.4pmol/L) when the

highest level of PP was observed. Then, PP concentration showed fluctuating decrements until 120 minutes after smoothie ingestion (Figure 5.7). AUC for PP was comparable across three experiments (F=1.06, *p*=0.37).

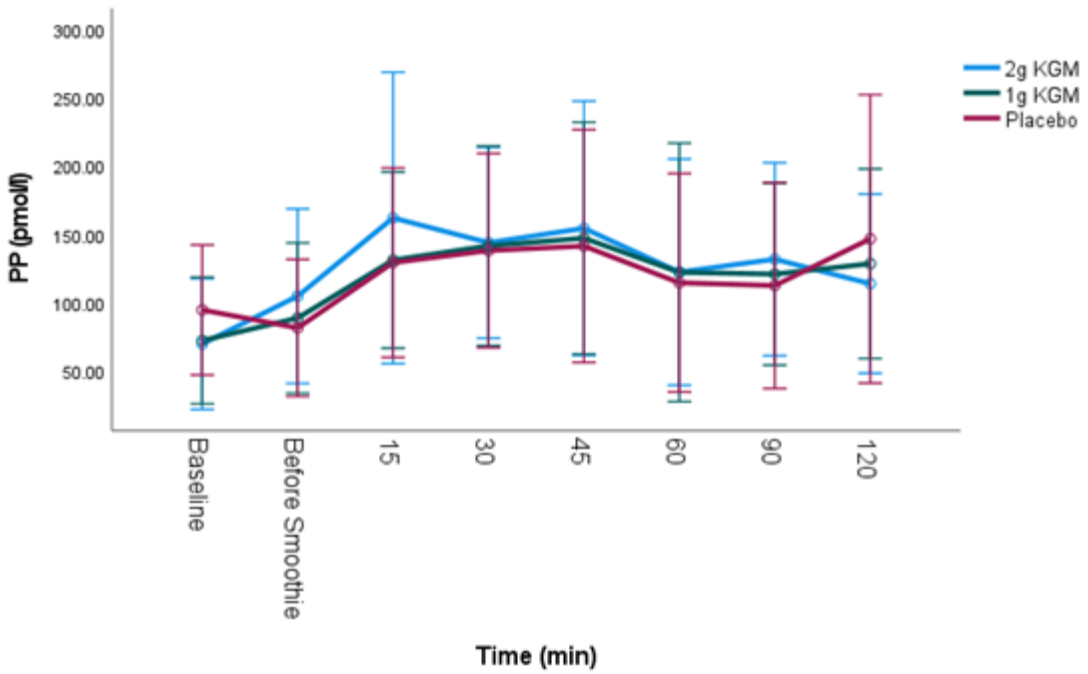


Figure 5-7 Changes in the appetite-regulating hormone PP. Serum concentrations of PP across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking 500 mL of a commercial fruit smoothie.

5.7.3.7 Lipid concentrations

The two-way repeated-measures ANOVA showed that the effect of treatment 1g and 2g KGM on TC levels was statistically non-significant (F=0.18, *p*=0.21). In addition, the effect of treatment*time interaction (F=0.30, *p*=0.14) had nonsignificant effects on blood TC levels (Figure 5.8).

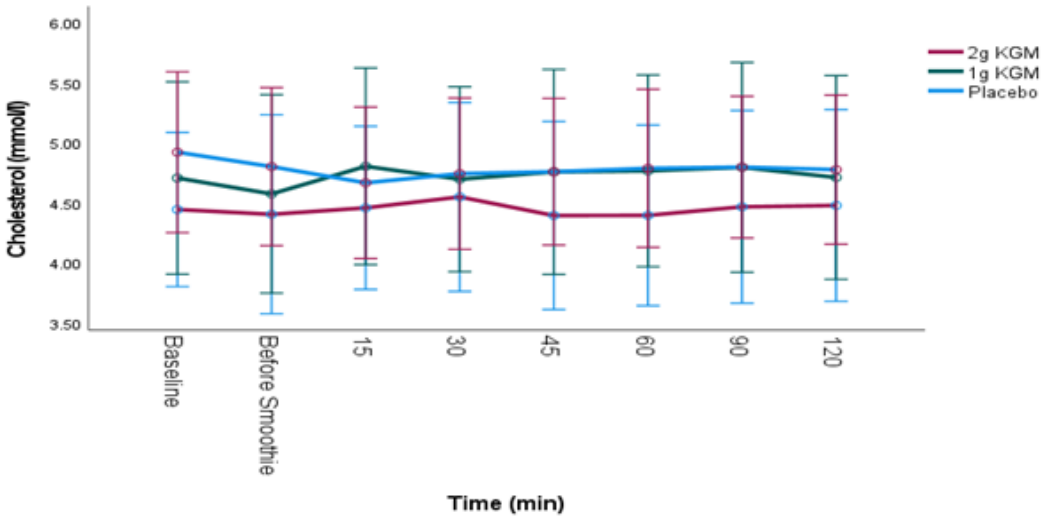


Figure 5-8 Changes in lipid responses during experiments. Serum concentrations of TC across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

Likewise, the effect of treatment on NEFA concentration was non-significant (F=0.21, *p*=0.80). In contrast, blood NEFA levels changed significantly from baseline to 120 minutes after smoothie ingestion (F=24.77, *p*<0.001). As presented in (Figure 5.9), NEFA levels decreased steadily from baseline (0.57±0.08mmol/L) to 120 minutes after smoothie ingestion (0.17±0.05mmol/L). The interaction effect of treatment * time on blood NEFA was non-significant (F=1.21, *p*=0.32).

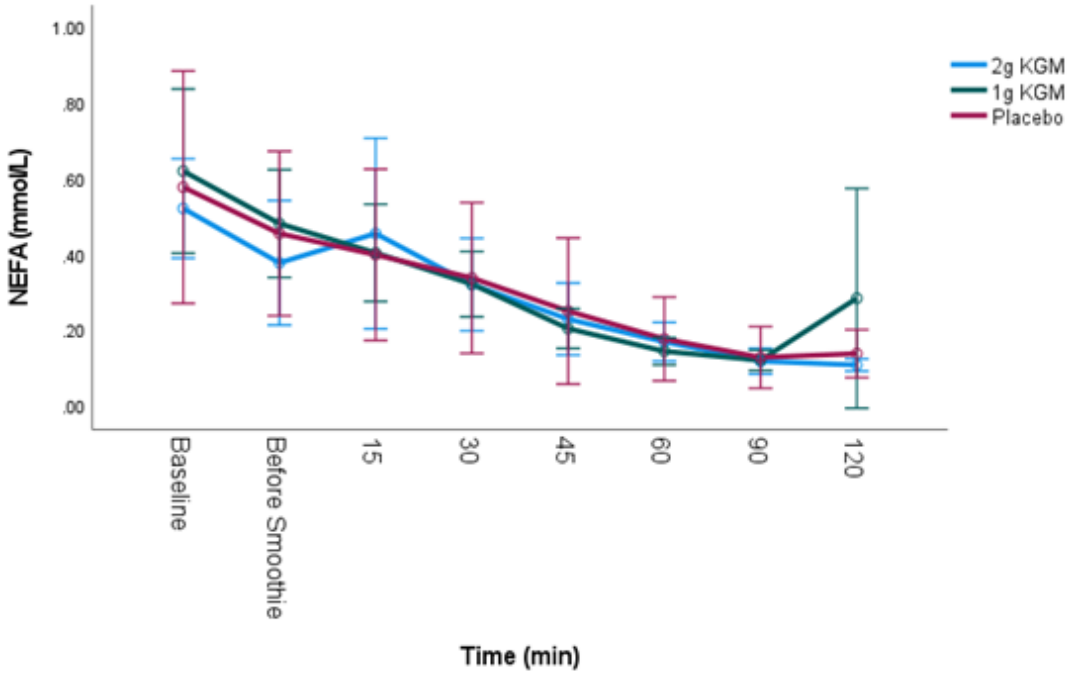


Figure 5-9 Changes in lipid responses during experiments. Serum concentrations of NEFA across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

Similarly, the effect of treatment (F=0.29, *p*=0.75), and treatment * time interaction (F=1.01, *p*=0.45) on serum TAG levels were nonsignificant (Figure 5.10).

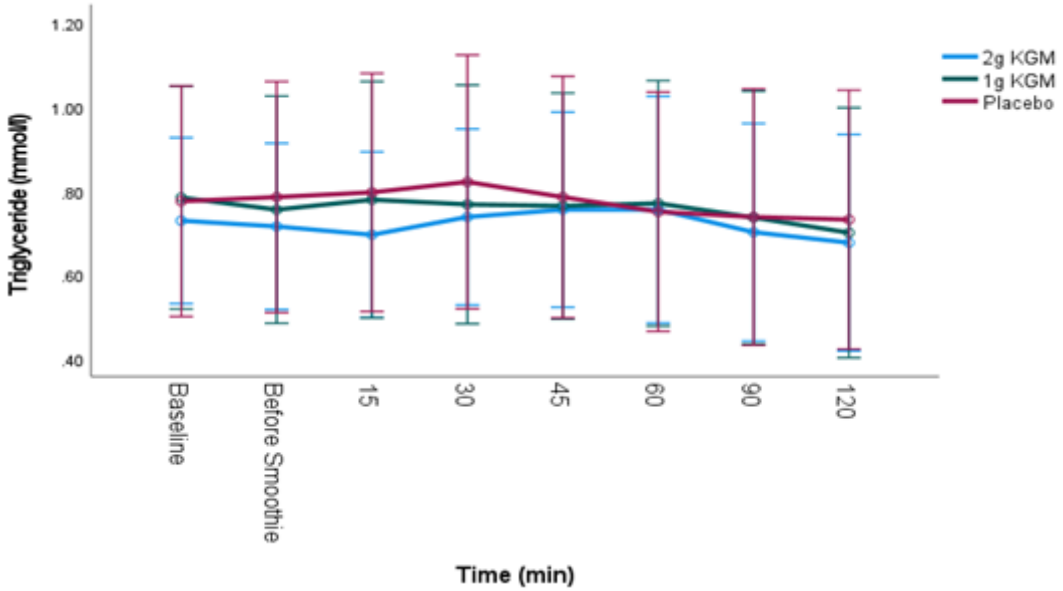


Figure 5-10 Changes in lipid responses during experiments. Serum concentrations of TG across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

5.7.3.8 Assessment of subjective appetite

Based on the two-way repeated-measures ANOVA, the main effect of treatment (F=1.15, *p*=0.35), and treatment * time interaction (F=0.43, *p*=0.92) on hunger rating were nonsignificant. However, hunger was less pronounced at all measurement points after supplementation with 2g KGM (37.9±4.5mm) compared to 1g KGM (44.1±6.3mm) and placebo (51.8±10.1mm) (Figure 5.11).

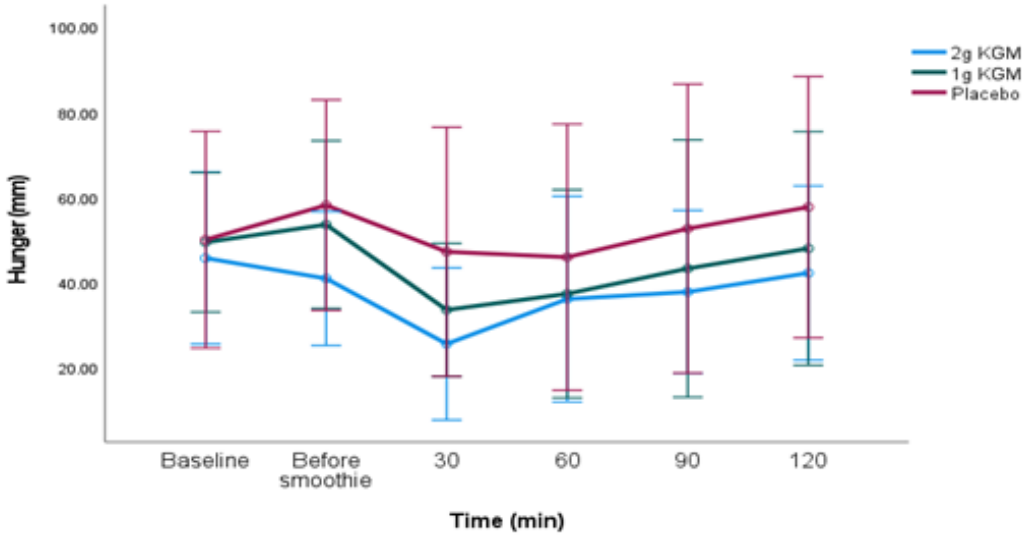


Figure 5-11 Changes in appetite scores, assessed by 100 mm VAS; hunger across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking a 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

The effect of treatment (F=0.59, *p*=0.48) and treatment * time interaction (F=0.31, *p*=0.78) also did not have a significant effect on fullness ratings. However, participants experienced greater fullness after 2g KGM (39.8±6.2mm) compared to 1g KGM (35.9±6.5mm) or placebo (33.2±6.7mm) (Figure 5.12).

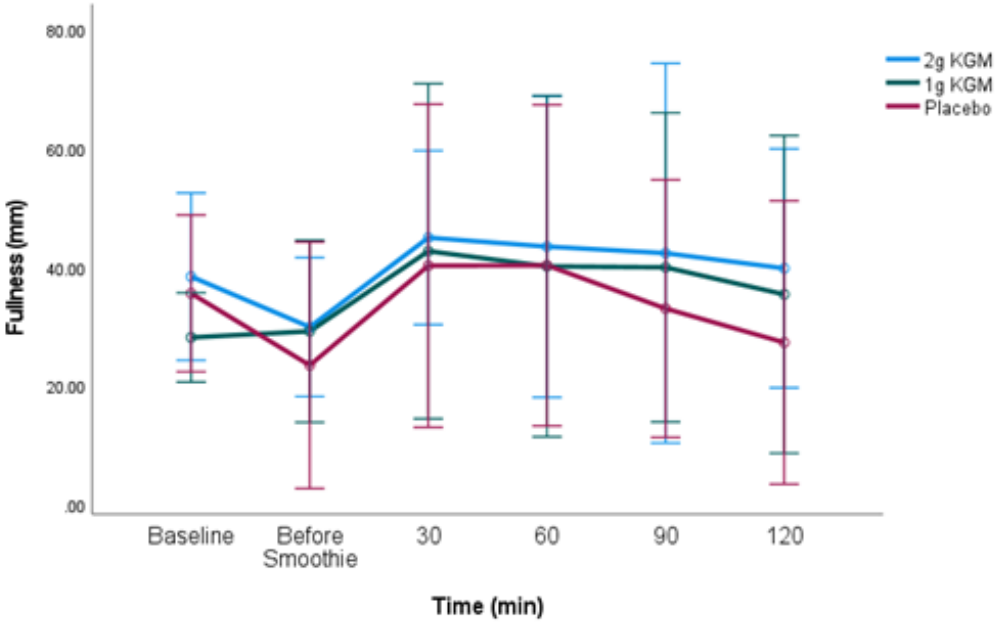


Figure 5-12 Changes in appetite scores, assessed by 100 mm VAS; fullness across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking a 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

The effects of treatment (F=1.06, *p*=0.38) and treatment * time interaction (F=0.72, *p*=0.69) on the prospective food consumption were also nonsignificant. Nevertheless, participants had lower prospective food consumption scores on 2g KGM (44.7±6.1mm) compared to 1g KGM (52.1±5.8mm) or placebo (57.1±7.9mm) (Figure 5.13).

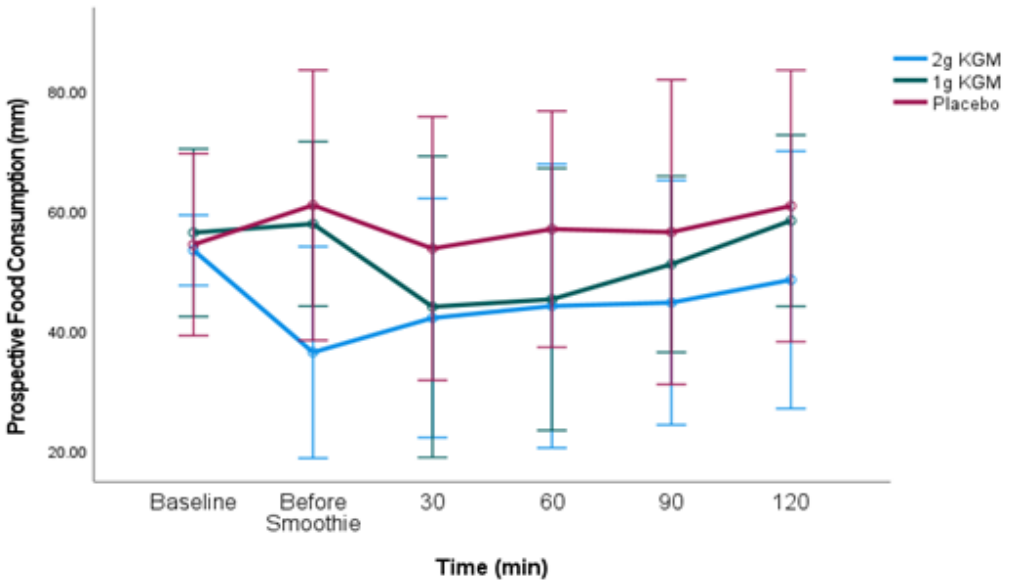


Figure 5-13 Changes in appetite scores, assessed by 100 mm VAS; prospective food consumption across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking a 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

In addition, participants expressed more satisfaction on 2g KGM group (37.8±6.8mm) compared to 1g KGM (31.8±6.7mm) or placebo (31.7±8.1mm). However, the effect of treatment (F=1.06, *p*=0.38) and treatment * time interaction (F=0.72, *p*=0.69) did not have a significant effect on satisfaction ratings (Figure 5.14).

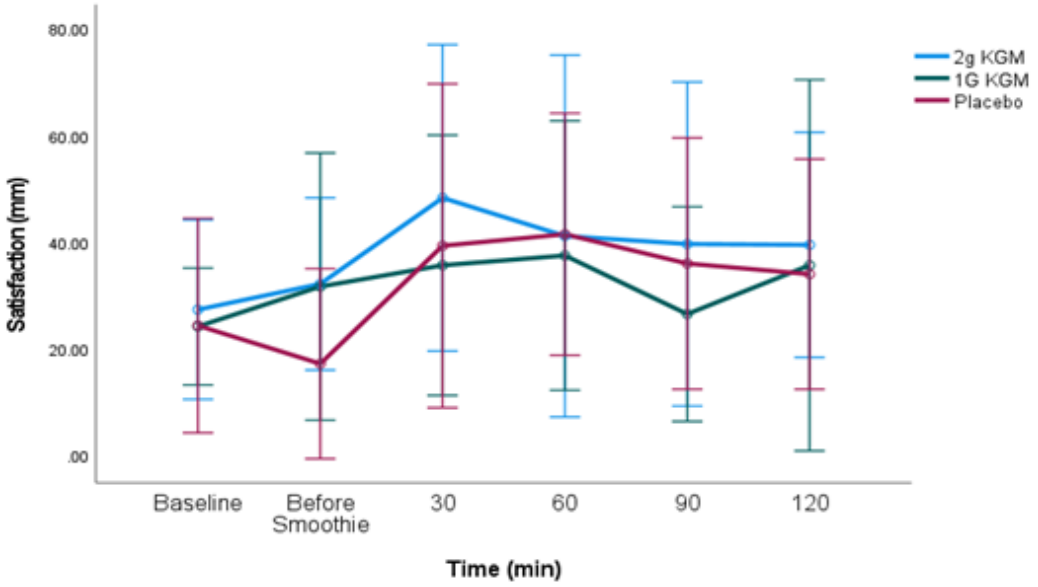


Figure 5-14 Changes in appetite scores, assessed by 100 mm VAS; Satisfaction across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking a 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

The effect of treatment (F=0.55, *p*=0.58) and treatment * time interaction (F=0.42, *p*=0.93) did not have a significant effect on bloating ratings. However, participants experienced felt more bloated after 2g KGM (8.55±4.80 mm) compared to 1g KGM (7.48 ± 4.02 mm) or placebo (6.96±4.60 mm) (Figure 5.15).

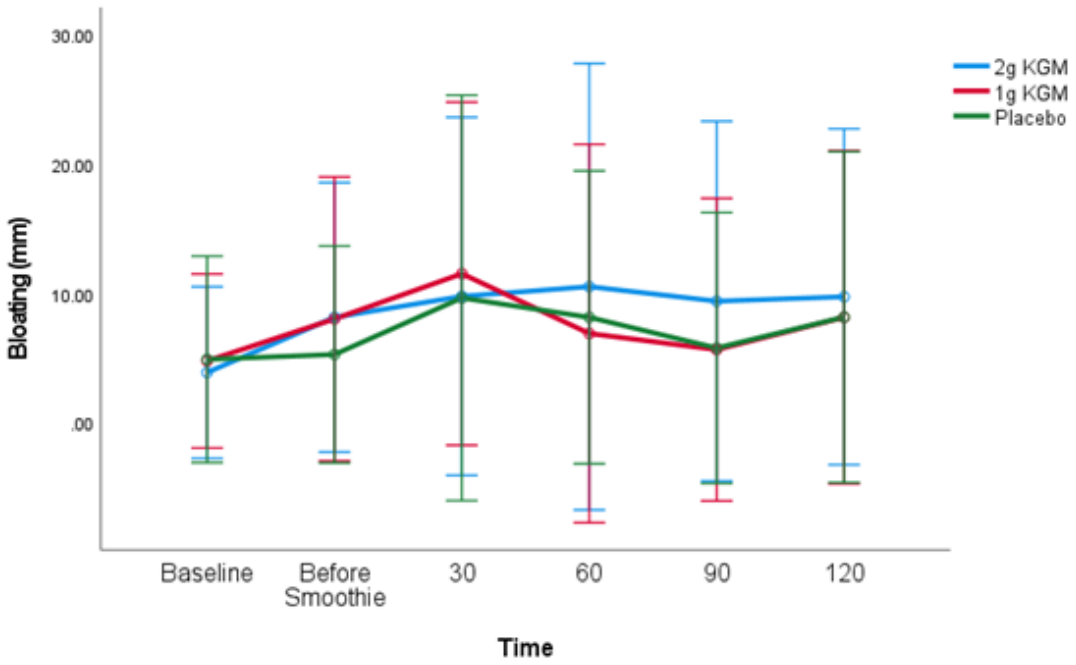


Figure 5-15 Changes in appetite scores, assessed by 100 mm VAS; Bloating across the three trials (2g KGM, 1g KGM and placebo capsules) from baseline to 120 minutes after drinking a 500 mL of a commercial fruit smoothie. Values represent mean ± 95% CI.

5.8 Discussion

This is the first study that measured the acute effect (2-hour) of supplementation with different doses of KGM capsules (1g and 2g) on the metabolic and appetite response to the ingestion of a semi-liquid meal with high sugar content (commercial fruit smoothie) in eight healthy adults.

5.8.1 Glycaemic responses

In the present study, blood glucose levels changed significantly during the 2-hour post-ingestion period in all experiments, steadily rising from baseline to 30 minutes after smoothie ingestion and then continuously decreasing to 120 minutes. Glucose concentrations were lower significantly in the 2g KGM experiment at all time points compared with placebo. This finding aligns with the thesis hypothesis that KGM delays nutrient absorption (McCarty, 2002).

In addition, the current study showed a significant effect of time on 2-hour changes in postprandial insulin levels (p=0.01). In all trials, serum insulin concentration increased gradually from baseline until 45 minutes post-ingestion, with a subsequent decrease from 45 to 60 minutes post-ingestion in 1 and 2 g KGM. During the second hour, insulin level remained unchanged in 2g KGM, had a slight increase in the placebo trail, but showed a steady decrease in the 1g KGM trail. However, the insulin levels at different time points were comparable between three trials.

These findings are consistent with previous trials, which demonstrated a time-specific pattern of glucose and insulin response to a carbohydrate-rich meal. A large interventional study of a Finnish cohort (4745 middle-aged Finnish individuals and a replication cohort of 595 senior Finnish participants) showed that, in people with standard glucose tolerance, blood glucose levels increased until 30 minutes after a normal 75g glucose load and then steadily decreased until 120 minutes (2-hour oral glucose tolerance test). Also, serum insulin concentration elevated from baseline to 30 minutes post glucose loading, remained unchanged until 60 minutes and then decreased steadily until 120 minutes after the ingestion of the glucose load (Wang et al., 2019). Notably, the present study showed that supplementation with higher doses of 2g KGM attenuated the postprandial rise in blood glucose levels over 120 minutes after smoothie ingestion compared to 1g KGM or placebo (p<0.001). Additionally, it provided some evidence on the effectiveness of 2g KGM for improving insulin AUC in response to a high sugar semi-liquid meal.

Two previous RCTs supported the beneficial effect of supplementation with KGM capsules on a 2-hour postprandial glucose response (Chen et al., 2003; Chearskul et

al., 2007). Chen et al. (2003) showed that consuming a 1.2g KGM capsule before each meal for 28 days was associated with significant (p = 0.014) reductions in postprandial glucose compared to placebo (↓12.2 % vs ↑12.6 %). In the study by Chearskul et al. (2007), the consumption of 1g KGM capsule before the standard 75g oral glucose tolerance test (OGTT) was associated with significantly reduced glucose AUC compared to placebo (↓12.88 % vs ↓3.3 %, p=0.032). This supports the finding of the present study, which showed that glucose AUC was greater in the placebo trail compared to trials with 2g KGM and 1g KGM. This is also supported by a recent SDF intervention (Clarke et al., 2022) that compared the effect of ingesting meals containing high versus low levels of SDF (20g and 10g) on postprandial blood glucose AUC. Clarke et al. (2022) showed that both low (<10 g) and high levels (>20 g) of SDF were associated with reduced blood glucose AUC values (<100 mmol/L × 120 minutes).

The current study also found a significant (p=0.01) effect of KGM supplementation on 2-hour changes in serum insulin levels. Serum insulin concentrations were lower over the entire 120 minutes after smoothie ingestion in a 2g KGM trial than in 1g KGM or placebo trials. McCarty (2002) reported that KGM reduced postprandial insulin response by up to 50%. However, the difference in insulin AUC between the three experiments was non-significant. Morgan et al. (1990) showed that the ingestion of a high-carbohydrate semi-solid drink containing 5g KGM significantly reduced the insulin levels compared with control over 90 minutes (p<0.02). Insulin concentrations were also significantly lower after the consumption of a fibre muffin compared with the control muffin at 30, 45, and 60 minutes post-ingestion (p = 0.001, p < 0.001, and p < 0.001, respectively) (Stewart and Zimmer, 2018). In contrast, a

previous KGM intervention Chearskul et al. (2007), found non-significant differences between KGM and placebo in postprandial serum insulin. The inconsistency in the previous studies on the effect of KGM on postprandial glycaemic responses could be explained by the longer duration of KGM supplementation, which may attenuate the initial effect of KGM intake on the gastrointestinal and metabolic parameters. Moreover, these studies mostly used a meal without high carbohydrate content (Chearskul et al., 2007). Compared to the study by Chearskul et al. (2009), the present study found a nearly significant acute difference in insulin AUC between KGM supplementation and placebo (p=0.051). The present study also showed that pre-ingestion of a higher dose of KGM (2g) led to lower AUC values following smoothie consumption compared to a lower dose of KGM (1g) or placebo, suggesting a potential benefit of supplementation with higher doses of KGM for improving insulin response to a sugar-rich meal.

It is worth mentioning that one of the functional benefits of SDFs, particularly VDFs is their ability to reduce the rate of glucose absorption after consuming high glycaemic carbohydrate-containing foods, leading to a blunted blood glucose response curve and less demand for insulin release (Goff et al., 2018). VDFs can slow glucose absorption by increasing the viscosity of the intestinal lumen and limiting the action of digestive enzymes on ingested carbohydrates (Singh et al., 2010). Another possible explanation of the beneficial effects of VDFs on the glycaemic response is that VDFs induced viscosity within the gut which slows the rate of sugar delivery to the intestinal lumen and limits the accessibility of sugar (i.e. glucose, galactose and fructose) to its enterocyte receptors, resulting in delayed uptake and associated postprandial glucose response (Cassidy et al., 2018). VDFs can also reduce

postprandial rise in glucose levels by slowing the gastric emptying rate and decreasing the accessibility of α-amylase to the carbohydrate substrate (Guillon and Champ, 2000; Brennan et al., 2004).

5.8.2 Gastric emptying rate

In the present study, KGM supplementation had a small and non-significant effect on the gastric emptying rate, with lower DOB values being observed in the experiment with 2g KGM compared to 1g KGM and placebo. In contrast, T_{half} and T_{lag} were longer on 2g KGM compared to 1g KGM and placebo. Therefore, a higher dose of KGM was associated with a slower gastric emptying rate in the present study. These findings align with the observation that KGM has a superior hydration ability to absorb up to 200 mL of water and becomes a voluminous mucilage. Its viscosity is also the highest among common hydrocolloids. Therefore, KGM can promote gastric satiation through gel-like viscous mass forming in the stomach (Vuksan et al., 2011). These results are comparable with the findings of Shang et al. (2020), who demonstrated a slower gastric emptying rate subsequent to the ingestion of a sample drink containing KGM with higher viscosity. Some previous studies also showed a slower gastric emptying rate with increasing viscosity of the food matrix (Meyer et al., 1986). This effect of KGM on gastric emptying rate may attenuate postprandial glucose and insulin responses to carbohydrate meals (Knudsen, 2001). The beneficial impact of KGM on decreasing gastric emptying rate is due to the “mass effect” of gel-like viscous KGM that distends the stomach and triggers afferent vagal signals of fullness (Guo et al., 2021).

5.8.3 Assessment of subjective appetite

The present study also demonstrated a small but non-significant effect of KGM supplementation on the subjective measures of appetite, i.e., hunger, fullness, satisfaction and prospective food consumption. Hunger after smoothie ingestion was less prominent in the experiment with 2g KGM than 1g KGM and placebo. In contrast, fullness increased slightly after drinking a smoothie until 30 minutes in all three experiments. Then, it remained unchanged until 90 minutes post-ingestion in 1g and 2g KGM experiments and decreased gradually afterwards. In the placebo experiment, the decrease in fullness started at 60 minutes after smoothie ingestion. The non-significant association between KGM supplementation and appetite measures could be possibly due to insufficient hydration of KGM in this experiment which prevents KGM from reaching the highest viscosity. Supplementation with 2g KGM was, however, associated with higher fullness ratings than 1g KGM and placebo. Breitman (2010) found that greater doses of SDF exert greater effects on appetite and food intake regulation.

In addition, participants reported higher satisfaction on 2g KGM than 1g KGM or placebo. The participants also expressed less desire for eating another meal after 2g KGM supplementation compared to 1g KGM or placebo. In line with this observation, Larson et al. (2021) demonstrated that the incorporation of SDF such as acacia gum 40 g into 228 mL orange juice after a 12-hour fast was associated with less hunger and greater fullness at 240 minutes compared with control (p=0.036 and p=0.05), respectively. They also reported more satisfaction at 240 minutes (p=0.011). These results indicate that a long duration of fibre consumption may increase the

effectiveness of SDF in appetite management. Furthermore, Vuksan et al. (2009) reported that KGM preloads decreased average appetite scores 15 minutes after ingestion of the test drinks (p<0.001). Also, food intake was significantly lower (p=0.008) after consuming KGM enriched drink (5g) compared to low viscosity DF (CE) (5g) enriched drink. It has been observed that there is an inverse relationship between DF viscosity and increased satisfaction or less desire to eat. It is speculated that participants have greater satisfaction because they do not feel hungry. It is also hypothesised that the superior thickening ability of VDFs such as KGM delays nutrient absorption and extends the release of appetite-related gut hormones that prolongs the sense of satiety. As well as the anaerobic fermentation of KGM by colonic microflora into SCFAs may also contribute to the enhancement of satiety (Cummings and Overduin, 2007). In addition, it has been reported by Guo et al. (2021) that the gel-like mass in the gastric tract reduces appetite at each meal.

In contrast, Jenkins et al. (2017) showed that fullness was lower, and prospective food consumption was higher after the consumption of 100% KGM noodles compared to 50% KGM (p=0.03). This is align with a more recent experiment which found that ratings of hunger were 31% higher (p =0·03) after the 100-KGM meal than the control meal, while fullness scores were 19% lower (p =0·04) and prospective food consumption was 28% higher (p=0·04) when comparing 100-KGM to 50-KGM. Subsequent differences in satiety over 90 minutes after an ad libitum dessert were non-significant (Au-Yeung et al., 2018). In addition, post-load energy intake was not significantly different between 50% and 100% KGM noodles. However, the consumption of 50% and 100% KGM noodles reduced cumulative energy intakes by 201 kcal and 421 kcal, respectively, compared to the control (p<0.001). Cumulative

energy intake was also significantly lower after the 100% KGM meal compared to the 50% KGM meal ($p<0.05$) (Jenkins et al., 2017).

In addition, the non-significant effect of KGM supplementation on appetite in the present study is in line with the findings of a previous RCT of healthy adults (Keithley et al., 2013), which showed comparable ratings of hunger and fullness in KGM (1.33g with each meal) (39.10 mm, 48.18 mm) than placebo (43.48 mm, 45.65 mm), respectively at 2 weeks. The effect of daily consumption of 3g KGM over 4 weeks on appetite ratings was also non-significant in a crossover study of diabetic adults (Chearskul et al., 2007). In diabetes, insulin resistance is unable the body to convert food into energy. This lack of energy causes an increase in the feeling of hunger. This may explain the non-significant effect of KGM on appetite in diabetic patients (Nagaraj, 2022).

Similarly, two older RCTs reported no effects of daily consumption of 3g KGM capsules (1g before each meal) on satiety either with a low-calorie diet (Reffo et al., 1990) or without a low-calorie diet (Walsh et al., 1984). Numerous studies have concluded that calorie restriction is associated with reduced prospective food consumption (Speakman, 2022).

The present study showed that although KGM reduced postprandial hunger and increased fullness across the experiments, these effects were non-significant. The findings may indicate satiety inducing effects of KGM, which suppress appetite and maintain fullness for a longer duration.

The lack of apparent beneficial effect of KGM in the present experiment can possibly be explained by the inadequate food matrix in smoothies that could allow KGM

capsules to develop their viscosity fully. Also, the 2-hour period may not be enough for the complete hydration of KGM fibres to exert their satiety inducing effects (Boers et al., 2017).

The effect of KGM supplementation on bloating ratings in the present study was non-significant. However, participants felt more bloated after 2g KGM compared to 1g KGM or placebo. This is in line with (Larson et al., 2021); participants reported more bloating, flatulence, and gastrointestinal rumbling on the 40 g acacia gum treatment compared to control. A possible explanation could be discomfort associated with adding large quantities of fibre which leads to abdominal discomfort, bloating and gas (So et al., 2022).

5.8.4 Appetite-regulated hormones

This experiment also demonstrated that KGM supplementation had a small and non-significant effect on postprandial levels of satiety hormones, including ghrelin, GLP-1, PYY and PP, over 120 minutes post-ingestion. Again, the ghrelin concentration or “hunger hormone”, was lower on 2g KGM. In contrast, the satiety-inducing hormones GLP-1, PYY, and PP were higher on 2g KGM than on 1g KGM and placebo groups. In all experiments, 2-hour changes in gut hormones ghrelin (p=0.01) and PP (p< 0.001) were significant. These results highlighted the relationship between lower ghrelin concentration in 2g KGM supplementation and its reverse effect on appetite reduction. Several studies reported that the "hunger hormone" increases food intake (Cummings et al., 2001). Consequently, KGM suppresses the role of ghrelin by regulating eating behaviour.

Thus, preloading with higher KGM concentrations may have a modest acute effect on improving gut hormone secretion after high carbohydrate semi-liquid meals in healthy adults. The modest ghrelin suppressing effect of KGM supplementation is supported by Chearskul et al. (2009). The researchers found that the consumption of 3g KGM capsules before OGTT was associated with a small and non-significant reduction in postprandial ghrelin in adults with T2DM. In addition, Shang et al. (2020) found that the secretion of CCK-8, GLP-1 and PYY_{3-36} was elevated, and that of ghrelin was reduced after ingesting a 250 mL drink contained higher viscosity of KGM over 4 weeks than low viscosity. Potentially, it represents the role of KGM viscosity rather than concentration in the postprandial secretion of gut hormones. However, food intake was comparable between groups and a significant difference in ghrelin AUC was not detected between KGM and placebo groups (Shang et al., 2020). The decreased fasting ghrelin concentration and increased active GLP-1 concentration observed in this study may have affected the gastrointestinal tract, possibly contributing to the sensation of satiety in diabetic patients (Ueno et al., 2021). Plasma ghrelin and GLP-1 levels tended to decrease (p=0.057) and increase (p=0.071), respectively (Ueno et al., 2021). It has been postulated that the gelling effect of KGM extends the release of appetite-regulating peptides such as GLP-1 in the distal ileum and proximal colon (Cummings and Overduin, 2007; Guo et al., 2021). The study also found a beneficial relationship between glucose metabolism and increased plasma GLP-1 concentration; however, further investigation is needed to include postprandial responses. However, there was no significant correlation between the actual intake of KGM and changes in appetite (Ueno et al., 2021).

5.8.5 Lipid concentrations

The present study did not find any significant effect of KGM supplementation on postprandial blood lipids, including TC, NEFA and TAG. This is in contrast to the previous clinical studies, which supported the effectiveness of KGM for reducing TC and TAG. In a study by Suwannaporn et al. (2015), the consumption of drinks containing 3.0g KGM powder for 14 days reduced elevated baseline TC (6.69 mmol/L) and TAG levels (2.88 mmol/L) by 3.74 % and 11.5 %, respectively. Also, 12-week supplementation with a combination of KGM (1.5 g) and Garcinia (2.4 g) in healthy adults before main meals was associated with significant reductions in TC (32.0mg/dL) compared to placebo (p= 0.008), despite comparable effects on TAG levels (Vasques et al., 2008). Similarly, in a study of adults with hypercholesterolaemia and T2DM (Chen et al., 2003), daily consumption of 3g KGM capsules for 28 days was associated with a significant reduction in TC concentration compared with control (p= 0.0001). However, TAG levels were comparable between KGM and placebo groups. In older RCTs, daily supplementation with KGM significantly reduced both TC and TAG in healthy adults (Walsh et al., 1984). These effects on TC were consistent with a previous meta-analysis by Sood et al. (2008), which suggested a lowering cholesterol effect of KGM.

The non-significant effect of KGM on TC and TAG in the present study can be due to using a fruit smoothie as the sample meal in the experiment. The smoothie sample was high in sugar, but it did not contain dietary fats. The mechanism for the lipid-lowering effect of KGM appears to be via interference with intestinal cholesterol absorption (Gallaher et al., 2002) and enhanced cholesterol loss caused by increased

faecal bile and neutral sterol excretion (Chen et al., 2003). In addition, KGM has a lowering effect on circulating TC by mechanisms that include blocking uptake in the gut and possibly increasing excretion into the bile (Gallaher et al., 2000; Chen et al., 2003; Kraemer et al., 2007; Guo et al., 2021).

To conclude, biologically, SDFs may promote satiety via mastication (chewing) effort associated with eating SDFs (Hu et al., 2018; Lian et al., 2022), delayed gastric emptying rate and small-bowel transit time, increased viscosity of the intestinal lumen and reduced absorption of nutrients in the small intestine, attenuated postprandial insulin surges, accelerated delivery of food to the terminal ileum, and increased levels of plasma cholecystokinin (Keithley et al., 2005). Therefore, clinical studies of SDF consumption on appetite and food intake are inconsistent. One possible explanation for these inconsistencies is that these studies used different types and concentrations of SDFs with variable physicochemical properties. For instance, differences in particle size may affect the rate at which dietary fibres with viscous properties solubilize in water and form viscous gels (Breitman, 2010). In addition, previous studies have found that greater doses of dietary fibre lead to greater effects; however, some researchers have demonstrated a threshold beyond which greater doses do not elicit greater effects (Breitman, 2010).

5.8.6 Study strengths and limitations

The study has several strengths. The crossover design assures individual control of effects. The conducted study adds to the available literature on the effectiveness of KGM consumption for the regulation of appetite and metabolic homeostasis. This experimental study compares the acute effect of two doses of KGM on a

comprehensive set of metabolic and gastrointestinal parameters. Further, it uses fruit smoothie as a high carbohydrate semi-liquid meal and explores continuous changes in the above parameters over a 2-hour postprandial period. Gastric emptying rate and some gut hormones such as (PP) have not been measured previously in the RCTs of KGM. methodologically, the study used a placebo-controlled randomised crossover design with uniformity in periods and sequences, blinding of the participants, appropriate washout interval between the experiments, valid and reliable measurement techniques, rigorous data collection methods, and precise statistical analysis. Our study is novel, being the first to study the acute effect of konjac glucomannan supplementation on metabolic and appetite responses to the consumption of fruit smoothies with high sugar content in healthy adults.

The study had some limitations. The first limitation was the small sample size. The second was the relatively short study period (2-hour). In addition, nonblinding of the researcher and smaller doses of KGM. Also, the analyses did not adjust for potential confounders such as age, energy and nutrient intake, physical activity, and anthropometric measurements. However, the baseline characteristics of the participants assigned to each experiment sequence were comparable. A larger sample size, longer duration, and higher dosage may be needed in future studies. In addition, a systematic review was conducted to evaluate the long-term effects of KGM capsules on a wider range of metabolic parameters.

5.9 Conclusion

The relevance of KGM in lower risk for obesity development is centred around the regulation of appetite. KGM has been found to promote short-term satiation and

maintain satiety, improve dietary compliance to low energy diets in the long term, assist in the physiological adaptations to healthier diets and achieve success in weight management strategy. KGM has the extraordinary ability to hydrate gradually and develop high viscosity and has the capacity to increase its volume at the lowest concentration of any known DF. Consequently, KGM can increase gastric retention and delay gastric emptying rate by a “mass effect” of gel-like viscous mass forming in the stomach, triggering afferent vagal signals of fullness that physically slow the absorption of nutrients in the lumen, which beneficially increases the levels of appetite-related hormones. The effect of KGM in the gastrointestinal tract may be mainly due to its molecular structure (Guo et al., 2021).

It has been demonstrated that KGM is highly effective in the treatment of obesity due to the satiety sensation that it produces as a remedy for constipation because it increases the faeces volume. To the beneficial properties of this VDF, several disadvantages can be added as the production of flatulence, abdominal pain, esophageal obstruction, lower gastrointestinal obstruction or even the possible modification of the bioavailability of other drugs (Sahagún et al., 2004).

The present study demonstrated that a 2-hour rise in serum insulin after consuming a high carbohydrate semi-liquid (fruit smoothie) meal was significantly attenuated by pre-supplementation with a higher dose of KGM. Although preloading with a higher dose of KGM slightly improved gastric emptying rate, subjective appetite, and postprandial concentrations of blood glucose, TC, TAG, NEFA and gut hormones (ghrelin, GLP-1, PYY and PP) over the 2-hour period after consuming the carbohydrate-rich semi-liquid meal, these effects were non-significant. KGM

supplementation demonstrated the expected postprandial response after fruit smoothie consumption with decreased plasma ghrelin and an increase in the concentration of other appetite regulation hormones. Specifically, the glucose and insulin levels of the 1g and 2g KGM groups were significantly lower than that of the control group, indicating a blood glucose-lowering effect due to the increased meal viscosity after KGM administration. This result was in line with much previous research, which hypothesized that a meal with a high viscosity could delay gastric emptying rate, disturb the proper mixing of food particles and digestive enzymes, and delay the absorption of nutrients in the intestine. Finally, the postprandial metabolic and appetite responses fluctuation were stabilized moderately for the 2g KGM.

These findings suggest that the consumption of KGM capsules at a dose of 2g before the meal may exert beneficial effects on the acute metabolic response to the ingestion of a high carbohydrate semi-liquid meal but do not significantly affect appetite, gastric emptying rate and gut hormone secretion over the 2-hour postprandial period. Further studies with larger sample size, longer duration, and higher dosage of KGM supplementation may be needed to elucidate the role of this viscous soluble fibre in the regulation of appetite and metabolic homeostasis.

Chapter 6: The efficacy of glucomannan supplementation on appetite regulation and metabolic control in healthy and adults with obesity and/or type 2 diabetes: A systematic review of randomised, controlled trials

6.1 Introduction

Obesity is associated with greater risks of cardiometabolic conditions, including insulin resistance, type 2 diabetes mellitus (T2DM), hyperlipidaemia, and cardiovascular disease (CVD) (Scherer and Hill, 2016). Lipid abnormalities in people living with obesity include elevated serum triglycerides (TAG), non-high-density lipoprotein cholesterol (non-HDL-C) and (VLDL) very-low-density lipoprotein. (Robinson et al., 2013). In addition, excessive accumulation of visceral adipose tissue increases the delivery of free fatty acids (FFAs) to the liver, induces insulin resistance and promotes de novo FFA synthesis in and accelerates the uptake of VLDLs and chylomicrons by the liver (Feingold, 2020; Ouchi et al., 2022). Increased levels of circulating FFAs contribute to the development of T2DM in people with obesity by inducing insulin resistance and reducing insulin secretion (Arner, 2001; Arner and Rydén, 2015). In addition, adipose tissue in people with obesity releases non-esterified fatty acids (NEFAs), hormones and pro-inflammatory cytokines, which are all involved in developing insulin resistance and β-cell dysfunction. The increased pro-inflammatory cytokines damage the β-cell membrane resulting in a reduction in the synthesis and subsequent secretion of insulin, leading to T2DM (Kahn et al., 2006; Ouchi et al., 2022). T2DM is a condition characterized by defective and delayed insulin secretion and abnormal postprandial suppression of glucagon (Hurtado and Vella, 2019). It is estimated that by 2040, over 642 million individuals worldwide will be diagnosed with T2DM (American Diabetes Association, 2014; IDF, 2015). T2DM is generally preventable and represents 90% of the total diabetic population of England (American Diabetes Association, 2014).

There is compelling evidence that increased intake of fibre-rich cereals, fruits, and vegetables may protect against the development of T2DM in adults. Dietary fibres (DFs) have been shown to positive effect on an individual's satiety and lower total energy consumption, resulting in a reduced risk of weight gain and improved insulin insensitivity (Ye et al., 2012; InterAct Consortium, 2015; Zhu et al., 2015). A large body of research has shown dietary fibres (DFs) to have a significant role in preventing T2DM. DFs are classified according to their main properties (i.e., viscosity, water solubility, and fermentation rate) into 1) non-viscous, insoluble, non-fermentable fibres; 2) non-viscous, soluble, fermentable fibres; 3) viscous, soluble, fermentable fibres and 4) viscous, insoluble, non-fermentable fibres. In addition, several meta-analyses have demonstrated that increased soluble DF (SDF) intake for a duration of 1 to 3 months is associated with a significant reduction in fasting blood glucose (FBG) levels in individuals with or without T2DM (Tiwari and Cummins, 2011; Gibb et al., 2015; Hou et al., 2015).

SDFs may contribute to glycaemic control several by reducing gastric emptying rate, modifying the release of glucose regulating hormones, inhibiting amylase activity and delaying starch hydrolysis, reducing the diffusion of amylolytic products to the small intestinal, and serving as an absorptive barrier through interactions with the mucosa. Scientific evidence suggests that all of these mechanisms are involved in the glucose lowering effects of SDFs (Goff et al., 2018; Ueno et al., 2021). However, some studies have found comparable effects on glycaemic control between fibre supplementation and placebo (Zou et al., 2015; F. Liu et al., 2017). The discrepancy between the studies could be partially explained by the differences in the DF intake and viscosity. The evidence for the effectiveness of increased SDF intake in improving the glycosylated

haemoglobin A1c (HbA1c) has been more consistent. Foods with high SDF content have a lower glycaemic index; consequently, increased SDFs intake significantly improve fasting blood glucose, postprandial glucose and HbA1c (Maćkowiak et al., 2016). A study by Ueno et al. (2021) found a significant decrease in HbA1c and fasting plasma glucose levels from 8.3% to 8.0% and from 173.2 to 152.8 mg/dL, respectively, after 12 weeks of KGM consumption in T2DM.

Additionally, two previous meta-analyses (Brown et al., 1999; Anderson et al., 2000) evaluated the effect of four different SDFs such as pectin, oat bran, guar gum, and psyllium on total and LDL cholesterol. It has been concluded that SDF intake (2–10 g/d) was associated with small but significant decreases in TC and LDL cholesterol. SDFs are responsible for increased viscosity of the food bulk and a rise in the viscosity of the colon's contents. This leads to a subsequent decrease in blood cholesterol (Russell et al., 2016; Stewart and Zimmer, 2018).

The literature also suggests a moderate dose-response relationship between the intake of non-viscous and viscous soluble dietary fibres and favourable changes in adiposity measures, including body weight (BW) and body mass index (BMI), which may be independent of the energy content of the diet (Thompson et al., 2017; Reynolds et al., 2019; Jovanovski et al., 2020). The improved adiposity status is related to a reduction in circulating levels of cholesterol and pro-inflammatory cytokines, , further supporting the role of SDFs in preventing T2DM.

GM is a commonly promoted dietary supplement, and some reports have suggested that GM intake prolongs gastric emptying, which may induce satiety, reduce food intake, and potentially decrease BW (Keithley et al., 2013). In 2010, the European

Food Safety Authority (EFSA) confirmed the positive effect of GM on the reduction of BW in overweight adults when a daily supplement of 3g (EFSA, 2010; Zalewski et al., 2015). In addition, Cheang et al. (2017) evaluated the effect of 2g GM over 4 weeks on BW and BMI in T2DM and metabolic syndrome individuals. Glucomannan noodles (GMN) group had significant decreases in the BW (↓74.42 ± 8.00 vs ↓73.71 ± 7.73 kg, p = 0.008), BMI (↓28.02 ± 3.19 vs ↓27.78 ± 3.22 kg/m^2, p = 0.011) compared to the control group (noodles without GM). Despite its widespread use, the long-term effects of GM consumption on metabolic homeostasis have not been thoroughly examined. Several clinical trials (Livieri et al., 1992; Arvill and Bodin, 1995; Vuksan et al., 2000; Birketvedt et al., 2005a; Yoshida et al., 2006; Chearskul et al., 2007; Wood et al., 2007) have investigated the impact of GM on total cholesterol (TC), LDL-C, HDL-C, TAG, BW, fasting blood glucose (FBG), systolic blood pressure (SBP), or diastolic blood pressure (DBP), but have yielded conflicting results and had modest sample sizes, short duration, heterogeneous designs, and used various forms of GM supplements. Therefore, further research is required to fully ascertain the effects of GM on the metabolic metrics discussed above. Additionally, previous systematic reviews have produced conflicting results about the efficacy of GM supplementation on glycaemic control, BW and lipid profile (Onakpoya et al., 2014; Zalewski et al., 2015). Further, they included children and adults (Han et al., 2017) and interventions using different forms of GM supplements (Au-Yeung et al., 2018). Also, a systematic review that was exclusive to adults (Mohammadpour et al., 2020) was limited to BW in healthy subjects. Future research should be more specific going forward to fully elucidate as to whether GM supplementation has differing efficacies across differing populations, i.e., males, females and adults/children.

The present systematic review was conducted to expand the scope of the previous experimental study on the effectiveness of KGM consumption for improving acute metabolic and appetite response to the ingestion of a smoothie drink with high sugar content (see chapter 5) in healthy adults and to evaluate both the short term and long term effects of GM supplementation on a wider range of metabolic parameters, including appetite, gut hormones, gastric emptying rate, glycaemia, BW and plasma lipid concentration in adults with or without T2DM.

6.2 Aim and Objectives

6.2.1 Aim

The aim of this comprehensive systematic review is to explore the efficacy of GM supplementation in appetite regulation and metabolic control across randomised controlled trials (RCTs).

6.2.2 Objectives

In order to achieve this aim, this review explored the short-term and long-term effects of GM supplementation on appetite, gastric emptying, gut hormones, glycaemic control, lipid profile, and body weight.

6.3 Methods

6.3.1 Search strategy

In order to ascertain the efficacy of GM supplementation on appetite regulation and metabolic control, a comprehensive search of the literature was undertaken according to the Preferred Reporting Items for Systematic Reviews and Meta-

Analyses (PRISMA) guidelines (Liberati et al., 2009). The research question was developed in alignment with that of the PICO framework (Table 6.1).

Table 6-1 PICO framework.

Population	**Healthy adults/ adults with obesity and/or type 2 diabetes**
Intervention	GM capsules
Control	Placebo
Outcome	Appetite regulation and metabolic control

The initial records were retrieved from three electronic databases, i.e., MEDLINE (R) (accessed via Ovid), Scopus and CENTRAL (Cochrane Library for RCTs). These databases were chosen as they represent the largest online collection of primary peer-reviewed articles within the field of clinical nutrition. In order to identify research articles that are specific to that of the research question, Boolean operators were employed. The search was limited to studies published in English between January 2000 and September 2021. The following keyword strings were searched (Table 6.2).

Table 6-2 Boolean search operators and search terms.

Boolean Operator	Search term
OR	“konjac*” AND/OR “konjaku” OR “konnyaku” OR “Amorphophallus” OR “Araceae” OR “snake palm” OR “voodoo lily” OR “glucoman*” OR “fibre supplement*”
AND	Randomised Controlled Trial” OR “RCT
AND	adult*
AND	“appetite*” OR “hunger” OR “hungry” “Satiet*” OR “Satiat*” OR “Fullness” OR “Gastric Emptying” OR “gut hormon*” OR “Gastrointestinal Hormone*” OR “Glucagon-Like Peptide 1” OR “GLP-1” OR “Ghrelin” OR “Pancreatic Polypeptide” OR “PP” OR “Gastric Inhibitory Polypeptide” OR “GIP” OR “Pancreatic Peptide YY” OR “PYY” OR “Peptide Tyrosine Tyrosine” OR “Cholecystokinin” OR “CCK” OR “Incretin” OR “Amylin” OR “Leptin”
AND	“Insulin” OR “Hyperglycemia” OR “Diabetes Mellitus” OR “Glucose” OR “Glycated Hemoglobin” OR “HbA1c” OR “Insulin Resistance” OR “Glycemic Index” OR “Glycemic Load”
AND	“lipid profile” OR “cholesterol” OR “triglyceride” OR “triacylglyceride” OR “TAG” OR “HDL” OR “LDL” OR “Non esterified Fatty Acids” OR “NEFA”
AND	“Body Weight” OR “BW” OR "body fat" OR “body composition” OR “body mass index" OR “BMI” OR “weight loss” OR “Weight Change” OR “Weight Maintenance” OR “obes*”

Boolean operators combined the search terms. Truncation was applied to improve the efficiency of the search strategy. Using appropriate key terms searched in the title, abstract or keywords section of the records. Where possible, MeSH terms were used.

6.3.2 Search strategy

The identified records from each database search were downloaded and imported into the EndNote reference manager. Duplicate records were removed. The title and abstract of the identified publications were screened based on the selection criteria to exclude irrelevant records. Then full-text publications were searched for conceptual relevance, and the studies which did not relate closely to the research question were removed. At this point, the reference lists of the screened publications were searched manually to identify any additional studies. During the full-text review, all studies were evaluated for (1) the relevance of intervention and outcome measures, (2) accessible full text in English, and (3) study design.

6.3.3 Inclusion criteria

In order to identify appropriate literature pertinent to the research question, a plethora of inclusion and exclusion criteria were employed. Only peer-reviewed publications of RCTs with placebo controls on healthy adults, adults with increased BMI levels, or T2DM were included in this review. The RCTs with a parallel, factorial or crossover design. The intervention of interest was GM supplementation (in the form of capsules or tablets) on at least one of the outcomes of interest as described below.

6.3.4 Exclusion criteria

The interventions that evaluated the effect of GM combined with other supplements or fibre (not the individual effect of GM supplements) on the outcomes of interest. Studies that did not specify the DF supplements. RCTs on individuals with malabsorption, including those who had undergone surgery or were taking medications that affect fibre absorption. RCTs that were conducted exclusively on children or adolescents. Non-placebo controlled RCTs, non-randomised trials and non-controlled interventions were all excluded. Studies addressing the same topic on animals.

6.3.5 Outcome measures

In order to ensure that articles were consistent in their findings and to allow for accurate comparisons to be drawn between articles, the following outcome measures formed a criterion for inclusion in this systematic review. Appetite was subjectively measured on a visual analogue scale (VAS), gut hormone levels (pmol/L or mmol/L. The gastric emptying rate was measured by (scintigraphy or breath tests using carbon 13 (C^{13}). Glycaemic status was assessed by fasting and postprandial blood glucose (mmol/L or mg/dl), glycated haemoglobin level (HbA1c) (mmol/L or %), serum fructosamine (µmol/L), glucose area under the curve (AUC), glucose AUC/2h, Insulin level (pmol/L or µU/mL), insulin AUC, or HOMA IR (mU/L*mmol/L). Lipid concentrations: TC and TAG (mmol/L or mg/dL), total, LDL and HDL cholesterol (mmol/L or g/dL), HDL ratio, LDL/HDL ratio, and FFAs (mmol/L or g/L). Obesity: body weight change (kg or %) and BMI (kg/m^2).

6.3.6 Data extraction

Each study was explored to extract the information about the authors, year of publication, country/region of study, setting, study design, characteristics of the study population, intervention and control, outcome measures and quantitative findings. The extracted data from all studies were presented in a separate table.

Subsequently, the findings from the included studies were narratively synthesised around the type of intervention, target population characteristics, type of outcome and intervention content. The acute effect includes a 2-hour postprandial period, and the chronic effect includes a period from 2 to 8 weeks.

6.3.7 Quality assessment

Included studies were critically appraised for risk of bias through the application of version 2 of the Cochrane risk of bias tools for randomised trials (RoB2) with specific variants for parallel-group and crossover designs. This validating tool comprises a set of domains focusing on different aspects of trial design, conduct, and reporting (Higgins et al., 2019).

The RoB2 for parallel-group RCTs consists of 5 domains:

Domain 1: Risk of bias arising from the randomisation process.

Domain 2: Risk of bias due to deviations from the intended interventions

Domain 3: Risk of bias due to missing outcome data.

Domain 4: Risk of bias in the measurement of the outcome.

Domain 5: Risk of bias in the selection of the reported result.

Each domain consists of a series of signalling questions (Appendix 13) to elicit information about features of the trial that are relevant to the risk of bias (Sterne et al., 2019).

The RoB2 checklist for crossover RCTs contains all the above 5 domains together with a specific domain, i.e., Domain S: Risk of bias arising from period and carryover effects.

Domain S covers three sources of bias:

1. Equal or nearly equal number of participants in each sequence of the crossover trial.

2. Accounting for the "period effect".

3. Accounting for the carryover effect (for example, using sufficient washout period between sequences).

This specific tool also has an additional item in domain 5 pertinent to selectively reporting the data from the first period because of the carryover effect.

RoB2 tool also provides algorithms for rating each domain as Low Risk of Bias, Some Concerns or High Risk of Bias based on the responses to each set of signalling questions (Higgins et al., 2019). Subsequently, the overall risk of bias in each study was determined based on the combined rating on all domains.

6.3.8 Literature search

A PRISMA flowchart of the study selection process is presented in (Figure 6.1). A total of 176 publications were identified from the three databases. 21 duplicate studies were removed, 155 article titles and abstracts were screened. Hundred-and-eleven records were excluded after scanning titles and abstracts. Ninety-eight publications had irrelevant intervention design, including non-randomised trials, studies without placebo controls, studies that used GM as the comparator but not the intervention, RCTs on individuals with malabsorption and those who had undergone surgery or were taking medications that affect fibre absorption. Two studies used different supplementations while six publications evaluated the effect of GM combined with other fibre or supplements or treatments and did not assess its effect alone. Five RCTs that were conducted on children or adolescents, and (7) type of publication.

A total of 44 publications were considered for full-text reading, on which 39 articles were removed due to the following reasons: 11 publications had irrelevant intervention design such as non-randomised controlled trials, RCTs without placebo controls, or an active placebo. 4 studies used different supplementation, 17 publications evaluated the effect of GM combined with other fibre or supplements or treatments and did not assess its effect alone, 5 studies did not specify the type of DF supplement, 1 study was nonrandomised controlled trial, and 1 study was conducted on animals (rats). After reading the full texts, 5 publications were included for final review (Figure 6.1).

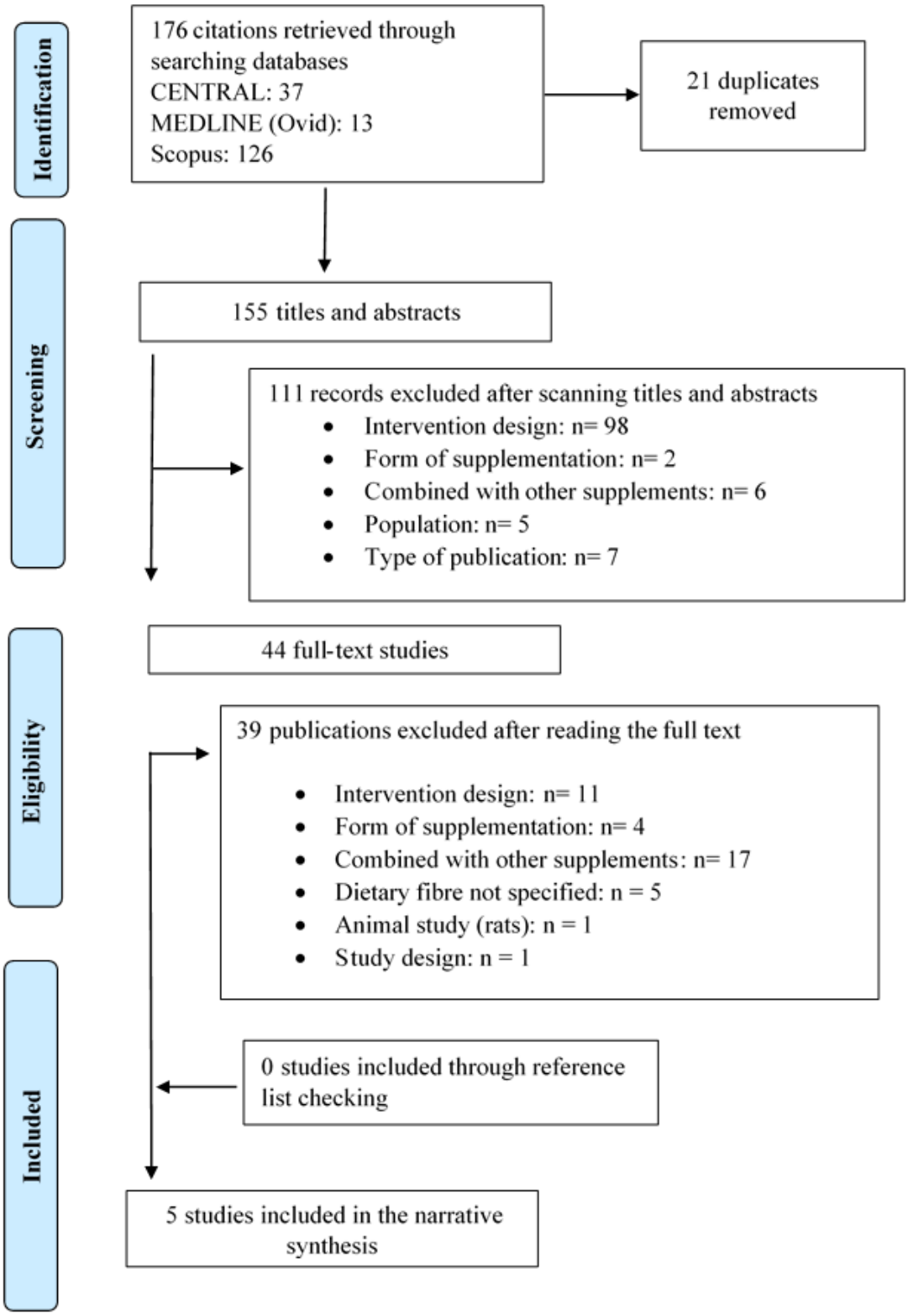


Figure 6-1 PRISMA flow chart of the study selection process.

6.4 Results

6.4.1 Study characteristics

Characteristics of the GM interventions included in this review are presented in (Table 6.3). Three studies were conducted in South East Asia (Chen et al., 2003; Chearskul et al., 2007; Chearskul et al., 2009), and two studies were undertaken in the USA (Birketvedt et al., 2005a; Keithley et al., 2013). Overall, this systematic review included 305 adults aged 18 to 70 years. Three studies were conducted on adults with T2DM (Chen et al., 2003; Chearskul et al., 2007; Chearskul et al., 2009), while two studies enrolled adults without T2DM (Birketvedt et al., 2005a; Keithley et al., 2013). In three studies, (Chen et al., 2003; Birketvedt et al., 2005a; Chearskul et al., 2007) participants had BMI levels mostly within the normal or overweight range (25.5 ± 3.2 kg/m^2), (>25.0 and <30.0 kg/m^2), (25.12 + 1.54 kg/m^2) in men and (27.41 + 1.44 (kg/m^2) in women, respectively (Chen et al., 2003; Birketvedt et al., 2005a; Chearskul et al., 2007). One study also included adults with obese BMI (25 to 35 kg/m^2) (Keithley et al., 2013), and one study (Chearskul et al., 2009) did not provide BMI levels. However, the article did not measure the height and weight of participants, and thus changes in BMI could have been reported in this article. Three RCTs had a parallel group design (Birketvedt et al., 2005a; Chearskul et al., 2009; Keithley et al., 2013), while two RCTs had a crossover design (Chen et al., 2003; Chearskul et al., 2007) although Chen et al. (2003) did not include a washout period. In both crossover RCTs (Birketvedt et al., 2005a; Chearskul et al., 2007), each period was for 4 weeks, while parallel-group RCTs had different follow-up durations, i.e., 4 weeks (Chearskul et al., 2009), 5 weeks (Birketvedt et al., 2005a) and 8 weeks (Keithley et al., 2013). One study used GM tablets (Birketvedt et al., 2005a), while

four other studies used GM capsules. GM doses ranged from 1.3g/d to 3.6g/d. The substances used as a placebo included corn starch (Chen et al., 2003), white rice flour (Chearskul et al., 2007; Chearskul et al., 2009) and inactive microcrystalline cellulose (Keithley et al., 2013). Birketvedt et al. (2005a) did not describe the content of placebo tablets. All studies explored the chronic effect (4-8 weeks) of GM on fasting glucose, insulin concentration, 2-hour postprandial glucose, glucose and insulin AUC, TC, TG, LDL-C, HDL-C, BW, hunger, fullness, ghrieln and lipten. Three RCTs also studied the acute effect (2-hour postprandial and OGTT 2 hours) of GM on the fasting glucose concentration, 2-h postprandial glucose TC, TG, LDL-C, HDL-C, BW, glucose insulin AUC 2h, gehriln and lipten (Chen et al., 2003; Chearskul et al., 2007; Chearskul et al., 2009). All studies except the RCT by Birketvedt et al. (2005a) measured changes in plasma glucose. Three studies evaluated the changes in lipid profile (Chen et al., 2003; Chearskul et al., 2007; Keithley et al., 2013). Also, three studies measured BW changes (Chen et al., 2003; Birketvedt et al., 2005a; Keithley et al., 2013). Only one study explored the changes in insulin levels (Chearskul et al., 2007). Appetite was the outcome measure in two studies (Chearskul et al., 2007; Keithley et al., 2013). Only one study by Chearskul et al. (2009) measured the changes in leptin and ghrelin levels. The gastric emptying rate was not measured in any of the included studies.

Table 6-3 Study characteristics of the GM interventions.

Authors (year)	Country and population	Study design	Intervention	Control	Outcome measure	Findings
(Chen et al., 2003)	Taiwan Outpatient 22 adults (10 male, 12 female) Age 64.2 ± 8.4 years no dropouts BMI (25.5 ± 3.2 kg/m^2)	Randomised double-blind placebo-controlled crossover design A two-month run-in period Two 28-day experimental periods	GM N=10 Gelatine capsules each containing 0.5g konjac glucomannan powder 3 times a day: 1 capsule 30 mins before each meal with a glass of water	Corn starch N=12 Gelatine capsules each containing 0.5 g food-grade corn starch capsules Similar dosing	Primary outcome: Fasting glucose concentration (mmol/L) Secondary outcomes:	% Change treatment versus (vs) placebo group Fasting glucose ↓12.3 ±15.2 vs ↑10.2 ±18.7 (p = 0.002)

	Hypercholesterolaemia and T2DM Not taking lipid-lowering medication		Titration: 1.2g/d for 3 days 2.6g/d for 3 days 3.6g/d for 22 days Total duration: 28 days Switched without a washout period to placebo for another 28 days		2-hour postprandial glucose (mmol/L) TAG (mmol/L) TC (mmol/L) LDL-C HDL-C	2-hour postprandial glucose ↓12.2 ± 25.5 vs ↑12.6 ± 32.0 (p = 0.014) TAG ↓5.9 ± 21.2 vs ↓2.5 ± 23.6 (p=0.078) TC ↓8.2 ± 7.8 vs ↑2.9 ± 10.1 (p = 0.0001) LDL-C ↓10.7 ± 23.3 vs ↑9.9 ± 24.7 (p = 0.0004) HDL-C ↑4.5 ± 9.3 vs ↓0.5 ± 7.7 (p = 0.392) Total/ HDL-C

						↓11.6 ± 10.2 vs ↑3.9 ± 13.0 (p = 0.011).
					Total/ HDL-C	LDL/HDL-C ↓13.6 ± 26.1 vs ↑6.4 ± 23.3 (p = 0.0005)
					LDL/HDL-C	BW ↓0.6 ± 1.4 vs ↑0.2 ± 1.7 (p = 0.115)
					BW (kg)	
Authors (year)	**Country and population**	**Study design**	**Intervention**	**Control**	**Outcome measure**	**Findings**
(Birketvedt et al., 2005b)	USA	Three randomised double-blind placebo control parallel group	Protocol for all 3 studies:	Placebo tablets with identical	BW (kg)	BW change (kg)

	176		6 tablets taken 3 times daily with 250 ml of water 15 minutes before meals, 4 tablets taken at 3 pm	taste and look		treatment vs placebo
	Otherwise, healthy overweight adults Primary care practice Age 30 to 60 years BMI>25.0 and <30.0 kg/m^2 (mean BMI = 27.7 kg/m^2) Following a calorie-restricted diet (1200 kcal/d, 35% fat, 15% protein, 55% carbohydrate)	Study 1: 53 women Glucosahl fibre supplement Study 2: 52 women Chourombalance fibre supplement Study 3:	Study 1: N=25 Glucosahl (Glucomannan 4320 mg/d, Guar 900 mg/d Alginate 900 mg/d) Study 2: N=23	Content not described Similar protocol and duration Study 1: N=28		Study 1:

		60 men and women Appe-Trim fibre supplement	Chourombalance (Glucomannan 1240 mg/d) Study 3: N=30 Appe-Trim (Glucomannan 420 mg/d, Guar 420 mg/d)	Study 2: N=29 Study 3: N=30		↓ 4.4 ± 2.0 in Glucosahl vs ↓ 2.7±1.3 in placebo (p < 0.001) Study 2: ↓3.8±0.9 in Chourombalance group vs ↓ 2.5 ± 0.5 in placebo (p < 0.01) Study 3: ↓ 4.1± 0.6 in Appe-Trim group vs ↓ 2.1 ± 0.5 in placebo (p < 0.01)
Authors (year)	**Country and population**	**Study design**	**Intervention**	**Control**	**Outcome measure**	**Findings**
(Chearskul et al., 2007)	Thailand Twenty T2DM patients 10 men and 10 women,	Single-blind placebo-controlled, crossover design Two separate protocols	Purified GM Protocol 1:	White rice flour Protocol 1:		MD changes GM vs placebo

	aged 30-70 years		12-hour overnight fasting	12-hour	Short-term (protocol 1)	Short-term effects
	BMI:	Duration:		overnight fasting	Glucose AUC	
	25.12 + 1.54(kg/m^2) in men	Protocol 1	N=10	N=10	(mg/dl 2h)	Glucose AUC
	27.41 + 1.44 (kg/m^2) in women	oral glucose tolerance test (OGTT) (2 hours)	2 capsules of purified GM	2 capsules of white rice flour		(↓12.88 ± 4.95% vs ↓3.3 ± 3.2%, p= 0.032)
	Received dietary control		(1g) with 200 mL water	(1g) with 200 mL water		
	or oral diabetic drugs or insulin therapy	Protocol 2	30 min prior to standard 75g OGTT	30 min prior to standard 75g OGTT	Insulin AUC (µU/ml 2h)	Insulin AUC
		4 weeks				(non-significant, statistics unavailable)
		supplementation or placebo	Protocol 2:	Protocol 2:		
			N=10	N=10	Long-term (protocol 2)	Long-term effects
		crossover after a 2-week washout interval	1g GM capsule before each meal (3g/d)	1g placebo capsule	Fasting glucose (mg/dL)	

			then OGTT	with antidiabetic drugs before each meal (3g/d) then OGTT	Fasting insulin (µU/mL) Lipid profile: TC (mg/dL) TAG (mg/dL) HDL-C (mg/dL) LDL-C (mg/dL) HOMAIR (mU/l*mmol/L) Appetite (VAS)	Fasting glucose, insulin, TC, TAG, and HDL-C: nonsignificant (statistics unavailable) LDL-C is lower after GM than placebo (p<0.01) (MD not reported) HOMA IR lower after GM than placebo in women (p<0.05) Appetite scores GM: 5.16 Placebo: 5.32 (p > 0.05)
Authors (year)	**Country and population**	**Study design**	**Intervention**	**Control**	**Outcome measure**	**Findings**

(Chearskul et al., 2009)	Thailand Twenty T2DM patients, Age, gender and BMI not reported	Randomised, controlled (blinding unclear) Two separate protocols	GM Protocol:1	White rice flour Protocol 1:	Immediate effect (Protocol 1) 2 hours postprandial	Immediate effect GM vs placebo Glucose and ghrelin concentration at 2 h lower in GM than in the placebo
	Taking antidiabetic drugs	2-week washout Timing unclear Duration: Protocol 1	N= 20 1 g GM capsule 30 min prior to standard 75-g OGTT	N= 20 1 g white rice flour capsule 30 min prior to standard 75-g OGTT	glucose (mmol/L) ghrelin (% change from basal) leptin (% change from basal)	with no statistically significant difference Leptin nadir at 2 h was significantly lower in the GM group than the placebo (p not reported) Long term effect

		2 hours Protocol 2 4 weeks supplementation or placebo	Protocol 2: N: unclear 1g GM capsule before each meal (3g/d)	Protocol 2: N: unclear 1g white rice flour capsule before each meal (3g/d)	Long- term (Protocol 2) ghrelin changes leptin changes	Comparable ghrelin AUC in GM and placebo groups leptin response not clearly described
Authors (year)	**Country and population**	**Study design**	**Intervention**	**Control**	**Outcome measure**	**Findings**
(Keithley et al., 2013)	USA	Randomised double-blind, placebo-controlled	GM	Inactive microcrystalline cellulose	Primary outcome	GM vs placebo

	47 otherwise healthy adults with overweight or moderate obesity					
		Duration:			weight loss (kg) from baseline to 2 weeks and 8 weeks	weight loss (MD)
	Aged 18 to 65 years	8 weeks		N= 24		no statistically significant difference either after two weeks (↓0.32 ± 0.04 kg vs ↓0.11 ± 0.02 kg) or
	BMI: 25 to 35 kg/m^2			Male = 4		eight weeks (↓0.43 ± 0.06 kg and ↓0.40 ± 0.07 kg)
			N = 23	Female = 20		
			Male = 3	two 666 mg (1.33 g)		
			Female = 20	Inactive microcrystalline cellulose	Secondary outcomes	comparable changes between GM and placebo groups either after 2 weeks or 8 weeks in:
			two 666 mg	capsules with 236.6 mL (8 oz.) of water one hour before		body composition

			(1.33 g) GM capsules with 236.6 mL (8 oz.) of water one hour before breakfast, lunch, and dinner 3.99 g/day) for 8 weeks	breakfast, lunch, and dinner 3.99 g/day) for 8 weeks	body composition (fat mass (kg), hunger (VAS, 100 mm scale) fullness (VAS 100 mm scale) fasting lipid concentration TC (mg/dL) TAG (mg/dL) LDL-C (mg/dL) HDL-C (mg/dL) glucose levels (mg/dL)	hunger/fullness fasting lipid concentration and glucose levels

6.4.2 Effect of glucomannan supplementation

6.4.2.1 Glycaemic control

Inconsistency was observed for the acute effect of GM supplementation on glycemic response. Chearskul et al. (2007) measured the acute effect of (1g) GM supplementation 30 minutes before standard 75-g OGTT in adults with T2DM who received dietary control or oral diabetic drugs or insulin therapy. The results showed a significant reduction in glucose AUC between the GM supplementation and placebo groups ↓12.88 ± 4.95% vs ↓3.3 ± 3.2% (p=0.032). However, insulin AUC showed non-significant effects (p-values not available available). In addition, the acute effect of (1g) GM supplementation 30 minutes prior to standard 75-g OGTT on glucose concentration was lower in GM than in the placebo, with no statistically significant difference (p-values not available available) (Chearskul et al., 2009).

The evidence regarding the chronic effect of GM supplementation on glycaemic control was inconsistent. Chen et al. (2003) measured such effect in hypercholesterolaemic patients with T2DM not taking lipid-lowering medication and a BMI within the normal or overweight range. They found that, compared to the placebo group, participants who received incremental doses of GM capsules (from 1.2 to 3.6g/d) had significantly greater reductions in fasting blood glucose ↓12.3 ±15.2 vs ↑10.2 ±18.7 (p=0.002) and postprandial blood glucose 2-hour postprandial glucose ↓12.2 ± 25.5 vs ↑12.6 ± 32.0 (p=0.014) after 4 weeks. In contrast, two studies (Chearskul et al., 2007; Keithley et al., 2013) on adults with T2DM and non-diabetic adults with overweight or obesity. They found no significant differences in

fasting blood glucose changes between the GM and placebo groups (1.3g/d to 3g/d for 4 or 8 weeks), respectively (p-values not available available).

Furthermore, the evidence from the two RCTs on adults with T2DM that was controlled by diet, oral antidiabetic drugs or insulin therapy (Chearskul et al., 2007; Chearskul et al., 2009) showed no significant differences of (1g) GM supplementation in acute (2-hour OGTT) and chronic (4 weeks) of (3g) GM on insulin concentration between the GM and placebo groups (p-values not available).

6.4.2.2 Appetite assessment

The acute effects of GM on appetite scores were not reported in any study. The chronic effects of 3g/d GM supplementation on appetite in adults with T2DM who received dietary control or oral diabetic drugs or insulin therapy over 4 weeks were statistically non-significant, 5.16mm vs 5.32mm (p>0.05) (Chearskul et al., 2007). Comparable changes in hunger 39.10mm vs 43.48mm and fullness 48.18mm vs 5.65mm of 3.99g/day GM supplementation and placebo in non-diabetic adults with overweight or obesity over 2 weeks. Of particular interest would be whether a long follow-up duration of GM supplementation might be less effective in hunger and fullness (Keithley et al., 2013). The changes in appetite scores (measured on the VAS) were not significantly different between the GM supplementation and placebo groups in both studies. Chearskul et al. (2009) found a significant acute (2-hour OGTT) effect of GM supplementation (1g) on reducing postprandial leptin concentration compared to placebo (p-value not reported) in patients with T2DM who used antidiabetic medications (unreported BMI). Likewise, The acute effect (2-hour OGTT) of 1g GM/day on ghrelin was lower in GM than in placebo groups. However, over 4

weeks of GM supplementation on ghrelin AUC, the chronic effect was comparable to GM and placebo, leptin response was not clearly described (Chearskul et al., 2009).

6.4.2.3 Body weight

The acute effects of GM supplementation on BW changes between the GM and placebo groups were not reported in any study. Of the three studies (Chen et al., 2003; Birketvedt et al., 2005a; Keithley et al., 2013) that measured the chronic effect (4,5 and 8 weeks) of GM supplementation on BW, only one study (Birketvedt et al., 2005a) reported significant between-group differences. In this RCT of overweight adults without T2DM who were on a calorie-restricted diet (1200kcal/d), supplementation with GM tablets (1240 mg/d) for 5 weeks resulted in greater BW reduction compared to placebo ↓3.8±0.9kg vs ↓2.5±0.5kg (p<0.01). However, the difference in BW reduction between GM (3.6g/d) for 4 weeks and placebo groups was nonsignificant ↓0.6kg ±1.4 vs ↑0.2kg ±1.7 (p=0.115) in a study of normal-weight to overweight adults with T2DM (Chen et al., 2003). Similarly, in the more recent study of non-diabetic adults with overweight or obesity, Keithley et al. (2013) did not find a significant between-group difference in BW reduction after either 2 weeks (↓0.32 ± 0.04 kg vs ↓0.11 ± 0.02 kg) or 8 weeks (↓0.43 ± 0.06 kg and ↓0.40 ± 0.07 kg) of GM supplementation (3.99 g/day).

6.4.2.4 Plasma lipids

The acute effect of GM supplementation on lipid concentrations was not measured in any study.

Three studies measured the chronic effect of GM supplementation on lipid concentrations, including TC and TAG, together with LDL-C and HDL-C (Chen et al.,

2003; Chearskul et al., 2007; Keithley et al., 2013). Between-group changes in TAG were nonsignificant in all three studies. In comparison, GM supplementation was associated with more significant reductions after gradually increasing the GM dose from 1.2 to 3.6g/d over 4 weeks than the placebo in normal-weight to overweight adults with T2DM and hypercholesterolaemia (Chen et al., 2003). TC ↓8.2 ± 7.8 vs ↑2.9 ± 10.1 (p = 0.0001), LDL-C ↓10.7 ± 23.3 vs ↑9.9 ± 24.7 (p = 0.0004) , HDL-C ↑4.5 ± 9.3 vs ↓0.5 ± 7.7 (p = 0.392), total/ HDL-C ↓11.6 ± 10.2 vs ↑3.9 ± 13.0 (p = 0.011) and LDL/HDL-C ↓13.6 ± 26.1 vs ↑6.4 ± 23.3 (p=0.0005). In contrast, between-group differences in lipid concentration changes were nonsignificant after 2 and 8 weeks of GM supplementation (3g/d) in non-diabetic and non-hypercholesterolemic adults with overweight or obesity (Keithley et al., 2013). RCTs by Chearskul et al. (2009) measured the effect of (3g) GM supplementation on TC, TAG and HDL-C in adults with T2DM controlled by diet, oral antidiabetic drugs or insulin therapy. The study did not observe significant differences (statistics unavailable).

6.4.3 Risk of Bias assessment

Three studies (Chen et al., 2003; Birketvedt et al., 2005a; Chearskul et al., 2007) were considered to raise some concerns of bias because they had some concerns on two domains of the RoB2 tool, while two studies (Chearskul et al., 2009; Keithley et al., 2013) were considered to be at a high risk of bias (Table 6.4). The study by Chearskul et al. (2009) had some concerns on multiple domains (domains 1, 4 and 5), while the RCT by Keithley et al. (2013) had a high risk of bias on domain 2.

Table 6-4 Risk of bias in the included studies.

Studies	Overall Risk of Bias	Domain-specific Risk of Bias					
		Domain 1: Risk of bias arising from the randomisation process	Domain 2: Risk of bias due to deviations from the intended interventions	Domain 3: Risk of bias due to missing outcome data	Domain 4: Risk of bias in measurement of the outcome	Domain 5: Risk of bias in selection of the reported result	Domain S*: Risk of bias arising from period and carryover effects
Chen et al., 2003	Some Concerns	Some Concerns	Low Risk	Low Risk	Low Risk	Some Concerns	Low Risk
Birketvedt et al., 2005	Some Concerns	Some Concerns	Low Risk	Low Risk	Some Concerns	Low Risk	
Chearskul et al., 2007	Some Concerns	Some Concerns	Low Risk	Low Risk	Some Concerns	Low Risk	Low Risk
Chearskul et al., 2009	High Risk	Some Concerns	Low Risk	Low Risk	Some Concerns	Some Concerns	
Keithley et al., 2013	High Risk	Some Concerns	High Risk	Low Risk	Low Risk	Low Risk	

6.5 Discussion

6.5.1 Glycaemic control

The findings on the acute or chronic effect of GM supplementation on blood glucose levels were inconsistent. In a study of hypercholesterolaemic patients with T2DM (Chen et al., 2003), participants who received GM capsules (gradually increased from 1.2g/d to 3.6g/d) had significantly greater reductions in fasting and postprandial blood glucose than the placebo group after 28 days. However, blood glucose levels increased during the second period of this crossover RCT, indicating that the effectiveness of GM on glycaemic control did not remain significant for 56 days. The more recent study by Keithley et al. (2013) did not observe significant differences in FBG between GM and placebo groups with overweight or obesity but without T2DM after 2 or 8 weeks of consuming GM capsules (1.3g/d). Regarding the acute effects (2-hour OGTT), the differences in fasting blood glucose between the GM and placebo groups were nonsignificant in adults with T2DM (Chearskul et al., 2007). However, hyperglycaemia had already been controlled by diet or medication in participants of the study by Chearskul et al. (2007). Interestingly, they found significant between-group differences in postprandial glucose concentration following a 2-hour OGTT. This was not supported by a later study of adults with T2DM (Chearskul et al., 2009), which did not find a significant effect of consuming 1g GM on blood glucose after a 2-hour OGTT, thus may differing results may be found following implementation with stronger doses of GM, or measuring blood glucose at later time points to observe a chronic effect.

Although the underlying mechanisms are not fully elucidated, it is thought that, similar to other VDFs, GM increases the viscosity of gastrointestinal contents, slows gastric emptying, and acts as a barrier to mucosal diffusion, thereby decreasing the postprandial surge in blood glucose (Behera and Ray, 2016). SDFs, particularly VDFs, are known to reduce postprandial glucose absorption by delaying the disintegration of long-chain carbohydrates and oligosaccharides via suppressing actions on α-amylase and α-glucosidase, respectively (Hu et al., 2018). In addition, viscous polysaccharides such as GM can bind with and adsorb glucose, thus maintaining a low glucose concentration in the small intestine (Hu et al., 2018). SDFs also contribute to the production of SCFAs in the colon, particularly butyric acids, which may improve insulin sensitivity, substituting a gluconeogenic response or enhancing glucose uptake by adipose tissue and skeletal muscle, thereby decreasing insulin excursions (Hu et al., 2018). Previously, Sood et al. (2008) found a significant effect of GM (>3g/d) with a duration of 4 to 12 weeks on decreasing FBG (WMD=7.44 mg/dL) based on a meta-analysis of 5 RCTs. However, they combined RCTs with parallel and crossover designs. Moreover, the effect of GM on FBG was nonsignificant in the subgroup analysis of patients with obesity, T2DM or impaired glucose tolerance, suggesting no effect of SDF on the aforementioned outcome variables. This may also explain the mixed finding in the present systematic review.

Based on the above evidence, it is possible that GM (3g/d) may confer some glycaemic benefits to people with T2DM but only in the short-term (4 weeks or less).

6.5.2 Appetite assessment

The RCTs included in the present systematic review did not find a significant effect of GM on reducing appetite in adults with T2DM (Chearskul et al., 2007) and non-diabetic adults who were overweight or obesity (Keithley et al., 2013). This is consistent with a previous meta-analysis (Zalewski et al., 2015) that found no significant change in appetite between adults receiving GM or placebo based on the study by Keithley et al. (2013). However, the authors did not use the intention to treat analysis (ITT) and measured only the effect of GM vs placebo in participants who completed the RCT. It is also noteworthy that the participants in the RCT by Chearskul et al. (2007) were already on a diet or antidiabetic treatment, and this may have had an impact on that of appetite on the participants within this study. Moreover, the overall quality of these studies was moderate. The doses utilized within the studies differed significantly, ranging from 1g to 3g daily, and the studies had a small sample size and short duration.

Therefore, the available studies do not support the effectiveness of GM capsules in decreasing appetite, however, further research is required to fully evaluate the efficacy of GM on appetite through application of more consistent study designs within larger sample sizes.

In terms of appetite hormones, one of the included studies, Chearskul et al. (2009), found significant reductions in circulating leptin levels 2 hours after glucose preloading in the GM group. Physiologically, GM increases the intraluminal viscosity of the gastrointestinal tract and reduces the absorption of nutrients in the lumen. Prolonged presence of nutrients in the small intestine, in turn, stimulates the release

of appetite-regulating hormones such as cholecystokinin (CCK) in the duodenum, peptide tyrosine tyrosine (PYY) and glucagon-like peptide 1(GLP-1) in the distal ileum and proximal colon (Vuksan et al., 2009). GM is also used for fermentation by gut bacteria, promoting short-chain fatty acids (SCFA) production in the colon. Increased SCFA could potentially trigger the secretion of GLP-1 and PYY (Tolhurst et al., 2012). Moreover, the observed decrease rather than an increase in leptin secretion in the above study could be due to the underlying leptin resistance in the participant as they had T2DM and increased fasting leptin levels at the baseline. Thus, it could be speculated that the decrease in leptin following GM consumption may indicate chronic improvement in the sensitivity of peripheral tissues to leptin. Further, patients with T2DM appear to have less pronounced postprandial changes in plasma ghrelin than non-diabetic individuals (Anderwald et al., 2003). This may partially explain the nonsignificant difference in ghrelin concentration between the GM and placebo groups in the study by (Chearskul et al., 2009). Also, GM supplementation was not associated with a significant rise in fasting ghrelin levels. This may indicate a slightly beneficial effect of GM on the regulation of ghrelin and appetite in diabetic patients. Since GM supplementation was also associated with improved insulin resistance in this study (Chearskul et al., 2009), at least in female participants, it is also possible that GM may indirectly prevent a rise in ghrelin via increasing peripheral insulin sensitivity. When participants were separated into tertiles of HOMA-IR as a measure of insulin resistance, those in the middle tertile in the GM group (insulin-sensitive participants) had the lowest postprandial ghrelin than those in the placebo group. However, the effect of GM on leptin and ghrelin is unclear, and future studies

should look at measuring all appetite associated hormones during the 2hr postprandial period.

6.5.3 Body weight

There was inconsistency across the included RCTs regarding the effect of GM on body weight. Birketvedt et al. (2005a) reported a significantly BW reduction after 5 weeks of supplementation with GM tablets (1240 mg/d) in overweight adults without T2DM who used an energy-restricted. This finding is supported by a recent systematic review of 6 RCTs (Mohammadpour et al., 2020) that demonstrated a small but significant decrease in BW following GM supplementation (1.24 to 3g/d) in adults (weighted MD=0.96kg), particularly in females (WMD=1.86kg) with overweight or obesity. Nevertheless, there was substantial variability across the studies in this systematic review; in terms of participant BMI and dietary interventions alongside that of GM supplementation, which may have impacted the results of the identified studies. Furthermore, between-group reductions in BW were significant only in RCTs of 8 weeks or shorter reported in this review. This corroborates with the findings of a previous systematic review and meta-analysis of RCTs (Zalewski et al., 2015) that found some evidence for the effectiveness of GM supplementation (1.24 to 3.99 g/d) for 2 to 8 weeks in reducing BW but not BMI among otherwise healthy adults with overweight or obesity (MD ranging from 0.21kg to 3.17kg).

The link between GM consumption and weight reduction is incompletely understood. GM is a VDF that may induce satiety and satiation by absorbing water, slowing the gastric emptying rate distending the gastrointestinal tract and displacing energy of the other macronutrients. This may reduce food and energy intake,

potentially promoting weight reduction (Doi, 1995; Keithley et al., 2013). However, it should be noted that in the study by Birketvedt et al. (2005a), both GM and placebo groups were on an energy-restricted diet (1200 kcal/d). Moreover, this study had some concerns of bias in the randomisation process and the outcome measurement. In two other RCTs, Chen et al. (2003) recruited normal-weight to overweight adults with T2DM, while Keithley et al. (2013) studied non-diabetic adults with overweight or obesity and did not use a calorie-restricted diet. The between-group difference in BW was nonsignificant, respectively, after 4 weeks of consuming GM capsules (gradually increased from 1.2g/d to 3.6g/d) or 8 weeks of supplementation with GM capsules (1.3g/d).

Nevertheless, participants in the study by Chen et al. (2003) used sulphonylurea agents (glinbenclamide and glipizide) potentially associated with weight gain, (Barbieri et al., 2022). This may have contributed to the observed nonsignificant weight reduction. There was also a high risk of bias regarding the deviation from the intended protocol in the study by Keithley et al. (2013). Collectively, the above evidence may imply that consuming GM supplements (1240mg/d) may be more effective for weight reduction when added to a reduced-calorie diet instead of a reduced-calorie diet alone.

6.5.4 Plasma lipids

Plasma lipids are important in the regulation of fasting plasma glucose and, as such, are a key variable to demonstrate the efficacy of GM supplementation. The present systematic review found some evidence on the short-term effectiveness of GM supplementation (gradually increased from 1.2g/d to 3.6g/d over 28 days or 3g/d for

8 weeks) in reducing LDL-C, particularly in adults with Hypercholesterolaemia. This is consistent with EFSA report on the beneficial effect of daily GM intake (4g/d) on cholesterol levels (EFSA, 2010). It has been suggested that the cholesterol-lowering effects of GM are due to its high viscosity rather than the quantity (Vuksan et al., 2011). VDFs increase intestinal viscosity, which interferes with the absorption of cholesterol from the intestinal tract as well as reabsorption of bile acids which may accelerate faecal bile acid excretion (Gallaher et al., 2000; Kraemer et al., 2007; Guo et al., 2021). In addition, GM as a VDF promotes the activity of gut microbiota and the formation of SCFA, which may alter cholesterol metabolism (Wong et al., 2006). Chen et al. (2003) also found significant differences in LDL/HDL cholesterol and total/HDL cholesterol reductions between the GM and placebo groups.

However, the evidence on KGM consumption and total cholesterol levels were mixed. In contrast, significant reductions in TC were observed in adults with T2DM and hypercholesterolemia (Chen et al., 2003) after 4 weeks of GM supplementation (1.2g/d gradually increased to 3.6g/d) compared to placebo. Changes in TC were comparable between GM and placebo groups that had normal cholesterol levels at baseline (Chearskul et al., 2007; Keithley et al., 2013). Also, the effect of GM supplementation on HDL-C and TAG was nonsignificant in all included studies. The predominant effect of GM on LDL-C, especially in patients with elevated cholesterol levels at baseline, is in line with previous meta-analyses of RCTs on GM. These reported significant mean differences of 15.99 mg/dL (Sood et al., 2008) and 0.35 mmol/L (Ho et al., 2017) in LDL-C reduction between the GM and placebo groups. The above finding is clinically meaningful because LDL-C is found to be raised in people living with obesity and/or T2DM.

The finding of a nonsignificant difference in TAG conflicts with Sood et al. (2008), who demonstrated a significant difference in TAG (WMD=11.08 mg/dL) between the GM and control groups. The researchers attributed this to the preferential effect of GM on lipoprotein metabolism in the liver (Doi, 1995). However, Sood et al. (2008) highlighted that the effect of GM on TAG was less pronounced in the subgroup of patients with impaired glucose metabolism or those who were on a diet. Two of the studies that reported nonsignificant differences in TAG (Chen et al., 2003; Chearskul et al., 2007) enrolled patients with T2DM, and the other study (Keithley et al., 2013) was conducted on people with obesity who might have had dysregulated glycaemic control. Moreover, participants in these studies had normal baselines TAG levels. The above findings suggest that short-term consumption of GM is primarily effective for LDL-C reduction with minimal impact on TAG and HDL-C in patients with dysglycaemia.

6.5.5 Strengths and limitations

To the best of the author's knowledge, this is the first systematic review of GM effectiveness in adults that combines a wide range of cardiometabolic outcomes, including measures of glycaemic control, BW, appetite and appetite-regulating hormones, and total lipid profile.

The present systematic review followed the PRISMA guidelines in conducting and reporting systematic reviews. It also used a focused search strategy using the PICO framework and specifically defined inclusion criteria. The study included only blinded RCTs with placebo controls that used GM supplementation without combined intervention. The included studies were critically appraised using the valid Cochrane

risk of bias tools for parallel and crossover design RCTs. In addition, it provided a review of the more recent GM interventions.

This systematic review also had some limitations. Due to the small number of studies included in this review and substantial heterogeneity in their outcome measures, meta-analysis was not performed. This might have affected the estimated effect of GM supplementation on the outcome measures. The present study reviewed only the RCTs that used GM supplements in the form of capsules or tablets. This may have limited the scope of the review as several RCTs might have been excluded during the literature search. This systematic review was restricted to studies published in English, and the search was limited to online databases. Also, grey literature and other sources such as conference proceedings or unpublished RCTs were not included in the literature search. Further, the overall quality of evidence from the included studies was moderate because most of them had some concerns of bias in their methodology or data analysis due to inadequate randomisation, selective reporting of the findings and incomplete data. Moreover, the included studies had a small sample size and a short duration with substantial heterogeneity in the design, population characteristics and intervention protocols, including GM dosage.

Further research is required to study the longer-term effectiveness of GM supplementation on cardiometabolic risk and to compare the effect of various forms and doses of GM supplements. Also, future studies must elucidate the appetite-regulating effects of GM intake in adults, including changes in gastric emptying and a variety of gut hormones, while adjusting for the energy intake and baseline metabolic profile.

6.6 Conclusion

This systematic review demonstrated limited evidence on the short-term effectiveness of GM supplementation at reducing fasting and prandial glycaemia, BW, TC, and LDL-C, particularly in patients with dysglycaemia or hypercholesterolaemia. GM supplementation was not more effective than the placebo in regulating appetite or improving insulin, TAG, and HDL-C levels. These findings are comparable with previous systematic reviews and support the output from my human intervention study using GM supplements. However, there was substantial heterogeneity among the studies and inconsistency in the effects of GM in adults without T2DM. Further research is required to study the long-term effect of GM on cardiometabolic risk factors using an appropriate design and larger populations.

Chapter 7 : General discussion

7.1 General discussion

This research provided important insights into the behaviour, knowledge, and attitudes regarding dietary fibre and smoothie consumption among different groups of UK adults. It demonstrated that the consumption of smoothies amongst the university cohort was above the national level in the UK.

The smoothie survey showed that smoothies were the preferred and popular beverage among the university cohort. Thus, any changes in their ingredients would significantly impact overall health and acceptance. Importantly, sugar content was the most critical concern among smoothie consumers in the study population. This probably reflects the awareness of the study population regarding nutritional characteristics of the smoothies currently available in the UK market and their interest in consuming products with healthier nutritional profile. The present research also found a gap between the knowledge and consumption of dietary fibre in UK adults. The study population were aware of the benefits of fibre consumption for promoting health and preventing some chronic diseases and the strategies to increase fibre consumption. However, the knowledge about the fibre content of beverages and food products was low, and fibre intake from the diet was below the recommended levels. Less desirable taste, higher price, limited availability and the lack of nutritional information on the food labels were described as important barriers against the consumption of fibre rich foods. Nevertheless, the use of fibre supplements was common among the study population. The findings from these surveys informed the development of the subsequent experimental studies regarding the benefits of enriching fruit smoothies with the dietary fibre KGM to alter the absorption of the high amounts of sugars in fruit beverages and to enhance

satiety feeling after smoothie ingestion. This experiment provided objective evidence on the rheological changes in fruit smoothies following the incorporation of relatively small amounts of viscous dietary fibre powder (KGM). This underscores the technical challenges in the fortification of semisolid beverages such as smoothies with viscous soluble dietary fibres in the form of powders. In the smoothie fortification experiment, addition of KGM powder to commonly consumed fruit smoothies caused undesirable changes in their viscosity and texture including excessive viscosity, hardness, solidity and thickness particularly after overnight storage in a cool temperature, making the enriched fruit beverage unsuitable for drinking. Thus, KGM capsules rather than KGM powder were considered for the human intervention study.

This randomised crossover trial compared the effect of consuming 1g and 2g KGM capsules versus placebo on metabolic markers (blood glucose and insulin levels) and appetite-related measures, including a comprehensive gut hormone profile (ghrelin, GLP-1, PYY and PP) and gastric emptying rate following the ingestion of a sugar-rich smoothie drink. It demonstrated that consuming KGM capsules prior to fruit smoothie did not significantly improve 2hr postprandial metabolic response (blood glucose and lipid concentrations and the release of gut hormones), gastric emptying rate and appetite in healthy adults. However, the consumption of KGM capsules at a higher dose of 2g exerted beneficial effects on the acute glycaemic response to smoothie ingestion compared to placebo and 1g KGM capsules. Generally nonsignificant effect of KGM on the metabolic and appetite response to meal ingestion in the current study can possibly be explained by the following reasons i) the inadequate food matrix in smoothies could not allow KGM capsules to develop

their viscosity. ii) the 2-hour period may not be enough for complete hydration of KGM to exert their satiety inducing effects. iii) the non-significant effect of KGM capsules on TC, NEFA and TG in this study can be due to using a fruit smoothie as the sample meal however, smoothie samples were high in carbohydrate, and they did not contain dietary fibre. Thus, the single use of KGM capsules may not be effective for acute metabolic control and appetite regulation. Due to COVID related restrictions, conducting a human intervention on the chronic effect of KGM supplementation on metabolic balance and appetite regulation was not possible.

Therefore, a systematic review was conducted to expand the scope of the previous human intervention study on the effectiveness of KGM consumption at improving metabolic and appetite responses in longer term. The systematic review evaluated both acute and chronic effects of KGM capsules on a wider range of metabolic parameters including, glycaemia, lipid concentration, gut hormones, appetite and body weight in adults with and without type 2 diabetes. The findings were consistent with the previous systematic reviews and supported the output from the present human intervention study. The systematic review provided evidence on the modest acute and chronic (2h -up to 1 month) effectiveness of KGM capsule supplementation at reducing fasting and prandial glycaemia, total and LDL cholesterol, and body weight particularly in patients with dysglycemia or hypercholesterolaemia. However, supplementation with KGM capsules was not effective at inducing satiety, suppressing hunger, improving ghrelin or leptin secretion and decreasing serum triglyceride concentration. However, there was substantial methodological heterogeneity among the studies. Therefore, further research is required to study

the acute and chronic effects of KGM capsules on cardiometabolic risk factors using an appropriate design and larger population.

Chapter 8: Appendices

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8.1 Ethical approval for study 1 (Chapter 2)

Manchester Metropolitan
University

M E M O R A N D U M

FACULTY ACADEMIC ETHICS COMMITTEE

Faculty of Health,
Psychology & Social Care

Brooks Building
Birley Fields Campus
53 Bonsall Street
Manchester
M15 6GX

+44 (0)161 247 2569

HPSCresearchdegrees@mmu.ac.uk

To: Ohaad Awlya

From: Dr Ajay Patel

Date: 23/02/2017

Subject: Ethics Checklist 1458

Title: Consumer attitudes to smoothies, preference and health

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Thank you for your ethics checklist.

The Faculty Academic Ethics Committee review process has recommended approval of your ethics checklist. This approval is granted for 42 months for full-time students or staff and 60 months for part-time students. Extensions to the approval period can be requested.

If your research changes you might need to seek ethical approval for the amendments. Please request an amendment form.

We wish you every success with your project.

PP

Dr Ajay Patel
Co-Chair
Faculty Academic Ethics Committee

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8.2 Information sheet from study 1 (Chapter 2)

Survey of Smoothie Consumption

Mrs. Ohaad Awlya, Dr Tom Butler and Dr Tristan Dew

Hello!

We are conducting research into making fruit smoothies healthier at Manchester Metropolitan University and would like you to be a participant in our survey. Your participation is greatly appreciated and will significant contribute to our analysis. It will approximately take 5 minutes of your time. All answers will be anonymous and used strictly for this project. Thank you very much for your time and support.

Purpose:

The purpose of this survey study is to more exhaustively understand smoothie consumption in the UK and abroad.

Objectives:

To determine which smoothie flavours are the most popular.
To determine why people drink smoothies.

Follow this link to the Survey:

Take the survey

Or copy and paste the URL below into your internet browser:

https://mmutourism.eu.qualtrics.com/SE?SID=SV_emREGh8xs7ty68t&Preview=Survey&Q_CHL=preview

Follow the link to opt out of future emails:

Click here to unsubscribe

Thank you for taking time complete this survey
Your participation is greatly appreciated
Have a great day!

8.3 Online survey questions from study 1 (Chapter 2)

Title: Smoothie consumption perceptions, preferences, and attitudes

Please check one that applies

1. Have you read the information sheet before signing the Consent Form?

Yes

No

2. Have you signed the Informed Consent Form?

Yes

No

Section 1: Personal and socio-demographic questions.

3. What is your gender?

Male

Female

Prefer not to say

4. What is your age?

18-25 years old

26-35 years old

36-45 years old

46-55 years old

Over 55 years old

5. What is your highest qualification?

Undergraduate

Postgraduate

6. What is your current employment status?

Academic

Support

Technical

Other

Section 2: Smoothie consumption frequency per month in the last three months.

7. How many times a month do you consume smoothies?

Section 3: Reasons for consuming smoothies.

8. Why do you personally drink smoothies? Tick as many as you like.

They are tasty

They are healthy

Meal replacement

To meet my 5-a-day

Other

Section 4: Favourite smoothie flavours and brands in the UK market.

9. What is your favourite smoothie brand?

Innocent

Savse

Naked

Tropicana

Tesco

Spar

M&S

Pret

Sainsbury's

Other

10. Which one of the flavours below is your favourite?

Strawberry and Banana

Mango and passion fruits

Blueberry

Strawberry, Raspberry and Cranberry

Apple, Pineapple and Kiwi

Mango

Other

Section 5. Nutrition-related information

11. Please rank the following options in order of importance for a healthier smoothie. A scale of 1 to 5, with 1 indicating the highest importance and 5 indicating the lowest importance

Low sugar

High fibre

Low fat

High protein

High vitamins and minerals

Other

Section 6: Factors contributing to the preference for freshly made smoothies or available commercial smoothies.

12. What factors might contribute to the preference for freshly made smoothies or available commercial smoothies?

Commercial smoothies too expensive

Freshly made smoothies are healthier

Freshly mad smoothies do not taste as good

Other

Thank you for taking time to participate in this survey

8.4 Risk assessment from study 2 (Chapter 3)

Manchester Metropolitan University

RISK ASSESSMENT

FACULTY/DEPARTMENT Faculty of Health, Psychology and Social Care/ Department Of Health Professions	**BUILDING** Righton/Cavendish Building

1) ACTIVITY

- Smoothies will be fortified with a range doses of soulible diatry fibres (SDFs) such as, konjac glucomannan (KGM) and guar gum (GG) from 0-10 % (w\v) as a starting point for acceptability testing. Subsequently the level of enriched smoothies with SDFs, will be based on the results will be obtained from the sensory analysis test.
- Trial-meals will be presented in a Food Product Testiong Laboratory (C.G.10) (this is not visible from the laboratory where the participants rested).
- Consumer panellists will be recruited in a Sensory Analysis Suite (C.G.22) to evaluate the acceptability of control smoothies and enriched smoothies with the three different SDFs KGM and GG.
- The proposed serving size for sensory evaluation will be around 30 to 35ml.
- A rank preference test will be used to evaluate the acceptability and preference of enriched smoothies in comparison with control.
- A triangle test will be used to compare enriched smoothies to control to see if the consumers can recognise the difference.

2) PERSONS AT RISK

Participants.

3A) HAZARDS

The risks involved in sensory assessment are minimal.

- Non identified hazard issue of the proposed SDFs except some minor warning of choking upon ingestion SDFs with people with swallowing difficulties.
- As smoothies are rich in naturally sugars will affect people with medical conditions such as diabetes.
- Possibility of exposure to food allergies and food intolerance.
- Potential contamination during preperation.

3B) Hazard Rating **Low** ☒ **Med** ☐ **High** ☐

4A) RISK CONTROL METHODS

- The actual form of SDFs (POWDER) may not let that happen by making sure that the fibres completely dissolve in the smoothies.
- Sugars will affect people with medical conditions such as diabetes, however, the current study is restricted to healthy people with no medical conditions.
- Health screening record required to prevent the occurrence of allergies and food intolerance..
- Hygiene requirements will be deliberated by keep food in the detected area and follow hygiene instructions while samples preparation.

4B) Hazard Rating with control methods **Low** ☒ **Med** ☐ **High** ☐

5) FURTHER ACTION REQUIRED

Smoothie should be served chilled.

NAME AND TITLE OF ASSESSOR Ohaad Awlya	**SIGNATURE** Ohaad	**DATE** 21.03.18
		REVIEW DATE
SIGNATURE OF DEAN/HEAD OF DEPT. pp. Dr D Anang		**DATE** 23.04.18
		REVIEW DATE 31.10.18

8.5 Nutritional information for Innocent® strawberries and bananas smoothie

	per 100ml	per serving (250ml)
energy	228 kJ (54 kcal)	570 kJ (136 kcal)
protein	0.6g	1.5g
carbohydrate	11.9g	29.75g
carbohydrate (of which sugars)	10.5g	26.25g
fat	0.2g	0.5g
fat (of which saturates)	0.1g	0.25g
fibre	1g	2.5g
sodium	trace	trace
vitamin c	8mg	20mg (33% rda)

250ml as a % of an adult's guideline daily amount:

calories	sugars	fat	saturates	sodium	fibre
136	26.25g	0.5g	0.25g	trace	2.5g
7%	29%	1%	1%	trace	10%

8.6 Ethical approval from study 3 (Chapter 4)

Manchester Metropolitan University

17/01/2022
Project Title: Knowledge, perception, attitude, and awareness regarding the consumption of dietary fibre among UK adults

EthOS Reference Number: 34196

Ethical Opinion

Dear Ohaad Fahad A Awlya,

The above application was reviewed by the Science and Engineering Research Ethics and Governance Committee and, on the 17/01/2022, was given a favourable ethical opinion. The approval is in place until 11/04/2022 .

Conditions of favourable ethical opinion

Application Documents

Document Type	File Name	Date	Version
Additional Documentation	Survey - word document	05/10/2021	1
Project Protocol	Protocol online survey 2021	01/11/2021	2
Additional Documentation	Ethics 18 Oct 21	09/11/2021	4
Additional Documentation	Answering the reviewers comments - 18 Oct 21	09/11/2021	4
Consent Form	24 Nov 21 Consent Form	11/01/2022	5
Information Sheet	MMU Participant-Information-Sheet 24 Nov 21	11/01/2022	5
Additional Documentation	Survey poster 24 Nov 21	11/01/2022	5
Additional Documentation	24 Nov 2021 Answering the reviewers comments - Ohood	11/01/2022	5

The Science and Engineering Research Ethics and Governance Committee favourable ethical opinion is granted with the following conditions

Adherence to Manchester Metropolitan University's Policies and procedures

This ethical approval is conditional on adherence to Manchester Metropolitan University's Policies, Procedures, guidance and Standard Operating procedures. These can be found on the Manchester Metropolitan University Research Ethics and Governance webpages.

Amendments

If you wish to make a change to this approved application, you will be required to submit an amendment. Please visit the Manchester Metropolitan University Research Ethics and Governance webpages or contact your Faculty research officer for advice around how to do this.

We wish you every success with your project.

Science and Engineering Research Ethics and Governance Committee

Science and Engineering Research Ethics and Governance Committee

For help with this application, please first contact your Faculty Research Officer. Their details can be found here

8.7 Information sheet & informed consent form - study 3 (Chapter 4)

You are invited to participate in this online questionnaire which aims to explore adults' knowledge, attitude, and perceptions about dietary fibres.

Dietary fibre is considered a key component of a healthy diet. However, several studies have demonstrated that the average intake of dietary fibre is below the recommended levels in all age groups.

Low consumption of dietary fibre has been linked to several chronic diseases.

Consumers need to develop their knowledge and competence as informed consumers can perform their food choices in a complex environment with a wide variety of foods available. Therefore, studying the knowledge, awareness, and attitude towards consuming food and beverages containing dietary fibre is important.

Why have I been invited?

You are invited because your participation will provide an idea about the level of knowledge and awareness towards consuming diets rich in dietary fibre and their health benefits among the UK population.

Do I have to take part?

It is up to you to decide. You are required to have a minimum level of English to take part in the survey. Then you will be asked to sign a consent form to show you agreed to take part.

Those with gastrointestinal medical conditions, such as inflammatory bowel disease or coeliac disease, should not participate in this study as dietary advice is to avoid fibre in these populations.

You are free to withdraw at any time without giving a reason.

Given the anonymous nature of the survey, it is not possible to link your answers to you after they have been submitted, so, once submitted, it is not possible to withdraw your data from this study.

Are there any risks if I participate?

There are minor risks linked with using the computer. Would you please take several breaks when you are completing the survey online?

Potential participants who have inflammatory bowel disease (IBD) and coeliac disease should not participate in this study.

You will only need 10-15 minutes to complete the entire survey unless you revisit your answers multiple times.

Are there any advantages if I participate?

You will be required to sign the consent form before the commencement of the study. Once this step is completed, all further steps will be completed anonymously. You will access the survey using an online link without any need to include your names and any other personal details. After completing the study, data will be anonymously stored/used with the principal investigator using MMU computers.

What will happen to the results of the research study?

Data will be confidentially stored with the principal investigator, Dr Adora Yau & the director of studies (Dr Gethin Evans) at all times. In the case of academic publication, the authors will make sure the results of this study will be anonymously published.

Who has reviewed this research project?

The principal investigator: Mrs Ohaad Awlya. Email address: ohaad-fahad.a.awlya@stu.mmu.ac.uk

The first supervisor: Dr Adora Yau. Email address: a.yau@mmu.ac.uk

The director of studies: Dr Gethin Evans. Email address: gethin.evans@mmu.ac.uk

Whom do I contact if I have concerns about this study or I wish to complain?

If you have general questions about the project, you can contact the principal investigator Ohaad Awlya. Email address: ohaad-fahad.a.awlya@stu.mmu.ac.uk. Don't hesitate to contact the Faculty ethics for any concerns/complaints about the project. Email address: ethics-scieng@mmu.ac.uk and the DPO & ICO for complaints about data. Email address: legal@mmu.ac.uk

The investigators have provided me with an information sheet on the above investigation, which I have read and have had the opportunity to ask questions regarding the purpose of the study. I understand that the investigators may publish the findings gathered from this investigation in abstracts, journals, conferences or other media formats. However, I know that all my personal information will remain confidential so that nobody can identify me from such publications. I have read and agreed to the above terms and conditions.

○ Yes

○ No

8.8 Online survey questions from study 3 (Chapter 4)

Title: Knowledge, perception, attitude, and awareness regarding the consumption of dietary fibre among UK adults

1) Have you read the information sheet before signing the Consent Form?

Yes

No

2) Have you signed the Informed Consent Form?

Yes

No

Section 1: Personal and socio-demographic questions.

3) What is your gender?

Male

Female

Prefer not to say

4) What is your age?

18-25 years old

26-35 years old

36-45 years old

46-55 years old

Over 55 years old

5) Where do you live in the UK?

England

Northern Ireland

Scotland

Wales

6) What is your highest qualification?

GCSEs

A level

Bachelor's degree

Master's degree

PhD or another Doctorate

7) What is your current employment status?

Employed Full-Time

Employed Part-Time

Unemployed

Retired

Prefer not to say

Section 2: Knowledge regarding dietary fibre.

8) What would you change in your diet if you would like to have a healthier diet? Please rank the following options in order of importance: (1= most important) and (4= least important).

Please don't select more than one answer(s) per row.

Consume more vegetables and fruits

Consume less sugar

Consume less fat

Consume more whole grain products

9) Which of the following statements is/are true? Select all that apply.

Fibre reduces the risk of type 2 diabetes by slowing down the absorption of glucose (sugar)

Fibre reduces cholesterol

Fibre lowers the risk of cardiovascular diseases such as stroke and heart disease

Fibre supports weight loss

Fibre improves digestion and bowel health

10) What foods are considered high in fibre? Select all that apply.

Vegetables

Cereal's fibre

Fruit and berries

Wholegrain products

Other

Section 3: Attitude regarding dietary fibre.

11) Which of these methods is a good way to increase your daily fibre intake? Select all that apply

Eat whole fruits instead of drinking fruit juices

Snack on raw vegetables instead of chips or crackers

Add fruits or vegetables to your meals

12) How often do you eat fibre in your diet?

At least once a day

At least once a week

Once a month or less

13) What is your main fibre source?

Diet

Supplements

Both diet and supplements

14) What may prevent you from consuming fibre rich food and beverages? Select all that apply

Do not like the taste

Cost "e.g., wholegrain bread can be more expensive than white versions."

Availability "e.g., less choice of wholemeal products, particularly when eating out."

Waste "e.g., rapid spoilage of fruit."

Lack of information about the content and the health benefits of the fibre in the nutritional label.

Section 4: Perception of dietary fibre content in whole fruit compared with fruit beverages.

15) Do you agree or disagree with the following statement?

"Removal of the peel during processing may lead to reduced dietary fibre content after fruit beverage consumption compared with whole fruit."

Agree

Neither agree nor disagree

Disagree

16) Do you agree or disagree with the following statement?

"Satiety sensation is greater after consuming whole fruit compared to fruit juice."

Agree

Neither agree nor disagree

Disagree

17) Do you agree or disagree with the following statement? " Whole fruits are healthier than fruit juice because their ingestion leads to less increase in blood sugar."

Agree

Neither agree nor disagree

Disagree

Section 5: Awareness regarding dietary fibre.

18) How important is it for you to eat enough fibre on a daily basis?

Important

Neutral

Not important

19) Select all that apply. "Eating too much fibre will."

Make you feel gassy

Make you feel bloated

Causes constipation

Causes diarrhoea

Other

None of the above

20) How important is it to provide information about fibre content on the back-of-pack label?

Very important

Somewhat important

Not important at all

Thank you for taking time to participate in this survey

8.9 Ethical approval form study 4 (Chapter 5)

Manchester Metropolitan University

19/11/2018

Project Title: Effect of soluble dietary fibre on metabolic response

EthOS Reference Number: 0480

Ethical Opinion

Dear Ohaad Fahad A Awlya,

The above application was reviewed by the Science and Engineering Research Ethics and Governance Committee and, on the 19/11/2018, was given a favourable ethical opinion. The approval is in place until 03/07/2019 .

Conditions of favourable ethical opinion

Application Documents

Document Type	File Name	Date	Version
Consent Form	Consent-Form for senssory 14 Mar 18 senssory	22/03/2018	1
Project Proposal	Smoothie and fibre proposal	12/10/2018	1
Recruitment Media	Advertising poster	12/10/2018	1
Consent Form	Consent form	12/10/2018	1
Information Sheet	Participant information sheet	12/10/2018	1

The Science and Engineering Research Ethics and Governance Committee favourable ethical opinion is granted with the following conditions

Adherence to Manchester Metropolitan University's Policies and procedures

This ethical approval is conditional on adherence to Manchester Metropolitan University's Policies, Procedures, guidance and Standard Operating procedures. These can be found on the Manchester Metropolitan University Research Ethics and Governance webpages.

Amendments

If you wish to make a change to this approved application, you will be required to submit an amendment. Please visit the Manchester Metropolitan University Research Ethics and Governance webpages or contact your Faculty research officer for advice around how to do this.

We wish you every success with your project.

Science and Engineering Research Ethics and Governance Committee

8.10 Informed consent form study 4 (Chapter 5)

Name of volunteer:

School of Healthcare Science

Manchester Metropolitan University

Informed Consent form

Project title: **"Effect of soluble dietary fibre on metabolic response."**

Investigators: **Mrs Ohaad F Awlya, Dr Adora Yau, Dr Stephen White and Dr Gethin Evans.**

To be completed by participant:

The investigators have provided me with an information sheet on the above investigation which I have read and have had the opportunity to ask questions regarding the purpose and protocol of the investigation. The investigators have outlined any potential risks or discomforts associated with the experimental protocol.

The investigators have informed me of my right to withdraw from this investigation at any time without giving any reason for doing so.

I fully and freely give my consent to participate in this investigation as it has been described to me and understand that participation in this investigation may not benefit me in any way.

I understand that the investigators may publish the findings gathered from this investigation in abstracts, journals, conferences or other media formats. However, I understand that all my personal information will remain confidential so that nobody can identify me from such publications.

Signature: **Date:**

To be completed by researcher:

I have explained the experimental protocol to the participant and have informed the participant of any risks or discomforts associated with the protocol. I have informed the participant of the purpose of the experiment and of their right to withdraw from the investigation without giving any reason for doing so.

Signature: **Date:**

8.11 Information sheet form study 4 (Chapter 5)

Manchester Metropolitan University
School of Healthcare Science

Manchester Metropolitan University

Volunteer Information

Project title: **"Effect of soluble dietary fibre on metabolic response."**

Background

The purpose of this study is to determine how different quantities of commercially available dietary fibre effects postprandial glucose, gut hormones, subjective appetite and gastric emptying rate after ingestion of commonly ingested high sugar products.

One of the proposed mechanisms to alter the rate of absorption of the high amounts of sugars that exist naturally in fruit beverages is to increase dietary fibre intake. Key studies in this area have concentrated on konajc glucomannan (KGM) soluble dietary fibre. Dietary fibre is the part of the plant that is not broken down in the intestines by human digestive enzymes because it is not digested nor absorbed in the body. Soluble dietary fibre is beneficial for a number of reasons as it may delay the rate of sugar absorption in the gastrointestinal tract via increasing the viscosity of the intestinal contents, which, in turn, may effect glycaemic and appetite responses to sugar ingestion. This could have an important implication on health outcomes.

Soluble dietary fibre may also stimulate secretion of gastrointestinal hormones involved in subjective feeling of appetite. The most well-studied hormones secreted from the gastrointestinal tract involved in this process are Ghrelin, Glucagon-like peptide-1 (GLP-1), Glucose-dependent insulinotropic peptide (GIP) and Peptide tyrosine tyrosine (PYY).

The aim of this research project is to investigate immediate response of postprandial glucose, gut hormones, gastric emptying and appetite perception post ingestion of commercially available high sugar products with different quantities of KGM.

Study protocol

Should you agree to participate in this study you will be asked to complete; one familiarisation trial (1-h), where your height and body mass will be measured in addition to demonstrating to you the techniques to be used in the experimental trials.

The main trials will consist of a 2.5-hour visit to the laboratory on three separate occasions. Each visit will be preceded by a 24-hour dietary and physical activity log. You will be asked to refrain from alcohol consumption and strenuous exercise in the 24 hours prior to attending the laboratory. At 2200-h the evening before your visit you will be asked to fast, except for the consumption of water. Upon arrival at the laboratory in the morning, (0900-1000) you will rest for 15 min in a semi-supine position, and then we will insert a cannula into a forearm vein to monitor blood glucose, insulin and gut hormones within the blood. You will then be asked to ingest some commercially available capsules that will either contain a placebo or KGM 30 minutes before ingesting 500 mL of a commercially available smoothie. Blood samples will be collected 15, 30, 45, 60, 90 and 120 min after ingestion of the smoothie and you will be asked to complete a questionnaire regarding your subjective feelings of appetite at intervals throughout the protocol. Finally, breath samples will also be collected before and after smoothie ingestion in order to assess the gastric emptying rate of the smoothie. All of these measurements are made routinely in our laboratory.

Following the last sample collection 2h-post smoothie ingestion you will be free to leave the laboratory.

8.12 Appetite questionnaire on a 100 mm visual analogue scale (VAS) form study 4 (Chapter 5)

How hungry do you feel?

I am not hungry at all _____ I have never been more hungry

How full do you feel?

Not at all full _____ Totally full

How much do you think you could eat?

Nothing at all _____ A lot

How Satisfied

Not satisfied at all _____ Very satisfied

How bloated do you feel?

Not at all bloated _____ Very bloated

8.13 The main sources of bias addressed by each domain of the RoB2 tool for parallel-group RCTs form study 5 (Chapter 6).

Domain	Specific items						
Domain 1	Random allocation sequence	Allocation sequence concealment	Baseline differences between intervention groups				
Domain 2	Blinding participants	Blinding researchers	Deviations from the planned intervention because of trial context	Outcomes affected by deviations from the protocol	Deviations balanced between the groups	Appropriate analysis of outcome data	Impact of excluding participants with incomplete data
Domain 3	Availability of data for 95% of participants in each group	Biased caused by missing outcome data	Systemic missing data				
Domain 4	Appropriate assessment method	Differential bias in outcome measurement	Blinding of assessors to the received intervention	Effect of unblinding on the outcome measurement			
Domain 5	Data analysis according to the protocols	Selectively reporting multiple measures of outcome	Selectively reporting the outputs of multiple analytical tests				

Chapter 9 : References

9.1 Refrences

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