The effect of a 14-day sugar reduction intervention on individuals with a ‘sweet tooth’ on intake, desire, and preference for sweet foods

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Wei-Hsi Hsiao
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Abstract

Background: People who identify as having a sweet tooth, may find it difficult to control their sugar intake. Gymnema sylvestre is a plant that contains a chemical compound called gymnemic acid which can reversibly suppress sweet taste responses.

Objectives: The study aimed to investigate whether supplementing Gymnema sylvestre (GS) can reduce sugar cravings, sweet food desire and consumption among adults that identify as high sweet food consumers (sweet tooths).

Method: On day zero, 32 healthy participants who self-classified as having a sweet tooth underwent baseline sensory testing for sweet taste perception using the placebo mint (PLAC). Participants then went through the randomisation process into the two groups. On day 15, participants underwent further sensory testing (with GS mint) before embarking on 14 days' supplementation using the GS mints following either a systematic (3 times/day at specified times; SYS) or ad libitum (up to 6 mints/day at times of their choosing; AD-LIB) regimen. On day 30, participants swapped over to the other trial (using the other regimen). On day 45, participants completed final questionnaires and anthropometric measurements. At each visit, participants were required to complete questionnaires (food frequency questionnaire, beverage questionnaire and cravings questionnaire), sensory testing and measurement of anthropometry. At all visits participants completed questionnaires, anthropometric measures, and sensory testing. Sensory testing was not required for day 45.

Results: AD-LIB reduced daily sugar-sweetened beverages (SSB) intake by 42% relative to PLAC ($p=0.015$). AD-LIB reduced overall sugar cravings by 28% relative to PLAC ($p=0.045$) AD-LIB and SYS reduced pleasantness ratings ($p<0.005$) and desire for more chocolate ($p=0.005$).

Conclusion: Gymnema sylvestre consumption using an ad libitum regimen reduced sugar cravings and changed sweet food desire and consumption.

Keywords: Sugar reduction; sensory evaluation; cravings questionnaire

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Contents

List of Tables

List of Figures

Abbreviations

ADLIB	Ad libitum
BIA	Bioimpedance machine
BMI	Body Mass Index
DEBQ	Dutch Eating Behaviour Questionnaire
FFQ	Food Frequency Questionnaire
GA	Gymnemic acid
GI	Glycaemic index
GPCR	G-protein coupled receptor
GS	Gymnema sylvestre
HSF	High sugar foods
NNS	Non-nutritive sweeteners
PLAC	Placebo
SAQ	Sugar Addiction Questionnaire
SSB	Sugar-sweetened beverages
SSF	Sugar-sweetened foods
SYS	Systematic
T2DM	Type 2 diabetes
TCQ	The Cravings Questionnaire
WHO	World Health Organisation

Chapter 1 Introduction

1.1 Background

Sugary foods are a delight to the senses and are often classified as treats and eaten on special occasions. Sugar is a white sweet crystalline substance derived from plants like sugar cane. Sugar is used in many different products and for many different reasons. Therefore, it is easy to consume, especially when sugar may not be obvious in food and beverage products, including breakfast cereals, muesli bars, and yoghurt. In addition, soft drinks are usually highly prevalent with sugar. Glucose, fructose and sucrose are the simple sugar types most commonly found in human diets (NZ Nutrition Foundation, 2018)

Sugar has become a controversial topic due to its potential health risks. Consuming too much sugar can increase the risk of developing obesity, diabetes, and cardiovascular problems (DiNicolantonio et al., 2016). Humans are habitual creatures, and habits are built from repeated behaviour or actions until they become automatic without purposeful thinking or awareness; as we age, it is harder to change certain habits (Nilsen et al., 2012). In terms of sugar consumption, an individual may develop a sugar-eating habit, which could be developed internally through culture, beliefs and attitudes (Nilsen et al., 2012). Consuming 330 mL of sugar-sweetened beverages a day (each containing ~30 g of sugar and ~140 kJ) may easily be enough and contribute to excessive sugar consumption, ultimately increasing that individual's risk of developing health problems later in life (Nilsenet al., 2012).

The New Zealand Ministry of Health Survey (2020-2021) found that about a third of adults aged at least fifteen and one in eight children are affected by obesity (Ministry of Health, 2020). Excessive sugar consumption increases susceptibility to debilitating medical complications like diabetes mellitus-related problems such as insulin resistance or hypertension prevailing over a significant period due to severe inflammation associated with such conditions. Earlier studies carried out by Pagidipati & Gaziano (2013) & DiNicolantonio et al. (2016) advocate that sugary food products lead to these disease outcomes. The World Health Organization defines sugar-sweetened beverages (SSB) as all drinks containing added sugars; examples include juices (fruit/vegetables), carbonated drinks and powdered juice mixes. (World Health, 2017). Excessive consumption of SSB increases the likelihood of childhood obesity and SSB’s provide limited nutritional value (Ludwig et al., 2001; Hoare et al., 2017). The WHO notes that

increasing or decreasing the amount of sugar consumed is associated with body weight changes and excess body weight is corelated with excess energy intake from sugars (World Health Organization, 2015). Some strategies to reduce sugar intake include reduction and replacement, where the total sugar amount is reduced in foods and replacement, where the sugar is replaced with an artificial sweetener (Sadler & Stowell, 2012).

Gymnema sylvestre, also known as ‘gurmar’, the sugar destroyer, is a plant native to Asia (Anjum & Hasan 2013). Gymnema sylvestre has been used in Ayurvedic practices to treat sugar-related illnesses such as diabetes and insulin resistance (Anjum & Hasan, 2013). Gymnema sylvestre can decrease blood sugar in fasting individuals (Chattopadhyay, 1998), improve glycaemic control (Devangan et al., 2021), and it has shown to reduce the lipid levels and fasting blood glucose in Type 2 diabetes mellitus ([T2DM], Chattopadhyay, 1998; Devangan et al., 2021). Gymnema sylvestre is considered safe, and there are no reported side effects, GS also has anti-inflammatory, antioxidant and glucoside inhibition properties, which can further treat T2DM (Le et al., 2021). Gymnemic acids (GA) are the active compounds in GS that block the sweet receptors in the tongue, preventing the individual from tasting anything sweet for a short period (30-60 minutes; Preuss et al., 2004). Lozenges containing GS can reduce the desire and consumption of sweets; as it is evident that GA is blocking sweet receptors, decreasing the desire to eat sweet-tasting foods (Stice et al., 2017).

Individuals having a ‘sweet tooth’ have a fondness or craving for sweet food; some people taste sweetness stronger, and some may taste it weaker depending on the individual (Hwang et al., 2015). If a person has a ‘softer’ sweet taste, that individual could tolerate and handle sugar at a higher amount and consume more sugar (Hwang et al., 2015). The softer the sweet taste means more sugar is needed to satisfy the ‘craving’. Sweetness sensitivity decreases with age (Hwang et al., 2015). Vennerød et al., (2017) showed that high exposure to fruit could lead to reduced added sugar consumption, indicating that the sugars in fruits are enough to satisfy sugar ‘cravings’.

Sugar can be an addictive substance due to the increased consumption and availability of refined sugar. High glycaemic index (GI) foods can trigger neurochemical responses and activate addiction-related brain regions (Bocarsly et al., 2011; Lennerz & Lennerz, 2018). Sugar addiction shows the same neurochemical reactions on the same receptors as drugs and alcohol (Lennerz & Lennerz, 2018). Humans have not adapted to this high concentration of refined

sugars (Lennerz & Lennerz, 2018). The high consumption of refined sugar can override self-control mechanisms that lead to sugar addiction (Bocarsly et al., 2011; Lennerz & Lennerz, 2018). Although animals showed no interest in foods sweetened with artificial sweeteners and non-caloric sweeteners, the animals showed a dopaminergic response similar to addiction-like behaviour when sugar was eaten, although dopamine is not the sole cause of addiction (Westwater et al., 2016; Lennerz & Lennerz, 2018). People find sugar's ability to provide quick energy and excellent taste appealing. The dopaminergic responses from sugar can cause binge eating (Fullerton et al., 1985). Many binge eaters prefer sweet items, as sugar consumption can elevate endorphins, which plays a role in the pathophysiology of obesity (Fullerton et al., 1985). Gymnema sylvestre could be used to combat sugar's addictive properties by blocking sweet receptors and reducing the reward response trigger (Stice et al., 2018)

There is strong evidence that links high sugar intake and obesity. The WHO recommends no more than 10% of daily total energy intake is from free sugar (Ludwig et al, 2001; Pagidipati & Gaziano 2013; World Health Organisation, 2015; DiNicolantonio et al., 2016; Puddu & Menotti, 2021). Individuals with a sweet tooth may find it hard to control the amount of sugar consumed and may have a higher desire to eat sugary foods and drinks.

There have been studies that have looked into GS-containing mints. Studies by Turner et al., (2020), Turner et al. (2022), Nobel et al. (2017) and Stice et al. (2017); looked into the application and measured desire, pleasantness and hunger towards sugar-sweetened foods. Stice et al. (2017) used a randomised between-subjects, placebo-controlled experiment with 67 participants. Before tasting the candy and after candy consumption, participants were asked to rate their desire for another candy. Stice et al. (2017) showed a 44% reduction in total candy intake compared to placebo. However, participants were only given a placebo or an active mint (not both), making it difficult to determine whether the observed effects were caused by the treatment or by other external factors and placebo effect and expectancy bias. Nobel et al. (2017) used a placebo-controlled double-blind crossover and found a significant reduction in the desire for high-sugar foods and totally candy consumption. Nobel et al. (2017) did not use standardised confectionery serving sizes; without standardised servings, the variation of the sugar content may affect the effectiveness of GS. Turner et al. (2020) found a 22.7% decrease in the desire to eat sweet foods and a 31% reduction in pleasantness. Turner et al. (2020), Stice et al. (2017) and Nobel et al. (2017) completed their study in a laboratory setting and with acute mint consumption; the lack of long-term data makes it challenging to determine if the findings of

these studies are suitable in the future. Turner et al. (2022) examined the effects of consuming GS-containing mints three times per day for 14 days. The study was the first to examine the long-term effects of GS use outside of a laboratory setting. Turner et al. (2020) found that participants with a sweet tooth had a greater reduction in pleasantness ratings when compared to participants without a sweet tooth; participants in this study also did not consume both mints. The current study will address the gaps in previous studies, focusing on the habitual side of sweet food consumption, craving levels of individuals with a sweet tooth and whether a systematic or ad-libitum method would decrease sweet food consumption.

1.2 Aims/objectives

1.2.1 Aims

Investigate whether consuming a GS-containing mint by ad-libitum (as required) or systematic (following a set of instructions) method for 14 days can reduce intake, desire and preference for sweet foods in individuals with a sweet tooth.

1.2.2 Objectives

Investigate whether consuming a GS-containing mint for in individuals who identify as having a sweet tooth can:

· Reduce sugar-related cravings

· Decrease the intake of free sugar-containing foods and beverages

· Decrease the ratings of hunger, pleasantness and desire of consuming free sugar-containing confectionary

· Result in a decline in sweet food desire and consumption depending on systematic or ad-lib intake.

1.3 Structure of the thesis

This thesis is written following thesis guidelines provided for students enrolled in the MSc Nutrition and Dietetics programme and is divided into four chapters with the addition of appendices and references. Chapter 1 will introduce the key concepts of this thesis, its aims and objectives and the significance of this study. Chapter 2 is a critical review of the current literature on the background of sugar, how sugar links with obesity, an introduction to gymnema

sylvestre, and strategies that have been used to reduce sugar intake. Chapter 3 will be presented as a manuscript of the data collected as part of this thesis. The manuscript will contain an abstract, introduction, methods, results, discussion and conclusion. The manuscript has been formatted for Nutrients, a peer-reviewed, open-access journal of human nutrition published online by MDPI. Chapter 4 provides the conclusion of the thesis. This chapter will contain the strengths and weaknesses and present the findings of this thesis and any recommendations for future studies that look at gymnema sylvestre-containing mints.

Table 1.1 Researchers' contributions

David Hsiao, Masters student.	Thesis author
Prof Ajmol Ali	Main supervisor
Prof Rozanne Kruger	Thesis co-supervisor
Imogen Nelson, Masters student.	Data collection partner
Sophie Turner	Thesis supporter
Prof Eric Stice	Thesis supporter
Dr Hajar Mazahery	Thesis statistic supporter
Dr Charles Diako	Thesis sensory testing supporter

Chapter 2 Literature Review

2.1 introduction

Many foods and drinks contain sugar. In 2005 the average New Zealander consumed over 158 g (equivalent to 31.6 teaspoons) of sugar per day, which is four times the suggested daily quota of 40 g (equivalent to eight teaspoons; World Health Organisation, 2015). High sugar intake has been shown to have adverse health effects such as obesity, diabetes, high blood pressure, heart related conditions, and poor oral health (Hu & Malik, 2010; Kaplowitz, 2011). Diabetes occurs when the body is unable to utilise and store glucose, and T2DM is prevalent with individuals who have obesity and is related to insulin resistance (Goyal & Jialal, 2022). Individuals who regularly indulge in sugar are at risk of insulin resistanace, weight gain and glucose intolerance (Hu & Malik, 2010).

‘Sweet tooth’ is a colloquial term that refers to an individual with intense sweet preferences or cravings. The scientific reasoning for sweet tooth is complex and there is no clear answer on why individuals prefer sweet things. It is speculated that genetics, nutrition, and psychology play a part in determining a sweet tooth (Reed & McDaniel, 2006). Gymnema sylvestre (GS) is a slow-growing native plant to India and parts of Africa (Anjum & Hasan, 2013; Schroeder & Flannery-Schroeder, 2005). When GS is ingested, the plant provides a bitter taste (Anjum & Hasan, 2013; Schroeder & Flannery-Schroeder, 2005). Gymnema sylvestre is a potent herb used in Ayurvedic medicine and given the name Gurmar 'sugar destroyer' thanks to its ability to block sweetness in foods (Schroeder & Flannery-Schroeder, 2005; Anjum & Hasan, 2013). The GS plant has been utilised for a number of ailments ranging from, obesity (Anjum & Hasan, 2013; Devangan et al., 2021), metabolic syndrome (Anjum & Hasan, 2013; Tiwari et al., 2014) and diabetes (Kanetkar et al., 2007). Furthermore, its versatility extends to treat snake bites and malaria (Anjum & Hasan, 2013; Tiwari et al., 2014). However, the primary use of GS is the ability to supress the taste of sugar; thus making it a promising tool for sugar reduction

Gymnema sylvestre is a taste modulator and prevents sucrose and other sweets from triggering the tongue's sweet receptors, making it difficult to taste and detect sugar. This mechanism is short-term and reversible (Schroeder & Flannery-Schroeder, 2005). Research on the effects of GS on sugar intake has shown promising results, particularly a significant reduction in their

desire for sweet food compared to those who received the placebo (Turner et al., 2022, Turner et al., 2020, Nobel et al., 2017 Stice et al., 2017).

This literature review aims to gather information about sugar and why people may have a ‘sweet tooth’ (people who have a high affinity and preference for sweets). This review will elaborate on the background of taste mechanisms and the reasons for sweet preference, with the main focus on methods that can potentially reduce sugar intake. In particular, the background and uses of Gymnema sylvestre to combat excessive sugar intake will be explored. Literature was searched using Massey library database, Google Scholar and Pubmed were used to conduct literature searches. The search criteria: (Sugar OR Sucrose OR Glucose) AND (Reduc* OR Substi*) AND (strateg* OR method*) AND (Gymnema Sylvestre OR Gymnemic acid) AND (history OR Background) AND (use*) AND (Sweet* tast*) AND (Recept*). For “sweet tooth” the following search terms were used (Sweet*) AND (Preferenc*) AND (suga*) AND (Consumption) AND (Habits). Filters Past: 5 years, past 10 years, past 15 years. In order to search the databases, keywords and keyword combinations were found in the free text, article titles, and abstracts. Additionally, references from relevant articles were further examined.

2.2 What is sugar?

Sugars are classed as carbohydrates and are readily available in our diet. Common sugars include glucose, sucrose and fructose. Table sugar (sucrose) is a disaccharide composed of glucose and fructose monosaccharides. Complex carbohydrates contain multiple sugar molecules strung together in a long complex chain and are known as starches and fibre, which are usually found in whole grains and vegetables (Puddu & Menotti, 2021). Ultimately simple and complex carbohydrates provide the same function, which is to be turned into glucose to be used as fuel and converted into glycogen for later utilisation; glucose is safe to eat and poses no immediate threat when ingested (Puddu & Menotti, 2021).

There are two types of sugar classifications namely intrinsic sugars, which are naturally found in foods, e.g., fruits, and extrinsic sugars, which are added sugars, e.g., lollies (Tasevska et al., 2009). Sugars are naturally occurring substances and can come in granules and syrups like honey or tree sap, e.g., maple syrup. Sugars may also be ‘hidden’ in processed foods such as cakes, cookies, ready-to-eat desserts, juices and carbonated drinks (Harshman et al., 2019). Added sugar in processed foods makes them more appealing and helps preserve certain foods (jams and jellies). Any processed foods will increase the number of dietary sugars consumed;

processed foods contain higher sugar concentrations, such as fructose and sucrose (Harshman et al., 2019).

Sugar-sweetened beverages (SSB) are a common source of extrinsic sugar in the average New Zealand diet (NZ Nutrition Foundation, 2018). Carbonated water was created as a means of safe drinking water i.e., the carbonation and acidity killed potential pathogens in the water. Carbonated water flavouring became popular in the past few decades and was produced by the food industry (Michael Goran et al., 2014). Energy obtained from sugar-sweetened beverages may induce less satiety than from solid foods (Pan & Hu, 2011). The quick passage of liquids through the stomach and intestines will lessen the stimulation of satiety signals (Pan & Hu, 2011). Higher intakes of free sugars are considered hazardous to dietary nutritional quality since they provide considerable energy without specific nutrients.

2.3 Strategies to reduce sugar consumption

Excessive sugar consumption has detrimental health consequences (Hu & Malik, 2010). Therefore, individuals have utilised various methods, including sugar reduction without replacement and sugar reduction with replacement, to assist them in cutting back on their sugar intake to minimise health consequences like T2DM (Hu & Malik, 2010). Sugar reduction without replacement is when sugar is reduced in food products; examples include reducing the sugar in baked goods and replacing the sugar with extracts to improve and enhance cooking flavours. Also, adding fresh fruit as an alternative to added sugar in cereals, oats, and porridge (Warshaw & Edelman, 2021). The sugar-reduction-with-replacement method replaces sugar with non-nutritive sweeteners. Often, a high-intensity sweetener is mixed with a low-intensity bulking agent, such as aspartame and sugar alcohol (Deis & Kearsley, 2012).

Weber-Fechner's law states that different thresholds are a constant percentage of stimulus intensity (Watt, 1988). Therefore, estimating the gradual sequential sugar decreases that can be performed without the consumer's knowledge may be possible by using different thresholds for individual products with a given sugar concentration (Oliveira et al., 2016). Lima et al. (2019) explored two methods (stepwise and gradual) of reducing sugar in fruit drinks for children. The stepwise method used a significant decrease in sugar fruit drinks, whereas the gradual method gradually declined in sugar content. Lima et al. (2019) hypothesised that children exposed to lower-sugar-content juices would become accustomed to them and prefer the lower sugar

content. However, when the same children were given fruit drinks with higher sugar content, their expectations were unmet, and their fondness for high sugar increased.

A study by Torrico et al. (2020) used full-fat milk and strawberries to create yoghurt. Each yoghurt sample had a different amount of sucrose, which ranged from 0% to 58.33% sucrose reduction. Any sugar reduction in yoghurt samples will affect the acceptability and characteristics. The potential for lowering sugar content in food products has been explored by Lima et al. (2019) and Torrico at el. (2020). Lower sugar content is viable, but reduction in sugar may affect the characteristics and palatability of food items. The ideal range where yoghurt samples were accepted ranged from 5-8% reduction. Nectars, yoghurts and fruit juices were among popular items examined (Torrico at el., 2020; Oliveira et al., 2016; Oliveira et al., 2018). These studies demonstrated that such small reductions could be accomplished without negatively affecting consumers' sensory experience with these products. Overall, a 5-8% decrease of sugar in foods may not be enough to reduce an individual’s overall sugar intake, and manufacturers may not risk a greater reduction at the cost of product quality.

2.3.1 Sugar replacement method

The replacement method preserves sweetness while lowering energy levels by replacing sugar with non-nutritive sweeteners. Non-nutritive sweetener (NNS) molecules are similar to sugar molecules, where NNS can fit into sweet receptors and trigger a sweet taste response but provide less or no energy (Drewnowski et al., 2012). Children have a high affinity for sweets and using a low-calorie sweetener could lower children's energy levels when consuming sweet products (Drewnowski et al., 2012). However, using low-calorie sweeteners has raised additional concern that separating sweetness from energy may disturb the equilibrium between taste response, hunger, and consumption habits, particularly during growth and development (Drewnowski et al., 2012).

Although a diet incorporating sugar reduction strategies (reduction with and without replacement) has effectively decreased sugar consumption during the week, regardless of whether sugar was restricted or not, the diet throughout the weekend was compromised with a higher intake of sugar (Czlapka-Matyasik et al., 2018). To maintain a healthy diet, it may be helpful to further limit the sugar intake during the week and the weekend (Czlapka-Matyasik et al., 2018). Therefore, although NNS can potentially reduce sugar intake in adults and children,

this may disrupt the equilibrium between eating and hunger cues, and so needs to be treated with caution.

2.3.2 Non-nutritive sweeteners

Intense, NNS can play a role in the diet by supplying sweetness without calories (Sadler & Stowell, 2012). Non-nutritive sweeteners provide less energy than sugar which can potentially reduce energy intake, and NNS are marketed and valued as a calorie free alternative (Sadler & Stowell, 2012). In contrast, some sugar alcohols and rare sugar (sugars that are not found in large quantities in nature, such as aspartame) have fewer calories per gram, ranging from 0.2 to 2.4 kcal/g, so small that it is effectively non-caloric, as opposed to 4 kcal/g for sucrose (de la Hunty et al., 2006; McKenzie & Lee., 2022). Sugar reduction with replacement has proven effective in reducing calorie intake and addressing the growing concern about excessive sugar consumption (Fakhouri et al., 2012).

Although sweeteners can help with reducing sugar intake, there are limitations with its use. Most sweeteners do not have the same properties as sugar; for example, using sweeteners in baked goods can produce textures and tastes that are not desirable (Zacharis, 2012). In addition, overconsumption of some sweeteners can cause laxative and gastrointestinal side effects (Deis & Kearsley, 2012; Zacharis, 2012). Sweeteners have shown a mixed result in sugar related cravings in the short term (Szalavitz, 2006). Individuals who are likely to use NNS are more likely to be overweight than non-users because the individuals using the sugar substitutes want to lose weight (Szalavitz, 2006).

De la Hunty et al. (2006) reviewed studies about aspartame consumption's potential impact on maintaining or losing weight. In particular their findings suggest that when compared to food or beverages sweetened with sucrose those utilizing aspartame had a demonstrable effect on decreasing energy consumption while also contributing to lowered body mass for healthy adults.

The study's findings showed consistency and participants had an overall 0.2 kg of weight loss rate per week. Using aspartame-sweetened beverages instead of those sweetened with sucrose is an efficient strategy to maintain weight loss without compromising the taste of the diet (de la Hunty et al., 2006). The reduction in energy consumption and the speed of weight loss of aspartame's impact on weight management is minimal but significant and reasonably achievable (de la Hunty et al., 2006). De la Hunty et al. (2006) concluded that all studies took

place over short term, and studies that were not randomised controlled trials in healthy adults and did not measure energy intakes for at least 24 hours were excluded. The deployment of NNS has yielded promising outcomes, however, there are concerns regarding its impact on the microbiome have emerged. Suez et al. (2014) detected that rodents (transplanted with human microbiome) administered with NNS (saccharin, aspartame and sucralose) exhibited a distorted microbiome, which was associated with metabolic syndrome and diabetes. The popularity of artificial sweeteners has soared as a low-calorie substitute for sweetness; however, the study mentioned above unveil the absence of pliability in other food products and the potential damage to the microbiome. Therefore, additional research is required to understand the possible long-term repercussions on health. After discussing artificial sweeteners and their potential drawbacks, it may be beneficial to introduce Gymnema sylvestre, a natural option for reducing sugar intake and a possible alternative to NNS and the potential health risks NNS has.

2.4. Gymnema Sylvestre

2.4.1 Gymnema sylvestre and taste receptors

Taste buds are peripheral gustatory organs that are mostly found on the epithelium cells of the tongue, as well as other areas in the oral cavity (throat, the roof of the mouth and oesophagus (Roper & Chaudhari, 2017). The bumps on the tongue are papillae, and each papillae contain hundreds of taste buds that are used to detect gustatory chemicals (Rohland, 2017). Humans have four types of papillae: fungiform, foliate, circumvallate and filiform. Fungiform, foliate and circumvallate are taste buds that can detect taste, whereas the filiform papillae sense touch and temperature (Gravina et al., 2013). Gymnema sylvestre acts on the absorptive surface of the taste buds in the mouth cavity and intestines. The gut's tissue that absorbs sugar has a structure comparable to the taste buds that sense sugar in the mouth (Anjum & Hasan, 2013). Taste sensations are divided up into five distinct areas on the tongue: sweet, salty, umami, bitter, and sour (Dalesio et al., 2018). Salty and sour uses ion channels, and bitter, sweet and umami use G-protein coupled receptors. Sweet and umami receptor proteins are TAS1R, whereas bitter receptor proteins are TAS2R (Dalesio et al., 2018). Detection is crucial in recognising nutrients and avoiding potential hazards (Roper & Chaudhari, 2017). Gymnema-saponins are triterpene saponins also known as gymnemic acids (GA; Kanetkar et al., 2007; Anjum & Hasan, 2013; Tiwari et al., 2014). Gymnemic acid is the active compound found in GS and it is the phytoconstituents in plants that can reduce the appetite for sweets (Kanetkar et al., 2007; Anjum & Hasan, 2013; Tiwari et al., 2014). The GA molecules fill the receptor locations on

the taste buds for a period of thirty minutes to an hour, preventing the taste buds from being activated by any sugar molecules present in the food (Anjum & Hasan, 2013; Tiwari et al., 2014; Turner et al., 2022).

Taste is a sense dedicated to the interaction between animals and their food. Taste perception starts with food chemical compounds binding to taste receptor cells in the papillae, where the nerve fibres transfer gustatory information to the brain (Sjöstrand et al., 2021). Steiner (1974) suggests a relationship between bitter taste, which causes intrinsic aversion in neonates, and harmful chemicals in plants, such as alkaloids. On the other hand, sweet taste is naturally pleasurable and linked to dietary energy levels (Gravina et al., 2013; Breslin & Spector, 2008). The presence of minerals is indicated by a salty taste, which is vital for land animals that lose minerals through perspiration and excretion and must maintain body mineral balance (Lindemann, 1996). Tastes provides essential information for avoiding dangerous foods and helps identify food that organisms need (Lindemann, 1996). It is in innate human nature to want sweet tastes as it directly links to dietary energy (Breslin & Spector, 2008; Gravina et al., 2013).

2.4.2 Sweet taste detection and gymnemic acid

The chemical compositions of foods and beverages are identified through G-protein coupled receptors and ion channels (GPCRs). One of the most hedonically enjoyable senses is the sweet taste, utilised to detect high-energy food organisms should consume (Gravina et al., 2013). Usually, these are carbohydrates, sources of energy often associated with sweetness; sweet foods provide us with essential minerals, vitamins and energy that the human body needs to survive (Ventura & Mennella, 2011). Several GPCRs are involved in the perception of sweet tastes. Sweet taste perception is complex and involves a multitude of GPCRs. T1R2 and T1R3 receptors reside within the sweet-sensitive type 2 taste cells (Gravina et al., 2013). When sugar molecules bind to these GPCRs, the proteins undergo a shape-shifting metamorphosis, unleashing a flurry of activity within the alpha, beta, and gamma subunits of an intracellular heterotrimeric G-protein (Gravina et al., 2013). This molecular cascade can trigger a variety of downstream pathways, such as activating phospholipase beta 3, regulating phosphodiesterase, or even calling upon the mighty AC/guanylyl cyclase duo to mobilize calcium stores from the endoplasmic reticulum (Gravina et al., 2013). Molecules with similar structures can act as inhibitors on the site that blocks or slows down activation. All sweet-tasting molecules, including carbohydrates and non-caloric sweeteners, are detected by activating this single receptor. The

ability to detect sweetness plays a crucial role in sweet preferences, which can help formulate strategies to reduce sugar intake.

Gymnemic acids have a cascade of actions that contribute to their hypoglycaemic effect, beginning with the modification of incretin activity, which causes insulin secretion and release. Additionally, it promotes pancreatic islet cell regeneration for improved enzyme-mediated glucose uptake (Tiwari et al., 2014). Glyceraldehyde-3-phosphate dehydrogenase is a crucial enzyme to the glycolysis biochemical pathway. Gymnemic acids inhibits the activity of G3P dehydrogenase, which will stop the glycolysis pathway and prevents glucose being converted to energy (Ishijima et al., 2008; Tiwari et al., 2014). In an animal study, GA caused hypoglycaemia, further supporting the effects it has on incretin activity (Kanetkar et al., 2007).

Gymnemic acids also affects sweetness perception of artificial sweeteners via inhibition. Five sweeteners were used by Frank et al. (1992) to determine if GA could affect NNS. The sweeteners were acesulfame K, aspartame, sodium cyclamate, stevioside and xylitol. Gymnema sylvestre tea solution and a placebo commercial tea was used. All artificial sweeteners showed a reduction in sweetness rating whereas the commercial tea did not reduce any sweetness apart from stevioside. The datum from this study support GA's sweetness inhibition mechanism even with artificial sweeteners, meaning that NNS sweetness can also be inhibited.

2.4.3 Gymnema sylvestre-containing mint studies

It is important to note that there are limited studies on GS-mint intervention use (Table 1). Current research indicates that supplementing GS-mint reduced desire, pleasantness and intake of confectionary (Stice et al., 2018; Nobel et al.,2018; Turner et al., 2020; Turner et al., 2022). Stice et al. (2018) showed a 44% reduction in total confectionary intake and a significant reduction in desire to eat another confectionary. Nobel et al. (2017) showed a significant reduced desire for high-sugar foods (HSF) following GS-mint intake. Turner et al. (2020) showed that after GS-mint supplementation there was a reduced intake of chocolate, desire for another confectionary, and pleasantness ratings; participants who self-identified as a 'sweet tooth' showed a greater reduction in these ratings compared to those without a sweet tooth. The GS-mint significantly reduced the number of chocolates eaten versus placebo. The results from Turner et al. (2022) showed a decrease in desire and pleasantness compared to the placebo

when GS-mint was supplemented. All studies except Turner et al 2022 was used in an acute laboratory setting. Turner et al. 2022 was the first to investigate the effect of longer-term GS use outside of a laboratory setting, and chronic use and acute use showed similar findings. However, as there is only one study conducted in a chronic setting, further research is needed to support these findings.

Stice et al. (2017) used a randomised between-subjects, placebo-controlled design involving 67 participants over one visit. Participants were randomised into two groups (intervention and control) and were given a placebo or GS mint. Participants in Stice et al. (2017) did not consume both the active mint and the placebo mint, therefore baseline comparison and control for individual differences may affect the results. Nobel et al. (2017) included two visits in their study (washout period of 7 days) and demonstrated a significant reduced desire for high-sugar foods (HSF) following GS intake. This study only investigated acute use of GS-mints in a laboratory setting and had inconsistent sugar content in confectionaries, which does not allow for a comparison against baseline. Turner et al (2022) used multiple statistical programmes which may have affected the consistency of data handling, which can increase risk of error. Turner et al (2022) had a systematic approach asking participants to take GS-mint thrice daily. However, a systematic approach does not mimic real world settings where individuals may want to consume the GS-mints in a less constrained way.

Considering the insufficient results on chronic use of GS-mints and limitations of previous studies, future research should investigate short and long-term use to confirm whether the GS-mint has an acute and/or chronic effect.

Table 2.1 Summary of studies investigating the effect of gymnema sylvestre-containing mints on sugar intake

Study	Study design	Methods and Sample	Results	Limitations and Strengths
Stice et al., 2017	-Randomised between-subjects placebo-controlled experiment	n=67 -Targeted participants with a sweet tooth, measured over one visit -Pleasantness, desire and hunger was measured -One laboratory visit with a sensory testing and questionnaire	-GS-mint supplementation showed a 44% decrease in overall candy consumption -The GS mint reduced candy consumption and desire for candy immediately after supplementation -GS-mint might have a cumulative reduction in desire for high sugar foods -GS-mint reduced candy pleasantness ratings (novel finding)	**Limitations** - Participants did not taste both placebo and GS containing mints -Acute / short term use of GS-mints -Confectionaries' sugar content was not equal **Strengths** -Strong sample size -In-depth participant screening -Controlled timing of candy consumption
Nobel et al., 2017	-Placebo controlled double blind, randomised	n=44 -14 day intervention with a	-GS containing lozenges significantly reduced the desire for high sugar food	**Limitations** -No carbohydrate measures

Study	Study design	Methods and Sample	Results	Limitations and Strengths
	crossover study. -Tested the effectiveness of GS-mint in reducing desire for high sugar foods	1 week washout between each visit, 2 visits in total. -Pleasantness, desire and hunger was measured -Two visits with a seven day wash out period	consumption. -Desire rating for a second confectionary immediately after GS-mint supplementation resulted in a significantly reduced desire compared to placebo -Pleasantness rating after GS-mint was significantly reduced	on confectionaries and no measures of a standard serves -Participants did not self-identify as a sweet tooth. -Acute/short term use of GS-mints **Strengths** -Two laboratory visits -Controlled timing candy consumption -Followed a standardised procedure
Turner et al., 2020	-Single-blind, crossover design comparing the outcome of a placebo mint against	n=56 -Two visits seven days apart.	- Overall chocolate bars decreased -Desire to eat more of the high-sugar sweet food	**Limitations** -Did not mention sweet consumption habits -Acute/short term use of GS-

Study	Study design	Methods and Sample	Results	Limitations and Strengths
	a mint containing 4mg of Gymnemic acid	-Questionnaire and sensory test -Self-reporting of sweet tooth -Pleasantness, desire and hunger was measured -Two visits: placebo at first visit and active mint at second visit	decreased -Pleasantness of the high-sugar sweet food reduced after GS mint intake. -Self-identified 'sweet tooth' had a greater reduction in the pleasantness and desire -Consuming GS-containing mints compared to placebo	mint -Male participants were under-represented -Participants continued to consume sweets even though they rated pleasantness lower, which may have been due to 'curiosity factors' -Limited to two visits **Strengths** -Large sample size -Adjusted for confounding variables (age, sex)

Study	Study design	Methods and Sample	Results	Limitations and Strengths
Turner et al., 2022	-Double-blind, RCT -Systematic intake of GS-mints	n= 58 -Questionnaires and sensory testing, -Two visits, visit 1 and 2 were 14 days apart, with chronic use of mints thrice daily. -Included self-reporting of sweet tooth -Pleasantness, desire and hunger was measured	-Consumption of GS-mint reduced amount of chocolate bars and pleasantness -Participants in control group reduced chocolate consumption, pleasantness and desire for further servings on day 15 -The consumption of GS mints within a behaviour modification programme was most effective in those with a sweet tooth	**Limitations** -Male participants were under-represented -Did not mention sweet consumption habits -Multiple statistical programmes were used -Prebiotic sachet and healthy eating guide may have confounded the results **Strengths** -Chronic GS-mint use outside of a laboratory setting -Adequate sample size

2.5. What is a sweet tooth and how is it assessed?

2.5.1 Sweet preference and neurochemistry responses

Humans have a high affinity for the taste of sugar and have an innate preference for sugar. Glucose (monosaccharide) is the fuel source for the brain and provides a pleasant taste (Levine et al., 2003; Reed & McDaniel, 2006). The word ‘sweet’ is used to describe a variety of desirable or pleasurable experiences in addition to this fundamental taste characteristic (Reed & McDaniel, 2006). Even while sweetened meals and sugar are frequently among the top choices, not everyone enjoys sugar, especially in high doses (Reed & McDaniel, 2006). Sweetness sensitivity decreases with age which may increase or decrease sugar enjoyment (Hwang et al., 2015).

Having a ‘sweet tooth’ is defined as a fondness or craving for sweet food (Hwang et al., 2015). Some individuals may taste sweetness stronger, and some may taste it weaker depending on genetics (Hwang et al., 2015). If a person has a ‘softer’ sweet taste, that individual can tolerate and handle sugar at a higher amount and potentially consume more sugar (Hwang et al., 2015). The softer the sweet taste means that a higher amount of sugar is needed to satisfy the ‘craving’ (Hwang et al., 2015). Compared to adults, children are found to have a greater affinity for sweet foods; children's fondness for all things sweet results from their innate physiological basic nature, not just modern-day technology and advertising (Vennerød et al, 2017; Ventura & Mennella, 2011). A possible reason for sweet tooth development is the innate preference for sweet foods and the repeated exposure of these sweet foods which causes a typical preference for sweet foods (Cooke, 2007). Also, a repeated exposure of fruit at a younger age can lead to reduced added sugar consumption (Vennerød et al., 2017).

Nowadays, sugar has been refined and processed to form white crystals and sugar canes are crushed and drained of all their liquid, and all the vitamins and other substances are stripped away. The refinement process is like other illicit substances such as cocaine from the coca leaf, opium from poppy seeds and cyanide from apple seeds (DiNicolantonio et al., 2018). The sugar refinement process may cause overstimulation of neurochemistry and trigger addictive-like responses (DiNicolantonio et al., 2018). Evidence shows that there are similarities in neurochemistry responses to drugs and food. Sugar has shown enough symptoms to be classified as an addictive substance, symptoms include bingeing, seeking, withdrawal, cross-

dependence, reward and opioid effects (DiNicolantonio et al., 2018). The cause may be the hyperactivation of the reward system when sugar is consumed (Stoeckel et al., 2008). When food was limited, hyperresponsivity of this brain mechanism may have been acceptable and adaptive, but in today's environment, it may cause challenges with intake management (Stoeckel et al., 2008).

2.5.2 Increased consumption of sugar and increased disease risk

Noncommunicable diseases (NCDs) are responsible for many deaths worldwide and often result from a combination of genetic, environmental and behavioural factors (World Health Organisation, 2022). Overweight and obesity are the major factors of NCDs. The prominent causes of obesity are overconsumption of dietary sugar and high-fat foods (Mojto et al., 2019). Fructose (monosaccharide) consumption has been linked to increased visceral adiposity, which has severe implications for T2DM risk (Hu & Malik, 2010). Fructose can increase serum uric acid levels by increasing the degradation of ATP to AMP, which is a uric acid precursor (Hu & Malik, 2010; Mojto et al., 2019; Puddu & Menotti, 2021). Excess serum uric acid may increase blood pressure and contribute to hypertension (Mazzali et al., 2010).

Carbonated SSB contain acids that can dissolve the enamel on teeth (Kaplowitz, 2011). The sugar in SSB is a food source for bacteria in the mouth. The by-product of bacteria metabolism of sugar can lower the saliva pH and produce an acidic environment in the mouth, which can demineralise enamel causing dental erosion (Kaplowitz, 2011).

There is no need for additional extrinsic sugars in the diet and lowering intake to 5% of total energy has been found to reduce the risks of glucose intolerance and metabolic disorders (DiNicolantonio et al., 2015). The total recommended intake / allowance of free sugar should be less than 10% of the total daily energy intake. If the average energy intake of an adult is 8700 kJ, this would translate to 870 kJ or 51.2 g of extrinsic sugar a day (Tasevska et al., 2009; World Health Organization, 2015). A 500 mL drink of kola contains ~53 g of extrinsic sugar, exceeding the recommended daily allowance of extrinsic sugar (Puddu & Menotti, 2021).

2.6 Summary

Sugar is added to many foods, and high sugar consumption has been associated with the development of NCDs. Many strategies have been implemented to reduce sugar consumption, with the most effective being reduction of intake by substitution. Due to its impact on taste-perception, GS-containing mints could be a new solution to combat the overconsumption of sugar. In conclusion, Gymnema sylvestre is a promising and natural tool for reducing sugar intake. Its ability to block the taste of sweetness in the mouth makes it an effective aid for people who want to reduce their sugar intake and improve their overall health. More studies are needed to investigate the chronic versus acute use of GS to reduce sugar intake. Further research is needed to fully understand the potential of GS as a natural remedy for sugar addiction and as a tool for improving overall health.

Chapter 3 Research study manuscript

The following chapter is presented as a manuscript prepared for Nutrients*, a peer-reviewed, open-access journal of human nutrition published online by MDPI.*

Title: The effects of a 14-day *Gymnema sylvestre* intervention to reduce sugar intake in people self-identifying with a sweet tooth.

Background: Gymnema sylvestre contains a chemical compound called gymnemic acid which can reversibly suppress sweet taste responses. *Objectives:* This study aimed to investigate whether supplementing Gymnema sylvestre (GS) can reduce sugar cravings, sweet food desire and consumption among adults that identify as high sweet food consumers ('sweet tooths'). Method: On day zero, 32 healthy participants underwent baseline sensory testing for sweet taste perception using the placebo mint (PLAC). Participants then went through the randomisation process into the two intervention groups. On day 15, participants underwent further sensory testing (with GS mint) before embarking on 14 days' supplementation using the GS mints following either a systematic (3 times/day at specified times; SYS) or ad libitum (up to 6 mints/day at times of their choosing; AD-LIB) regimen. On day 30, participants swapped over to the other trial (using the other regimen). On day 45, participants completed final questionnaires. At all visits participants completed questionnaires (food frequency questionnaire, beverage questionnaire and cravings questionnaire), anthropometric measures, and sensory testing. Sensory testing was not required for day 45. *Results*: AD-LIB reduced daily sugar-sweetened beverages (SSB) intake by 42% relative to PLAC ($p=0.015$). AD-LIB reduced overall sugar cravings by 28% relative to PLAC ($p=0.045$). AD-LIB and SYS reduced pleasantness ratings ($p<0.005$) and desire ($p=0.005$) for more chocolate. Conclusion: GS consumption using an ad libitum regimen reduced sugar cravings and changed sweet food desire and consumption in people identifying as sweet tooth.

Keywords: Sugar reduction; sensory evaluation; cravings questionnaire;

3.1 Introduction

Sugar intake is rising globally due to shifting dietary patterns, such as the increased availability of highly processed foods (Machado et al., 2020). Increased dietary sugar intake has been linked to obesity, diabetes, increased blood pressure, heart disease, stroke, and poor oral health (Hu & Malik, 2010; Kaplowitz, 2011; Ministry of Health, 2022; World Health Organisation, 2015). There have been strategies to reduce dietary sugar intake, such as reducing the amount of sugar in food products and replacing sugar with artificial sweeteners/ non-nutritive sweeteners (McKenzie & Lee, 2022). Non-nutritive sweeteners (NNS) are often used as sugar substitutes, as they provide sweetness, but without the energy, and are an effective tool in reducing energy intake and sugar intake (Sadler & Stowell,2012). Although NNS is a helpful tool, NNS is not equivalent to sugar in terms of taste and textures, and during processing NNS may provide unwanted tastes and textures that can affect overall enjoyment (Zacharis, 2012). Additionally, some studies suggest that sweeteners showed gastrointestinal distress including bloating and laxative effects (Deis & Kearsley, 2012; Zacharis, 2012). Although NNS can provide sweetness without the energy, some studies show mixed results in NNS causing increased sugar cravings (Szalavitz, 2006). Suez (2014) found that gut microbiomes that had regular NNS exposure showed the same microbiome associated with metabolic syndrome and diabetes. Overall, NNS may be seen as a healthier alternative to sugar, but they do come with potential health risks and side effects, and therefore an alternative method of reducing sugar intake should be considered.

Gymnema sylvestre (GS), also known as 'gurmar', the sugar destroyer, is a plant native to Asia with anti-sugar properties (Chattopadhyay, 1998). Gymnema sylvestre has been used in traditional Ayurveda practice to treat sugar-related illnesses such as diabetes (Chattopadhyay, 1998). The active compounds in GS are gymnemic acids (GA) which act on the absorptive surface of the intestine and the taste buds in the mouth cavity (Preuss et al. 2004; Anjum & Hasan, 2013; Tiwari et al, 2014). The gut's tissue that absorbs sugar has a structure comparable to the taste buds that sense sugar in the mouth (Preuss et al. 2004, Anjum & Hasan, 2013). The sweet taste suppression from GS intake is reversible and generally lasts 30-60 min (Turner et al., 2020). Several studies using formulated GS-containing products (e.g., mints, lozenges) found that supplementing GS-mints reduces pleasure, desire and total confectionary intake (Stice et al., 2017; Nobel et al., 2017; Turner et al., 2020, Turner et al., 2022).

Stice et al. (2017) found a 44% reduction in total candy intake (when compared to the placebo) using a GS-containing product in both acute and laboratory settings. The GS mint immediately reduced consumption of confectionary. Nobel et al. (2017) found a significant reduction in the desire for high-sugar foods once GS-mint was supplemented. They found that subjects who were given the GS-mint ate less candy, less often and their perceived pleasantness for their preferred confectionary was reduced. Overall, Nobel et al (2017) suggest that GS-mints can help reduce the intake of high sugar foods (HSF) by reducing their pleasantness and desire. Turner et al. (2020) found that participants consumed 21.3% fewer chocolate bars, reduced desire to eat more HSFs, as well as reduced pleasantness following GS mint intake. Moreover, participants who also reported as having a 'sweet tooth' showed a greater reduction in pleasantness and desire for another chocolate after GS-mint supplementation (Turner et al 2020). Turner et al., (2020) showed that consuming GS-mints significantly reduced the quantity of chocolates eaten. Stice et al. (2017), Nobel et al. (2017) and Turner et al. (2020) all conducted studies in a laboratory setting and over a short period of time and conducted acutely, with no trials longer than 7 days. Although, there are no studies that investigated chronic use of GS-mints, a longer-term intervention period can provide insight and a comprehensive understanding on whether GS-mints are an effective tool for reducing sugar intake.

Turner et al. (2022) examined the effects of consuming GS-containing mints thrice daily for 14 days and was the first study to investigate a slightly longer-term impact of GS-mint use outside of a laboratory setting. The intervention group consumed fewer chocolates at day zero than the control group, and the 14-day behavioural intervention reduced pleasantness and intake of chocolates (Turner et al., 2022). However, this study also provided a healthy eating guide and a water-soluble vitamin and fibre blend sachet as part of the intervention so the true effect of GS-mints may not be apparent.

'Sweet tooth' is a colloquial term that refers to an individual with an intense sweet preference or cravings (Reed & McDaniel, 2006). Sweet tooth can also be defined as a fondness or craving of sweet foods (Reed & McDaniel, 2006).The scientific reasoning for being a sweet tooth is complex and there is no clear answer why individuals prefer sweet things; variables like genetics, nutrition, culture and psychology all play a part in determining a sweet tooth (Reed & McDaniel, 2006)

A systematic approach of ingesting three mints daily for 14 days was used by Turner et al., (2022) in hopes to reduce overall total sugar intake. Participants were required to supplement

the mint at 'snack time' hours (between meals, i.e., mid-morning, mid-afternoon and post-supper), but some subjects (unpublished data) indicated they wanted to use mints at times they felt the cravings, therefore an ad-libitum method may be appropriate for these individuals. Ad libitum intake is an effective way for taking supplements. For example, Jakše et al. (2019) showed that plant-based supplements taken when participants felt the need to take them was effective in improving LDL cholesterol. Silagy et al., (2002) demonstrated that a nicotine patch, and another form of nicotine replacement, taken when participants wanted to use them was more effective than a systematic approach. An ad libitum schedule with behavioural treatment showed an abstinence towards smoking at a rate of 37% (Goldstein et al., 1989). Therefore, based on information from other behaviour-modification studies, it would seem likely that ad libitum, as opposed to a systematic approach to GS ingestion, may reduce sugar intake to a greater extent.

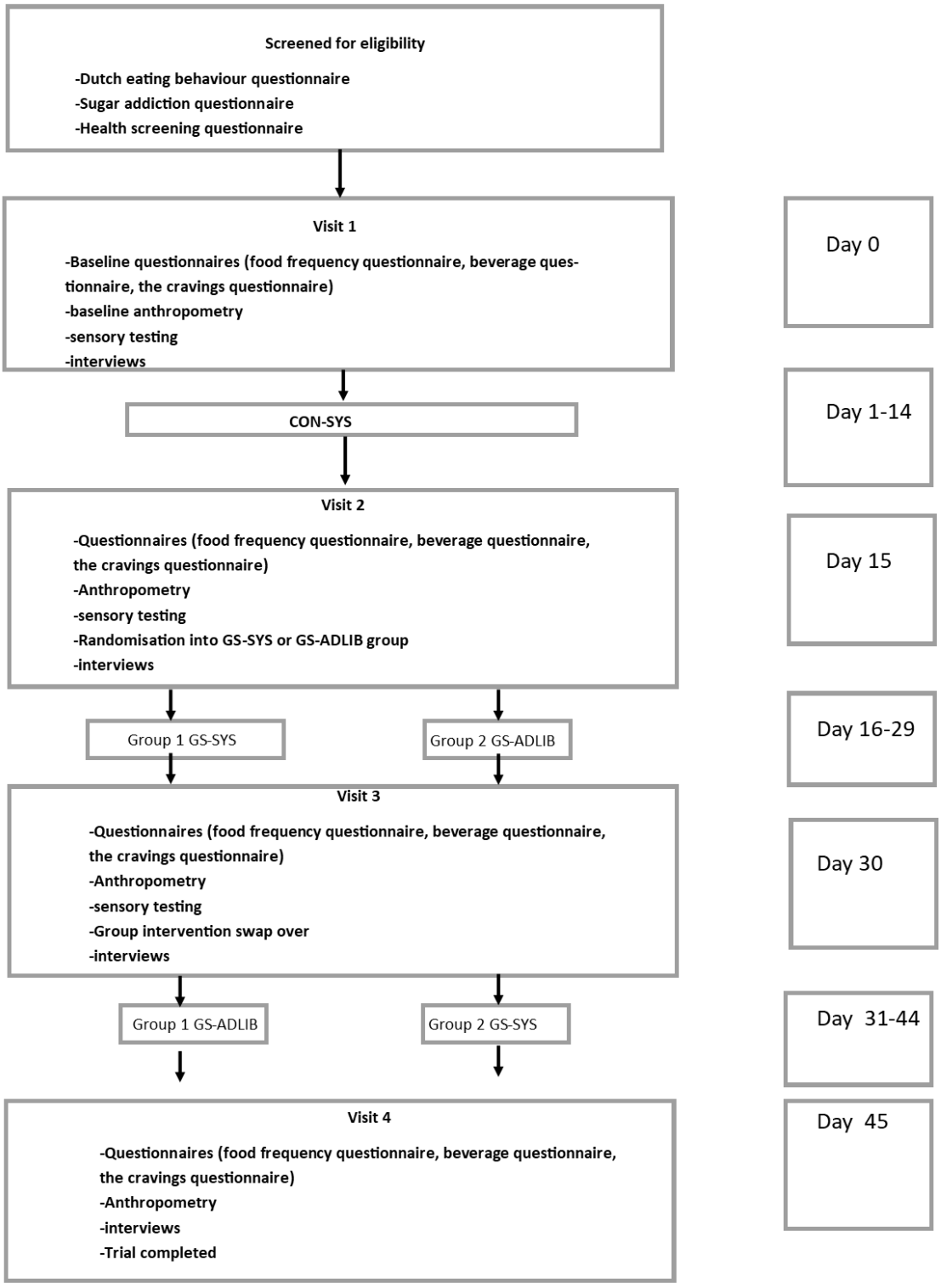
This study aims to investigate whether consuming a GS-containing mint by ad libitum or systematic regimes for 14 days can reduce intake, desire, cravings and preference for sweet foods in individuals with a sweet tooth.

3.2 Materials and Methods

3.2.1 Study design

This study used a randomised crossover design to examine the effects of a GS-mint supplementation using two methods of intake to reduce intake of sugar-containing foods and beverages and cravings and desire for these types of food. Participants came in for four visits approximately 1 h in duration 14 days apart. The 14-day programme consisted of a GS-mint or placebo-mint intake and sensory testing, and questionnaires at each visit (Figure 3.1). Participants completed a daily food diary but were only required to record anything they had eaten during the mints` activation period of 1 h. Participants in the SYS and AD-LIB group received the Gymnema-containing mints (GS mint; "Sweetkick"), and the PLAC group was given the isocaloric placebo; both mints were provided by Nu Brands Inc. (Los Angeles, CA, USA). Participants were told three different mints were trialled to avoid bias. Potential participants were invited to complete an online pre-screening questionnaire (Qualtrics, Provo, Utah) to establish if they met the inclusion criteria. Ethical approval for this study was granted by the Massey University Human Ethics Committee Southern A (SOA 22/21). The trial was

registered with the Australia New Zealand Clinical Trials Registry (ACTRN12622001023741). Participants provided written consent before taking part in the study.



Con-SYS (Control systematic), GS-SYS (Gymnema sylvestre containing systematic group), GS-ADLIB (Gymnema sylvestre containing Adlibitum group).

Figure 3.1 participant flow chart.

3.2.2 Participants

Participants who self-identified as having a sweet tooth, were in good health and between the ages of 18-60 years were invited to take part in the study. Participants were excluded if they did not identify as having a sweet tooth, currently smoking, pregnant, having a pacemaker, head trauma, undergoing any medical investigations and affected by Covid-19 and loss of senses from Covid-19. Screening for sweet tooth was undertaken using a combination of the Sugar Addiction (Fawzy & El-Deen, 2018) and the Dutch Eating Behaviour (Christopher , 2007) questionnaires. The Sugar Addiction Questionnaire was used to determine the level of 'addiction' and assess the level of sugar consumption. The Sugar Addiction Questionnaire is based on a scoring system, with a higher score indicating the likelihood of a sugar addiction (Fawzy & El-Deen, 2018). The Dutch Eating Behaviour (DEBQ) was used to assess eating behaviours and attitudes toward food. The DEBQ assesses different aspects, such as emotional eating, external eating and restrained eating, which can potentially influence a person's sugar intake. A total of 192 participants participated in the screening questionnaire, 82 participants were invited to the study and 32 responded back and accepted the invitation offer. Participant characteristics are presented in Table 3.1.

Table 3.1 Participant characteristics

Characteristics	
Age (years) #	27 (24.0-30.7)
Gender (n=32)	
Male (%)	5 (15.6%)
Female (%)	27 (84.4%)
Height (m) *	1.66 ± 0.87
Weight (kg) *	74.0 ± 17.3
Body fat mass (kg) #	21.9 (18.6-25.8)
Body fat (%) *	31.5 ± 10.4
BMI (kg/m^2) *	26.8 ± 4.93
Waist-to-hip ratio *	0.91 ± 0.56
Fat free mass (kg) #	49.1 (45.5-52.8)

** mean ± standard deviation, # geometric mean confidence interval 25th -75th*

3.2.3 Sensory testing

Sensory evaluation was carried out at each visit to the laboratory in individual booths; red lights were used to mask the colour of the mints. Participants first rated their hunger and desire levels 30 s prior to consuming their confectionary of choice (Maltesers, Mars Incorporated, Slough, UK; vegan jellies (The Natural Confectionary Co, Melbourne, Australia, 1940) and Whittaker's 33% milk chocolate (Whittaker's, Porirua, New Zealand)). Confectionary was standardised and contained the same amount of sugars. Data was collected using Compusense Cloud (Guelph, ON, Canada) sensory software via iPads (Apple inc., Cupertino, CA, USA). After consumption of the first confectionery, participants rated their pleasantness and their desire for further confectionary servings. After the mint had completely dissolved, participants rated their hunger and desire levels, a second compulsory serving was given and pleasantness and desire for more confectionary was rated again. Desire, hunger and pleasantness were assessed using a 100-point VAS. Desire for another confectionery was rated from *'No, not at all'* to *'Yes, very much'.* Hunger was rated from *'I am not hungry at all'* to *'I am extremely hungry',* and pleasantness ratings were rated from *'Not at all pleasant'* to *'Very much pleasant'*. After consumption of two pieces of confectionary, which was compulsory, the subsequent confectionaries were optional. Participants then had to indicate whether they would like another serving. If participants chose *'yes'*, the procedure mentioned above was repeated until participants chose *'no'*, which would end the sensory testing. This methodology followed the methods of Turner et al. (2020) and Turner et al. (2022).

3.2.4 Anthropometry

Subjects were asked to be at least 1-h fasted before anthropometry measurements; participants were allowed to drink water. At each visit fat-free mass, weight, percent body fat and muscle mass were measured using bioelectrical impedance analysis (BIA; In-Body 230 BIA, Biospace Co., Ltd., Seoul, Republic of Korean). Height was recorded with a stadiometer (single measure; Seka 213, Sweden).

3.2.5 Questionnaires

The food frequency questionnaire (FFQ) (Jayasinghe et al., 2017), was designed to record the number of sweet foods subjects consumed during the month (Jayasinghe et al., 2017). The FFQ

is a validated questionnaire that contains 69 sweet foods which includes natural and processed foods within various categories including fruits and vegetables, dairy products, cereals, biscuits, cakes, desserts, spreads and sauces; sweeteners and beverages. All items in the FFQ were scored for frequency of use: *never, less than once a month, 2–3 times per month, once per week, 2–4 times per week, 4–6 times per week, once a day, and twice or more a day*. The beverage questionnaire (BevQ; Hedrick et al., 2010), was designed to record the number of items and total amount of sweet beverages consumed, the questionnaire was validated for use in healthy adults. The BevQ contains 15 beverages which include diary, sugar-free, water, alcoholic, sports drinks, energy drinks, coffee and tea. The BevQ was scored for frequency of use: *never, less than once a week, 1 time per week, 2–3 times per week, 4–6 times per week, once a day, twice or more a day and thrice or more a day*.

The cravings questionnaire (TCQ; Meule, 2020a) consisted of 39 questions categorised in 9 groups that measure specific craving cues. The TCQ questionnaire was validated for use in healthy adults and in relation to eating disorders and psychological traits (Meule, 2020a). The TCQ was scored for frequency of use with responses: *Never/not applicable, rarely, sometimes, often, usually and always*. The responses were given a number value starting from 1 (never/not applicable) and ascending to 6 (always). Dutch Eating Behaviour (DEBQ) (Christopher, 2007), and Sugar addiction questionnaire (SAQ) (Fawzy et al., 2018). The DEBQ is reliable and has been validated for use in healthy adults. The DEBQ contains 33 questions on restrained eating, emotional eating, and external eating. The SAQ contains 20 questions on sugar addiction attributes. The questionnaires DEBQ and SAQ was a part of screening, the responses were given a number value no = 0, maybe/sometimes = 1, and yes = 2. All questionnaires were administered online via Qualtrics. The SAQ is validated and was tested by a panel of medical surgical nursing staff (Fawzy et al., 2018).

3.2.6 Data handling

BMI was calculated using the Quetelet index (weight (kg)/height $(m)^2$) and reported as a continous variable. The FFQ, TCQ, and BevQ was downloaded from Qualtrics as a spreadsheet (Excel, Microsoft Office 365, Redmond, WA, USA). FFQ and BevQ food and drink items were recorded as frequencies and were converted into g/day and BevQ items were converted into mL/day. Sensory data was recorded and stored online using Compusense Cloud (Guelph, ON, Canada).

3.2.7 Statistical analysis

Analysis was performed with Statistical Package for Social Sciences (SPSS) version 20 (SPSS Inc. Chicago, Illinois, US). Normality was tested using Shapiro-Wilk test, skewness and kurtosis, alongside Normal Q-Q box histograms. Normally distributed data was reported as mean and standard deviation (SD). If the data was not normally distributed, they were log transformed and normality was checked again. Geometric mean and 95% CI were used to report log transformed data. Non-normally distributed data were reported as median with 25^{th}-75^{th} percentiles. Repeated measures analysis, with intervention as the within-subjects variable and intervention order as between-subjects factor, was used to analyse the change in normally distributed data (body composition, servings of chocolate consumed, and food and beverage consumption). When an intervention order was identified, the data was stratified by intervention order and reanalysed using ANOVA repeated measures analysis. Non-parametric test Kendalls w was used to investigate the change in cravings over time, and the data was reported as rank. The change in hunger, pleasantness and desire was analysed using mixed effects longitudinal models. Intervention and confectionary number (1, 2,3, and up to 6) were included as fixed effects, participant was included as a random effect to account for the repeated measures within individuals, and intervention order as a between-subjects factor to investigate intervention order effect. Thus, interactions between intervention and confectionary number indicate differences in these outcomes after each confectionary consumed in response to intervention. All analyses were adjusted for age and sex. A *p* value less than 0.05 was considered statistically significant. Cohen (1988) indicates that a power of 0.1 indicates a small effect size, 0.3 a medium effect size and 0.8 a large effect size.

3.3 Results

3.3.1 Sensory testing

Figure 3.2 shows ratings of pleasantness after confectionary consumption. The first two points (x-axis) were compulsory, however after the first confectionary, any further confectionary eaten were optional. There was a main effect of treatment on ratings of pleasantness (p<0.001), with lower ratings for AD-LIB (30.9 ± 14 mm, p=0.001, 2.192 η^2) relative to PLAC (61.6 ± 24 mm).

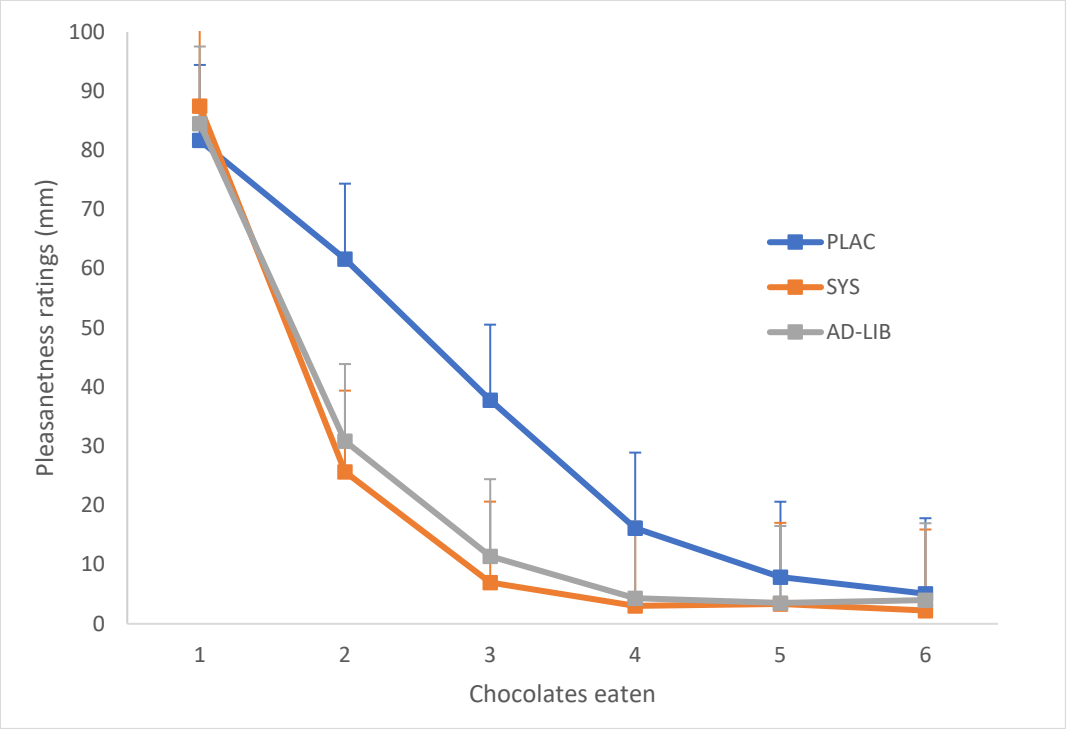


Figure 3.2 Interaction between pleasantness rating and number of confectionary eaten.

Placebo (PLAC), Systematic intervention (SYS), Adlibitum intervention (AD-LIB)

There was a main effect of desire for chocolate (p=0.018; Figure 3.3); AD-LIB (p=0.01) and SYS (p=0.001) was greater than PLAC. There was a main effect of treatment on ratings of desire (p<0.001) with lower ratings for AD-LIB (28 ± 26 mm, p=0.01, 0.65 η^2) relative to PLAC (44 mm ± 31).

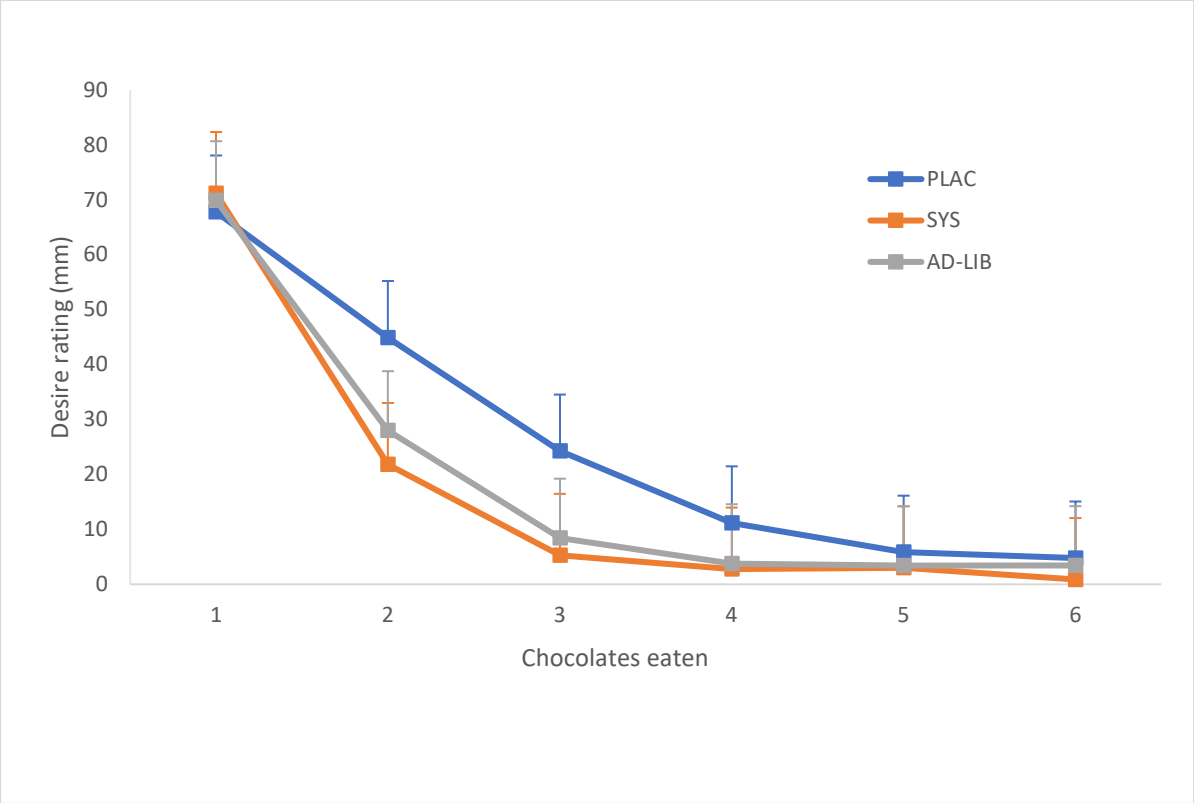


Figure 3.3 Interaction between desire rating and number confectionary eaten.

Placebo (PLAC), Systematic intervention (SYS), Adlibitum intervention (AD-LIB), Effect size η^2

There were no statistically significant differences between trials with regards hunger and number of confectionary eaten (p=0.25; Figure 3.4).

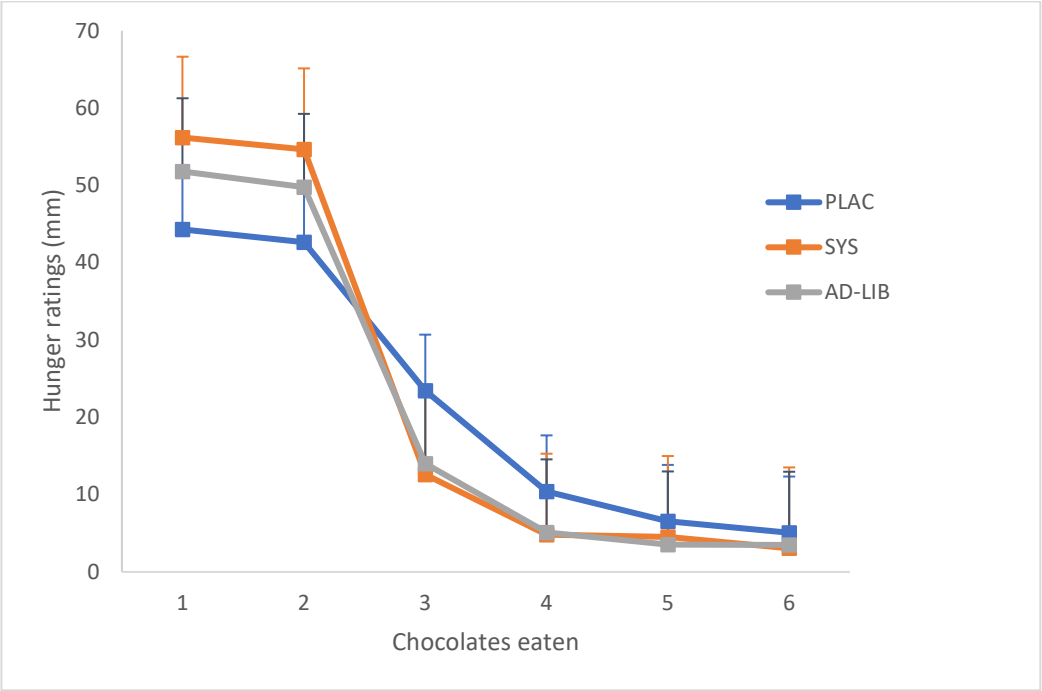


Figure 3.4 Interaction between hunger ratings and number of confectionary eaten

Placebo (PLAC), Systematic intervention (SYS), Adlibitum intervention (AD-LIB), Effect size η^2

3.3.2 Cravings

Table 3.2 shows the rank of total cravings score over each methodology period. There was an effect of treatment on total cravings score (p=0.006). There was also an effect on total cravings when AD-LIB was compared to baseline (p=0.045). There was no difference when AD-LIB was compared with SYS (p=0.095) and PLAC (p=0.450).

Table 3.2 Total cravings questionnaire score (n=32)

The Cravings Questionnaire	Baseline	PLAC (Placebo)	SYS (Systematic)	AD-LIB (Ad libitum)	*p*-value Friedman test	Kendall's w effect size
Total cravings score	2.92	2.70	2.44	1.94*	0.045	0.107

*Friedmans test, non-parametric on total cravings score, not adjusted for age or sex. *Significant effect against placebo.*

Table 3.3 shows the cravings questionnaire group 'lack of control and overeating'. There was a significant effect for AD-LIB (2.02, p=0.033), and SYS (2.59 p=0.039) for the question 'If I give in to a food craving, I keep thinking about eating until I actually eat the food' was compared to PLAC. Only AD-LIB showed a significant effect for the question 'If I eat what I am craving, I often lose control and eat too much' (2.02, *p*=0.033).

Table 3.3 The cravings questionnaire; Lack of control and overeating (n=32)

The cravings questionnaires 'lack of control and overeating'	Baseline	PLAC (Placebo)	SYS (Systematic)	AD-LIB (Ad libitum)	*p*-value Friedman test	Kendall's w effect size
When I crave something, I know I will not be able to stop eating once I start.	2.69	2.64	2.47	2.20	0.219	0.46
If I eat what I am craving, I often lose control and eat too much.	2.73	2.67	2.58	2.02* *p*=0.033 0.142[&]	0.025	0.98
When I eat what I crave I feel great.	2.78	2.42	2.44	2.36	0.339	0.035
I have no will power to resist my food crave.	2.83	2.38	2.59	2.20	0.101	0.065
Once I start eating, I have trouble stopping.	2.63	2.67	2.47	2.23	0.258	0.042
If I give in to a food craving, all control is lost	2.97	2.34	2.56* *p*=0.039 0.133[&]	2.13* *p*=0.007 0.232[&]	0.011	0.119

*Friedmans test, non-parametric on total cravings score, not adjusted for age or sex *Significant effect against placebo. [&] Partial eta Kendalls W*

Table 3.4 Shows the cravings questionnaire group 'anticipation of positive reinforcement that may result from eating', there was a significant effect for both SYS (2.45, *p*=0.012) and AD-LIB (2.07, *p*=0.003) when compared to PLAC for the question 'I eat to feel better'. Additionally AD-LIB also showed a significant effect for another question 'eating what I crave makes me feel better' (2.03, *p*=0.005).

Table 3.4 The Cravings Questionnaire; Anticipation of positive reinforcement that may result from eating (n=32)

The cravings questionnaire 'anticipation of positive reinforcement that may result from eating'	Baseline	PLAC (Placebo)	SYS (Systematic)	AD-LIB (Adlibitum)	*p*-value Friedman test	Kendall's w effect size
I eat to feel better	3.15	2.33	2.45* p=0.012 0.208[&]	2.07* p=0.003 0.300[&]	0.001	0.194
Sometimes, eating makes things seem just perfect.	2.53	2.56	2.60	2.31	0.654	0.017
Eating what I crave makes me feel better.	2.98	2.45	2.53	2.03* p=0.005 0.251[&]	0.005	0.132
When I eat what I crave I feel great.	2.78	2.42	2.44	2.36	0.339	0.035
When I eat I feel comforted	2.64	2.55	2.56	2.25	0.445	0.028

Friedmans test, non-parametric on total cravings score, not adjusted for age or sex [*]Significant effect against placebo. [&] Partial eta Kendalls W

Table 3.5 shows the craving questionnaire group 'cravings on physiological state', only AD-LIB showed a significant effect for questions 'Thinking about my favourite foods makes my mouth water' (2.06, *p*=0.033) and 'I crave foods when my stomach is empty' (1.91, *p*=0.002) when compared to PLAC.

Table 3.5 The Cravings Questionnaire; Cravings as a physiological state (n=32)

The Cravings Questionnaire; Cravings as a physiological state	Baseline	PLAC (Placebo)	SYS (Systematic)	AD-LIB (Adlibitum)	*p*- value Friedman test	Kendall's w effect size
Thinking about my favourite foods makes my mouth water.	2.67	2.66	2.61	2.06* p=0.033 0.142	0.056	0.079
I crave foods when my stomach is empty.	2.91	2.61	2.58	1.91* p=0.002 0.306[&]	0.001	0.162
Certain foods I feel as if my body asks me for certain foods.	2.56	2.85	2.48	2.10	0.037	0.091
I get so hungry that my stomach seems like a bottomless pit.	2.44	2.53	2.64	2.39	0.760	0.012

Friedmans test, non-parametric on total cravings score, not adjusted for age or sex [*]Significant effect against placebo. [&] Partial eta Kendalls W

3.3.3 Sugar intake from foods

Table 3.6 shows the average mL/day for SSB and g/day for SSF intake over each intervention period. There was a main effect on treatment for SSB intake (p=0.047), SSB intake had a 42% decrease after AD-LIB intervention (p=0.015). When AD-LIB was compared to baseline there was a 48% decrease of SSB intake (p=0.032). AD-LIB showed a 32% decrease when compared to SYS (p=0.007). There was no significant effect on SSF intake from both treatments (p>0.05).

Table 3.6 Total sugar consumption on different treatments

Sugar consumption	Baseline	PLAC (Placebo)	SYS (Systematic)	AD-LIB (Ad libitum)	p-value	p-value [@]	η^2
Sugar beverages* (mL/day from sugary foods)	410 (298-563)	363 (249-530)	314 (190-519)	212 (117-382)[#]	0.047	0.038	0.273
Sugar Foods* (g/day from sugary foods)	81.7 (66.7-100)	65.9 (54.2-80.1)	51.2 (41.8-62.9)	46.4 (37.5-57.6)	0.353	0.338	0.116

*Repeated measure analysis adjusted for age and sex, not adjusted for multiple comparison. [@]Intervention effect *Geometric mean (95% CI) η^2 Partial eta*

[#]Significantly different from placebo (p=0.015)

There was no effect of treatment on body composition (p>0.05; Table 3.7)

Table 3.7 Body composition against treatment order

Body composition	Baseline Day 0	PLAC (placebo)	Post SYS (systematic)	Post AD-LIB (ad libitum)	p- value[@]	p-treatment order effect[%]	η^2
Weight (kg)*	74.0 ± 17.3	73.9 ± 17.4	73.8 ± 17.1	73.7 ± 17.1	0.146	0.914	.184
Body fat mass (kg)*	24.27 ± 11.9	24.03 ±12.1	23.7 ± 11.9	23.5 ± 11.8	0.649	0.699	0.060
Body fat (%)[1]	29.9 (26.5-33.7)	29.9 (26.6-33.7)	29.5 (26.0-33.5)	29.4 (26.0-33.2)	0.500	0.426	0.085
BMI (kg/m^2)[1]	26.4 (24.8-28.1)	26.4 (24.7-28.1)	26.3 (24.8-28.1)	26.3 (24.7-28.0)	0.224	0.605	0.152
Waist-hip ratio [1]	0.91 (0.89-0.93)	0.91 (0.89-0.93)	0.91 (0.90-0.93)	0.91 (0.89-0.93)	0.424	0.212	0.100
Fat-free mass (kg)*	50.1 ± 10.6	49.9 ± 10.6	50.1 ± 10.6	50.1 ± 10.5	0.993	0.715	0.003

** mean ± standard deviation [#] Geometric mean confidence interval 25th -75th[@]Intervention effect [%]P-value treatment order which order of intervention was started first η^2 partial effect size eta, Repeated measure analysis adjusted for age and sex*

3.4. Discussion

We examined the effect of GS mint supplementation on the desire and pleasantness of sweet foods, hunger, and cravings, and whether an application of either ad libitum or systematic use would affect HSF intake. The primary findings of this study were: (1) a reduction in cravings from the AD-LIB intervention group compared to baseline and placebo; (2) a 70% decrease in desire for another chocolate after GS-mint when SYS was compared to PLAC and a 59% decrease when AD-LIB was compared to PLAC. There was a 71% decrease in pleasantness when SYS was compared to PLAC after GS-mint was consumed and a 64% decrease in pleasantness when AD-LIB was compared to PLAC. (3) GS-mints taken with the AD-LIB method reduced the daily intake of SSB by 42% relative to PLAC. And (4) there was a 28% decrease in overall cravings when AD-LIB was compared to PLAC.

A novel finding is that the AD-LIB intervention group had a 28.1% decrease in sugar-related cravings relative to PLAC. These findings are similar to other behaviour-modification studies that found an ad libitum intake of a plant-based diet showed a reduction in total LDL and non-HDL-cholesterol (Jakše et al., 2019), reduction in nicotine intake (Silagy et al., 2002) and an abstinence towards smoking (Goldstein et al., 1989).

The reduced consumption of confectionary servings following GS-mint intake in this study is consistent with previous findings (Nobel et al 2017., Stice et al 2018., Turner et al 2020., Turner et al., 2022). In addition, desire and pleasantness ratings were also reduced following GS-mint administration, which was also consistent with previous studies findings (Nobel et al 2017., Stice et al 2018., Turner et al 2020., Turner et al., 2022). A novel finding of this study is that treatment type (AD-LIB and SYS) showed no significant differences in servings, desire, hunger and pleasantness following sweet food intake. The GS-mints did not show any effect on hunger, which suggests that sweet food consumption is driven by pleasure rather than the physiological regulation of energy and satiety. Food cravings and hunger cues are distinct, but they can co-occur, and hunger can be relieved by eating any food, whereas cravings can only be satisfied by a specific food (Meule, 2020b). Although supplementing GS-mints may not affect hunger, in this study they did successfully affect cravings, especially the AD-LIB group which significantly reduced participants' craving ranks in the cravings questionnaire compared to SYS.

Increased SSB intake has shown a paralleled increase in global obesity prevalence (Hu & Malik 2010). A novel finding from this study is that there was a 42% reduction of SSB consumption in

AD-LIB administration of GS-mint relative to PLAC. Sugar-sweetened beverages consist largely of sugar which is also the major contributor to their taste and appeal. Due to GS specifically blocking sweet receptors (TS1R), it is posited that this meant the majority of flavour (and therefore palatability) from SSBs was negatively affected (Anjum & Hasan, 2013). Since AD-LIB GS administration significantly reduced intake and desire for SSBs, this suggests that this treatment could be beneficial outside the study for longer-term decreases in SSBs. Because SSBs are readily available and GS-mint poses a possible solution in reducing palatability.

Although both intervention methods (SYS and AD-LIB) showed decrease in SSF, this decrease was not statistically significant. One reason could be that SSF contains ingredients other than sugar which are unaffected by GA (i.e., GA only blocks sugar receptors). The SSF could still provide pleasurable tastes and sensations even if the sugar was not tasted (Turner et al., 2022). Multisensory experiences from foods such as smell, taste and fatty and smooth textures that coats the mouth can provide some sort of pleasurable sensations (Kringelbach et al., 2012).

The SYS group showed no statistical significance when compared to PLAC for both SSB and SSF consumption. Because of this we hypothesise that SYS administration of GS-mint may not be optimal in reducing sugar intake, simply because everyone has different schedules and eating habits. The AD-LIB administration may be more effective due to its flexibility and the fact that individuals can plan their intake around the consumption of the GS-mint, as indicated by our findings that AD-LIB GS-mint administration significantly reduced SSB intake. Systematic administration required only three mints to be taken a day at set hours of the day; however more than 3 mints may be needed to reduce overall sugar intake, and mints may be needed at different times. In addition, another reason the effect of SYS administered GS was not significant may be the fact that the GS-mints anti-sweet effect lasted for approximately 30 minutes. Participants may have waited until the mint was no longer active and then consumed SSB/SSF.

There was no significant effect of GS-mint, administered SYS or AD-LIB, on body composition, this finding is inconsistent with previous studies which have found supplementing GS reduced body fat over both a 6-week (Woodgate & Conquer 2003) and 8-week (Preuss et al., 2004) period. Due to the shorter intervention period of this study, body composition was not expected to change, however if a longer intervention period was to be conducted, we can hypothesise that the AD-LIB method may reduce body weight due to the significant reduction in sugar intake, cravings score and sensory testing aspects (desire and pleasantness). However, it should also be noted that the studies by Woodgate & Conquer (2003) and Preuss et al. (2004) did not assess the anti-sweet effect of GS and how this could indirectly affect body weight. Instead, they investigated whether

GS directly stimulates body fat loss; their findings indicate that GS may have potential longer-term benefits because of its direct effects on adiposity rather than its anti-sweet properties. However, further research that assess whether longer administration of GS affects body weight as a result of its anti-sweet properties is merited to confirm this.

This is the first study to investigate an AD-LIB administration of GS-mints. This study has shown that AD-LIB application decreased total SSB intake and total score of TCQ. Adlibitum-GS is a more practical and real-world approach for GS mint application. This may be because individuals have very different environmental settings and schedules. To fully optimise the use of the GS mints, the mints should be taken during any sweet cravings or before the individual is about to eat SSF. The SYS approach also reduced TCQ score and SSF/SSB, but without significance, therefore, the SYS method may not be enough to reduce overall sugar intake due to its strict parameters of 3 mints a day. Overall, AD-LIB has consistently performed better than PLAC and SYS. More research is needed to support AD-LIB GS-mint intake findings.

Limitations and future directions

Participants were given instructions on how to consume the mint (‘let the mint fully dissolve on your tongue and move the mint around to cover the whole surface area of the mouth’). However, we did not monitor participants when ingesting the mint. We encouraged the participant not to chew or swallow the mint and warned that the mint may not be as effective if this was done.

Following the consumption of the GS mint, several participants needed to follow the expected trend of reduced consumption of high-sugar sweet foods. Even though the same participants gave the high-sugar sweet food low pleasantness ratings, they ate more servings. We speculate that this is due to a 'curiosity factor,' as participants were unfamiliar with gymnema's sugar suppression effect and wanted to try it. We hypothesised that as participants became accustomed to the taste modulation, repeated exposure to this product would eliminate the 'curiosity factor.' Participants were told to record anything within the hour of the sweets. Participants may have ‘cheated’ this system and waited the full hour before eating sweets without needing to record intake. All participants in this study were self-identified sweet tooth, although there is no baseline standard for sweet tooth, meaning that the participants in this study may have different levels of a sweet tooth effect.

Participants may have reduced their sugar intake of HSF since they were informed that they would be taking part in a sugar reduction study designed for people with a sweet tooth. Participants may

have reduced their sugar intake without the taste-altering supplement simply because they were in a study that aimed to reduce sugar.

Future research should explore the effect of this intervention in people who have impaired glucose tolerance; GS has shown to have anti-diabetic properties (Anjum & Hasan, 2013). Further research is warranted for potential MRI screening to check responsivity in brain regions and whether GS use would induce changes (Stice et al., 2018). Future research should also look into a strict diet consumption, e.g. intermittent fasting, keto diet, with GS-mint supplementation, to understand if GS-mints can curb cravings whilst being on a strict consumption diet. More research should explore the AD-LIB method longer and monitor body weight changes and metabolic health.

3.5 Conclusion

This study aimed to examine the effect of a 14-day GS-mint supplementation intervention on desire, pleasantness, high sweet food intake and further to determine which method of GS use (AD-LIB, SYS) is optimal. Consumption of GS-mint reduced desire, pleasantness and frequency of confectionery. The AD-LIB consumption of GS-mints reduced overall cravings and intake of SSB. This study was the first to investigate different applications of GS-mints; however, a more extended intervention period is required, and more comprehensive studies to look into other methods of taking GS-mints.

Chapter 4: Conclusion and Recommendations

4.1 Study summary/main findings

This randomised cross-over study aimed to determine which of two Gymnema sylvestre (GS) mint interventions, ad libitum (AD-LIB) or systematic (SYS), would be most effective for lowering intake, cravings, desire for, and pleasantness of sugar-sweetened food (SSF) in people who self-identify as having a sweet tooth.

The first objective of this study was to investigate whether consuming a GS-containing mint for individuals who identify as having a sweet tooth can reduce sugar-related cravings. Using the cravings questionnaire (TCQ) a significant decrease of 7.6% in rank was found with AD-LIB application when compared to PLAC application. Questions in the TCQ are categorised into specific sections. For the sections titled ‘cravings on a physiological state' and 'anticipation of positive reinforcement that may result from eating', both AD-LIB and SYS showed significant reductions in rank compared to PLAC. This study is the first to use GS-mints to assess effects on adult food cravings using TCQ.

The second objective of this study was to Investigate whether consuming a GS-containing mint for in individuals who identify as having a sweet tooth can decrease the intake of free sugar-containing foods and beverages. This study did not find any association between the total amount of sugar-sweetened foods (SSF) eaten and AD-LIB or SYS GS-mint intervention. However, the AD-LIB intervention successfully reduced sugar-sweetened beverage (SSB) intake compared to placebo (PLAC), there was a 42% decrease in total millilitres consumed over the 14-day testing period. This may be because SSBs usually consist of sugar and water; however SSF contains other substances, such as fat and protein. Gymnema sylvestre only blocks sweet receptors, which may indicate why there was no statistically significant SSF reduction (Anjum, 2013).

The third objective of this study was to investigate whether consuming a GS-containing mint for in individuals who identify as having a sweet tooth can decrease the ratings of hunger, pleasantness and desire of consuming free sugar-containing confectionary. The findings of this study are consistent with results previous studies investigating effects of GS on SSF intake. Pleasantness, desire and hunger ratings for SSF have all been shown to be significantly decreased with GS administration in similar studies (Stice et al., 2018; Nobel et al., 2019; Turner et al., 2020; Turner et al., 2022). Results showed a significant reduction in the number of chocolates eaten after the two compulsory chocolates. Participants for this study were likely in the early stages of

behavioural change, and the participants in this study would be actively trying to reduce sugar intake.

The last objective of this study was to investigate whether consuming a GS-containing mint for in individuals who identify as having a sweet tooth can experience a decline in sweet food desire and consumption depending on systematic or ad-lib intake. This study has shown that AD-LIB application consistently performed better than SYS for total cravings score and SSB intake. AD-LIB and SYS showed no difference when comparing desire and pleasantness.

4.2 Contributions, limitations and future directions

There are limited studies that test GS outside of laboratory settings. Turner et al. (2022) is the only other study that has completed research using similar GS-containing mints in the field, and tested how they affect parameters of SSF intake in participants' home settings. This study therefore supports the findings by Turner et al. (2022) by also showing that using GS-mints outside laboratory settings can result in decreased cravings, SSB intake, desire and pleasantness of confectionery. This study also further explored whether different administrations of GS were more effective in reducing overall sugar intake, i.e., whether AD-LIB or SYS produced more significant results. This is the first study investigating GS to assess the effects of using AD-LIB GS, as most of the previous research using the herb have used it acutely in single testing sessions. Turner et al. (2022) again was the first study to assess how SYS administration affected intake and pleasantness of, and desire for SSF, but they did not comment on whether the particular administration they used affected their participants. Using a GS AD-LIB approach in this study is a significant strength because it mimics non-research application and therefore provides evidence on realistic application of GS (Goldstein et al., 1989). Another strength of this study is the cross-over design. Participants tested both PLAC and mints containing GS, allowing each subject to act as their own control to minimise confounding variables. Using a cross-over design also allowed this study to effectively compare different administrations of GS (i.e., PLAC, ADLIB or SYS). As previously mentioned, this study is the first to use TCQ, a validated questionnaire that assesses multiple aspects related to food cravings. This questionnaire allowed in-depth investigations into the participants' food cravings, situational cravings and associated emotions, as well as assessing whether using GS affected these.

This study has several limitations, including researcher bias, uncontrolled variables and limited literature on GS-mints. The first limitation is related to participant adherence to how the GS mints

were actually taken. When mints were given to participants, they were also verbally provided instructions on how to take it, and they were asked to let the mint fully dissolve on the tongue, as well as move it around the mouth to cover its whole surface area. Participants were asked to not chew or swallow the mint, as doing so would reduce its effectiveness. However, observation of the participants ingesting the mint did not occur, as the researchers were in the sensory testing booths when mints were taken in the lab, and obviously they were not present when the participants took the mints at home. An additional limitation of this study is that following consumption of the GS mint, several participants did not follow the expected trend of reduced consumption of SSF. These participants ate more servings of confectionary but rated them a low pleasantness score, which may be due to a 'curiosity factor'. As participants were unfamiliar with the sugar suppression effects of GS and wanted to try it, they continued to eat offered confectionary even though it was unpleasant It is hypothesised that as participants became accustomed to the taste modulation, repeated exposure to this product will eliminate the 'curiosity factor'. This study is also limited by leading the participants to believe they were testing three different GS-containing products. They were instructed not to discuss their findings with other participants, as this may have impacted how others perceived the different treatments.

Gymnema sylvestre has been shown to have anti-diabetic effects and future research on GS should explore the effects of the herb in people with impaired glucose tolerance (Anjum & Hasan, 2013). Sugar has also been shown to activate brain regions associated with reward (Stice et al., 2017; DiNicolantonio et al., 2018), however more research is needed utilising MRI screens to see how responses in these regions changes with GS uses (Stice & Yokum, 2018). This study only investigated effects of GS on intake of SSF and SSB, since GS only affects sugar receptors. Its isolated action on sugar receptors may result in individuals wanting to avoid the unpleasant side effects of GS, which may inadvertently drive consumption of foods that are low in sugar but high in other nutrients that are also detrimental when eaten in excess (Kringelbach et al., 2012). such as fat. In addition, further research on the effects of GS on total food consumption, not just that of SSF and SSB. Future studies could assess the effects of GS-mint as a treatment for pre-diabetes or metabolic syndrome by measuring effects on blood glucose with glucose monitors. More research should be conducted to determine which method of taking GS treatments is the most effective, as well as the chronic use of GS on body composition.

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Appendices

Appendix A: Health screening questionnaire With DEBQ and SAQ

Liberate from sugar, Mate.

Start of Block: Health screening

Q1 What is your name?

- First name (1) _____
- Last name (2) _____

Q2 What is your gender?

- Male (1)
- Female (2)
- Non-binary / third gender (3)
- Prefer not to say (4)

Q3 What is your email address?

_____

Page Break

Q4 Are you currently taking any of these medications below? If you are not taking any of these, please select "none of the above" at the end

- [ ] Amoxicillin, azithromycin or ciprofloxacin (1)
- [ ] Amlodipine or enalapril (4)
- [ ] Atorvastatin, lovastatin, simvastatin or pravastatin (5)
- [ ] Levothyroxine (6)
- [ ] Furosemide, lisinopril, propranolol, hydrochlorothiazide or triamterene (7)
- [ ] Amphetamines (8)
- [ ] Metformin (9)
- [ ] Insulin (10)
- [ ] Albuterol (11)
- [ ] Ranitidine or omeprazole (12)
- [ ] Amitriptyline, bupropion, trazodone or diazepam (13)
- [ ] Prednisolone (14)
- [ ] None of the above (15)

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Amoxicillin, azithromycin or ciprofloxacin

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Amlodipine or enalapril

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Atorvastatin, lovastatin, simvastatin or pravastatin

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Levothyroxine

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Furosemide, lisinopril, propranolol, hydrochlorothiazide or triamterene

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Amphetamines

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Metformin

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Insulin

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Albuterol

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Ranitidine or omeprazole

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Amitriptyline, bupropion, trazodone or diazepam

Skip To: End of Survey If Are you currently taking any of these medications below? If you are not taking any of these, plea... = Prednisolone

Page Break

Q5 Are you currently affected by or have ever been affected by...

- [ ] Injuries to the head or ear (1)
- [ ] Traumatic brain injury (4)
- [ ] None of the above (5)

Skip To: End of Survey If Are you currently affected by or have ever been affected by... = Injuries to the head or ear

Skip To: End of Survey If Are you currently affected by or have ever been affected by... = Traumatic brain injury

Page Break

Q6 Are you currently affected by any of the following? If you are affected by none of these, please select "none of the above" at the end

- [ ] Influenza (flu) (1)
- [ ] Common cold (4)
- [ ] Strep throat (5)
- [ ] Salivary gland infection (6)
- [ ] Gum (periodontal) disease (7)
- [ ] Dry mouth (xerostomia) (8)
- [ ] Parkinson's disease (9)
- [ ] Multiple sclerosis (10)
- [ ] Nasal polyps (11)
- [ ] Deviated septum (12)
- [ ] Sinus infection (sinusitis) (13)
- [ ] Cancer (14)
- [ ] Cardiovascular disease (e.g. heart disease) (15)
- [ ] Respiratory disease (e.g. asthma, chronic obstructive pulmonary disease, pneumonia) (16)
- [ ] Diabetes (17)
- [ ] Alzheimer's disease (18)
- [ ] Non-alcoholic fatty liver disease (19)
- [ ] Alcoholic Fatty liver disease (20)
- [ ] None of the above (21)

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Influenza (flu)

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Common cold

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Strep throat

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Salivary gland infection

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Dry mouth (xerostomia)

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Parkinson's disease

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Multiple sclerosis

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Nasal polyps

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Deviated septum

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Sinus infection (sinusitis)

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Sinus infection (sinusitis)

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Cancer

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Cardiovascular disease (e.g. heart disease)

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Respiratory disease (e.g. asthma, chronic obstructive pulmonary disease, pneumonia)

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Diabetes

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Alzhemer's disease

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Non-alcoholic fatty liver disease

Skip To: End of Survey If Are you currently affected by any of the following? If you are affected by none of these, please... = Alcoholic Fatty liver disease

Page Break

Q7 Are you currently seeking medical advice, receiving treatment or having investigations?

- ○ Yes (4)
- ○ No (5)

Skip To: End of Survey If Are you currently seeking medical advice, receiving treatment or having investigations? = Yes

Page Break

Q8 Please tick if, for whatever reason, you are currently affected by:

- ☐ Loss of taste (1)
- ☐ Loss of smell (2)
- ☐ None of the above (3)

Skip To: End of Survey If Please tick if, for whatever reason, you are currently affected by: = Loss of taste

Skip To: End of Survey If Please tick if, for whatever reason, you are currently affected by: = Loss of smell

Q9 Do you smoke tobacco?

- ○ Yes (1)
- ○ No (2)

Skip To: End of Survey If Do you smoke tobacco? = Yes

Page Break

Q10 Are you currently pregnant?

- Yes (1)
- No (2)

Skip To: End of Survey If Are you currently pregnant? = Yes

Q11 Do you have a pacemaker?

- Yes (1)
- No (2)

Skip To: End of Survey If Do you have a pacemaker? = Yes

Q12 Do you live in the Auckland region and are able to visit the Massey Albany campus on four different occasions for data collection (dates tbc)?

- Yes (1)
- No (2)

Skip To: End of Survey If Do you live in the Auckland region and are able to visit the Massey Albany campus on four differe... = No

End of Block: Health screening

Start of Block: Main

Page Break

Q13 What is your age?

▼ Under 18 years old (1) ... Over 60 years old (7)

Skip To: End of Survey If What is your age? = Under 18 years old

Page Break

Q14 Do you consider yourself a sweet tooth?

- No (0)
- Sometimes (1)
- Yes (2)

Skip To: End of Survey If Do you consider yourself a sweet tooth? = No

Page Break

Q15 Does eating sugar-containing foods give you pleasure?
Note: sugar-containing foods in this context refer to those foods that have had sugar added to them e.g. cakes, cookies, sweets, chocolate, pastries etc.

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q16 Do you believe sugar can have a strong effect on someone's mental state?

- No (0)
- Sometimes (1)
- Yes (2)

Q17 Does eating sugar-containing foods make you feel better, even during a bad day?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q18 Would you buy sweet foods if you felt like eating them, even if it is late in the evening or inconvenient to do so?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q19 Do you ever experience feelings of guilt after eating sugar-containing foods?

- No (0)
- Sometimes (1)
- Yes (2)

Q20 Do you eat sugar-containing foods everyday?

- No (0)
- Sometimes (1)
- Yes (2)

Q21 Do you prefer to eat sugar-containing foods in secret or alone (i.e. not around other people)?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q22 Do you ever think about what sugar-containing foods you would want to eat next?

- No (0)
- Sometimes (1)
- Yes (2)

Q23 Do you "stockpile" sugar-containing foods?
(Stockpile - collect a large amount of sugar-containing foods to hold in reserve for times of shortage)

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q24 Do you feel exhausted after eating too many sugar-containing foods?

- No (0)
- Sometimes (1)
- Yes (2)

Q25 Do you find it hard to control or limit the amount of sugar-containing foods you consume?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q26 When you are deprived of sugar-containing foods for a long period of time, do you experience what you consider to be symptoms of withdrawal?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q27 Do you hide the amount of sugar-containing foods you've eaten from peers?

- No (0)
- Maybe (1)
- Yes (2)

Q28 Do you worry about how sugar-containing foods affect your health, but continue to consume them?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q29 Do you ever experience a "crash", or severe loss of energy, in the afternoon if you did not eat any sugar-containing foods prior in the day?

- No (0)
- Sometimes (1)
- Yes (2)

Q30 Could you open a packet of sweets / confectionary / chocolate and finish it in one sitting?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q31 Do you think celebrations must include sugar-containing food?

- No (0)
- Sometimes (1)
- Yes (2)

Q32 Would you choose sugar-containing foods over other foods that are offered to you (for example, savoury foods)?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q33 Do you think loving sugar-containing foods is a part of your personality?

- No (0)
- Unsure (1)
- Yes (1)

Q34 If you experience weight gain, do you eat less than you normally would?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q35 Do you try to eat less at meal times than you would like to eat?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q36 Do you refuse food or drink offered to you because you are concerned about your weight?

- No (0)
- Sometimes (1)
- Yes (2)

Q37 Do you watch what you eat?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q38 Do you deliberately eat foods that are considered slimming?

- No (0)
- Sometimes (1)
- Yes (2)

Q39 When you have eaten too much, do you eat less than usual the following days?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q40 Do you deliberately eat less in order in order to not gain weight?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q41 During the evening do you try not to eat because you are watching your weight?

- No (0)
- Sometimes (1)
- Yes (2)

Q42 Do you try not to eat between meals because you are watching your weight?

- No (0)
- Sometimes (1)
- Yes (2)

Q43 Do you take into account your weight with what you eat?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q44 Do you have the desire to eat when you are irritated?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q45 Do you have the desire to eat when you depressed or discouraged?

- No (0)
- Sometimes (1)
- Yes (2)

Q46 Do you have the desire to eat when you are feeling lonely?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q47 Do you have the desire to eat when somebody lets you down?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q48 Do you have the desire to eat when you are angry?

- No (0)
- Sometimes (1)
- Yes (2)

Q49 Do you have the desire to eat when you are anticipating something unpleasant will happen?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q50 Do you have the desire to eat when you anxious, worried or tense?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q51 Do you have the desire to eat when things are going against you or when things have gone wrong?

- No (0)
- Sometimes (1)
- yes (2)

Q52 Do you have the desire to eat when you are frightened?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q53 Do you have the desire to eat when you are disappointed?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q54 Do you have the desire to eat when you are emotionally upset?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q55 Do you have the desire to eat when you are bored or restless?

- No (0)
- Sometimes (1)
- Yes (2)

Q56 If food tastes good to you, do you eat more than usual?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q57 If you see or smell something delicious, do you have a desire to eat it?

- No (0)
- Sometimes (1)
- Yes (2)

Q58 If food smells or looks good, do you eat more than usual?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q59 If you have something delicious to eat, do you eat it straight away?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q60 If you walk past a bakery, do you have the desire to buy something?

- No (0)
- Sometimes (1)
- Yes (2)

Q61 If you walk past a snack bar or café, do you have the desire to buy something?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q62 If you see others eating, do you also have the desire to eat?

- No (0)
- Sometimes (1)
- Yes (2)

Q63 Can you resist eating delicious foods?

- No (0)
- Sometimes (1)
- Yes (2)

Page Break

Q64 Do you eat more than usual when you see others eating?

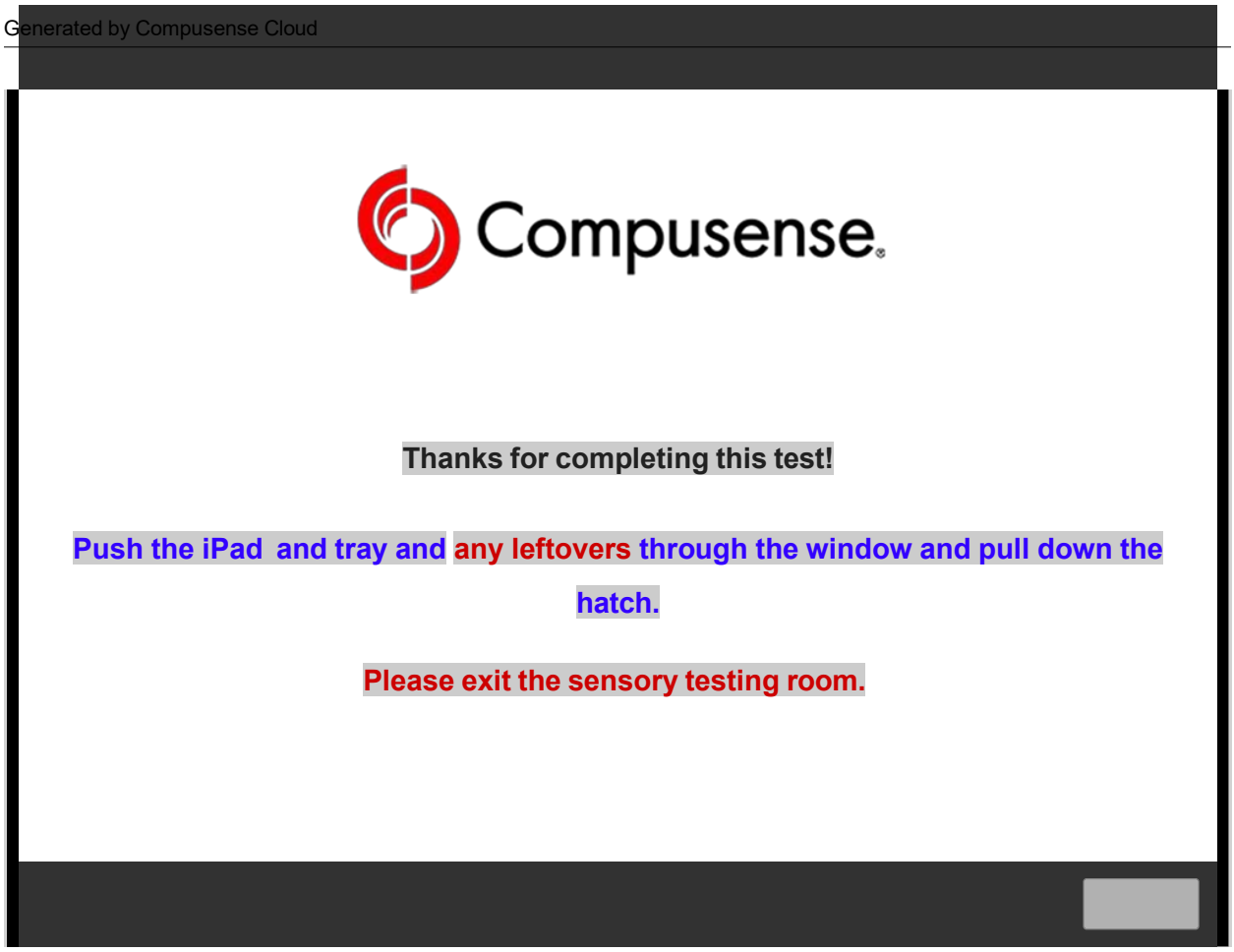
- No (0)
- Sometimes (1)
- Yes (2)

Q65 When preparing a meal, are you inclined to eat something?

- No (0)
- Sometimes (1)
- Yes (2)

End of Block: Main

Appendix B: Sensory testing



You will be provided with **servings** of confectionary. On the consent form provided, please write whether you prefer to receive:

a) Whittaker's Creamy Milk Chocolate

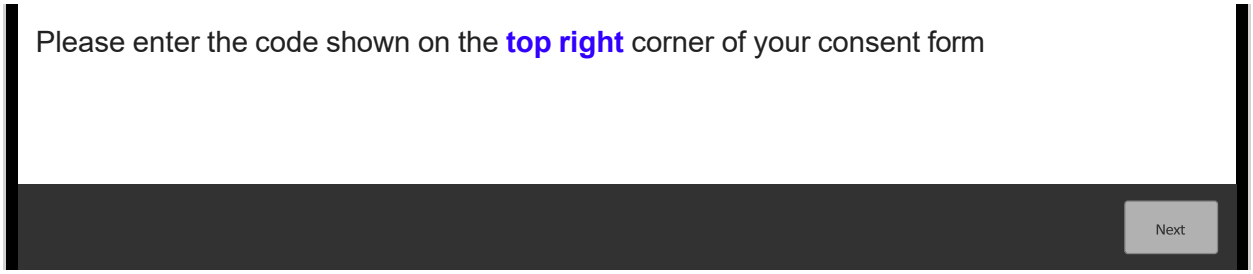
b) The Natural Confectionary Co. Vegan Fruity Flavoured Jellies

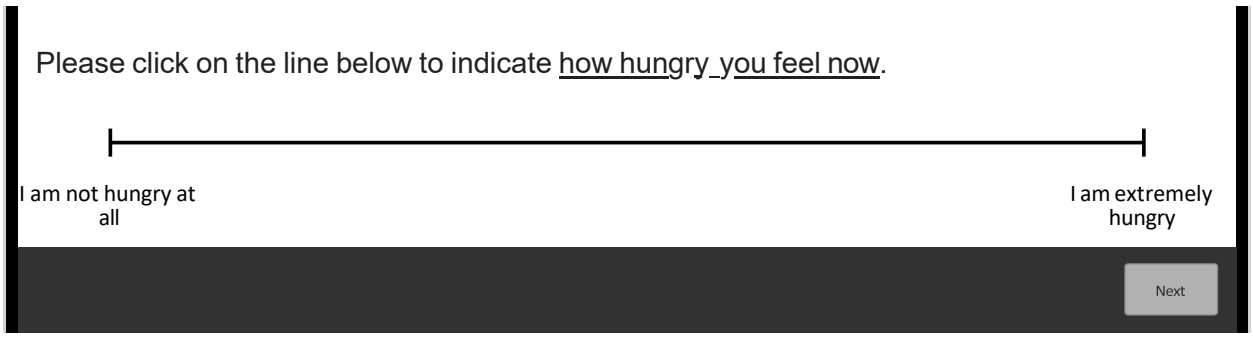
or

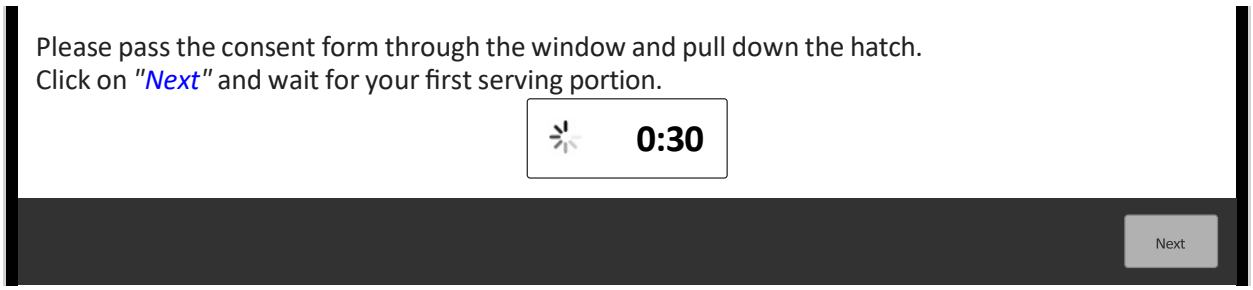
c) Maltesers

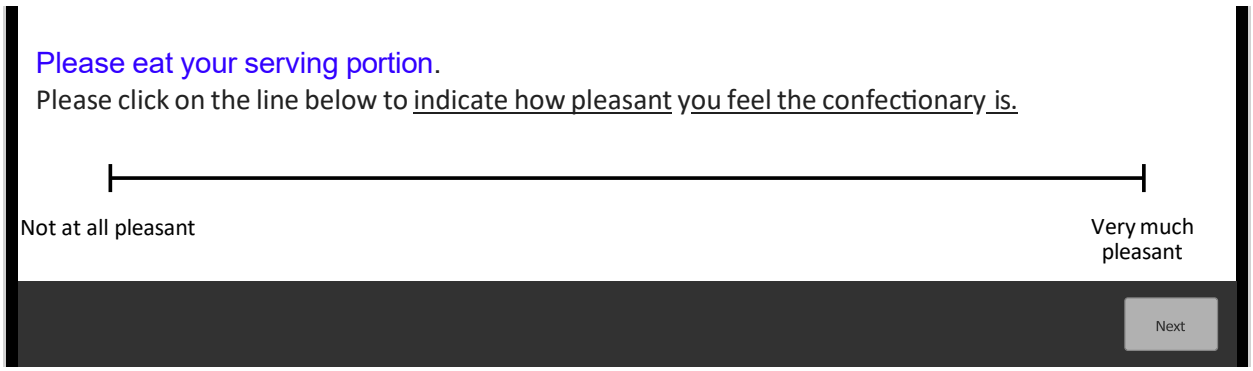
Set aside the consent form for now.

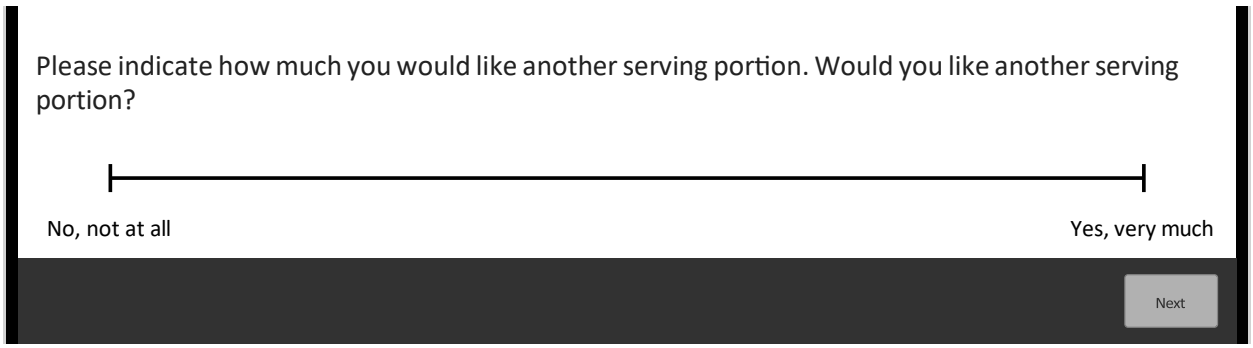
Next


Please enter the code shown on the top right corner of your consent form
Next


Please click on the line below to indicate how hungry you feel now.
I am not hungry at all
I am extremely hungry
Next


Please pass the consent form through the window and pull down the hatch.
Click on "Next" and wait for your first serving portion.
0:30
Next


Please eat your serving portion.
Please click on the line below to indicate how pleasant you feel the confectionary is.
Not at all pleasant
Very much pleasant
Next


Please indicate how much you would like another serving portion. Would you like another serving portion?
No, not at all
Yes, very much
Next

Please push the tray through the window and **wait for your mint sample**.
After pushing the tray through the window, pull down the hatch

Next

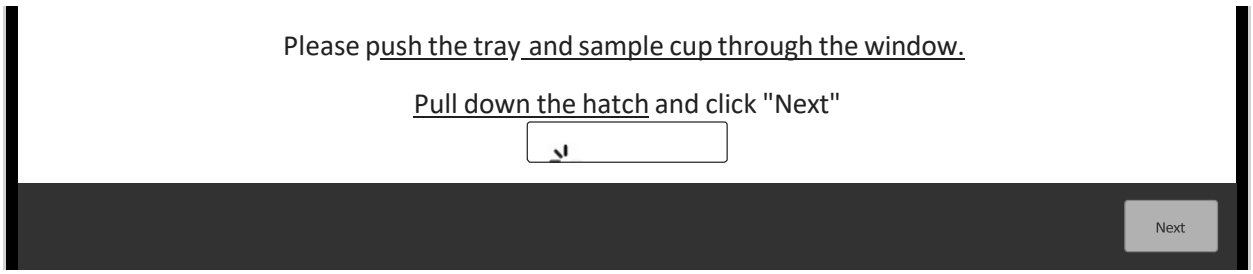
Please put the mint into your mouth and suck on it until it is completely dissolved.

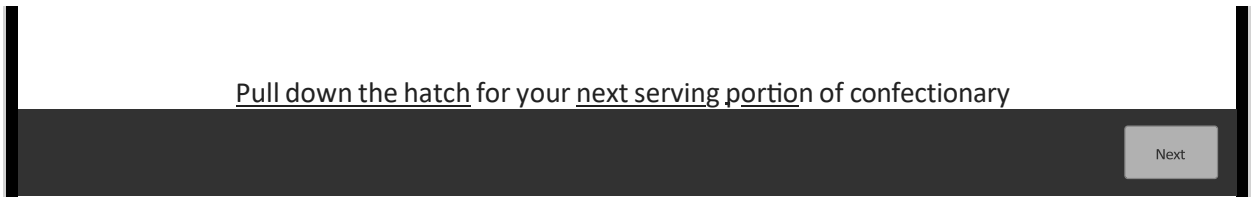
Do this by placing it on your tongue and suck on it until it has completely dissolved.

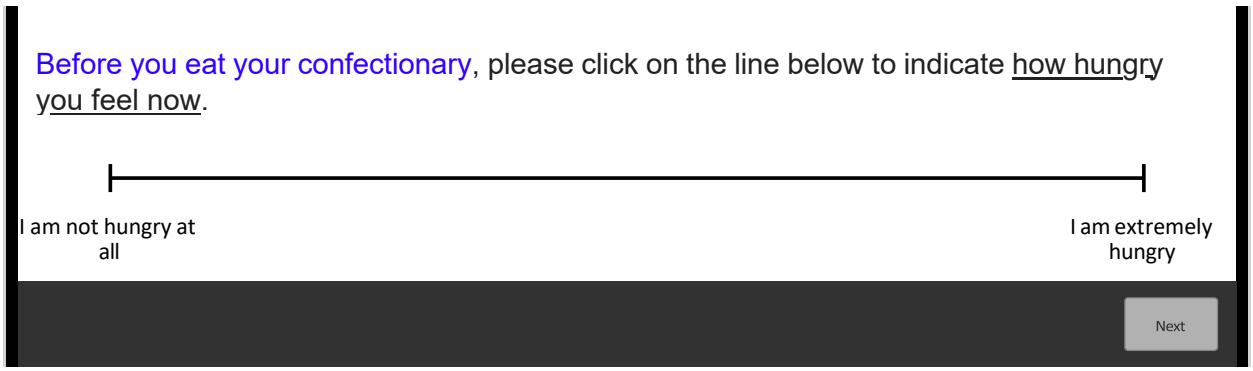
Move the mint around your tongue as it dissolves so it coats the entire layer of your tongue. We want you to completely coat your palate with the mint as well.

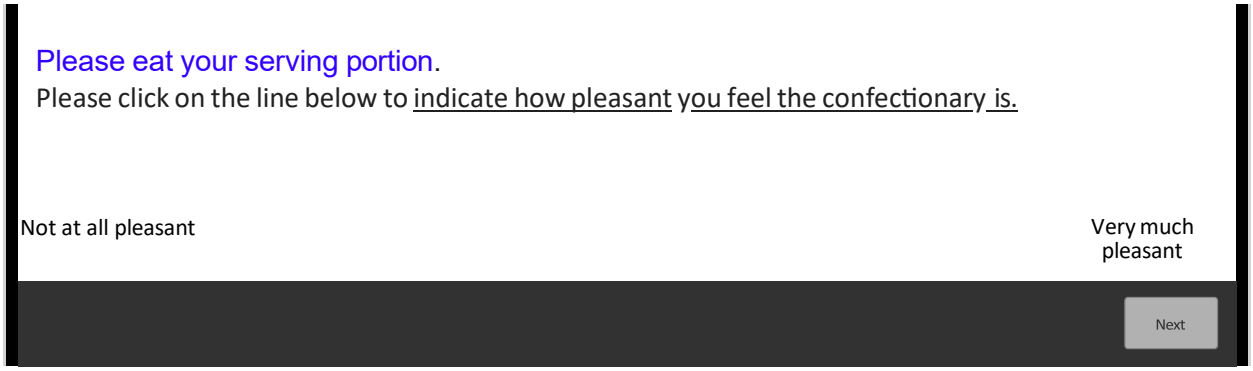
Click "Next" **AFTER** the mint has **completely dissolved**.

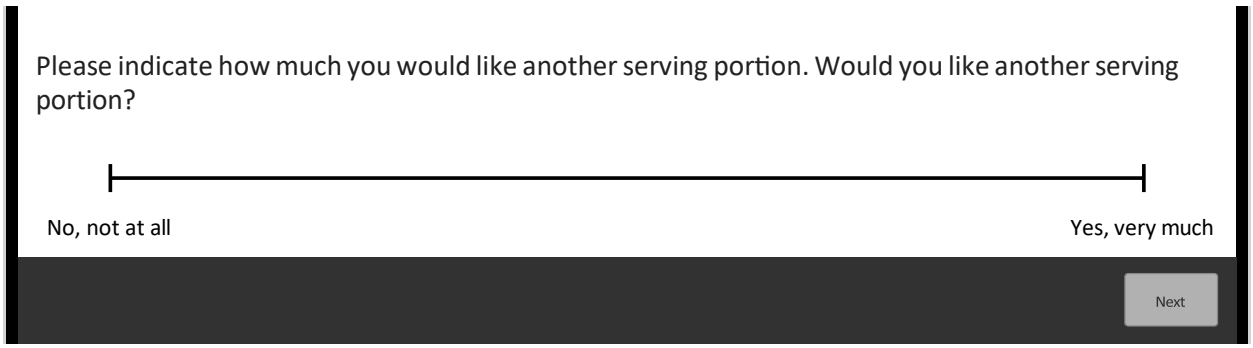
Next

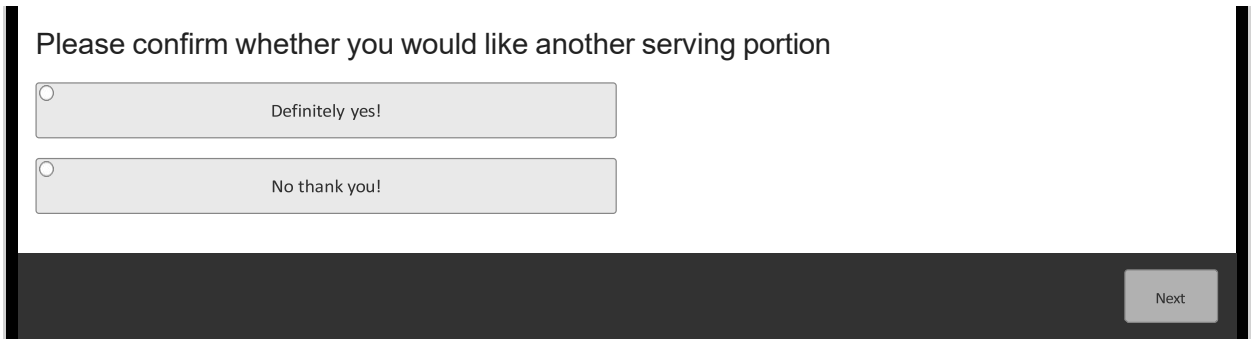

Please push the tray and sample cup through the window.
Pull down the hatch and click "Next"
Next

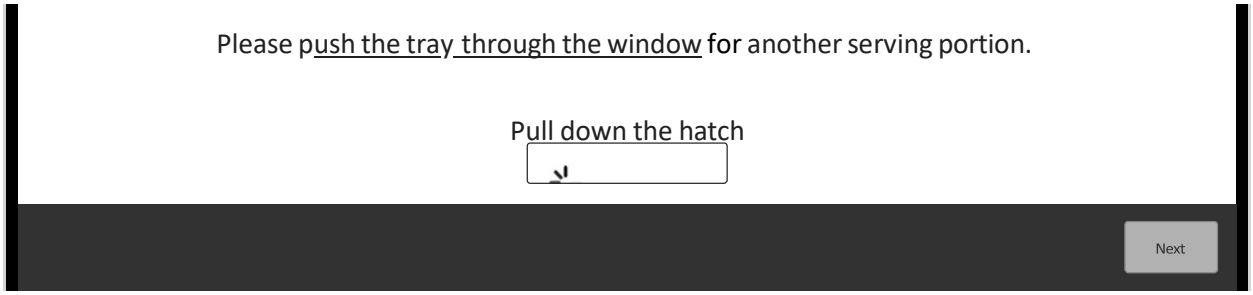

Pull down the hatch for your next serving portion of confectionary
Next

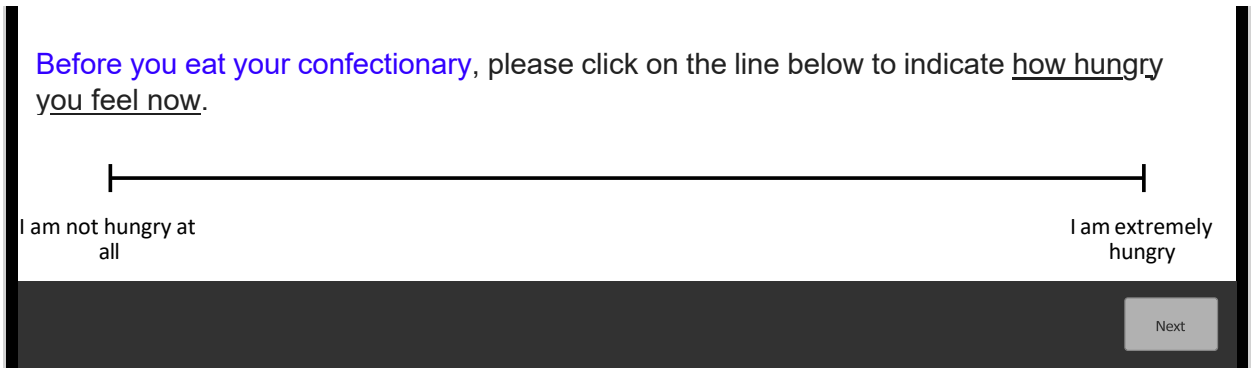

Before you eat your confectionary, please click on the line below to indicate how hungry you feel now.
I am not hungry at all
I am extremely hungry
Next

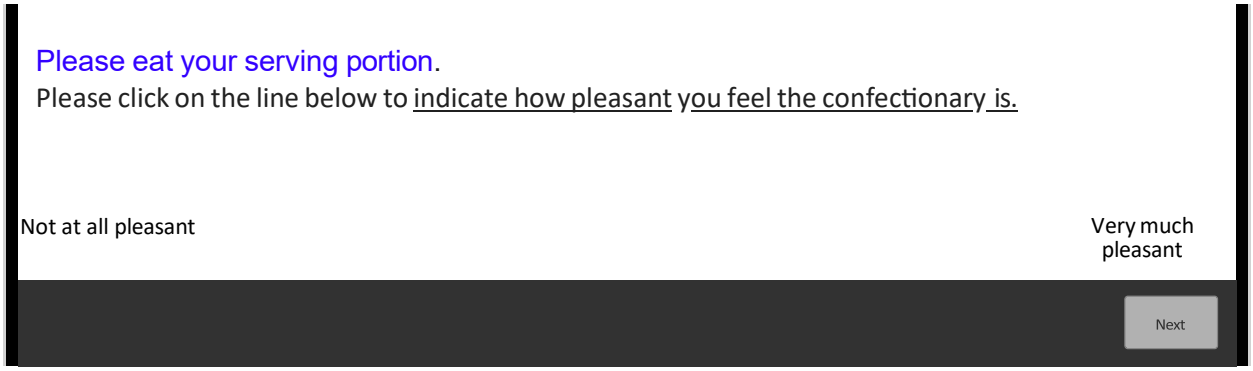

Please eat your serving portion.
Please click on the line below to indicate how pleasant you feel the confectionary is.
Not at all pleasant
Very much pleasant
Next

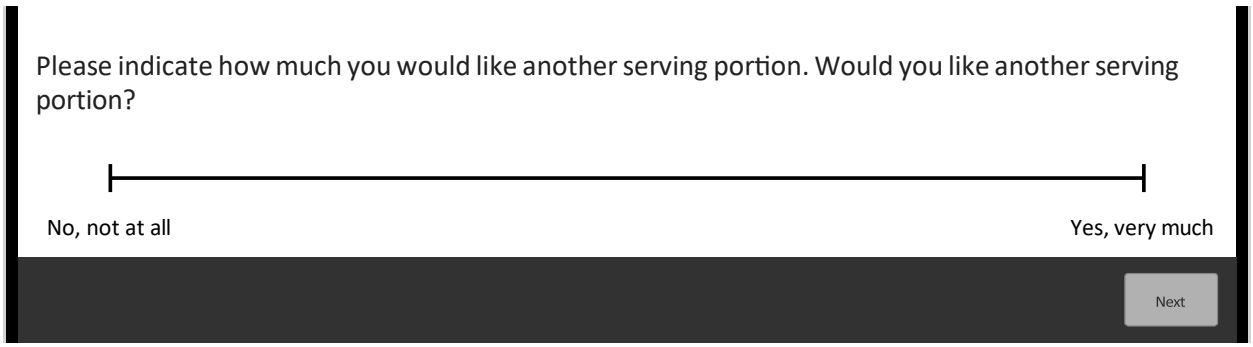

Please indicate how much you would like another serving portion. Would you like another serving portion?
No, not at all
Yes, very much
Next

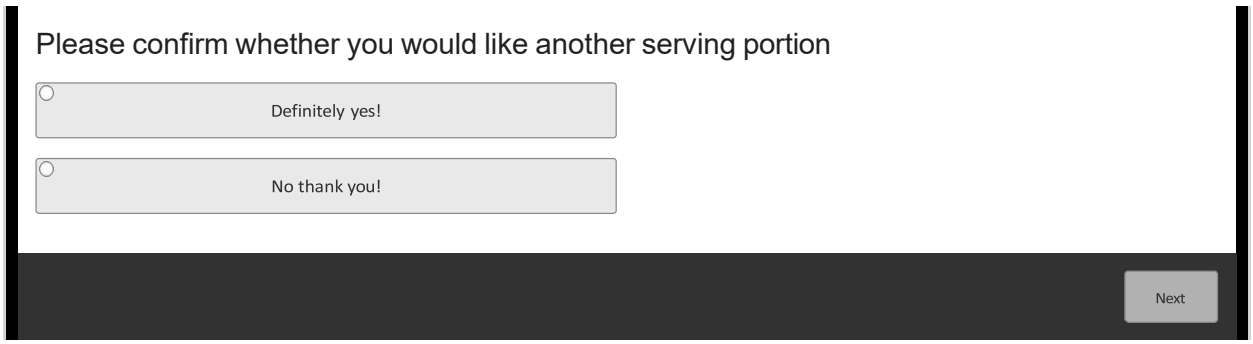

Please confirm whether you would like another serving portion
Definitely yes!
No thank you!
Next

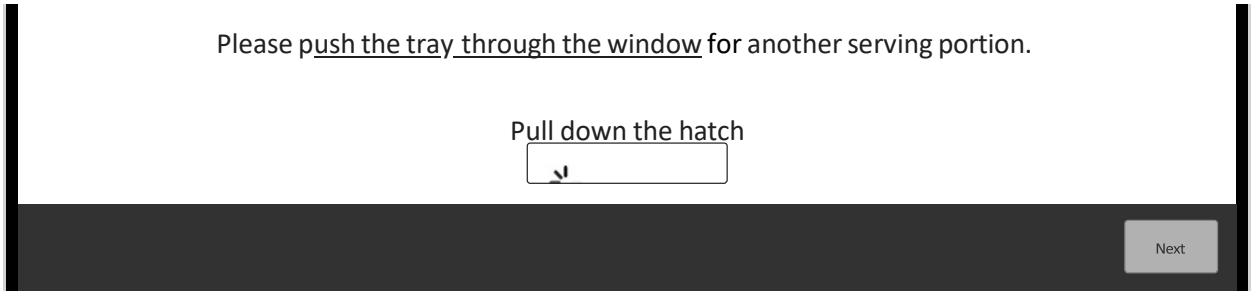

Please push the tray through the window for another serving portion.
Pull down the hatch
Next

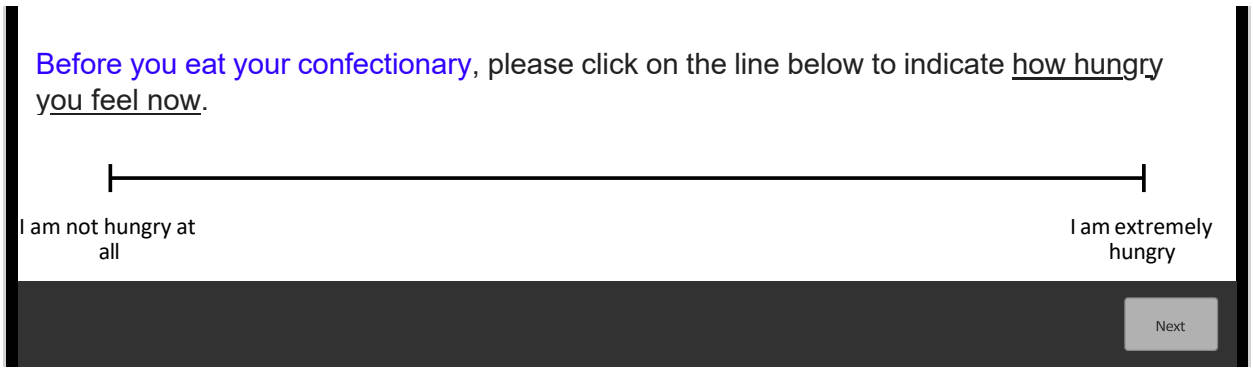

Before you eat your confectionary, please click on the line below to indicate how hungry you feel now.
I am not hungry at all
I am extremely hungry
Next

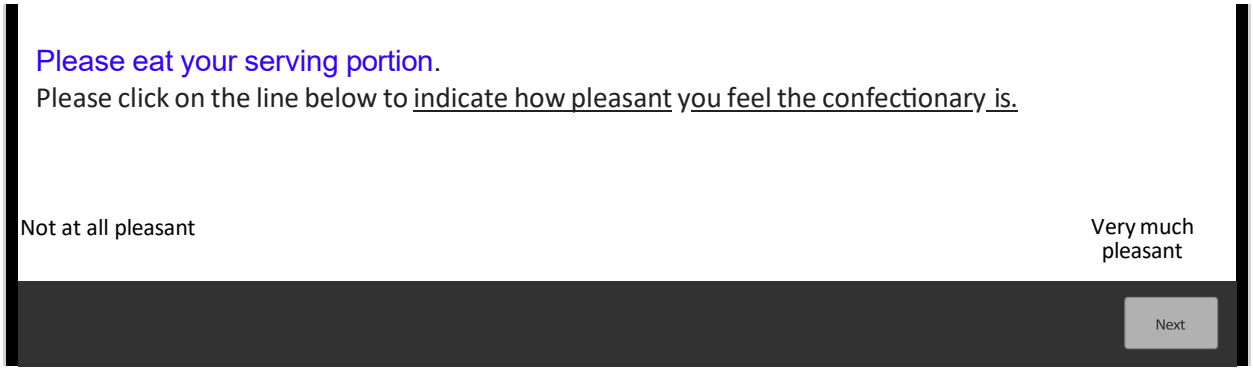

Please eat your serving portion.
Please click on the line below to indicate how pleasant you feel the confectionary is.
Not at all pleasant
Very much pleasant
Next

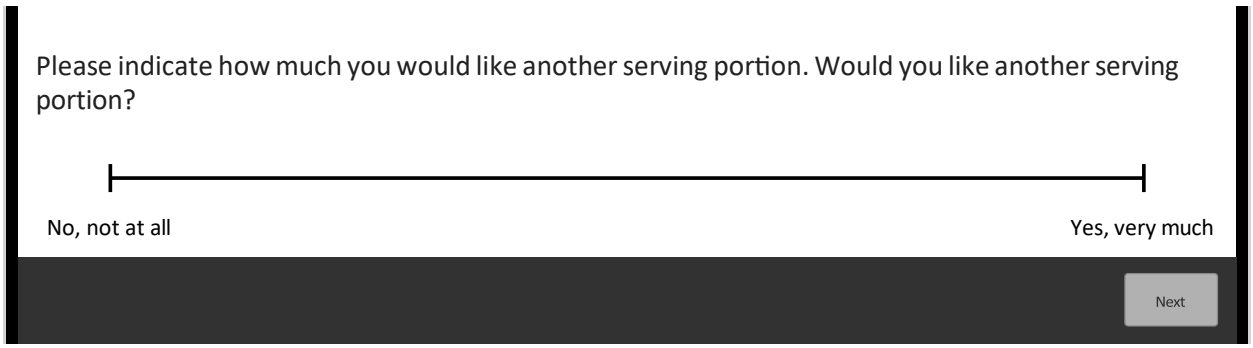

Please indicate how much you would like another serving portion. Would you like another serving portion?
No, not at all
Yes, very much
Next

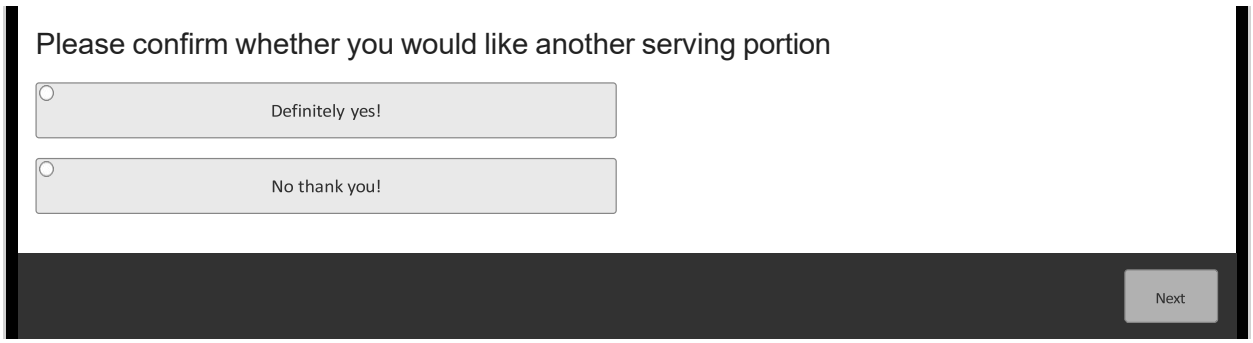

Please confirm whether you would like another serving portion
Definitely yes!
No thank you!
Next

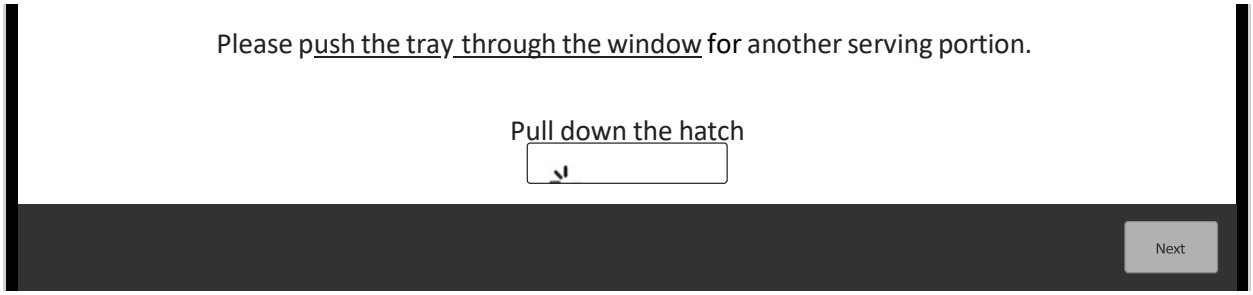

Please push the tray through the window for another serving portion.
Pull down the hatch
Next

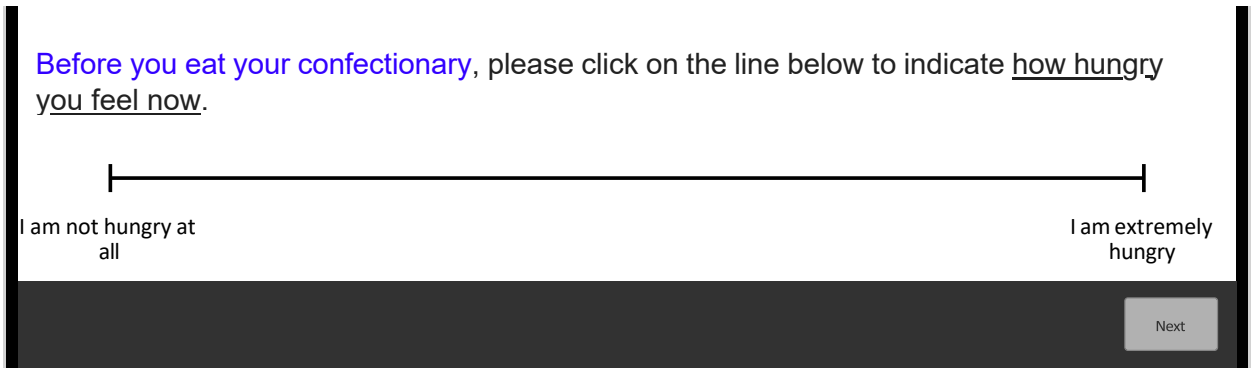

Before you eat your confectionary, please click on the line below to indicate how hungry you feel now.
I am not hungry at all
I am extremely hungry
Next

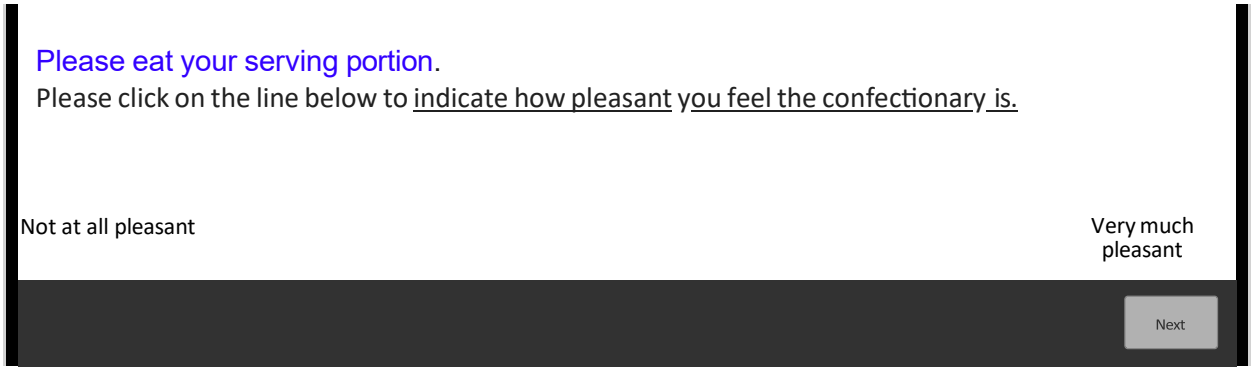

Please eat your serving portion.
Please click on the line below to indicate how pleasant you feel the confectionary is.
Not at all pleasant
Very much pleasant
Next

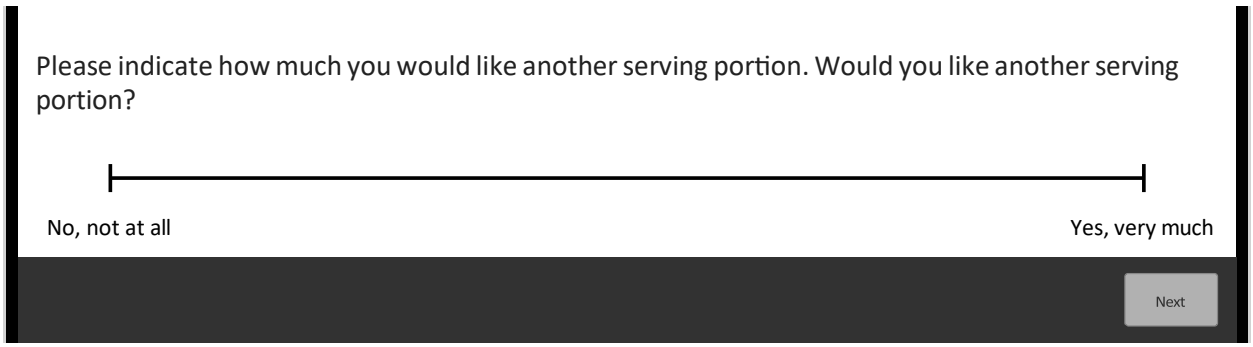

Please indicate how much you would like another serving portion. Would you like another serving portion?
No, not at all
Yes, very much
Next

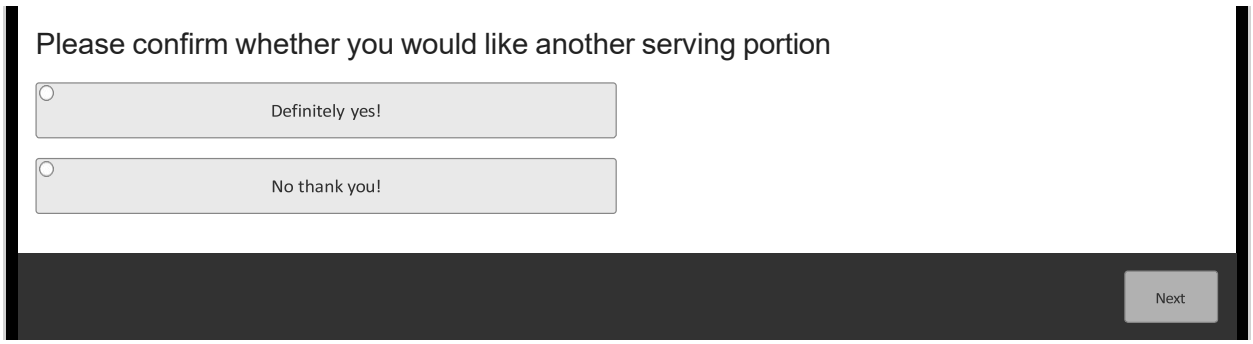

Please confirm whether you would like another serving portion
Definitely yes!
No thank you!
Next

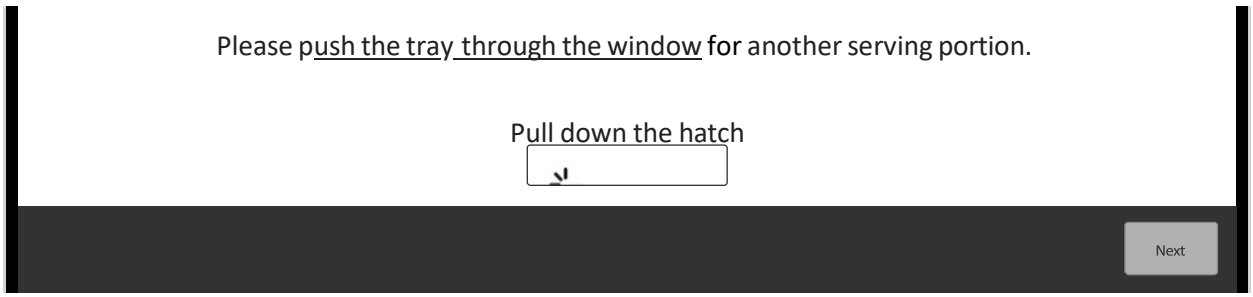

Please push the tray through the window for another serving portion.
Pull down the hatch
Next

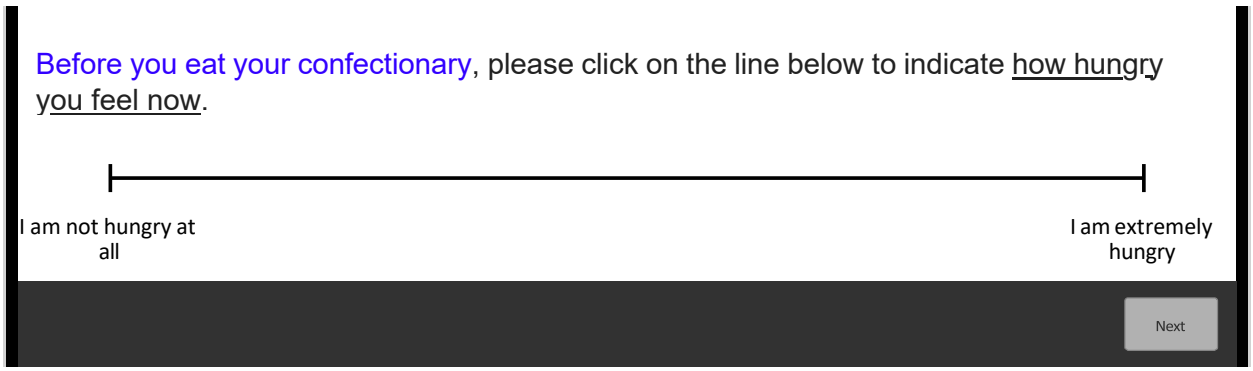

Before you eat your confectionary, please click on the line below to indicate how hungry you feel now.
I am not hungry at all
I am extremely hungry
Next

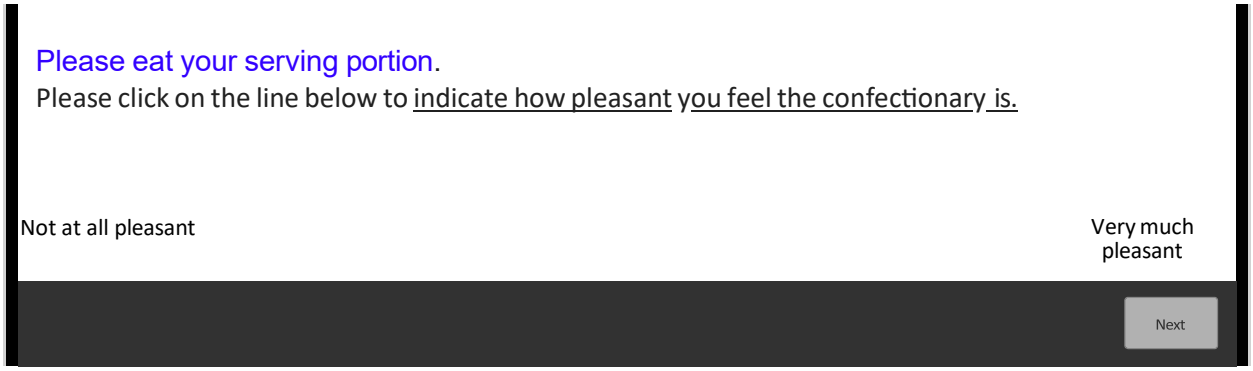

Please eat your serving portion.
Please click on the line below to indicate how pleasant you feel the confectionary is.
Not at all pleasant
Very much pleasant
Next

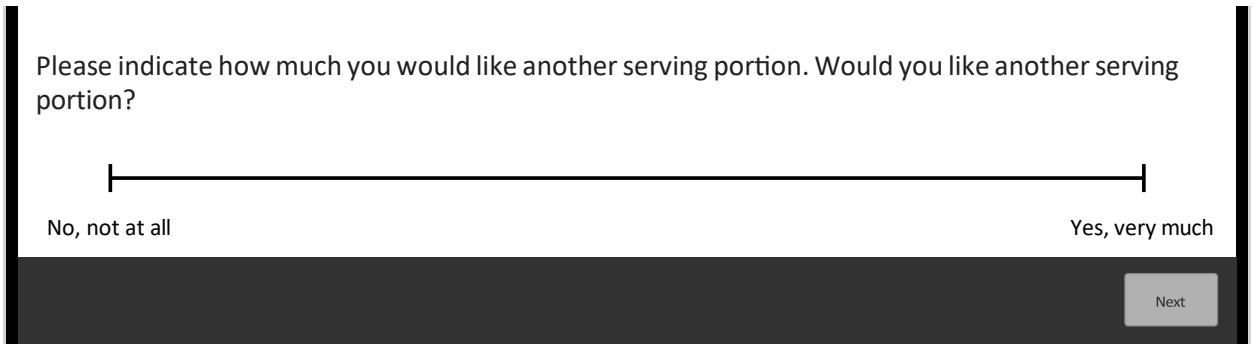

Please indicate how much you would like another serving portion. Would you like another serving portion?
No, not at all
Yes, very much
Next

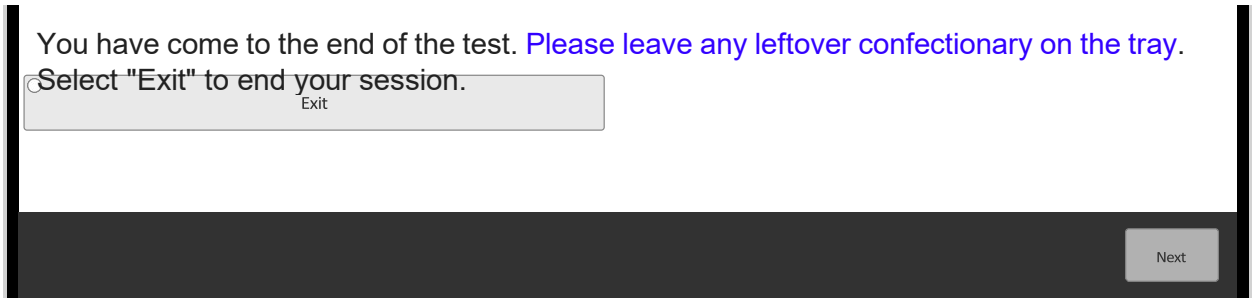

Please confirm whether you would like another serving portion
Definitely yes!
No thank you!
Next

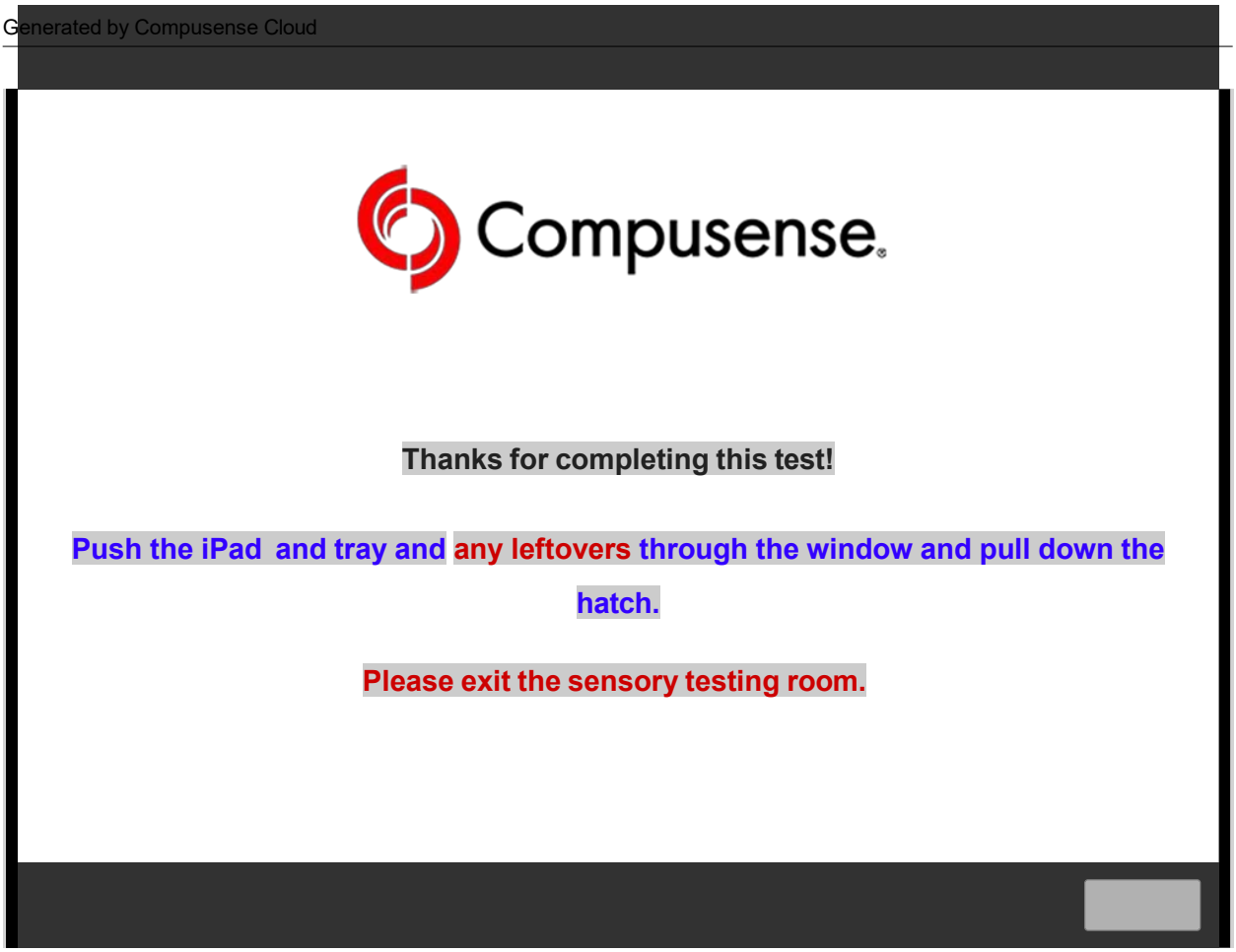

Please push the tray through the window for another serving portion.
Pull down the hatch
Next


Before you eat your confectionary, please click on the line below to indicate how hungry you feel now.
I am not hungry at all
I am extremely hungry
Next


Please eat your serving portion.
Please click on the line below to indicate how pleasant you feel the confectionary is.
Not at all pleasant
Very much pleasant
Next


Please indicate how much you would like another serving portion. Would you like another serving portion?
No, not at all
Yes, very much
Next


You have come to the end of the test. Please leave any leftover confectionary on the tray.
Select "Exit" to end your session.
Exit
Next


Compusense
Thanks for completing this test!
Push the iPad and tray and any leftovers through the window and pull down the hatch.
Please exit the sensory testing room.

Appendix C: Visitation questionnaires which includes FFQ, BevQ and TCQ

Visitation questionnaires

Start of Block: Identification

Q1 Kia Ora, Welcome from the sweet-as team. Please complete these questions to the best of your ability.

Q2 What is your name?

_____

Q3 What is your age?

_____

End of Block: Identification

Start of Block: Food Frequency Questionnaire

Q4 How often do you have the following drinks? Please check the boxes that suit you best.

	Never (	1-3 per month (2)	Once a week (3)	2-4 per week (4)	5-6 per week (5)	Once a day (6)	2-3 per day (7)	4+ a day (8)
Fruit drink 180ml	○	○	○	○	○	○	○	○
Soft drink 330ml	○	○	○	○	○	○	○	○
Energy drink 250ml	○	○	○	○	○	○	○	○
Flavoured milk 180ml	○	○	○	○	○	○	○	○
Smoothies 200ml	○	○	○	○	○	○	○	○

Q5 How often do you have the following foods? Please check the boxes that suit you best.

	Never (	1-3 per month (2)	Once a week (3)	2-4 per week (4)	5-6 per week (5)	Once a day (6)	2-3 per day (7)	4+ a day (8)
Breakfast cereals 30g	○	○	○	○	○	○	○	○
yeast breads 35g	○	○	○	○	○	○	○	○
Cake 1 30g	○	○	○	○	○	○	○	○
Cheesecake 30g	○	○	○	○	○	○	○	○
Cookies 30g	○	○	○	○	○	○	○	○
Brownies 30g	○	○	○	○	○	○	○	○
Doughnuts 30g	○	○	○	○	○	○	○	○
Biscuit 30g	○	○	○	○	○	○	○	○
Muffins 30g	○	○	○	○	○	○	○	○
French toast 30g	○	○	○	○	○	○	○	○
Waffles or Pancakes 30g	○	○	○	○	○	○	○	○
Sweet pastries 30g	○	○	○	○	○	○	○	○
Lollies containing chocolate 30g	○	○	○	○	○	○	○	○

Lollies not containing chocolate 15g	○	○	○	○	○	○	○	○
Ice cream 125g	○	○	○	○	○	○	○	○
Popsicle 125g	○	○	○	○	○	○	○	○
Gelatin 125g	○	○	○	○	○	○	○	○
Pudding 125g	○	○	○	○	○	○	○	○

Page Break

Q6 How often do you have the following foods? Please check the boxes that suit you best.

	Never (	1-3 per month (2)	Once a week (3)	2-4 per week (4)	5-6 per week (5)	Once a day (6)	2-3 per day (7)	4+ a day (8)
Pizza or burger, all varieties, take out 140g	○	○	○	○	○	○	○	○
Tomato sauce 15g	○	○	○	○	○	○	○	○
Salad dressing, Mayonnaise 30g	○	○	○	○	○	○	○	○
BBQ sauce 30g	○	○	○	○	○	○	○	○
Canned Fruits 125g	○	○	○	○	○	○	○	○

End of Block: Food Frequency Questionnaire

Start of Block: Beverage questionnaire

Q7 How often would you have these beverages?

	Never or less than 1 time per week (1)	1 times per week (2)	2-3 times per week (3)	4-6 times per week (4)	1 time per day (5)	2+ times per day (6)
Water	○	○	○	○	○	○
100% fruit juice	○	○	○	○	○	○
Sweetened Juice/Drink/Beverage	○	○	○	○	○	○
Whole milk	○	○	○	○	○	○
Reduced Fat Milk (2%)	○	○	○	○	○	○
Low Fat/Fat free Milk (skim milk, soymilk)	○	○	○	○	○	○
Soft drinks	○	○	○	○	○	○
Diet soft drinks	○	○	○	○	○	○
Sweetened Tea	○	○	○	○	○	○
Tea or Coffee with cream and / or sugar	○	○	○	○	○	○
Alcoholic drinks (Beer, Ales, cider or non-alcoholic or light beer)	○	○	○	○	○	○
Hard liquor (shots, rum, vodka)	○	○	○	○	○	○
Wine (red or white)	○	○	○	○	○	○

Energy and sports drinks (Powerade, Redbull)	○	○	○	○	○	○
Other	○	○	○	○	○	○

Page Break

Q8 How much would you have each time?

	Less than 187ml (3/4 cup) (1)	250ml (1 cup) (2)	375ml (1 1/2 cups) (3)	500ml (2 cups) (4)	More than 625ml (2/12 cups) (5)
Water	○	○	○	○	○
100% fruit juice	○	○	○	○	○
Sweetened Juice/Drink/Beverage	○	○	○	○	○
Whole milk	○	○	○	○	○
Reduced Fat Milk (2%)	○	○	○	○	○
Low Fat/Fat free Milk (skim milk, soymilk)	○	○	○	○	○
Soft drinks	○	○	○	○	○
Diet soft drinks	○	○	○	○	○
Sweetened Tea	○	○	○	○	○
Tea or Coffee with cream and / or sugar	○	○	○	○	○
Alcoholic drinks (Beer, Ales, cider or non-alcoholic or light beer)	○	○	○	○	○
Hard liquor (shots, rum, vodka)	○	○	○	○	○
Wine (red or white)	○	○	○	○	○

Energy and sports drinks (Powerade, Redbull)	○	○	○	○	○
Other	○	○	○	○	○

End of Block: Beverage questionnaire

Start of Block: Cravings

Q9 Please check the boxes that suit you best.

	Never not applicable (1)	Rarely (2)	Sometimes (3)	Often (4)	Usually (5)	Always (6)
Being with someone who is eating often makes me hungry.	○	○	○	○	○	○
When I crave something, I know I will not be able to stop eating once I start.	○	○	○	○	○	○
If I eat what I am craving, I often lose control and eat too much.	○	○	○	○	○	○
I hate it when I give in to cravings.	○	○	○	○	○	○
Food cravings invariably make me think of ways to get what I want to eat.	○	○	○	○	○	○
I feel like I have food on my mind all the time.	○	○	○	○	○	○
I often feel guilty for craving certain foods.	○	○	○	○	○	○

I find myself preoccupied with food.	○	○	○	○	○	○
I eat to feel better.	○	○	○	○	○	○
Sometimes, eating makes things seem just perfect.	○	○	○	○	○	○
Thinking about my favorite foods makes my mouth water.	○	○	○	○	○	○
I crave foods when my stomach is empty.	○	○	○	○	○	○
I feel as if my body asks me for certain foods.	○	○	○	○	○	○
I get so hungry that my stomach seems like a bottomless pit.	○	○	○	○	○	○
Eating what I crave makes me feel better.	○	○	○	○	○	○
When I satisfy a craving I feel guilty about myself.	○	○	○	○	○	○

Whenever I have cravings. I find myself making plans to eat.	○	○	○	○	○	○
Eating calms me down.	○	○	○	○	○	○
I crave foods when I feel bored, angry, or sad.	○	○	○	○	○	○
I feel less anxious after I eat.	○	○	○	○	○	○
If I get what I am craving I cannot stop myself from eating it. (22)	○	○	○	○	○	○
When I crave certain foods, I usually try eat them as soon as I can.	○	○	○	○	○	○
When I eat what I crave I feel great.	○	○	○	○	○	○
I have no will power to resist my food crave.	○	○	○	○	○	○
Once I start eating, I have trouble stopping.	○	○	○	○	○	○

I cannot stop thinking about eating no matter how hard I try.	○	○	○	○	○	○
I spend a lot of time thinking about whatever it is I will eat next.	○	○	○	○	○	○
If I give in to a food craving, I keep thinking about eating untill I actually eat the food	○	○	○	○	○	○
If I am craving something, thoughts of eating it consumes me.	○	○	○	○	○	○
I daydream about food.	○	○	○	○	○	○
Whenever I have food craving, I keep on thinking about eating until I actually eat the food.	○	○	○	○	○	○
My emotions often make me want to eat.	○	○	○	○	○	○

Whenever I go to a buffet I end up eating more than what I needed.	○	○	○	○	○	○
It is hard for me to resist the temptation to eat appetizing foods that are in my reach.	○	○	○	○	○	○
When I am with someone who is overeating, I usually overeat too.	○	○	○	○	○	○
When I eat food, I feel comforted.	○	○	○	○	○	○
I crave foods when I'm upset.	○	○	○	○	○	○

End of Block: Cravings

Appendix D: Participant information sheet

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Liberate From Sugar, Mate!

PARTICIPANT INFORMATION SHEET

Researcher Introduction
We are student dietitians completing Master's of Nutrition & Dietetics. Our supervisors and collaborators work in the areas of sport and exercise science, health science, nutrition and food technology at Massey University.

Invitation to Participate in Research Study
If you identify as having a "sweet tooth", we would like to invite you to take part in our study. Gymnema sylvestre (GS) is a plant that contains ingredients that prevent sugar from activating sweet receptors on the tongue. This results in a reversible reduction in perception of sweet flavours for 30 – 60 minutes. Several GS-containing mints have been developed to reduce cravings for sugar-sweetened food products. You will need to be available to take part in **three separate interventions** during the course of the study (each 14 days long) **in addition to four visits** to the Massey University Albany Campus.

Participant Recruitment
Healthy men and women (aged 18-60 years) not currently affected by medical conditions including (but not limited to) diabetes, heart disease or cancer; not currently smoking; and not currently taking medications that affect taste and smell are invited to participate in this study. Participants will undertake a general health screening questionnaire to ascertain whether they are able to be recruited into the study.

The four visits will each be of approximately 45 - 60 minutes duration. There will also be the (optional) opportunity for 10 participants to be interviewed as part of this study, which will increase the visit time by **30 minutes**.

Project Procedures and Participant Involvement
If you agree to participate, you will be asked to participate in **three 14-day experiments** that are designed to assess the effects of several GS-containing mint products on 1) motivations to consume sugar-sweetened food, 2) cravings for sugar-sweetened food and 3) total intake of sugar-sweetened food. In each 14-day trial you will be asked to undertake the following:

Take allocated mint orally three times per day at specified time points: between breakfast and lunch, between lunch and dinner, after dinner but before bed OR to take the allocated mint orally as many times as you like / need throughout the day (up to six mints per day) at times that suit you. The specific procedure will be explained to you prior to each trial. You will also need to complete a Compliance Diary each day during each of these 14-day interventions: the Compliance Diary will help researchers be able to see what time and the reason why you took the GS-containing mint, or alternatively any reason why the GS-containing mint was not taken (for example, you forgot to take the mint).

Possible side effects: Similar GS-containing mints have been used in many other studies and side effects are rare. Those that have experienced any reported mild gastrointestinal upset. Taste effects rarely last longer than 30 - 60 minutes. If you experience any persisting side effects during the study, we encourage you to get in contact with your health professional.

For **all four visits**, you will be asked to complete the following:

- A food frequency questionnaire: specifically developed for assessing sweet food consumption as well as related behaviours.
- A beverage questionnaire
- A food cravings questionnaire
- Bioelectrical Impedance Analysis (BIA)
    - A machine that assesses your body composition. The machine passes a small electrical current through your body. The conductivity of this current is higher through muscle and bone, and lower through fat mass.
    - You will be required to not eat for two hours before your scan.
    - The researchers will sanitise the machine before you use it, which will involve stepping onto the BIA machine with bare feet.
    - Your height (which will be take prior to stepping onto the BIA machine), age, gender and weight (which is measured by the BIA machine) will be entered into the machine by the researcher, and then you will hold onto two handles on either side of the machine and the analysis will begin. The machine will print out the results of the analysis, which the researchers will keep securely and allow you to see **after the research project has finished** if you wish.
    - **Risks**: The BIA does not involve exposure to radiation and is considered safe for most people to use. All body measurements will be taken in a private room for your comfort, and you are encouraged to discuss any feelings of discomfort with the researchers, your health professionals, or to contact any of the numbers listed below (Samaritans or Lifeline) if you experience psychological distress related to the body measurements.

For the **first three visits** you will also be asked to complete sensory testing with the different kinds of GS mints you will be taking for the three 14-day interventions. This will involve the following:

1. Record your hunger and desire for sugar-sweetened food
2. Consume a serving of confectionary
3. Record how pleasant you found the confectionary AND your desire for a second serving
4. You will be given a mint and instructed on how to take it orally
5. AGAIN record your desire for a second serving of confectionary
6. Consume a second serving of confectionary
7. Record how pleasant you found the second serving of confectionary AND your desire for a third serving
8. From this point, any further servings of confectionary are optional (with steps 5 to 7 being repeated in between consumptions). You can at any point decide you would not like another serving of confectionary, at which point sensory testing will stop.

Interviews: We will ask 10 participants to volunteer for interviews, **which will be taken at each of the four visits to campus**. The **same people** will be interviewed at each visit. We will ask questions related to nutrition, behaviour and sensory aspects related to sugar-sweetened food. Sessions will be audio-recorded. You will be asked to sign a separate consent form if you wish to be involved in the interviews and consent to having your answers recorded.

After each visit to the Massey University Albany Campus you will receive $20 koha.

Participant's Rights

Te Kunenga ki Pūrehuroa

School of Sport, Exercise and Nutrition
Private Bag 102904, North Shore City 0745, New Zealand T +64 9 414 0800 www.massey.ac.nz

You are under no obligation to accept this invitation. Should you choose to participate, you have the right to:

- Decline to answer any particular question
- Withdraw from the study at any time, even after signing a consent form (if you choose to withdraw you cannot withdraw your data from the analysis after the data collection has been completed)
- Ask any questions about the study at any time during participation
- Provide information on the understanding that your name will not be used unless you give permission to the researcher
- Be given access to a summary of the project findings when it is concluded

Good Practice and Cultural Safety for Massey University Research

We have considered the inclusion of Māori and indigenous values and concepts, allowing for the use of whānau support and appropriate Māori protocols. We acknowledge the concept of manaakitanga, respecting the participants' inherent dignity and acting in a caring manner towards them by way of:

- Taking full responsibility to perform research in a safe and ethical manner (aroha)
- Providing the participant with all of the critical information regarding the study in a clear way, so they can make informed decisions (tūmanako and whakapono)
- An awareness of the cultural significance and sensitivity for a culturally safe implementation of the study (māhaki)
- Respect for the privacy and confidentiality of Māori participants

Confidentiality

All data collected will be used solely for research purposes and has the possibility of being presented in an international journal. All personal information will be kept confidential by assigning numbers to each participant. No names will be visible on any papers on which you provide information. All data / information will be dealt with confidentiality and will be stored in a secure location for five years on the Massey University Albany Campus. After this time, it will be disposed of by an appropriate staff member from the School of Sport, Exercise and Nutrition.

Project Contacts

If you have any questions regarding this study, please do not hesitate to contact any of the following people for assistance:

Mr David Hsiao (student dietitian)
D.Hsiao@massey.ac.nz (021) 114 8776

Ms Imogen Nelson (student dietitian)
I.Nelson@massey.ac.nz (027) 614 4045

Prof Ajmol Ali
School of Sport, Exercise and Nutrition
A.Ali@massey.ac.nz (09) 213 6414

Prof Rozanne Kruger
School of Sport, Exercise and Nutrition
R.Kruger@massey.ac.nz (09) 213 6661

Dr Warrick Wood
School of Sport, Exercise and Nutrition
W.Wood@massey.ac.nz (09) 213 6663

Ms Sophie Turner
School of Sport, Exercise and Nutrition
S.Turner1@massey.ac.nz (021) 208 2631

Dr Charles Diako
School of Food and Advanced Technology
C.Diako@massey.ac.nz (09) 213 663

Appendix E: Recruitment posters

GOT A SWEET TOOTH MATE?

We want you to take part in our study!

- Do you identify as having a "sweet tooth"?
- Are you physically available to visit the Massey University Albany campus on four occasions for data collection? (You will receive $20 koha after each visit.)

Scan me for more information!

Got questions or want to get involved? Email:
D.Hsiao@Massey.ac.nz
I.Nelson@Massey.ac.nz

MASSEY UNIVERSITY
UNIVERSITY OF NEW ZEALAND

Appendix F: Participant consent form

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Liberate From Sugar, Mate!

PARTICIPANT CONSENT FORM - INDIVIDUAL

I have read and I understand the Information Sheet about the study. I have had the details of the study explained to me, any questions I had have been answered to my satisfaction, and I understand that I may ask further questions at any time. I have been given sufficient time to consider whether to participate in this study and I understand participation is voluntary and that I may withdraw from the study at any time.

1. I agree to participate in this study under the conditions set out in the Information Sheet.
2. I agree to take photos of any treatments being orally administered (i.e. any mints I am given) under the conditions set out in the Information Sheet.

Declaration by Participant:

I _____ [print full name] hereby consent to take part in this study.

Signature: _____ Date: _____

Are you willing to be contacted regarding future research projects within the School of Sport, Exercise and Nutrition? Your name and email address will be saved in a secure location. You will be sent periodic newsletters regarding research studies within the School. You can opt out of this at any time.

□ Tick here if you accept

Appendix G: Ethics approval

ReviewerGroup:
Imogen Nelson, Prof Aj Ali, and Prof Rozanne Kruger
Researcher: David Hsiao
Title: Liberate From Sugar, Mate!
Dear David,
Thank you for the above application that was considered by the Massey University Human Ethics Southern A Committee at their meeting held on 15/07/2022.
On behalf of the Committee I am pleased to advise you that ethical approval has been granted for your research.
Approval is for three years. If this project has not been completed within three years from the date of this letter, reapproval must be requested by contacting the Research Ethics Office at humanethics@massey.ac.nz.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee.
If you wish to print an official copy of this letter:

1. Please login to the RIMS system (https://rme.massey.ac.nz).
2. In the Ethics menu, select Ethics Applications.
3. Using the Advanced search with appropriate criteria to find only this application.
4. With the application on the Results tab, select Reports from the toolbar.
5. Select the "Human Ethics - Full Application Letter" link, this will open the report viewer.
6. Select the application code from the Report Parameters dropdown and submit. You can then select an export option from the top toolbar (Print, Save).

Yours sincerely
Professor Craig Johnson
Chair, Human Ethics Chairs' Committee and
Director (Research Ethics)