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The effect of a 14-day Gymnema sylvestre intervention to reduce sugar intake in people self-identifying with a sweet tooth

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ABSTRACT

Gymnema sylvestre (GS) contains gymnemic acids which can reversibly suppress sweet taste responses. This randomised crossover study aimed to investigate whether supplemental GS use can reduce sugar cravings, sweet food desire and consumption among adults that identify as high sweet food consumers (having a 'sweet tooth'). Participants were told three different mints were trialled to avoid bias. On day zero, 32 healthy participants underwent baseline sensory testing for sweet taste perception using the placebo mint (PLAC). Participants were then randomised into the two intervention groups. On day 15 and 30, participants underwent further sensory testing using the GS mints, before embarking on each 14-day intervention using the GS mints, using either a systematic (at 3 specified times/day; SYS) or ad libitum (up to 6 mints/day at times of their choosing; AD-LIB) regimen, as assigned. On day 30, participants swapped over to the other intervention (using the other regimen), completing final data collection in day 45. 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. The AD-LIB condition reduced daily sugar-sweetened beverages (SSB) intake by 42% relative to PLAC ($p = 0.015$) and reduced overall sugar cravings by 28% relative to PLAC ($p = 0.045$). Both AD-LIB and SYS reduced pleasantness ratings ($p < 0.005$) and desire ($p = 0.005$) for more chocolate. Using GS with an ad libitum regimen reduced sugar cravings and changed sweet food desire and consumption in people identifying as having a sweet tooth.

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; World Health Organization, 2015; Ministry of Health, 2020). There are various strategies to reduce dietary sugar intake including 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 some, but not all, studies show them to be an effective tool in reducing energy intake and sugar intake (Rogers & Appleton, 2021; Rogers et al., 2016; 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). Moreover, sweeteners may induce gastrointestinal distress including bloating and laxative effects (Deis & Kearsley, 2012; Zacharis, 2012). Although NNS can provide sweetness without the energy, research shows mixed results in NNS causing increased sugar cravings (Szalavitz, 2006). Suez et al. (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

Abbreviations: GS, Gymnema sylvestre; PLAC, placebo; SYS, systematic trial; AD-LIB, ad libitum trial; SSB, sugar-sweetened beverages; VAS, visual analogue scale; FFQ, food frequency questionnaire; BevQ, beverage questionnaire; TCQ, the cravings questionnaire; DEBQ, the Dutch eating behaviour questionnaire.

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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-sweet properties (Chattopadhyay, 1998). Gymnema sylvestre has been used in traditional Ayurveda practice to treat sugar-related illnesses such as diabetes (Chattopadhyay, 1998). Gymnema sylvestre specifically acts on these sweet taste receptors. Inside the taste receptor cell, two proteins combine to create a heterodimer or sweet receptor which binds with sugars and other sweeteners. These are the T1R2 and T1R3 proteins for taste receptor family 1, and the associated genes for these proteins are TAS1R2 and TAS1R3. These proteins are not only expressed in the taste bud cells, but in various other body organs and tissues (Lee & Owyang, 2017; Treesukosol et al., 2012). 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 (Anjum & Hasan, 2013; Preuss et al., 2004; Tiwari et al., 2014). Gastrointestinal tissue that absorbs sugar has a structure comparable to the taste buds, enabling detection of sugar in the mouth (Anjum & Hasan, 2013; Preuss et al., 2004). The sweet taste suppression from GS intake is reversible and generally lasts about 30–60 min (Turner et al., 2020). Several studies using formulated GS-containing products (e.g., mints, lozenges) found that supplementing GS-mints reduced pleasure, desire and total confectionary intake (Nobel et al., 2017; Stice et al., 2017; Turner et al., 2020, 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) reported a significant reduction in the desire for high-sugar foods once a 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) found that GS-mints can help reduce the intake of high sugar foods (HSF) by reducing their pleasantness and desire. Turner et al. (2020) reported that participants consumed 21.3% fewer chocolate bars, had reduced desire to eat more HSFs, and had reduced pleasantness following GS mint intake. Moreover, participants who also reported having a 'sweet tooth' showed a greater reduction in pleasantness and desire for another chocolate after GS-mint supplementation (Turner et al., 2020). In addition, 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 acute studies in a laboratory setting, over short periods of time, with no trials longer than 7 days. However, there are no studies that investigated chronic or longer-term use of GS-mints. Therefore, 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 effect of GS-mints in isolation may not be clear.

'Sweet tooth' is a colloquial term that refers to an individual with an intense sweet preference or cravings (Reed & McDaniel, 2006). A sweet tooth can also be defined as a fondness or craving of sweet foods (Reed & McDaniel, 2006). The scientific reasoning for having a sweet tooth is complex and there is no clear answer why some 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) to investigate whether GS could 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 a smoking abstinence 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.

Therefore, this study aimed 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.

2. Methods

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 completed four visits approximately 1 h in duration, 14 days apart across three testing periods. Each of three 14-day programmes was followed, consisting of a sensory test of using GS-mints (twice) or placebo-mints, and questionnaires at each visit (Fig. 1). Participants were asked to complete a daily food diary but were only required to record anything they had eaten during the mint's activation period of 1 h (please note this was not compulsory and we did not use this data for any analysis). Participants in the systematic (SYS) and ad libitum (AD-LIB) groups 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). Each GS mint contained 4 mg of Gymnema sylvestre containing 75% gymnema acids (GA). Participants were told three different mints were being trialled to avoid bias, and therefore each participant acted as their own control. In the SYS and PLAC trials, participants had to consume one mint, three times *per* day at specified times throughout the day (mid-morning, mid-afternoon, after dinner/before bedtime). In the AD-LIB group participants could consume the GS mint at times they needed to (up to six mints *per* day).Potential participants were invited to complete an online pre-screening questionnaire (Qualtrics, Provo, Utah) to establish if they met the inclusion criteria. Participants received written and verbal information about the study, after which they provided written consent before taking part in the study. A G*power calculation was used to determine the sample size. A single power value of 0.80, an effect size of 0.30 (medium effect), a significance level of 0.05 and data from a previous study (Nobel et al., 2017), suggested that 30 participants would be sufficient to detect changes in sweet taste preference. However, to account for dropouts we aimed to get 40 participants for the study. Once the participant went through the screening process, an envelope was opened to indicate which group they would be starting in following the initial PLAC group (i.e. either SYS or AD-LIB).

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). The hypotheses were specified before the data were collected, and the analytical plan was pre-specified.

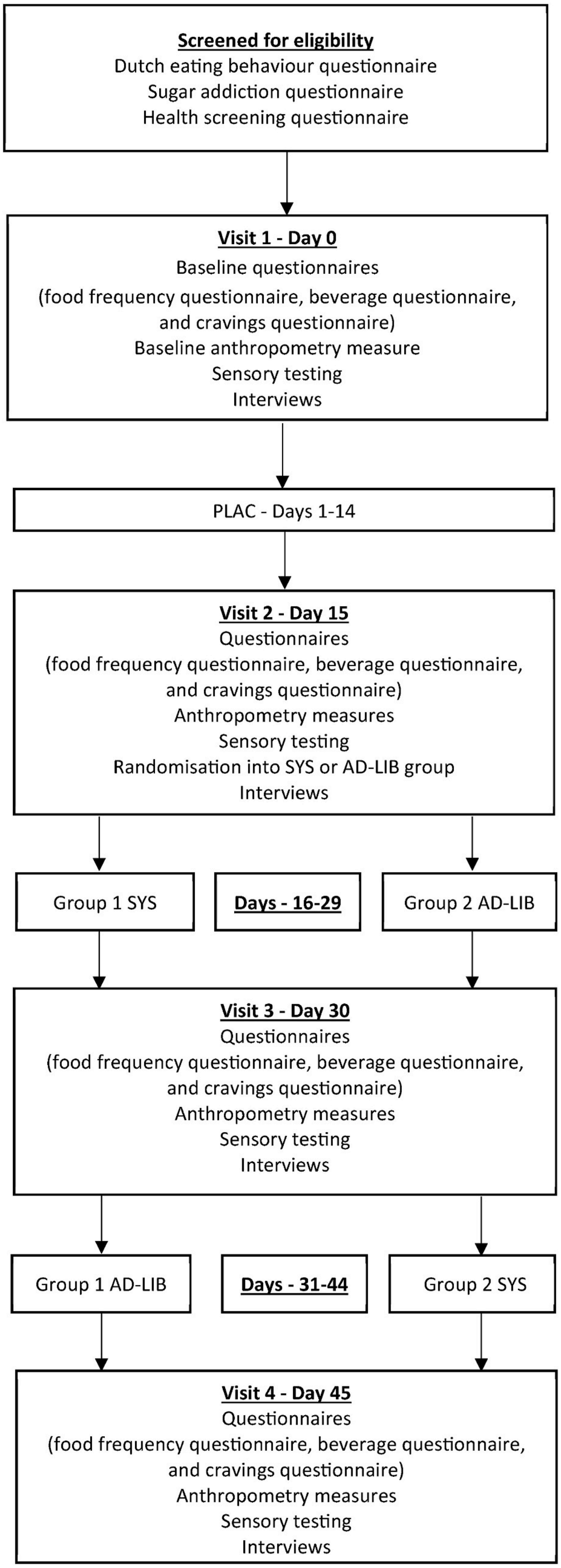


Fig. 1. Participant recruitment flow chart
PLAC (placebo), SYS (Gymnema sylvestre, systematic intake group), AD-LIB (Gymnema sylvestre, ad libitum intake group).

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. Social media posts were shared and handouts were posted in the community such as supermarkets, library, gyms and other universities. Social media posts and handouts contained a QR code that linked participants to a screening questionnaire. Participants were excluded if they did not identify as having a sweet tooth, were current smokers, were pregnant, had a pacemaker, experiencing head trauma, were undergoing any medical investigations and/or were 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; van Strien et al., 1986) 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 assessed different aspects, such as emotional eating, external eating and restrained eating, which can potentially influence an individual's sugar intake. A total of 192 individuals completed the screening questionnaire, 82 individuals were invited to take part in the study and 32 consented to complete the study. Participant characteristics are presented in Table 1.

2.3. Sensory testing

Sensory evaluation was carried out at each laboratory visit in individual booths; red lighting was used (in the sensory booths) 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) and Whittaker's 33% milk chocolate (Whittaker's, Porirua, New Zealand)). Confectionary was standardised and each serving contained the same quantity of sugar. 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 visual analogue scale (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

Table 1
Participant characteristics.

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

[a] mean ± standard deviation.
[b] geometric mean confidence interval 25th −75th.

'yes', the procedure mentioned above was repeated until participants chose *'no'*, which would end the sensory testing. This methodology followed the protocols of Turner et al. (2020, 2022).

2.4. Anthropometry

Participants were asked to be at least 1-h fasted before anthropometric measurements were taken (only water intake was allowed). 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).

2.5. Questionnaires

The food frequency questionnaire (FFQ) was designed to record the number of sweet foods participants consumed during the month (Jayasinghe et al., 2017). The validated FFQ contains 69 sweet foods which include natural and processed foods within various categories including fruit 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 validated beverage questionnaire (BevQ; Hedrick et al., 2010), was designed to record the number of items and total amount of sweet beverages consumed. The BevQ contains 15 beverages which include water, dairy-, sugar-free-, alcoholic-, sports-, and 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) consists of 39 questions categorised in 9 groups that measure specific craving cues. The TCQ questionnaire is 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*).

The Dutch Eating Behaviour Questionnaire (DEBQ; Van Strien et al., 1986; Christopher, 2007), validated for use in healthy adults, contains 33 questions on restrained eating, emotional eating, and external eating. The Sugar Addiction Questionnaire (SAQ; Fawzy et al., 2018), validated using a panel of medical surgical nursing staff, contains 20 questions on sugar addiction attributes. Completion of the DEBQ and SAQ formed part of the initial screening procedures; the responses were given a number value (no = 0, maybe/sometimes = 1, and yes = 2) and were used to assess inclusion in the study. All questionnaires were administered online via Qualtrics.

2.6. Data handling

Body mass index (BMI) was calculated using the Quetelet index (weight (kg)/height (m)^2) and reported as a continuous variable. The FFQ, TCQ, and BevQ was downloaded from Qualtrics as a spreadsheet (Excel, Microsoft Office 365, Redmond, WA, USA). The 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 were recorded and stored online using Compusense Cloud (Guelph, ON, Canada).

2.7. Statistical analysis

Analysis was performed using the 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 25th-75th 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 repeated measures analysis of variance (ANOVA). The non-parametric test Kendall's 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 indicated 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's d (1988) of 0.1, 0.3 and 0.5 were used to indicate small, moderate and large effect sizes, respectively.

3. Results

3.1. Sensory testing

Fig. 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).

There was a main effect of desire for chocolate ($p = 0.018$; Fig. 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 ± 31 mm).

There were no statistically significant differences between trials with regards to hunger and number of confectionary eaten (p = 0.25; Fig. 4).

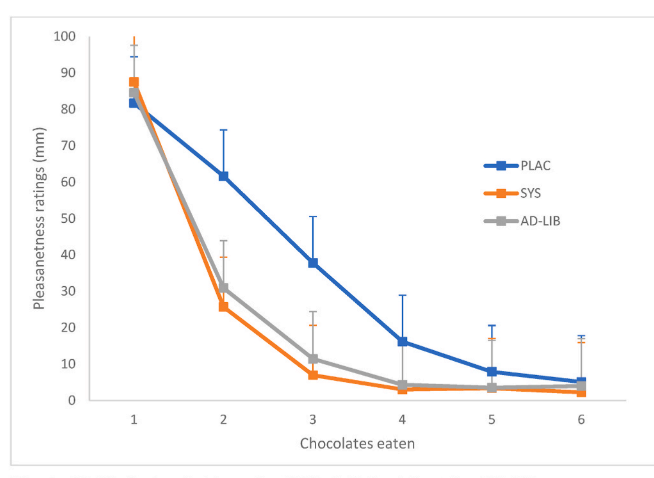
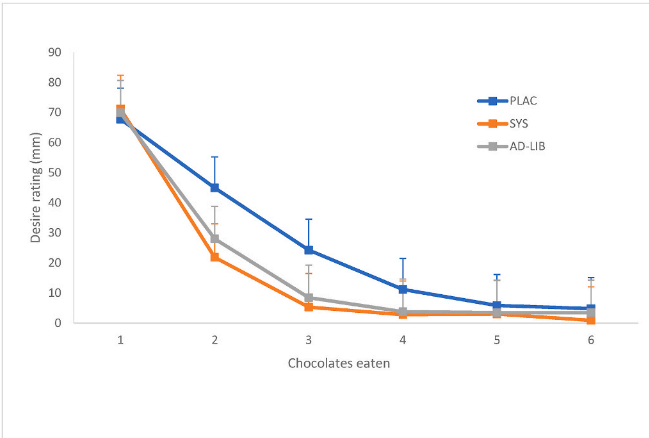
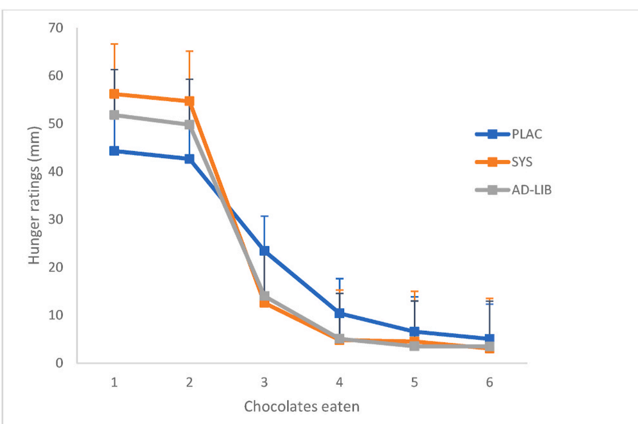


Fig. 2. Interaction between intervention and number of confectionary eaten on participants' pleasantness ratings
Placebo (PLAC), Systematic intervention (SYS), Ad libitum intervention (AD-LIB).



Placebo (PLAC), Systematic intervention (SYS), Ad libitum intervention (AD-LIB)

Fig. 3. Interaction between intervention and number of confectionary eaten on participants' desire ratings
Placebo (PLAC), Systematic intervention (SYS), Ad libitum intervention (AD-LIB).



Placebo (PLAC), Systematic intervention (SYS), Ad libitum intervention (AD-LIB)

Fig. 4. Interaction between intervention and number of confectionary eaten on participants' hunger ratings
Placebo (PLAC), Systematic intervention (SYS), Ad libitum intervention (AD-LIB).

3.2. Cravings

Table 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 2 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) (when compared to PLAC) for the question *'If I give in to a food craving, I keep thinking about eating until I actually eat the food'*. Only AD-LIB showed a significant effect (relative to PLAC) for the question *'If I eat what I am craving, I often lose control and eat too much'* (2.02, $p = 0.033$).

Table 2 also 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 (relative to PLAC) for the question, *'eating what I crave makes me feel better'* (2.03, p = 0.005).

Table 2 shows the craving questionnaire group *'cravings on physiological state'*. Only AD-LIB showed a significant effect (relative to PLAC) for the 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.

3.3. Sugar intake from foods

Table 3 shows the average mL/day for SSB and g/day for SSF intake over each intervention period. There was a main effect of treatment for SSB intake (p = 0.047); specifically, SSB intake showed a 42% decrease after AD-LIB intervention (p = 0.015) relative to PLAC. 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 of SSF intake between AD-LIB and SYS (p > 0.05).

3.4. Body composition and sweet food intake

There was no effect of treatment on body composition (p > 0.05; Table 4).

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 regimen would affect high sweet food 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 from this study 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 reported 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., 2017; Stice & Yokum, 2018; Turner et al. 2020, 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., 2017; Turner et al. 2020, 2022). A novel finding of this study is that treatment type or regime (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

Table 2
The cravings questionnaire.

The Cravings Questionnaire	Baseline	PLAC (Placebo)	SYS (Systematic)	AD-LIB (Ad libitum)	*p*-value Friedman test	Kendall's w effect size
The cravings questionnaire result						
Total cravings score	2.92	2.70	2.44	1.94*	0.045	0.107
The cravings questionnaires 'lack of control and overeating'						
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
The cravings questionnaire 'anticipation of positive reinforcement that may result from eating'						
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
The Cravings Questionnaire; Cravings as a physiological state						
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, the cravings score was converted into ranks before conducting statistical analysis, not adjusted for age or sex *Significant effect against placebo ($p < 0.05$). [&] Partial eta Kendall's W.

Table 3
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[a] (mL/day from sugary foods)	410 (298–563)	363 (249–530)	314 (190–519)	212 (117–382)[b]	0.047	0.038	0.273
Sugar Foods[a] (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.
[a] Geometric mean (95% CI). η^2 Partial eta.
[b] Significantly different from placebo ($p = 0.015$).

Table 4
Body composition and 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)[a]	74.0 ± 17.3	73.9 ± 17.4	73.8 ± 17.1	73.7 ± 17.1	0.146	0.914	0.184
Body fat mass (kg)[a]	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)[a]	50.1 ± 10.6	49.9 ± 10.6	50.1 ± 10.6	50.1 ± 10.5	0.993	0.715	0.003

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

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, 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 regime could be beneficial outside the study for longer-term decrease in SSB consumption (because SSBs are readily available and GS-mint poses a possible solution in reducing their palatability).

Although both intervention methods (SYS and AD-LIB) showed decrease in SSF intake, 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 why the effect of systematic-administered GS was not significant may be the fact that the GS-mint's anti-sweet effect lasted for approximately 30 min. 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 systematically or ad libitum, 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 (2 weeks each), body composition was not expected to change, and so future studies should investigate whether a longer intervention period (with an ad libitum regimen) is likely to reduce body mass and/or fat mass. However, it should also be noted that the studies by Woodgate and 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 stimulated body fat loss; their findings indicated 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 assesses whether longer administration of GS affects body weight as a result of its anti-sweet properties, is merited.

This is the first study to investigate an AD-LIB administration of GS-containing mints alongside a SYS administration. We have shown that AD-LIB application decreased total SSB intake and total score of TCQ. Ad libitum intake 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 on set times of the day. Overall, AD-LIB has consistently performed better than PLAC and SYS. Moreover, there were no side effects reported by any participants for any of the trials.

4.1. 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' techniques 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. After the consumption of the GS mint, several participants did not follow the expected trend of reducing consumption of high-sugar sweet foods. Although these participants gave the high-sugar sweet food (confectionary) low pleasantness ratings, they continued to eat more servings. We speculate that this was due to a 'curiosity factor', as participants were unfamiliar with Gymnema sylvestre's sugar suppression effect and wanted to try it. We hypothesise that as participants became accustomed to the taste modulation using the GS mint, repeated exposure to this product would eliminate the 'curiosity factor'. Participants were asked to record anything they consumed within the hour of taking the mints (but this was not compulsory and we did not undertake any analysis on this information). However, participants may have 'cheated' this system by waiting the full hour before eating sweets without needing to record their intake of sweet foods.

All participants in this study were a self-identified sweet tooth; however, 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. Therefore, some participants may have reduced their sugar intake without the taste-altering supplement simply because they were in a study that aimed to reduce sugar. Other limitations of this study include the small sample size and we did not estimate fidelity to the treatment instructions (e.g., taking the mints when required for SYS and PLAC trials).

Future research should explore the effect of this intervention in people who have impaired glucose tolerance as GS has been 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 investigate strict dietary regimes such as intermittent fasting, or the keto diet, with GS-mint supplementation, to understand if GS-mints can curb cravings whilst being on a restrictive food consumption diet. We also recommend future research studies should use larger sample sizes, explore the ad libitum regimen for longer, monitor body weight changes as well as investigate potential changes to metabolic health.

4.2. 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.

CRediT authorship contribution statement

Hsiao WH: Writing – review & editing, Writing – original draft, Visualization, Investigation, Formal analysis, Conceptualization. **Kruger R:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Diako C:** Writing – review & editing, Software, Methodology, Formal analysis. **Nelson I:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Stice E:** Writing – review & editing, Methodology, Conceptualization. **Ali A:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Conceptualization.

Ethical approval

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).

No AI was used to generate the contents of this paper.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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