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ORIGINAL ARTICLE

SUGAR-SWEETENED BEVERAGE CONSUMPTION AND RISK OF VISCERAL FAT ACCUMULATION AMONG UNIVERSITY STUDENTS IN THAILAND

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ABSTRACT

Background. Increased consumption of sugar-sweetened beverages (SSBs) is associated with obesity and metabolic health risks.

Objective. This study determined the relationship between SSB intake and body composition, with a focus on visceral fat accumulation among Thai university students.

Material and Methods. A cross-sectional study was conducted with 387 university students aged 19-22 years. Dietary intake was assessed using a 3-day, 24-hour dietary recall conducted on three consecutive day to quantify SSB consumption. Body composition metrics, including body mass index (BMI), fat mass, and visceral fat levels (VFL), were measured using bioelectrical impedance analysis. Statistical analyses, including t-tests and linear regression, were used to identify the associations between SSB intake and body composition.

Results. Sweetened tea, particularly freshly prepared iced milk tea, was most frequently consumed. High sugar consumption from SSB ($\geq$ 24 g/day) was significantly associated with increased fat mass (16.9 ± 9.9 vs. 14.8 ± 7.8 kg, $p = 0.021$), BMI (22.6 ± 5.0 vs. 21.3 ± 4.2 kg/m², $p = 0.007$), and VFL > 9 (83.3% vs. 16.7%, $p = 0.013$). Sugar intake increased progressively across BMI categories: underweight (25.21 g/day), normal-weight (28.78 g/day), overweight (32.18 g/day), and obese (34.00 g/day). Participants with a VFL above 9 consumed over 40 g/day of SSB-derived sugar. At VFL exceeding 10, males had an average BMI of 30.06 ± 2.40 kg/m², whereas females exhibited a dramatically higher BMI of 41.20 ± 3.27 kg/m².

Conclusion. Excessive SSB consumption, particularly sweetened tea, is strongly associated with higher visceral fat and unfavorable body composition in young adults. Public health interventions targeting reduced SSB intake are urgently required to address obesity and metabolic health risks. Further longitudinal studies are recommended to confirm causality and inform dietary guidelines.

Keywords: *sugar-sweetened beverages (SSBs), visceral fat accumulation, body composition assessment, adolescent health, metabolic health risks, dietary assessment*

INTRODUCTION

Obesity has been reported as a critical global public health problem, contributing significantly to the prevalence of non-communicable diseases (NCDs) such as type 2 diabetes, cardiovascular disease, and metabolic syndrome [1]. Among the dietary factors driving obesity, sugar-sweetened beverage (SSB) consumption has been a major concern because of its high simple sugar (sucrose, fructose) content (readily absorbable sugars) and widespread accessibility [2]. Therefore, public health strategies worldwide have prioritized reducing sugar intake (to less than 24 g/day of added sugar) to combat obesity and its associated health risks [3]. However, the recent COVID-19 pandemic, accompanied by quarantine measures, has complicated public health efforts by encouraging unhealthy changes in dietary habits, prompting increased reliance on energy-dense beverages, including sugar-sweetened beverages (SSBs) [4, 5].

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Moreover, periods of lockdown and social distancing have been associated with reduced physical activity, elevated stress levels, and disrupted daily routines, all of which have been linked to unhealthy eating and drinking patterns [6].

Adolescents and young adults may be particularly susceptible to these changes as they often experience heightened psychological stress and exhibit a greater propensity to consume convenience-oriented food and beverage products. Sugar-sweetened beverages (SSBs) contain large amounts of sucrose, which are digested into glucose and fructose. Fructose undergoes rapid metabolism in the liver, where it is converted into lipids. This process contributes to fat accumulation in the liver and visceral organs, leading to adverse health outcomes such as insulin resistance. Additionally, fructose metabolism in the liver can be converted into lipids that promote rapid proliferation of cancerous cells, as shown in animal models [7]. Thailand presents a compelling case study for examining the health impacts of sugar-sweetened beverage (SSB) consumption due to its elevated baseline levels of intake. In particular, the Bangkok Metropolitan Region demonstrates a significantly higher consumption rate compared to other parts of the country, including the southern region, where consumption levels tend to be more moderate. These regional disparities underscore the importance of considering local cultural norms, availability of beverage products, and socioeconomic determinants in dietary behavior analysis [8]. Thailand provides a unique context for addressing this research gap. According to a 2019 national survey, 34% of Thai residents aged 15 and older consumed SSBs at least three times per week, and 14.3% consumed them daily, far exceeding global averages and the World Health Organization recommendation for free sugar intake of less than 24 g/day [9]. University students represent a particularly high-risk subgroup within this population due to their distinct dietary practices and transitional lifestyle behaviors. As they gain autonomy over food choices during the transition to adulthood, many rely increasingly on convenient high-sugar beverages. The widespread availability and affordability of SSBs on university campuses further exacerbate this issue. Moreover, academic and social stressors, coupled with high levels of sedentary behavior related to academic demands, place this demographic at heightened risk for weight gain, adverse metabolic outcomes, and related comorbidities. Although substantial evidence links SSB consumption to obesity, research on the specific effects of SSB intake on body composition, particularly the accumulation of visceral adipose tissue (VAT), remains less well documented [10]. This gap in evidence is particularly relevant in young adults from low- and middle-income countries (LMICs), including Thailand, where dietary patterns are strongly influenced by cultural and environmental factors. Addressing this knowledge deficit is critical for the development of effective, context-specific public health strategies.

This small-scale, cross-sectional study aimed to (1) quantify total sugar intake from SSB consumption, including taxed and non-taxed beverages, among Thai university students and (2) examine the association between sugar intake from SSB and body composition metrics. Specifically, this study was designed as a small-scale survey to gather data on these factors from university students in Thailand. This study determined SSB consumption patterns and their impact on visceral adipose tissue (VAT) in a population vulnerable to pandemic-related lifestyle disruptions. By examining the relationship between SSB intake and VAT, this study highlighted the metabolic risks associated with dietary behaviors among Thai university students. The findings contribute to post-pandemic dietary research and inform evidence-based public health interventions, supporting Thailand's obesity prevention efforts, while providing actionable insights for similar global contexts to mitigate long-term health risks in young adults.

MATERIAL AND METHODS

Study design and participants

This cross-sectional study was conducted between July and October 2022 at Walailak University, Nakhon Si Thammarat, Thailand. Walailak University was chosen as the study site because of its diverse student population, which includes individuals from varied socioeconomic and cultural backgrounds, making it an ideal setting for investigating dietary and lifestyle behaviors. The university also represents a microcosm of the broader Thai adolescent and young adult demographic, particularly in terms of dietary transitions and lifestyle changes influenced by urbanization and academic pressures. Ethical approval for the study was granted by the Walailak University Ethics Committee (WUEC-22-207-01) and all participants provided written informed consent prior to participation. Eligible participants were undergraduate students aged 19-22 years who met the following criteria: (1) enrolled in a full-time academic study (6-8 hours per day), (2) no underlying medical conditions that could influence metabolic health, and (3) regular consumption of sugar-sweetened beverages (SSBs) at least three times per week. Exclusion criteria included physical, mental, or cognitive limitations that might affect the reliability of the questionnaire. A target sample size of 387 students was calculated using the Taro

Yamane formula (e = 0.05) to ensure adequate statistical power and representativeness. Systematic random sampling was used to reduce selection bias, while ensuring proportional representation across academic disciplines.

Data collection and measurements

Setting-specific context and questionnaire development

Walailak University was selected not only for its diverse demographics, but also for its location in a semi-urban area of southern Thailand, where dietary patterns often reflect a mix of traditional and modern influences. The availability of low-cost, high-sugar beverages on and around campus further highlights the relevance of studying SSB consumption in this setting. Data were collected through face-to-face interviews using a pre-validated questionnaire (index of item-objective congruence = 0.89). The questionnaire was tailored to reflect the common dietary habits and beverage consumption patterns among Thai university students, particularly in a semi-urban context. The key components are as follows: (1) Demographics: Age, gender, income, and academic background, (2) Lifestyle Factors: Physical activity, smoking, and alcohol use, (3) SSB Consumption: Types, frequency, and volume of beverages consumed.

Dietary intake assessment

A 3-day, 24-hour dietary recall was used to quantify sugar-sweetened beverage (SSB) consumption over three consecutive days, as previously described by Schröder et al. [11]. Students provided detailed information about the types, brands, and quantities of beverages consumed, as well as the context of consumption (e.g., alone, socially, with meals). To ensure accuracy, nutritional labels and previously published LC-MS/MS data [12] were used to estimate the sugar contents of both labeled and unlabeled beverages. Trained interviewers provided guidance to minimize reporting bias.

Body composition analysis

Body composition metrics were assessed using bioelectrical impedance analysis (BIA) (TANITA Model BC-418MA, Tokyo, Japan) in a controlled environment at the School of Public Health to ensure participant convenience while maintaining standardized conditions. All assessments were performed by a single trained research assistant who received standardized training to ensure consistency in measurement procedures. This same assessor was responsible for all measurements to minimize variability. To enhance measurement accuracy and reduce potential confounding factors, participants adhered to strict pre-assessment conditions, including conducting measurements in the early morning following an overnight fast ($\geq$ 8 hours), wearing light clothing, and emptying their bladders before assessment. Additionally, participants were required to abstain from vigorous physical activity for at least 12 hours and avoid alcohol consumption for 24 hours before the assessment. Measurements were taken after five minutes of rest in a standing position to ensure fluid stabilization, while room temperature was maintained between 22°C and 24°C to minimize temperature-related variations in bioelectrical impedance. Female participants were scheduled to avoid measurements during menstruation to account for potential fluid retention effects. The potential error rate in body composition assessment could arise from both device-related and human-related factors. The TANITA Model BC-418MA is a validated BIA device, though BIA generally has an error margin of ± 3-8%, with variability influenced by hydration status, body temperature, and compliance with pre-measurement protocols. Human-related error, such as slight variability in participant posture, electrode contact, or adherence to pre-assessment instructions, was minimized by strictly following a standardized protocol. These precautions were implemented to ensure measurement consistency and enhance the accuracy of body composition assessments. The BIA provides detailed metrics, including body fat percentage (BFP%), fat mass (FM), fat-free mass (FFM), muscle mass (MM), basal metabolic rate (BMR), visceral fat levels (VFL),visceral fat levels (VFL): A score $\leq$ 9 was considered healthy, while $\geq$ 10 indicated increased metabolic risk. To enhance accuracy, participant-specific characteristics (age, sex, and height) were inputted into the BIA system. body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2).

Statistical analysis

Descriptive statistics (means, standard deviations, and percentages) were used to summarize demographic, dietary, and body composition data. The statistical methods used were as follows:

- *Chi*-square and Fisher's Exact Tests: For Associations between categorical variables (e.g. SSB consumption levels and BMI categories).
- Independent t-tests: To compare the mean differences in SSB intake and body composition metrics between groups.

Statistical significance was set at $p < 0.05$, and all analyses were performed using GraphPad Prism (version 10). Limitations related to the cross-sectional nature of the study and potential biases in self-reported dietary data were addressed through methodological rigor and the contextual focus provided by Walailak University.

RESULTS

Demographic and body composition characteristics of participants

This small-scale cross-sectional study recruited 387 Thai university students to investigate the relationship between sugar-sweetened beverage (SSB) consumption, lifestyle behaviors, and body composition. Participants were classified into two groups based on their sugar intake from SSBs: high sugar intake (> 24 g/day) and low sugar intake (≤ 24 g/day) (Table 1). The results revealed significant differences in the body composition metrics between these groups. Participants in the high SSB intake group demonstrated significantly higher mean body mass index (BMI) (22.6 ± 5.0 vs. 21.3 ± 4.2, p = 0.007, t-test) and fat mass (16.9 ± 9.9 kg vs. 14.8 ± 7.8 kg, p = 0.021, t-test). Elevated visceral fat levels (VFL > 9) were notably more prevalent in the high SSB group (83.3% vs. 16.7%, p = 0.013, *Chi*-square test), indicating a heightened metabolic risk associated with consuming more than 24 g/day of sugar. Additionally, participants whose energy intake from SSBs exceeded 10% of their basal metabolic rate (BMR) had significantly higher total energy requirements (1326.9 ± 245.5 kcal vs. 1239.5 ± 208.9 kcal, p < 0.001). Differences in body composition appeared to be associated with SSB consumption. Lifestyle behaviors also differed significantly between the two groups. Alcohol was more common among participants with high SSB intake (61.4% vs. 38.6%, p = 0.037, *Chi*-square test), whereas regular physical activity was slightly less frequent in this group (48.4% vs. 51.6%, p = 0.010, *Chi*-square test). These findings suggest that excessive SSB intake may be associated with unhealthy lifestyle behaviors, including alcohol consumption and reduced physical activity.

SSB consumption and visceral fat risks

Excessive consumption of sugar-sweetened beverages (SSBs) was associated with obesity-related risks, including elevated fat mass and visceral adiposity. To further elucidate this association, distinct SSB consumption patterns were analyzed, and their relationship with obesity-related risks was examined. As illustrated in Figure 1, there were significant variations in sugar-sweetened beverage (SSB) consumption patterns among the participants; freshly prepared iced milk tea was identified as the most frequently consumed SSB, followed by carbonated, freshly prepared iced milk coffee, and fruit juice drinks. Participants with elevated visceral fat levels (VFL > 9) consumed nearly double the amount of added sugar from SSBs compared to those in the normal VFL group (49.7 g/day vs. 26.9 g/day). Notably, sweetened tea accounted for a substantial proportion of this sugar intake, with high-risk individuals consuming an average of 42.2 g/day compared with 21.3 g/day in the lower-risk groups. Participants categorized as high-sugar

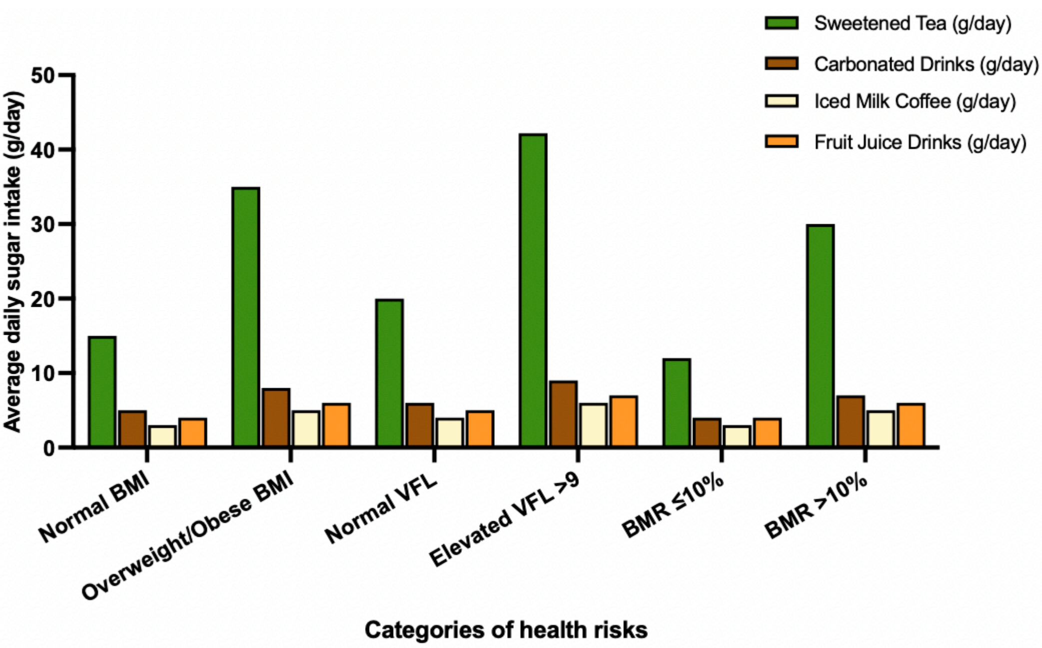

Figure 1. Average daily sugar intake from different SSB types across health risk categories among Thai university students (n = 387). The bar graph shows the average daily sugar intake (g/day) for four categories of sugar-sweetened beverages (SSBs): sweetened tea, carbonated drinks, iced milk coffee, and fruit juice drinks. Participants were categorized based on BMI (normal vs. overweight/obese), visceral fat level (VFL; normal vs. elevated VFL > 9), and the percentage of basal metabolic rate (BMR) derived from sugar (≤ 10% vs. > 10%). Data were analyzed using GraphPad Prism (version 10).

Table 1. The association between sociodemographic factors, body composition metrics, and sugar consumption

Variables	All participants n (%) or mean ± SD	Sugar-sweetened beverages consumption n (%) or mean ± SD		p-value
		> 24 g/day (n = 215)	≤ 24 g/day (n = 172)	
Age[a], years	21.52 ± 2.8	20.91 ± 2.5	21.01 ± 2.1	0.249
Gende[rb])				
– Male, n	65 (16.8)	45 (69.2)	20 (30.8)	0.472
– Female, n	322 (83.2)	170 (52.8)	152 (47.2)	
Income[b] (Bath)				
– < 5,000 (150 USD), n – 5,000-10,000, n – > 10,000 (286 USD), n	150 (38.8) 197 (50.9) 40 (10.3)	83 (55.3) 107 (54.3) 25 (62.5)	67 (44.7) 90 (45.7) 15 (37.5)	0.535
Exercise[b], n	192 (49.6)	93 (48.4)	99 (51.6)	0.017*
Smoking[b], n	9 (2.3)	3 (33.3)	6 (66.7)	0.185
Alcohol[b], n	158 (40.8)	97 (61.4)	61 (38.6)	0.037*
BMI[b] (kg/m^2)				
– Underweight, n	92 (23.7)	39 (42.4)	53 (57.6)	0.033*
– Normal, n	163 (42.0)	92 (56.4)	71 (43.6)	
– Overweight, n	51 (13.4)	33 (64.7)	18 (35.3)	
– Obesity, n	81 (20.9)	51 (63.0)	30 (37.0)	
BMI[a], kg/m^2	22.1 ± 4.7	22.6 ± 5.0	21.3 ± 4.2	0.007*
BMR				
– ≤ 10% BMR[b], n	254 (65.6)	174 (68.5)	80 (31.5)	< 0.001*
– BMR[a], kJ	5389.0 ± 977.3	5552.0 ± 1027	5186 ± 874	< 0.001*
Fat				
– Risk[b),c)], n	251 (64.9)	106 (42.2)	145 (57.8)	0.142
Fat mass[a], kg	16.0 ± 9.0	16.9 ± 9.9	14.8 ± 7.8	0.021*
VFL				
– VFL > 9 (Risk)[b),d)], n	18 (4.7)	15 (83.3)	3 (16.7)	0.013*
– Visceral fat level[e] (Medium (Q2, Q3))	3 (1, 5)	3 (2, 6)	2 (2.5)	0.002*
Total body water[a], %	52.2 ± 26.1	51.1 ± 4.3	50.9 ± 4.0	0.6898
Bone mass[a], kg	2.7 ± 0.5	2.4 ± 0.5	2.2 ± 0.4	< 0.001*
Muscle mass[a], kg	39.2 ± 8.4	40.6 ± 8.7	37.7 ± 7.2	< 0.001*

[a] Difference in mean were determined by a t-test, with *p-value < 0.05; [b] Difference in percentage were determined by a *Chi*-square test, with *p-value < 0.05; [c] Body Fat Percentage: mormal male (14-20%), normal female (17-24%); [d] For individuals under 30 year of age, a normal visceral fat level is less than 9; BMI – body mass index, BMR – basal metabolic rate, VFL – visceral fat level; [e] For non-normally distributed variables (e.g., visceral fat level), Mann-Whitney U tests were applied (p < 0.05).

consumers (> 24 g/day) exhibited significantly higher mean BMI and fat mass, demonstrating an association between SSB consumption and increased abdominal fat. Additionally, participants whose sugar-derived energy intake surpassed 10% of their basal metabolic rate (BMR) consumed significantly more sugar from SSBs (48.9 g/day) than those within the recommended threshold (17 g/day). This finding highlights that sweetened tea, as the primary contributor to excessive sugar intake, was associated with an elevated body fat percentage and a higher likelihood of being overweight or obese.

Associations between sugar intake and body composition metrics

Given the significant association between daily sugar intake from SSBs and various body composition measures, the relationship between SSB-derived sugar intake and specific body composition metrics was further investigated. As depicted in Figure 2,

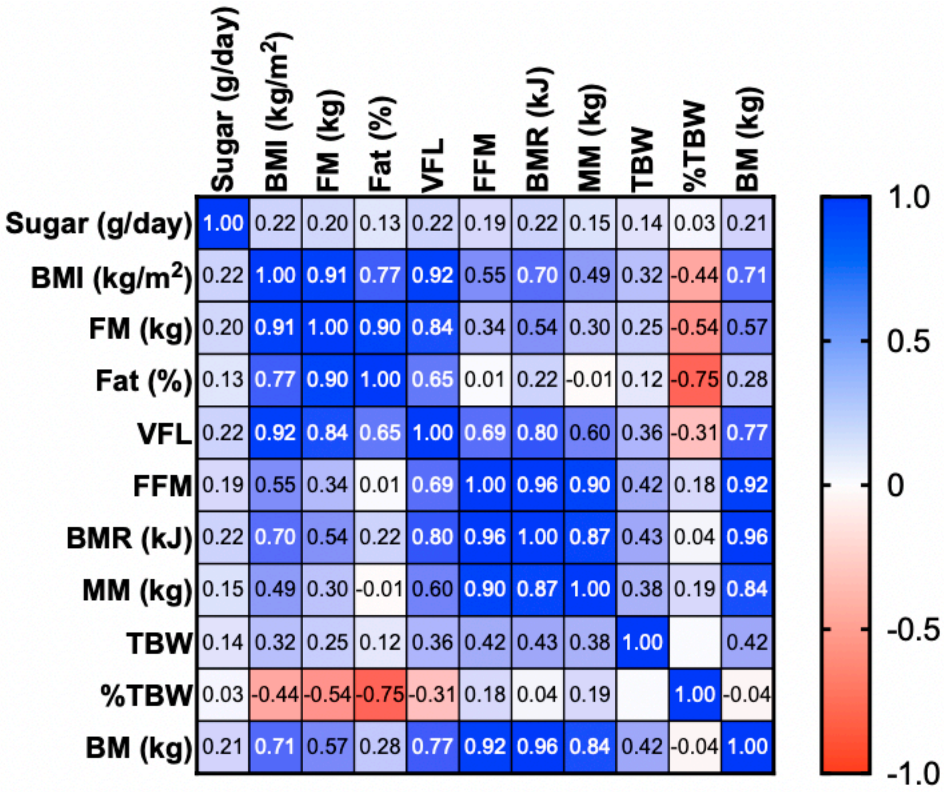

Figure 2. The heatmap displays the Pearson correlation coefficients (r) between sugar-sweetened beverage (SSB) consumption and body composition metrics. Sugar intake showed a weak positive correlation with BMI ($r = 0.22$), fat mass ($r = 0.20$), fat percentage ($r = 0.13$), and visceral fat levels (VFL; $r = 0.22$). Strong correlations were observed between BMI and fat mass ($r = 0.91$), BMI and % of fat ($r = 0.77$), and fat mass and VFL ($r = 0.84$), indicating the interconnected nature of adiposity measures. The color intensity indicates the strength and direction of the correlation, with red representing a positive correlation and blue representing a negative correlation. Data were analyzed using GraphPad Prism (version 10).

the correlation matrix revealed a weak positive relationship between sugar intake and obesity-related measures. The correlation coefficients were 0.22 for fat mass, 0.20 for BMI, 0.13 for fat percentage (visceral fat), and 0.22 for visceral fat levels (VFL). BMI displayed a strong positive correlation with fat mass ($r = 0.91$) and a moderate correlation with % fat ($r = 0.77$), whereas fat mass showed a robust correlation with % fat ($r = 0.90$) and a moderate correlation with VFL ($r = 0.84$). Higher SSB consumption was associated with slight increases in BMI, fat mass, and VFL, particularly among individuals whose sugar-derived energy intake exceeded 10% of their BMR. Stronger correlations were observed in body composition measures, emphasizing the link between adiposity and fat distribution. These findings highlight the importance of reducing SSB intake and incorporating comprehensive body composition assessments to mitigate metabolic health risk.

Figure 3A shows a significant mean difference between sugar-sweetened beverage (SSB) consumption and body mass index (BMI) categories. Daily SSB-derived sugar intake progressively increased across BMI categories, with underweight individuals (BMI < 18.0 kg/m²) consuming an average of 25.21 g/day, normal-weight participants (BMI 18.0-22.9 kg/m²) consuming 28.78 g/day, overweight individuals (BMI 23.0-29.9 kg/m²) consuming 32.18 g/day, and obese individuals (BMI ≥ 30.0 kg/m²) consuming the highest amount at 34.00 g/day. This trend suggests that a higher SSB intake is closely associated with increased BMI, potentially contributing to body weight gain and fat accumulation. Additionally, Figure 3B shows a strong positive correlation ($r = 0.77$) between BMI and body fat percentage, with each 1-unit increase in BMI corresponding to a 1.4% increase in body fat percentage. This observational study highlighted a positive association between daily sugar intake from SSBs and BMI, suggesting a potential link between higher SSB consumption and increased body weight and fat accumulation.

Gender-specific differences in visceral fat and BMI associated with SSB consumption

As previously reported, given the potential influence of sex-specific physiological and metabolic processes as well as potential variations in consumption behaviors, sex-specific differences in the associations between SSB consumption, visceral fat, and BMI were further investigated. In males (Figure 4A, mean-connecting plot), a visceral

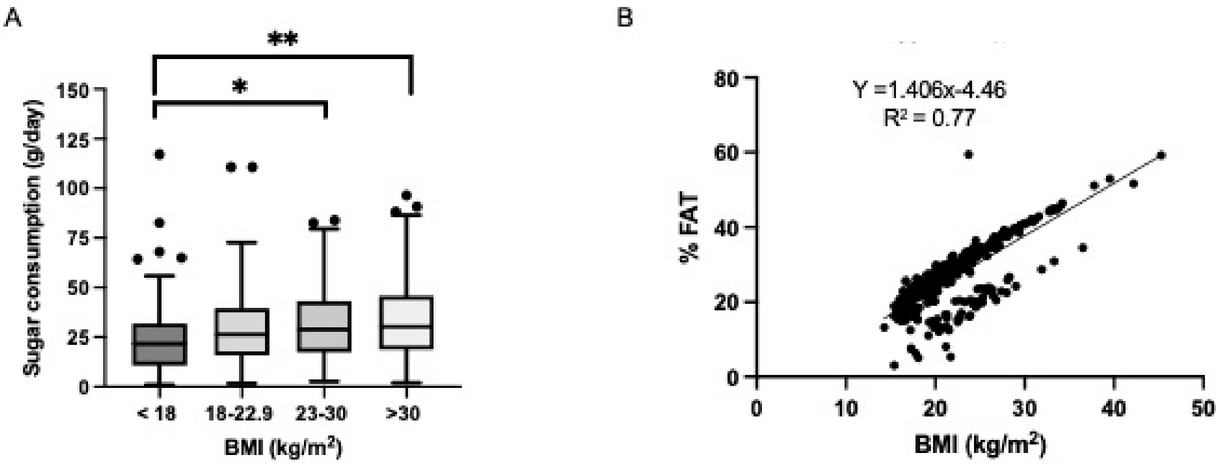

Figure 3. Relationship between sugar consumption, BMI, and body fat percentage in Thai university students (n = 387). (A) Sugar consumption (g/day) across BMI categories (<18, 18-22.9, 23-29.9, ≥ 30 kg/m²). Data are presented as box-and-whisker plots showing the median, interquartile range (IQR), and minimum/maximum values. *$p < 0.05$, **$p < 0.01$ (one-way ANOVA with Tukey's post hoc test). (B) Correlation between BMI (kg/m²) and body fat percentage (%). The line represents the linear regression fit, with the regression equation and the coefficient of determination indicated ($R^2 = 0.77$). Data were analyzed using GraphPad Prism (version 10).

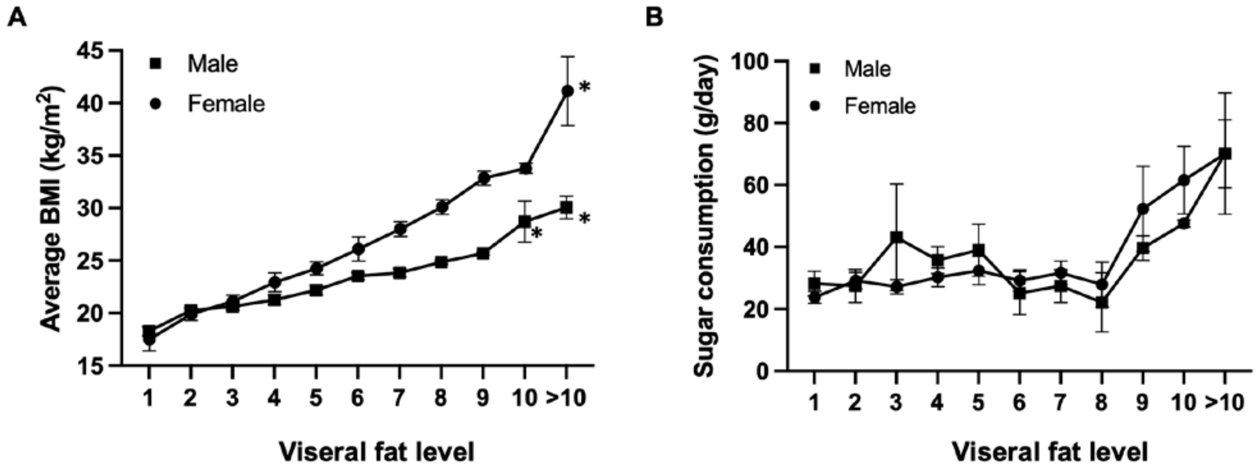

Figure 4. Mean-connecting plot of sex-specific associations between visceral fat level (VFL), body mass index (BMI) (A), and SSB-derived sugar consumption (B). *$p < 0.05$, (t-test).

fat level (VFL) of 10 or higher was associated with significantly elevated BMI values: 28.72 ± 4.67 kg/m² ($p = 0.0159$, t-test) for VFL = 10 and 30.06 ± 2.40 kg/m² ($p = 0.0159$, t-test) for VFL > 10, compared to a BMI of 25.70 kg/m² for a normal VFL of 9. In females, BMI also increased with higher VFL, reaching 32.91 ± 0.67 kg/m² ($p = 0.0667$, t-test) for VFL = 10 and 41.20 ± 3.27 kg/m² ($p = 0.0061$, t-test) for VFL > 10. This suggests that visceral fat accumulation is associated with an increased BMI, indicating a potential risk factor for obesity-related health issues. As illustrated in Figure 4B, the mean-connecting plot shows that students with a normal visceral fat rating (VFL = 9) consume approximately 30 g/day less sugar from SSBs, while individuals with a VFL greater than 9 tend to increase their sugar consumption from SSBs, exceeding 40 g/day for both males and females. Although this upward trend was not statistically significant, it was particularly pronounced in females, with consumption exceeding 70 g/day among those with the highest VFL. This observation underscores the potential association between excessive SSB consumption and increased visceral fat accumulation, particularly among females. Given their potentially heightened susceptibility to the adverse effects of excessive SSB consumption on visceral adiposity, further focused investigations of this demographic are warranted.

DISCUSSION

The rising prevalence of obesity and metabolic disorders has been strongly associated with sugar-sweetened beverage (SSB) consumption, which is a key source of added sugars in modern diets. Although significant research has examined the impact of SSB intake on weight gain and metabolic health, this study sought to address critical gaps in understanding how specific SSB consumption patterns influence body composition metrics and their relationship with unhealthy lifestyle behaviors, particularly in young adults. This study identified a significant association between high sugar consumption from SSBs (> 24 g/day) and adverse body composition metrics, including increased body mass index (BMI) and visceral fat levels. Notably, individuals with elevated visceral fat levels (VFL $\geq$ 10) consumed nearly twice the amount of sugar from SSBs than those with normal VFL. Participants who derived more than 10% of their daily energy needs (basal metabolic rate, BMR) from sugar exhibited a three-fold higher sugar intake than those who consumed less than 10% of their BMR from sugar. This higher sugar consumption was further linked to significantly elevated overall calorie intake (1326.93 $\pm$ 245.45 kcal vs. 1240.45 $\pm$ 208.89 kcal, $p < 0.001$). These findings align with those of previous studies highlighting the metabolic risks associated with SSB consumption. Park et al. [13] reported that sweetened tea, carbonated beverages, sweetened coffee, and fruit drinks are the most frequently consumed SSBs, consistent with the results of the present study. Sweetened tea, particularly freshly prepared iced green tea and sweetened coffee, were identified as prominent contributors to SSB consumption. These beverages often surpass traditional sodas in terms of consumption frequency [14] and present unique challenges for sugar reduction efforts, especially when prepared in small shops where sugar content is difficult to regulate [15, 16]. The cultural significance, perceived health benefits (particularly for green tea), and widespread appeal of sweetened beverages underscores the need for targeted public health interventions. These interventions should prioritize reducing sweetened tea and coffee consumption as part of broader strategies to reduce dietary sugar intake. High SSB consumption was associated with clustering unhealthy habits, including increased alcohol consumption, which may exacerbate metabolic risks associated with excessive sugar intake [17]. Addressing these intertwined behaviors is critical for mitigating obesity-related health risks. Although this study provides valuable insights, it is essential to note its cross-sectional design, which precludes causal inferences. The observed associations reflect correlation rather than causation, emphasizing the need for longitudinal studies to confirm these findings and to better understand the temporal relationship between SSB consumption and body composition changes. Additionally, variations in sugar content due to unregulated preparation methods in small shops may introduce measurement variability, highlighting the importance of further studies to more accurately quantify sugar intake. This study underscores the significant metabolic risks associated with high SSB consumption, particularly its effect on BMI and visceral fat accumulation. Targeted public health strategies should promote healthier beverage alternatives, such as water, unsweetened drinks, and reduced-sugar options, while addressing broader lifestyle behaviors associated with excessive sugar intake. Longitudinal research is necessary to strengthen the evidence base and guide effective interventions to curb the rising prevalence of obesity and related metabolic disorders.

This study identified sweetened tea (particularly freshly prepared iced green tea) as the primary source of dietary sugar across all participant groups, with a significant contribution among overweight and obese individuals. These findings emphasize the need to focus on public health strategies to reduce sweetened tea consumption and mitigate obesity-related risks [18]. Conversely, lower SSB consumption among underweight and normal-BMI individuals may reflect healthier dietary patterns or higher physical activity levels [14]. However, additional research is warranted to further explore these associations and examine the causal pathways involved. Considering the potential role of caffeine in obesity, its combined effects with dietary sugars in beverages warrant further investigation. Global caffeine consumption remains high, with coffee and tea serving as predominant sources [19]. The patterns of caffeine intake are influenced by sociocultural factors and vary widely across regions. For instance, a 2015 U.S. survey reported an average daily caffeine intake of 164.5 mg, primarily derived from coffee [19]. In contrast, rural Thai populations demonstrated significantly higher intakes (302.5 mg/day), driven predominantly by sweetened tea consumption among working-age adults (15-59 years). This trend underscores the role of cultural preferences for sweetened caffeinated beverages in contributing to the rising obesity rates in specific populations. The complexity of the factors that influence obesity must also be acknowledged. Anthropometric changes often reflect the interplay of reduced physical activity, increased sedentary behaviors (exacerbated during the COVID-19 lockdowns), dietary shifts, and greater reliance on refined carbohydrates in fruits and vegetables [4, 19, 20]. Significant differences in lifestyle behaviors further underscored these relationships. For example, this study found that higher alcohol consumption among high-SSB consumers (61.4% vs. 38.6%, $p = 0.037$) highlights the clustering of unhealthy habits with excessive SSB intake. Recognizing the multifaceted nature of obesity is crucial in designing effective public health interventions. To combat the growing prevalence of obesity and related health risks, comprehensive public health strategies must prioritize the reduction of added sugars from sources such as sweetened tea. Promoting healthier beverage options, such as water and unsweetened alternatives, while addressing societal and behavioral dynamics that drive excessive SSB consumption is essential. Targeting cultural and behavioral factors influencing dietary patterns can bolster efforts to mitigate the metabolic risks posed by high sugar and caffeine intakes [3, 18]. By addressing these interconnected factors through targeted public health strategies, meaningful progress can be made to reduce the global burden of obesity and its associated health complications. Long-term interventions must consider regional and cultural dynamics to ensure sustainable dietary behavioral changes.

This study investigated the relationship between sugar intake from sugar-sweetened beverages (SSBs) and body composition, with a focus on BMI and body fat percentage. The findings revealed a significant association between higher daily sugar intake from SSBs and increased BMI. For instance, participants classified as underweight (BMI < 18.0 kg/m²) consumed an average of 25.21 g/day of sugar from SSBs, while those categorized as overweight or obese (BMI > 25.0 kg/m²) exhibited significantly higher consumption levels, ranging from 32.18 to 34.00 g/day. These results align with prior research, such as the work of Malik et al. [16], who established a strong link between excessive SSB consumption and an increased risk of overweight and obesity among children and adolescents. In addition to its association with BMI, SSB consumption is associated with higher body fat percentage. Specifically, a 1.4% increase in body fat percentage was observed for every unit increase in BMI. This is consistent with the findings of English et al. [20], who reported significant increases in both body fat percentage and waist circumference among adolescents with high SSB intake over a two-year period, even in the absence of notable BMI changes [21]. These results highlight the disproportionate impact of SSB intake on adiposity, reinforcing its role as a key contributor to metabolic health risk. Our correlation analysis revealed modest yet significant associations between daily sugar intake from SSBs and obesity-related body composition measures, as evidenced by the correlation coefficients of 0.22 (fat mass), 0.20 (fat percentage), and 0.22 (visceral fat rating). While these correlations were modest, they underscored the role of SSB consumption in slight elevations in visceral fat, a critical determinant of metabolic health risks, including type 2 diabetes and cardiovascular diseases [16]. Stronger correlations were observed within body composition metrics, such as the robust association between BMI and fat mass (r = 0.91), and a moderate correlation between fat percentage and visceral fat rating (r = 0.84). These interconnected pathways highlight the complexity of adiposity development and emphasize the need to evaluate multiple body composition metrics to fully understand associated health risks. Sex-specific differences in SSB consumption and their impact on body composition were notable. Males with a borderline high visceral fat level (VFL = 10) had an average BMI of 28.72 ± 4.37 kg/m², while females exhibited a significantly higher mean BMI of 33.83 ± 0.47 kg/m² at the same VFL. Similarly, males consumed 47.60 ± 2.56 g/day of free sugar from SSBs, while females consumed considerably more (62.23 ± 19.03 g/day). This finding suggests potential sex-specific susceptibility to the adverse effects of SSB consumption on visceral fat accumulation. High SSB intake was also associated with the clustering of unhealthy behaviors. For instance, participants who derived more than 10% of their daily energy needs (BMR) from sugar exhibited elevated BMI, fat mass, and VFL compared to those adhering to dietary guidelines. This clustering reinforces the role of excessive SSB consumption in abdominal fat accumulation, which is a well-documented precursor of metabolic disorders [22]. These findings underscore the importance of dietary interventions targeting SSB reduction to combat central obesity and mitigate associated health risks. Promoting the substitution of high-sugar beverages with healthier alternatives such as water or unsweetened options is critical for addressing the increasing prevalence of metabolic disorders. Special attention should also be directed toward sex-specific differences in SSB consumption patterns and their implications for body composition, particularly among females, who demonstrated higher sugar intake levels and BMI at comparable visceral fat levels.

Although this study provides valuable insights, its cross-sectional design limits the ability to infer causality. The observed associations between SSB consumption and body composition reflect a correlation rather than causation, necessitating longitudinal studies to confirm these findings and elucidate the underlying mechanisms. The variability in sugar content due to the preparation methods, particularly in sweetened beverages, also warrants further investigation to enhance the accuracy of dietary assessments.

CONCLUSIONS

This study highlighted a significant association between daily sugar intake from SSBs and increased BMI, body fat percentage, and visceral fat levels, reinforcing the metabolic risks posed by high SSB consumption. These findings contribute to a growing body of evidence supporting the need for public health strategies focused on reducing SSB consumption and promoting healthier dietary behaviors. By addressing the complex interplay between behavioral, dietary, and biological factors, future research can guide the development of effective nutrition policies to mitigate obesity-related health risks and improve metabolic outcomes.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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