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REVIEW

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The relationship between dietary sugar consumption and anxiety disorders: A systematic review

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Abstract

High-sugar intake is a risk factor for chronic diseases such as cardiovascular disease and type 2 diabetes, but less is known about its role in anxiety disorders. This systematic review aimed to systematically synthesise and assess the existing evidence regarding the association between dietary sugars intake and anxiety disorders. Following PRISMA guidelines, a systematic search of PubMed, MEDLINE, Embase, APA PsycArticles and APA PsycINFO was conducted up to 19th August 2022. Study quality was assessed by the Newcastle-Ottawa scale (NOS) and the Cochrane risk of bias tool. Eleven studies (10 cross-sectional and 1 randomised controlled trial [RCT]) were included. Seven cross-sectional studies had very good quality or good quality, and the quality of the RCT was at low risk of bias. These studies examined sugar-sweetened beverages ($n = 7$), sugar-sweetened foods ($n = 4$) and/or added sugar ($n = 5$). The findings suggest a possible positive relationship of added sugar consumption with anxiety disorders, with age as a potential moderator in such association. No conclusions can be drawn on the associations between sugar-sweetened beverages, sugar-sweetened foods consumption and anxiety disorders. Due to the included studies being mostly cross-sectional, the conclusions drawn from the existing evidence should be interpreted with caution. The longitudinal design is warranted to investigate any causal relationship and the potential mechanisms underlying these heterogeneous results. The potential difference in effect at different ages observed in this review should be further examined.

KEYWORDS
added sugar, anxiety disorders, dietary sugars, sugar-sweetened beverages, sugar-sweetened foods

INTRODUCTION

Anxiety disorders are characterised by apprehensiveness of danger or misfortune accompanied by worry, distress and somatic symptoms of tension (World Health Organization, 2023), and affect approximately 7.3% of people worldwide. A systematic review summarised that the prevalence of anxiety disorders ranged from 3.8%–25% in adults and 1.4%–70% in people with chronic diseases (Remes et al., 2016). Another recent meta-analysis reported a relatively high prevalence among college students ranging from 17.5%–48.3%. The prevalence was especially higher after the COVID-19 outbreak than before the pandemic (Li et al., 2022). Anxiety disorders are associated with worsened medical conditions (e.g., cardiovascular diseases and gastrointestinal diseases), increased healthcare utilisation and significant impairment in social,

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educational and occupational functioning (Szuhany & Simon, 2022). It is estimated that the disorders cause 28.68 million disability-adjusted life years (DALYs) in the Global Burden of Diseases (Yang et al., 2021) and lead to 4.6 lost workdays per month and more than $4 billion in workplace costs (Szuhany & Simon, 2022).

The well-studied risk factors of anxiety disorders summarised by previous systematic reviews include biological factors (e.g., risk genes and structural brain changes), demographic factors (e.g., female sex), psychosocial factors (e.g., stressful life events in childhood and adulthood, intolerance of uncertainty and personality traits) and lifestyle factors (e.g., insomnia and physical inactivity) (Moreno-Peral et al., 2014; Stein & Sareen, 2015; Zimmermann et al., 2020). Over the past decade, the relationships between nutrition and mental health have gained considerable interest (Aucoin et al., 2021; Gibson-Smith et al., 2018; Murphy & Mercer, 2013; Opie et al., 2015). A list of suggested nutritional components that may be beneficial for anxiety are omega-3 fatty acids, high fibre diet, broad-spectrum micronutrient supplementation, zinc, magnesium, selenium and probiotics (Aucoin et al., 2021). By contrast, high-fat diets and protein malnutrition are considered detrimental to mental health (Aucoin et al., 2021). Nevertheless, limited studies have discussed sugars intake as a modifiable factor.

Dietary sugars are usually defined as monosaccharides (e.g., glucose, fructose and galactose), disaccharides (e.g., sucrose, lactose and maltose), polyols (e.g., sorbitol, mannitol and lactitol) and added sugars (i.e., all monosaccharides and disaccharides added to foods by the manufacturer, cook or consumer and sugars present in alcohols, beverages and fruit juices) (Te Morenga et al., 2012). Animal experiments have shown that exposure to sugar overconsumption impairs prefrontal and hippocampal function and augments the neuroinflammatory processes, facilitating anxiety-like behaviours in mouse models (Gomes et al., 2020; Kruse et al., 2019; Murphy & Mercer, 2013). There is emerging research on the association between sugars consumption and anxiety disorders in humans. However, the findings are inconsistent. For instance, some studies reported that a high intake of dietary sugar was associated with an increased risk of anxiety disorders (Kose et al., 2022; Zahedi et al., 2014; Zhang et al., 2019), while others showed inverse associations (Sangsefidi et al., 2020; Zahedi et al., 2014). Therefore, a systematic review that comprehensively synthesises human research in this area is warranted.

To our best knowledge, only three systematic/scoping reviews were identified trying to summarise the associations between dietary patterns and anxiety disorders in humans. One is a systematic review showing that the UK traditional dietary pattern (i.e., vegetables in combination with red meat and poultry) and the Brazilian traditional dietary pattern (i.e., rice, beans in combination with meats, eggs and vegetable spices) were associated with a lower risk of prenatal anxiety and postpartum anxiety (Silva et al., 2019). Another systematic review summarises diet interventions on anxiety, reporting that healthy diet interventions had no significant impact on anxiety (Opie et al., 2015). However, these two systematic reviews failed to differentiate various nutrients (e.g., sugar consumption). The third one is a scoping review, which further investigated nutritional factors and suggested that a high-fat diet, inadequate-protein diet and high-sugar and refined carbohydrates diet were risk factors for anxiety disorders (Aucoin et al., 2021). However, this review only included two studies on human sugar consumption; thus, an updated review is needed. Therefore, the current systematic review aims to synthesise and evaluate the quantitative human studies on the association between dietary sugar consumption and anxiety disorders. The roles of different dietary sugar categories (i.e., added sugar, sugar-sweetened beverages, sugar-sweetened foods) and population characteristics (i.e., age and sex) in such associations are further discussed.

METHODS

Inclusion and exclusion criteria

Studies were included if they met the following criteria: (1) The exposure of interest was dietary sugars, including monosaccharides, disaccharides, polyols and added sugars (i.e., sweetened beverages or food); (2) The outcome of interest was anxiety disorders, which were assessed by clinician diagnoses or validated questionnaires; (3) Investigating the relationship between dietary sugar and anxiety disorders using quantitative methods; (4) Human studies; and (5) English language. Studies were excluded if they were (1) Articles that included carbohydrates without specifying the type of sugar or the food source; (2) No full text; and (3) Review articles.

Sources and search strategy

This systematic review was conducted according to the guideline of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (Page et al., 2021) and was pre-registered on PROSPERO (ID: CRD42023410694). Electronic databases, MEDLINE, Embase, APA PsycArticles, PsycINFO and PubMed, were searched from inception to 19th August 2022. The search was limited to human studies and the English language. Search terms included “sweetening agents” or “sugar alcohols” or “sorbitol” or “saccharin” or “carbohydrates” or

"monosaccharides" or "glucose" or "fructose" or "galactose" or "sucrose" or "sugar" or "added sugar" or "dietary sucrose" or "lactose" or "maltose" or "beverages" or "sugar-sweetened" or "sweetened" or "carbonated beverages" or "fruit juice" or "fruit drinks" and "anxi*." The search terms for dietary sugar and anxiety were adapted from published articles (Aucoin et al., 2021; Te Morenga et al., 2012). Search terms such as panic and phobia, did not yield any relevant results in our preliminary searches, which, hence, were excluded from the final search strategies.

Screening procedure

Two reviewers, AW and ZS, assessed the titles and abstracts of all identified studies independently to determine which of these studies should go forward for full-text screening. The third reviewer, XW, resolved discrepancies in opinions. A similar approach was used to determine the eligibility of full-text articles.

Data extraction and quality assessment

Two reviewers, AW and ZS, conducted data extraction and quality assessment independently, and discrepancies were resolved by discussion.

The following information was extracted from each study according to a pre-specified protocol: author, year, country, study population (age range /mean), study design, sample size, measures of dietary sugar category, measures of anxiety disorders, results and adjustments.

The quality of included cross-sectional studies was assessed using the Newcastle-Ottawa Scale (NOS) adapted for cross-sectional studies (with 9–10 being very good, 7–8 good, 5–6 satisfactory and 0–4 unsatisfactory) (Appendix 1; Herzog et al., 2013); the quality of included trials was evaluated by the updated Cochrane risk of bias tool (Sterne et al., 2019).

METHODS OF DATA SYNTHESIS

Due to the heterogeneity in the exposures (i.e., dietary sugar consumption) and the analyses for the relationships (i.e., OR, mean difference, correlation coefficients) reported in the limited studies, we performed a narrative synthesis following the principles of the Synthesis Without Meta-analysis (SWiM) reporting guideline (Campbell et al., 2020). We grouped the studies by the different measures of dietary sugars used (i.e., sugar-sweetened beverages [SSB], sugar-sweetened foods and added sugar). We conducted vote counting to determine the direction of any association between measures of dietary sugar and anxiety. The results were summarised by calculating (1) the percentage of studies including each factor, (2) the percentage of studies that found a significant positive/non-significant positive/significant negative/non-significant negative association for a factor out of all studies that included the factor and (3) the consistency of the findings (i.e., the number of good to satisfactory quality studies pointing in the same direction/total number of good to satisfactory quality studies measuring the same factor). If most studies (>50%) found a positive/negative association between a factor and anxiety, the factor was regarded to have a possible positive/negative association with anxiety. Data showing the significance and direction of the associations were recorded and tabulated.

RESULTS

Study selection

The search identified 3441 unique articles after removing duplicates. After screening titles and abstracts for relevant terms and content, 37 articles were selected for full-text screening. Among these articles, 24 studies were excluded: 11 had no specific measures of dietary sugars; one used an unvalidated measure of anxiety; six were review articles; six had no full text/only abstract. Hence, 13 eligible studies were included. Since three included articles (Kose et al., 2022; Kose, Cheung, et al., 2021; Kose, Fezeu, et al., 2021) used overlapping samples of the NutriNet-Santé web-cohort, the three articles were considered to be one study. Finally, 11 eligible full-text studies were included for data extraction (Gao et al., 2021; Keck et al., 2020; Kose et al., 2022; Kose, Cheung, et al., 2021; Kose, Fezeu, et al., 2021; Liu et al., 2022; Sangsefidi et al., 2020; Scholey et al., 2014; Shi et al., 2010; Vassou et al., 2021; Wattick et al., 2018; Zahedi et al., 2014; Zhang et al., 2019). Detailed steps for article selection are shown in Figure 1.

Study design and participants

Study characteristics are shown in Table 1. Ten included studies were cross-sectional surveys, and one was a randomised controlled trial (RCT) (Scholey et al., 2014). The studies were conducted in China ($n=3$) (Gao et al., 2021; Liu et al., 2022; Zhang et al., 2019), Iran ($n=2$) (Sangsefidi et al., 2020; Zahedi et al., 2014), Australia ($n=2$) (Scholey et al., 2014; Shi et al., 2010), the United States ($n=2$) (Keck et al., 2020; Wattick et al., 2018), France ($n=1$) (Kose et al., 2022; Kose, Cheung, et al., 2021; Kose, Fezeu, et al., 2021) and Greece ($n=1$) (Vassou et al., 2021). The sample size of the included studies varied greatly from 225 to 24 771. Most studies ($n=10$) recruited predominantly female samples (54.5%–85% females). Regarding

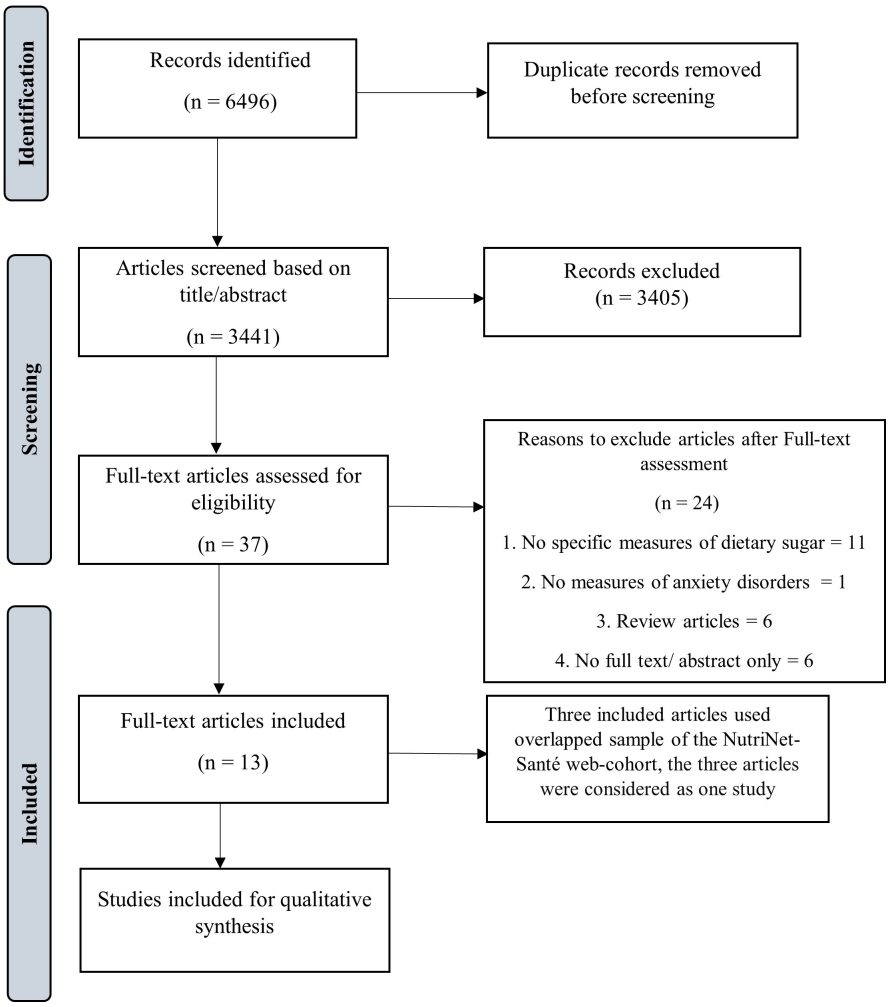

FIGURE 1 PRISMA flow chart. From: Moher et al. (2009).

the age groups, eight studies included adults (mean age ranged from 18.9 to 53.7 years old), in which three recruited college students only; three studies included children and adolescents (mean age ranging from 12.07 to 18.4 years old). In terms of the RCT, it included two sessions at least 24 h apart. Subjects fasted for 12 h before receiving the assigned drink and were instructed to abstain from alcohol and caffeinated beverages for 24 and 12 h respectively. Upon arrival, the subjects filled in the baseline questionnaires. Treatment beverages (i.e., 30/60 g glucose) were then administered, questionnaires were administered 30 min later to measure mood, including state anxiety.

Measures of dietary sugars

Among the cross-sectional studies ($n = 10$), four studies used food frequency questionnaires and eight of them estimated sugar intake by the self-reported daily/monthly consumption frequency of sugar-sweetened foods and sugar-sweetened beverages. As for the RCT, it used prescribed sugar (e.g., 60 g glucose) in a carbonated, fruit-flavoured drink as the exposure. The dietary sugars included three main categories: (1) SSB, (2) sugar-sweetened foods (e.g., biscuits, cookies, cakes, chocolates, candies, desserts, sugar cubes) and (3) added sugars, including those that are added during food processing.

Measures of anxiety disorders

Seven studies measured anxiety disorders by tools including the Spielberger State–Trait Anxiety Inventory (STAI; $n = 3$) (Kose et al., 2022; Kose, Cheung, et al., 2021; Kose, Fezeu, et al., 2021; Scholey et al., 2014; Vassou et al., 2021), the 21-item Depression, Anxiety and Stress Scale (DASS-21; $n = 1$) (Sangsefidi et al., 2020), the Global School Health Survey (GSHS; $n = 1$) (Zahedi et al., 2014), the Healthy Days Measures ($n = 1$) (Wattick et al., 2018) and the 28-item General Health Questionnaire (GHQ-28; $n = 1$) (Shi et al., 2010), respectively. Three studies measured general anxiety disorder using the General Anxiety Disorder Scale (GAD), usually the 7-item version ($n = 3$) (Gao et al., 2021; Keck et al., 2020; Zhang et al., 2019); One study adopted Social Anxiety Scale

TABLE 1 Description of included studies.

Author, year, country	Study population (age range /mean)	Study design	Sample size	Dietary sugar category (measure)	Anxiety disorder measure	Results	Adjustments
Cross-sectional studies							
Sangsefidi et al. (2020) Iran	Adults (20–70 y)	CSS	9965	SSB; Sugar-sweetened foods[a] (Frequency; Daily amount)	DASS 21	Participants with SSB consumption for once or more/week had a significantly lower level of anxiety symptoms compared with non-consumption participants (OR = 0.76 (95% CI 0.62–0.93)) No significant association between sugar-sweetened foods (1–2 cubes/more than 2 cubes per day) and anxiety symptoms. Not stratified by gender or age	Age, education, physical activity, chronic diseases, smoking, BMI
Zahedi et al. (2014) Iran	Adolescents (12.47 y)	CSS	13486	SSB; Sugar-sweetened foods (Frequency)	GSHS	Participants who consumed SSB weekly (OR = 1.12 (1.00–1.24))/daily (OR = 1.47 (1.29–1.69)) increased the odds of anxiety compared with participants who seldom consumed SSB Participants who consumed sugar-sweetened foods weekly (OR = 0.82 (0.73–0.92))/daily (OR = 0.88 (0.78–0.99)) decreased the odds of anxiety compared with participants who seldom consumed sugar-sweetened foods. Not stratified by gender or age	Age, sex, family history of chronic diseases, mother's education, screen time, physical activity, socioeconomic status, BMI
Gao et al. (2021) China	College students (19 y)	CSS	1017	SSB; Sugar-sweetened foods (Frequency)	GAD-7	No significant association between SSB/desserts and anxiety disorder. Not stratified by gender or age	Age, gender, education, family income, religion chronic disease, smoking, alcohol consumption, diet pattern (e.g., regular meals, snack) and physical activity
Vassou et al. (2021) Greece	Adults (40–45 y)	CSS	853	SSB; Sugar-sweetened foods (Monthly amount)	STAI	No significant differences in sugar-sweetened foods and soft drinks consumption were found between participants with high-irrational beliefs/low-STAI and participants with high-irrational beliefs /high-STAI. Not stratified by gender or age	-

(Continues)

TABLE 1 (Continued)

Author, year, country	Study population (age range /mean)	Study design	Sample size	Dietary sugar category (measure)	Anxiety disorder measure	Results	Adjustments
Zhang et al. (2019) China	Adolescents (18.4)	CSS	8085	SSB; Added sugar[b] (Frequency; daily amount)	GAD-2	Students consuming soft drinks ≥7 times/ week had significantly higher GAD-2 scores (mean difference = 0·15; 95% CI 0.07, 0.23) compared with those barely consuming soft drinks. Those consuming >25 g of sugar from soft drinks daily had significantly higher GAD-2 scores (mean difference = 0.11; 95% CI 0.04, 0.18) compared to non-consumer. The mediation effect of body mass index (BMI) was significant. Not stratified by gender or age	Age, gender, ethnicity, original region, household annual income, disease history, cigarette smoking, passive smoking, alcohol drinking, water intake, exercise, BMI
Liu et al. (2022) China	Children (12.07 y)	CSS	1311	SSB (Daily amount)	SASC	No significant association between SSB consumption and social anxiety symptoms in both boys and girls Not stratified by age	Age, gender, parental educational attainment, maternal smoking status, single-child status, BMI, incomes, fruit consumption, physical activity, screen time and friend food consumption
Kose, Cheung, et al. (2021)[#] France	Adults without diabetes and pregnancy (53.68 y)	CSS	20231	Sweet food & beverages; Added sugar; (Daily amount)	STAI	Among adults aged <45, participants with high trait anxiety had a significantly higher level of added sugars consumption (LS mean = 43.9 g/day vs. 42.3 g/day, $p < 0.001$) than those with low trait anxiety; There were no significant differences in sweet food/beverage except fresh fruit Among adults aged ≥45, there were no significant differences in added sugars and sweet food/ beverage except fresh fruit	Mean total energy intake, age, gender, BMI, alcohol consumption, smoking stat us, physical activity level, socio-professional category, marital status and number of 24-h dietary records
Kose, Fezeu, et al. (2021)[#] France		CSS	24771	Added sugar; (Daily amount)	STAI	Among males, no significant association was found between added sugar intake and trait anxiety Among females, no significant association was found between added sugars intake and trait anxiety	Age, BMI, alcohol consumption, smoking status, physical activity level, educational level, socio-professional category, marital status, number of 24-h dietary records
Kose et al. (2022)[#] France	(53.2 y)	CSS	24771	Added sugar; (Daily amount)	STAI	Participants with pure anxiety disorder had a significantly higher intake of added sugar (LS mean = 38.0 g/day vs. 37.1 g/day, $p < 0.001$) compared to 'no disorder' group (all $p < 0.001$)	Age, sex, BMI, smoking status, physical activity level, socio-professional category, marital status, alcohol consumption and number of 24-h dietary records

TABLE 1 (Continued)

Author, year, country	Study population (age range /mean)	Study design	Sample size	Dietary sugar category (measure)	Anxiety disorder measure	Results	Adjustments
Shi et al. (2010) Australia	Adults (46.7 y)	CSS	4741	SSB; (Daily litre)	GHQ-28	No significant association was found between SSB intake and risk of anxiety disorder Not stratified by gender or age	Age, gender, education, income, area of residence, smoking status, drinking, physical activity, overweight, diabetes, asthma, CVD, arthritis, osteoporosis, COPD, intake of fruit and vegetable
Keck et al. (2020) US	College students (18.9 y)	CSS	225	Added Sugar; (Daily amount)	GAD-7	Among all participants, added sugar ($b = -0.16$ (0.05), $p < 0.001$) was negatively associated with GAD-7 score. No sex difference was found. Not stratified by age	Sex
Wattick et al. (2018) US	College students (19–21 y)	CSS	1956	Added Sugar (Frequency)	Healthy Days Measures	Daily frequency of added sugar intake increased the risk of anxiety in females (OR = 1.18 (1.05–1.32)), but not in males (OR = 1.09 (0.91–1.30)). Not stratified by age	Gender, BMI, fruit/vegetable intake, Food secure, food insecure
Randomised controlled trial							
Scholey et al. (2014) Australia	Adults (34.78 y)	RCT	25 g glucose condition group = 38; 60 g glucose condition group = 39; 40 mg caffeine and 60 g glucose condition group = 36; Placebo group = 37	Added Sugar; (Prescribed Glucose)	STAI	Glucose administration had no significant effect on STAI scores	—

Note: [#]Studies using the samples of the NutriNet-Santé web-cohort. [a]Sugar-sweetened foods (e.g., biscuits, cookies, cakes, chocolates, candies, desserts). [b]Added sugars are those that are added during food processing.

Abbreviations: CSS, cross-sectional study; DASS-21, 21-item Depression, Anxiety and Stress Scale; GAD, General Anxiety Disorder Scale; GHQ-28, 28-item General Health Questionnaire; GSHS, Global School Health Survey; RCT, randomised controlled trial; SASC, Social Anxiety Scale for Children; SSB, sugar-sweetened beverages; STAI, Spielberger State–Trait Anxiety Inventory.

for Children (SASC) to assess social anxiety disorder (Liu et al., 2022).

Study quality

Ten cross-sectional studies were evaluated by the adapted Newcastle-Ottawa Scale. The results indicated that two studies had good quality (Kose et al., 2022; Kose, Cheung, et al., 2021; Kose, Fezeu, et al., 2021; Sangsefidi et al., 2020), six with satisfactory quality (Gao et al., 2021; Liu et al., 2022; Sangsefidi et al., 2020; Shi et al., 2010; Vassou et al., 2021; Zahedi et al., 2014; Zhang et al., 2019), and two studies had unsatisfactory quality (Keck et al., 2020; Wattick et al., 2018) (Table 2). The quality of the included RCT (Scholey et al., 2014) was assessed by the Cochrane risk of bias tool, and it was at a low risk of bias (Table 3).

FINDINGS

The results of vote counting are shown in Table 4.

Sugar-sweetened beverages

Seven cross-sectional studies were examined, reporting eight outcomes, the association between the consumption of SSB and anxiety disorders. Two of them showed significant positive associations between reported weekly/daily consumption of SSB and anxiety disorders in adolescents; one ($n = 13486$) was conducted in Iran (Zahedi et al., 2014), and another one ($n = 8085$) was in China (Zhang et al., 2019). A further study conducted in children ($n = 1311$) in China found a non-significant positive association between daily SSB consumption and social anxiety in both boys and girls (Liu et al., 2022), while two study among adults also found non-significant positive associations with SSB consumption and anxiety (Shi et al., 2010; Vassou et al., 2021).

In contrast, one study conducted in Iranian adults found a significant negative association between reported once or more per week consumption of SSB and anxiety disorders (Sangsefidi et al., 2020). One further study in adults found a non-significant negative association, which utilised weekly frequency (Gao et al., 2021).

Six studies had satisfactory quality and one had good quality (Sangsefidi et al., 2020). All studies adjusted for demographic and behavioural factors, except one which didn't adjust for some important confounders (Vassou et al., 2021). Therefore, six out of eight outcomes reported an effect in a positive direction, so the consistency was 75%.

TABLE 2 Quality assessment for cross-sectional studies.

	Selection				Comparability	Outcome		Total points
	Representativeness of the sample	Sample size	Ascertainment of exposure	Non-respondents	Base on the design and analysis	Assessment of outcome	Statistical test	
Sangsefidi et al. (2020)	*	*	*		**	*	*	7
Zahedi et al. (2014)		*	*		**	*	*	6
Gao et al. (2021)			*		**	*	*	5
Vassou et al. (2021)	*	*	**			*	*	6
Zhang et al. (2019)			*		**	*	*	5
Liu et al. (2022)			*		**	*	*	5
Shi et al. (2010)	*		*		**	*	*	6
Kose, Cheung, et al. (2021)[#]	*	*	**		**	*	*	8
Kose, Fezeu, et al. (2021)[#]								
Kose et al. (2022)[#]								
Keck et al. (2020)			**			*	*	4
Wattick et al. (2018)			*			*	*	3

Note: [#]Studies using the samples of the NutriNet-Santé web-cohort, *Awarded 1 point. , **Awarded 2 point.

Sugar-sweetened foods

Four cross-sectional studies examined the association between the consumption of sugar-sweetened foods and anxiety disorders. One study in Iran ($n = 13\,486$) found that adolescents who reported having consumed sugar-sweetened foods weekly/daily had significantly lower odds of anxiety compared with those who seldom consumed sugar-sweetened foods (Zahedi et al., 2014). Two further studies reported non-significant negative associations with anxiety. One was conducted on Chinese college students ($n = 1017$; mean age = 19 years) and adopted weekly frequency to quantify dessert consumption (Gao et al., 2021). The second one ($n = 853$) was in Greek adults aged 40–45 years and used monthly amounts to quantify the consumption of sugar-sweetened foods (Vassou et al., 2021).

A fourth study in Iranian adults ($n = 9965$) only assessed the consumption of sugar cubes (i.e., not at all, 1–2 cubes and more than 2 cubes per day) and found a non-significant positive association with anxiety (Sangsefidi et al., 2020).

Three studies had satisfactory quality and one had good quality (Sangsefidi et al., 2020). All studies adjusted for demographic and behavioural factors, except one which didn't adjust for some important confounders (Vassou et al., 2021). Overall, therefore, three out of four studies reported an effect in a negative direction and so the consistency was 75%.

Added sugar

A total of five studies, reporting six outcomes, examined the association between added sugar and anxiety disorders. Four of them were cross-sectional studies. Three cross-sectional studies reported positive associations between the reported added sugar

TABLE 3 Quality assessment for randomised controlled trials.

Bias domain and signalling question	Response options
Bias arising from the randomisation process	
1.1 Was the allocation sequence random?	Y
1.2 Was the allocation sequence concealed until participants were enrolled and assigned to interventions?	PY
1.3 Did baseline differences between intervention groups suggests a problem with the randomisation process?	PN
Risk of bias judgement (low/high/some concerns)	*Low*
Bias due to deviations from intended interventions	
2.1 Were participants aware of their assigned intervention during the trial?	PN
2.2 Were carer and people delivering the interventions aware of participants' assigned intervention during the trial?	PN
2.6 Was an appropriate analysis used to estimate the effect of assignment to intervention?	PY
Risk of bias judgement (low/high/some concerns)	*Low*
Bias due to missing outcome data	
3.1 Were data for this outcome available for all, or nearly all, participants randomised?	N
3.2 Is there evidence that the result was not biased by missing outcome data?	N
3.3 Could missingness in the outcome depend on its true value?	PN
Risk of bias judgement (low/high/some concerns)	*Low*
Bias in measurement of the outcome	
4.1 Was the method of measuring the outcome inappropriate?	N
4.2 Could measurement or ascertainment of the outcome have differed between intervention groups?	N
4.3 Were outcome assessors aware of the intervention received by study participants?	N
Risk of bias judgement (low/high/some concerns)	*Low*
Bias in selection of the reported result	
5.1 Were the data that produced this result analysed in accordance with a pre-specified analysis plan that was finalised before unblinded outcome data were available for analysis?	Y
Is the numerical result being assessed likely to have been selected, on the basis of the results from	
5.2 Multiple eligible outcome measurements (e.g. scales, definitions, time points) within the outcome domain?	N
5.3 Multiple eligible analyses of the data?	PN
Risk of bias judgement (low/high/some concerns)	*Low*
Overall bias	
Risk of bias judgement (low/high/some concerns)	*Low*

consumption and anxiety disorders: one in Chinese adolescents ($n = 8058$) found that those who consumed added sugar >25 g per day from soft drinks had significantly higher levels of anxiety symptoms than non-consumers (Zhang et al., 2019). Similarly, the results of NutriNet-Santé web-cohort (France, $n = 24\,771$) showed that high levels of added sugar consumption (daily amount) significantly increased the risk of having pure anxiety disorder in adults (Kose et al., 2022). The third study in American college students ($n = 1965$) found that daily frequency of added sugar intake was significantly associated with anxiety disorder in female students but only non-significantly positively associated in male students (Wattick et al., 2018). Two studies had good or satisfactory quality and adjusted for demographic and behavioural factors (Kose et al., 2022; Kose, Cheung, et al., 2021; Kose, Fezeu, et al., 2021; Zhang et al., 2019), while the other, (Wattick et al., 2018), had unsatisfactory quality and didn't adjust for important confounders.

The remaining cross-sectional study, also among American college students ($n = 225$) reported a significantly negative association between added sugar consumption (amount per day) and anxiety symptoms (Keck et al., 2020). However, this study had unsatisfactory quality and didn't adjust for potentially important confounders.

The RCT indicated a non-significant negative relationship between acute glucose consumption and anxiety symptoms measured 30 min later (Scholey et al., 2014).

Overall, therefore, excluding the two low-quality studies, two out of three studies reported an effect in a positive direction, and the consistency was 67%.

EFFECT MEDIATORS/MODERATORS

One study explored the mediation effect of BMI in the association between consumption of SSB (weekly or more)/added sugar (>25 g per day) and anxiety symptoms and found that BMI was a significant mediator with a small effect size. Although the positive association of sugar intake with anxiety remained significant after adjusting for BMI (Zhang et al., 2019).

Four studies tested the moderation roles of sex in the association between added sugar/SSB and anxiety. No sex difference was observed in three studies (Keck et al., 2020; Kose, Fezeu, et al., 2021; Liu et al., 2022) while one study reported daily frequency of added sugar intake increased the risk of anxiety in females but not in males (Wattick et al., 2018). However, this study had unsatisfactory quality.

In terms of moderation effect of age, five cross-sectional studies on dietary sugars and anxiety were conducted in adolescents/young adults and four of

TABLE 4 The vote counting results of the included studies.

	Studies/outcomes including the variable	Studies found a significant positive association	Studies found a non-significant positive association	Studies found a significant negative association	Studies found a non-significant negative association	Consistency (%)
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	
SSBs	8 (64)	2 (25)	4 (50)	1 (13)	1 (13)	75
Sugar-sweetened foods	4 (36)	–	1 (25)	1 (25)	2 (50)	75
Added sugar	6 (45)	3 (50)	1 (17)	1 (17)	1 (17)	67

Abbreviation: SSB, sugar-sweetened beverages.

them found significant associations. Whereas two studies conducted among adults aged 40 years or above reported non-significant associations and these two studies had good/satisfactory quality (Kose, Cheung, et al., 2021; Vassou et al., 2021).

DISCUSSION

This systematic review synthesised and evaluated the associations between dietary sugar consumption and anxiety disorders. Across 11 studies reviewed, both positive and negative associations are suggested, as well as several potential moderators and mediators of these associations.

The results suggest a possible positive correlation between added sugar consumption and anxiety disorders after adjusting for a variety of potential confounders (e.g., demographic factors, family factors, lifestyles and health status). Furthermore, the association may be more significant among adolescents/young adults but not in middle-aged or older adults. Given that the identified studies were cross-sectional, a causal effect remains unclear. On the one hand, added sugar consumption may cause anxiety disorders (Zhang et al., 2019). Chronic consumption of a sugar-enriched diet could augment the neuroinflammatory processes (i.e., an elevation in IL-6, TNF-α, leptin and protein iNOS) in brain areas responsible for anxiety response (Gomes et al., 2020). Also, the inflammatory processes could lead to the overproduction of nitric oxide, which has been associated with anxiety behaviours in a wide range of animal model studies (Gomes et al., 2020; Gutierrez et al., 2020; Pitsikas, 2018). Nevertheless, the included RCT observed no significant changes in anxiety status after 30 min among groups consuming drinks containing a placebo, 25 g glucose or 60 g glucose (Scholey et al., 2014), suggesting the possibility that acute exposure to glucose in an experimental context, rather than chronic consumption of a sugar-enriched diet, may have different roles in altering brain inflammation and anxious responses. On the other hand, consuming added sugar can be a coping behaviour in response to stress and anxiety. Indeed, research has shown that stress and negative emotions induce unhealthy food consumption, including high-sugar foods (Bui et al., 2021). High-sugar intake facilitates dopamine release, enhancing feelings of pleasure and comfort (Jacques et al., 2019).

Furthermore, younger people may be more likely to adopt this stress-coping approach than adults. Previous research reported that younger people's comfort food consumption was motivated by negative effects, whereas positive effects triggered older people's comfort food consumption (Dube et al., 2005). Younger people consumed higher levels of added sugar (Kose, Cheung, et al., 2021) and experienced higher prevalence rates of anxiety disorders (e.g., GAD, social anxiety disorder and phobia) compared with their older counterparts (Bandelow, 2015). This scenario is possible because younger people, especially children and adolescents, are in the developmental and challenging stage of self-control and emotions, and food marketing exposure via social media often targets and easily affects their high-sugar food choices (Qutteina et al., 2019; Wang et al., 2022). The potential difference in effect at different ages observed in this review should be further examined.

Findings regarding the consumption of sugar-sweetened beverages and anxiety disorders suggest a positive association, but most of the results were non-significant positive associations. Several factors may explain the inconsistency. First, different types of sugar-sweetened beverages may have different roles in anxiety. For example, fruit juices and some manufactured or homemade beverages may also contain beneficial compounds, such as vitamins and polyphenols, which are beneficial for mental and physical wellbeing (Borges-Vieira & Souza, 2023; Melendez et al., 2022). Second, adjusting for different variables may influence the associations. For example, most studies failed to adjust for other dietary behaviours (e.g., high-fat food, fruit and vegetable consumption), which would impact anxiety disorders as well (Liu et al., 2020). Diet is a complex exposure. The food may be consumed unprocessed or processed, contain nutrients or additives and preservatives, and the overall dietary patterns, continuum of dietary exposures as well as food substitution effects should also be considered (Forouhi, 2023).

Regarding sugar-sweetened foods consumption, three studies showed an inverse association between sugar-sweetened foods consumption and anxiety disorders. Some sugar-sweetened foods (e.g., biscuits, cookies, cakes and chocolates) may be not only high in sugar but also high in fat, and an experimental study in mice found that diets high in fat and refined sugar were associated with increased levels of brain-derived neurotrophic factor (BDNF) and tryptophan, leading to decreased anxiety-like behaviours (Ohland et al., 2016). However, one of the three studies only measured limited types of sugar-sweetened foods (i.e., sugar cubes), and the other one did not adjust for some important confounders. Thus, the limited number and quality of the studies preclude a conclusion on the role of sugar-sweetened food consumption. More studies with rigorous study designs are needed to confirm the findings.

In addition, several knowledge gaps are identified in the included studies. First, only one study explored one of the potential mediators (i.e., BMI) underlying an association between dietary sugar consumption and anxiety disorders. Most previous studies discussed the potential mechanisms that were observed in mice models. Future studies should investigate potential

mechanisms, such as biological markers (e.g., cortisol, c-reactive protein and tryptophan) and gut microbes via the gut-brain axis in humans (Butler et al., 2023; Copeland et al., 2012; Di Polito et al., 2023; Madison & Kiecolt-Glaser, 2019; Ohland et al., 2016). Second, in addition to demographic factors (i.e., sex and age), other factors that may interact with sugar intake are mainly under-examined. For example, previous studies indicated a U-shape relationship between the physical activity (PA) spectrum and added sugar intake; both sedentary behaviours and vigorous physical activities elevated added sugar intake (Koehler et al., 2019). Thus, it is critical to understand the impact of various PA levels on the relationship between added sugar intake and anxiety. Third, food frequency questionnaires were widely used in the included studies, but they were unable to capture the habitual diet (Schatzkin et al., 2003), which could lead to an over/underestimation of the actual dietary intake (Scagliusi et al., 2008). On the other hand, 24-h dietary records were found to frequently under-report certain food categories (e.g., snacks) (Gemming & Ni Mhurchu, 2016). Future studies should use multiple and more objective dietary measures to capture the actual intake adequately. Furthermore, evidence from animal models has shown that different types of sugar (e.g., fructose and sucrose) may have different effects on anxiety disorders (Gancheva et al., 2017; Kim et al., 2018; Kruse et al., 2019). For example, the anxiety level was significantly lower in honey-fed rats compared to sucrose-fed ones (Chepulis et al., 2009). Future studies should differentiate sugar types to better understand their roles in human anxiety behaviours. Finally, studies with better designs are warranted (e.g., longitudinal, real-time assessment) to better understand the immediate and long-term effects of sugar consumption on anxiety and other emotional problems.

LIMITATION

Some limitations exist in the review process. First, a significant challenge was working toward an agreed conceptualisation of dietary sugars. The current review mainly focused on the added sugar in various foods and beverages. Although out of the scope of the current study, the roles of oligosaccharides, polysaccharides and sweeteners (e.g., aspartame) in anxiety disorders (Ashok et al., 2014; Smith, 2019) should be discussed in future systematic reviews. Second, the number of included studies is small, and most are cross-sectional studies. Thus, the conclusions drawn from the existing evidence should be interpreted with caution. Third, the conclusion of the review may also be influenced by how we grouped the studies. Other grouping methods (e.g., measurement used for dietary sugar intake is the frequency or the total amount) should be discussed in future reviews. Lastly, studies were included if they were available in English. This might have excluded some studies reported in languages other than English.

CONCLUSIONS

The results of this systematic review suggest a possible positive relationship between consumption of added sugar and anxiety disorders, while the associations between SSBs, sugar-sweetened foods consumption and anxiety disorders are inconclusive due to the limited number and quality of the existing studies. Further understanding of the causal directions and mediation and moderation mechanisms of their complex relationships is warranted, especially with regard to potentially different effects in younger and older people.

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DATA AVAILABILITY STATEMENT
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APPENDIX 1

Newcastle - Ottawa Quality Assessment Scale (adapted for cross-sectional studies)

Selection: (Maximum 5 scores)

1. Representativeness of the cases:
   a. Truly representative of the average in the target population. * (all subjects or random sampling)
   b. Somewhat representative of the average in the target group. * (non-random sampling)
   c. Selected group of users/convenience sample.
   d. No description of the derivation of the included subjects.
2. Sample size:
   a. Justified and satisfactory (national wide representative sample). *
   b. Not justified.
3. Ascertainment of exposure:
   a. Validated measurement tool.**
   b. Non-validated measurement tool, but the tool is available or described.*
   c. No description of the measurement tool.
4. Non-respondents:
   a. Proportion of target sample recruited attains pre-specified target or basic summary of non-respondent characteristics in sampling frame recorded. *
   b. Unsatisfactory recruitment rate, no summary data on non-respondents.
   c. No information provided

Comparability: (Maximum of 2 stars).

1. The subjects in different outcome groups are comparable, based on the study design or analysis. Confounding factors are controlled:

a. The study controls for important confounders, including demographic factors (e.g., age and gender) and health behaviour factors, especially physical.**
b. The study does not investigate important confounders.

Outcome: (Maximum 3 stars)

1. Assessment of the outcome:
   a. Independent blind assessment. **
   b. Record linkage. **
   c. Self-report. *
   d. No description.
2. Statistical test:
   a. The statistical test used to analyse the data is clearly described and appropriate, and the measurement of the association is presented, including confidence intervals or probability level (*p*-value).*
   b. The statistical test is not appropriate, not described, or incomplete.

Cross-sectional Studies:

Very Good Studies: 9–10 points.
Good Studies: 7–8 points.
Satisfactory Studies: 5–6 points.
Unsatisfactory Studies: 0 to 4 points.

This scale has been adapted from the Newcastle-Ottawa Quality Assessment Scale for cohort studies to provide quality assessment of cross-sectional studies.

*Extracted from: Herzog R, et al. Is healthcare workers' intention to vaccinate related to their knowledge, beliefs and attitudes? A systematic review. *BMC Public Health*. 2013, 13, 154.

Note: Each * indicates 1 point awarded if conditions were met, and 2 points awarded as **