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Review Article

The Association between Consumption of Bitter-taste Vegetables in Asian Culture and Metabolic Syndrome Risk Factors in Children: A Narrative Review

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Abstract

Childhood obesity has been escalating in Asian countries in recent decades resulting in the younger age groups being diagnosed with metabolic syndrome (MetS). *Brassicaceae* vegetables that contain high bioactive compounds with anti-inflammatory and anti-oxidative properties might be beneficial in preventing MetS. This narrative review presents; (a) the consumption of vegetables in the world population and the availability of bitter-taste vegetables in Asian culture; (b) the interaction between food preference and childhood obesity and (c) potential associations between the consumption of bitter-taste vegetables in Asian culture and clinical outcomes. A number of online searches were conducted for publications in the English language from the year 1990 until October 2022 with a two-step search strategy adopted: initial searches were conducted in four electronic databases (MEDLINE, CINAHL, EMBASE, and Cochrane Library), and a second search using all identified keywords and indexes by including two additional electronic databases (ProQuest and Scopus). The keywords included "bitter"; "vegetables"; "weight status"; "metabolic profile", "Asia", "culture", and "children". *Brassica vegetables* in Asian countries are abundantly available and commonly consumed, yet the overall vegetable intake in children was inadequate or below the recommended daily intake. Childhood obesity can be influenced by their preference for and consumption of bitter-taste vegetables, and excessive body weight is associated with the risk of developing MetS. It remains inconclusive whether *brassicas* vegetables play a dominant role in the group. Future longitudinal studies to investigate the taste sensitivity, vegetable acceptance, and effect of *brassicas* vegetables on the risk of MetS in Asian children are warranted.

Introduction

The worldwide rise in the prevalence of childhood obesity over the last decade continues to be a serious health concern, impacting approximately 340 million children and adolescents between 5 and 9 years old.[1] This was observed in both genders and with similar percentages of prevalence (18% in girls and 19% in boys).[2] For children below 5 years of age, overweight (weight-for-height >2 standard deviation (SD)) and obesity (weight-for-height >3 SD) cases were reported at 39 million in 2020.[1] In 2016, a global estimate of more than 41 million overweight children below 5 years of age was reported, with the Asian sub-population contributing up to 50%.[2] These findings were similar in the adolescent group, which recorded the highest obesity rates across developing countries in Asia. Furthermore, there were large variations within the different countries of the Asian continent with the lowest found in rural Bangladesh (3.5%), followed by China (12.5%), Iran, Saudi Arabia (30% respectively), and the Maldives (65%).[3]

Metabolic syndrome (MetS) is a cluster of cardiovascular risk factors that include abdominal obesity (WC: Waist Circumference

Keywords: Bitter; Vegetables; Weight status; Metabolic profile; Asia; Children.

Abbreviations: AVI, alanine-valine-isoleucine; GSL, glucosinolates; HDL-C, high-density lipoprotein-cholesterol; LDL-C, low-density lipoprotein-cholesterol; MetS, metabolic syndrome; PAV, proline-alanine-valine; PROP, 6-n-propylthiouracil; PTC, phenylthiocarbamide; TG, triglyceride.

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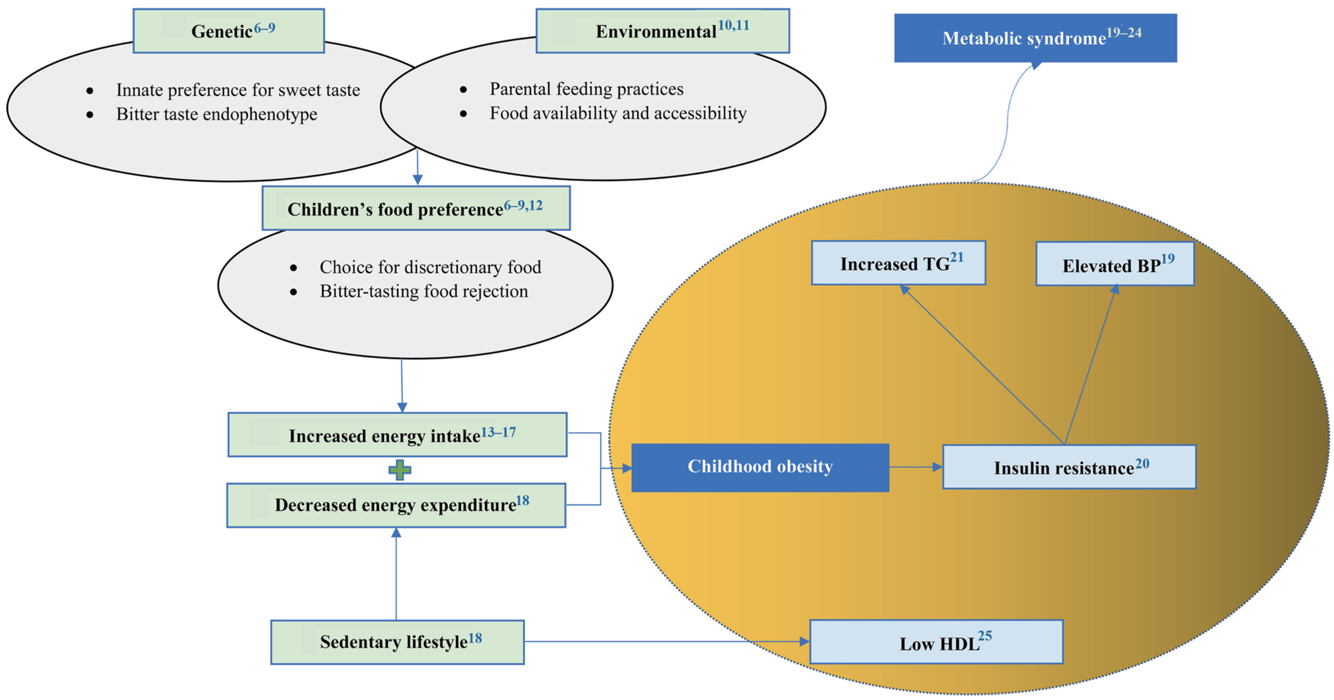

Fig. 1. Aetiology of childhood obesity and metabolic syndrome. BP, Blood Pressure; HDL, High-Density Lipoprotein; TG, Triglycerides.

≥90th percentile), elevated blood pressure (SBP: Systolic Blood Pressure ≥130 mmHg or DBP: Diastolic Blood Pressure ≥85 mmHg), impaired fasting blood glucose (FBG ≥ 100 mg/dL), high triglycerides (TG ≥ 150 mg/dL) and low high-density lipoprotein-cholesterol (HDL-C < 40 mg/dL).[4] Although there are some variations in the diagnostic criteria for MetS in children and adolescents in different countries, there is a strong association between childhood obesity and MetS where there is 11.9% and 29.2% of MetS prevalence among overweight and obese children, respectively (Figure 1).[5–25] These numbers were also higher in Hispanics than their Caucasians and African American equivalents.[19,26] Almost 90% of obese children and adolescents develop at least one MetS characteristic.[27]

In South Asia, nearly one-third of urban-dwelling children and adolescents present MetS characteristics,[28] with 30% of Asian Indians presenting with insulin resistance.[29] Furthermore, a review by Misra *et al.* indicated that MetS was more prevalent among Asian Indian adolescents when fasting hyperinsulinemia was accounted for in its defining criteria, from 0.8% to 4.2% (modified NCEP, ATP III definition).[30] An overall MetS prevalence of 2.3% was also recorded in China, which increased with age and peaked at 17 years of age (3.9%).[31] Dyslipidaemia defined by total cholesterol ≥170–200 mg/dL, low-density lipoprotein cholesterol (LDL-C) ≥110–130 mg/dL, high-density lipoprotein cholesterol (HDL-C) <35–45 mg/dL, TG ≥ 75–100 mg/dL for 0–9 years and ≥90–130 mg/dL for 10–19 years is one of the many components of MetS and had the greatest prevalence among Chinese school-aged children (21%), followed by hypertension (14%),[32] and obesity (6.7%).[33] In Taiwan, the prevalence of MetS was higher in boys than girls (5.56% *vs* 6.39%) in a group of 6 to 12-year-olds.[34] In contrast, MetS among Thai adolescents had a prevalence of 4.27%, with the prevalence among females being greater than that of their male counterparts (5.22% *vs* 3.36%).[35]

Taste sensitivity differs individually based on age, sex, ethnicity, body weight status, taste bud development, taste concentration, and saliva composition.[36–40] It is proposed that obese subjects must consume more to compensate for their impaired sensitivity and gain the same stimulation of taste and oral somatosensory system. This lacking sensitivity is hypothesized to have relationships with food intake and body weight variation with implications on long-term health outcomes. However, data concerning correlations between taste sensitivity and obesity are inconsistent[41] and centered mainly on bitter-taste responsiveness, whereas little is currently known about other taste qualities, especially in children.

Sensitivity to bitter taste has broad implications for taste perception, food preferences, and dietary behavior, with potential impacts on nutritional status and health outcomes.[42] Based on 6-*n*-propylthiouracil (PROP) or phenylthiocarbamide (PTC) sensitivity, individuals can be classified into three PROP taster categories: non-tasters (not at all or taste PROP at a high concentration of 0.32 mmol/l), medium tasters, and PROP super-tasters (perceive extreme bitterness when tasting PROP).[43] It has been proposed that those individuals identified as super-tasters are more responsive to other taste qualities including fats[44] and that PROP tasting is associated with variations in food acceptability, selection of vegetables and fruits, and increased health risk parameters for overweight and obesity.[45–47] A recent study amongst 156 Caucasians and 67 Asians aged 18–65 years in the UK reported a higher proportion of Asians were super-tasters as compared to Caucasians (55% vs. 24%, $p < 0.01$), however, evidence is scarce amongst children from Asia.[48] Our previous pilot study among Malay children aged 7 to 12 years in Kuala Lumpur found no difference between normal and obese children in taste sensitivity and preferences (All p's > 0.05).[49] Comparatively, there are more varieties of bitter-taste vegetables used in Asian than in European cuisine, however, their impact on children's weight status and metabolic profile is still relatively limited.[50,51]

While genetics is an important determinant, it is beyond the scope of this study. Given the lack of existing reviews specifically focusing on bitter-taste vegetables available in Asian culture and weight status and metabolic profile in children, the aim of the present narrative review was to describe the availability of bitter-taste vegetables in Asian culture and consumption of vegetables in the world population, discuss the potential interaction between food preference on childhood obesity and metabolic syndrome, and establish the potential associations between consumption of bitter-taste vegetables in Asian culture and clinical outcomes.

An online search was conducted for publications in English from 1990 until October 2022 with no restriction on the study design but only included studies conducted in humans. The keywords included "bitter"; "vegetables"; "weight status"; "metabolic profile", "Asia", "culture", and "children". A two-step search strategy was adopted with initial searches performed in four electronic databases (MEDLINE, CINAHL, EMBASE, and Cochrane Library) followed by an analysis of the text words contained in the title and abstract. A second search using all identified keywords and index terms was then undertaken in two additional electronic databases (ProQuest and Scopus). The systematic search strategy conducted in this review is shown in Supplementary Table 1.

Consumption of vegetables in the world population

Data from the Food and Agriculture Organization of the United Nations regarding global vegetable consumption in 2013 indicated the highest yearly consumption rate per capita in Asia (176.83 kg), followed by Europe (115.10 kg), North America (113.42 kg), Oceania (101.47), Africa (67.57 kg), and the lowest being South America (52.6 kg). Among different vegetable types, the intake of the *Brassica* family seems to mirror that of the global trend with Europe (85 million tonnes) and America (67 million tonnes) following behind Asia's consumption at 70% or 540 million tonnes. With 355 million tonnes, China was ranked first among the top 10 Brassica-consuming nations in the world, followed by India, the United States, Turkey, the Russian Federation, Japan, Egypt, the Islamic Republic of Iran, Italy, and the Republic of Korea. The population of Greece, however, had the highest per capita consumption (275 kg/person/year), with China coming in a close second (270 kg/person/year).[52]

Among children aged 6 to 23 months, the UNICEF Infant and Young Child Feeding (IYCF) Global Database showed a 47% and 27% global consumption of vitamin A-rich and other fruits and vegetables, respectively.[53] The intake of vitamin A-rich fruits and vegetables, when observed from the Demographic and Health Surveys data, was also 5.7 times more apparent in children from wealthier families as compared to their poorer counterparts.[54]

Despite inadequate fruit and vegetable consumption being common across all geographical regions, it was most apparent amongst South Asians, where 97% and 90% of girls consume fruits and vegetables below the recommended daily servings, respectively.[55] These numbers vary between countries, ranging from 60% in China,[56] 85% in India, 75% in Indonesia, 83% in Myanmar, 77% in Sri Lanka, 67% in Thailand, to over 95% in Nepal.[57,58] Similarly, the Malaysian Adolescent Nutrition Survey 2017 mirrored these findings where a majority of adolescents (10–17 years) did not achieve sufficient vegetable intake (92%).[59] However, compared to children from Asia, a lower number of European adolescent children from 12 to 17 years old evidenced a daily fruit and vegetable intake lower than the recommended amount at 35% (boys) and 21% (girls).[60,61]

Availability of bitter-taste vegetables in Asian culture and their nutritional composition

The *Brassicaceae*, often referred to as the *Cruciferae*, is one of the most commercially significant plant families globally with a diverse worldwide distribution of 372 genera and 4,060 species.[62] Around the world, various *Brassicaceae* vegetable species are cultivated, which include *Brassica oleracea* (cabbage, broccoli, and cauliflower), *Brassica rapa* (Chinese cabbage, pak choi, choy-sum, and turnips), *Brassica juncea* (mustard greens), and *Raphanus sativus* (daikon radish).[62]

Among the Asian varieties, *B. oleracea* and *B. rapa* are the most widely grown and consumed. In different countries and regions, the production and consumption of different *Brassicaceae* vegetable types are attributed to social and economic factors. In China, *R. sativus* is the main *Raphanus* species consumed, which mirrors the consumption in Japan, in addition to *B. oleracea*, *B. rapa*, and *B. juncea*.[62] Within Southeast Asia, the Chinese leafy vegetable kailan and choy-sum are the primary crops grown in varying climates, particularly in Thailand.[63] In 2017, the Thailand market supply identified the *Brassicaceae* varieties (*B. juncea*, *B. oleracea,* and *B. rapa*) to possess the greatest diversity in terms of species and cultivars.[64] Cruciferous vegetables of the *B. oleracea* species *i.e.*, cabbage, broccoli, and cauliflower were among the most common vegetables consumed in the Malaysian diet.[65,66] These vegetable crop types were also similarly yielded in central Taiwan, together with kailan, Chinese cabbage, and radish.[67]

The consumption of *Brassica* vegetables has been associated with anticarcinogenic, antioxidant, and anti-inflammatory properties and they serve as a source of vitamins, minerals, and several phytochemicals.[68] These vegetables, particularly broccoli, contain high quantities of carotenoid, tocopherol, vitamin C, and folic acid all of which have been associated with a reduction in the risk of the development of chronic diseases.[69] In a study by Wills and Rangga,[70] the analysis of seven leafy Chinese vegetables identified sixteen carotenoids in Chinese cabbage, pak choi, and choy-sum with lutein (20–36%) and β-carotene (16–21%) being the most abundant. Among the vegetable folate sources, broccoli was reported to have the highest levels (110–135 µg/100g).[71] Folate is also present in raw cauliflower (696 ± 111 µg/100g).[72]

In addition to being a rich source of vitamins, *Brassica* vegetables are also rich in dietary minerals.[69] One of the highest mineral sources includes kale with its high contents of potassium (24.2 to 40.8 g/kg), phosphorus (3.2 to 6.4 g/kg), calcium (2.8 g/kg), selenium (1.0 to 1.29 µg/kg), iron (23.5 to 45.7 mg/kg), and zinc (35.8 mg/kg).[73,74] Several other *Brassicas*, such as Chinese cabbage, white cabbage, Brussels sprouts, broccoli, and cauliflower also contain substantial amounts of essential minerals.[73] Besides being highly bioavailable in calcium, this plant family possesses high selenium levels, especially when cultivated and grown on selenium-rich soils. In vegetables such as broccoli, selenium is stored as selenocysteine[69] before being relatively quickly absorbed into the systemic circulation. As a prominent antioxidant, selenium has been associated with a reduction in obesity and the subsequent development of MetS through its influence on adipocyte physiology.[6]

The high antioxidant capacity of *Brassicas* is attributed to their high phenolic contents.[7] Flavonoids, being one of the most common phenolic compounds in these vegetables, play a vital role in maintaining good health via a reduction in the development of reactive oxygen species. Furthermore, the high polyphenolic content has also been associated with the reduction in oxidative stress-related diseases such as various types of cancer, obesity, and cardiovascular disease.[8] A study by Miean and Mohamed reported that, out of 62 vegetables analyzed, Chinese cabbage, green-white cabbage, kailan, broccoli, and cauliflower are high in flavonoids, ranging from 148–219 mg/kg.[9]

Brassicas vegetables have been identified as one of the richest sources of glucosinolates (GSL) in the human diet. These compounds are secondary plant metabolites responsible for the bitterness and pungency of several different plants such as kailan, kale, cabbage, turnip, broccoli, and cauliflower.[62] GSL-based research is predominately orientated towards their anticarcinogenic properties. However, relatively recent emerging evidence on the antioxidative impact of GSL-derived isothiocyanates in decreasing the risk of cardiometabolic disorders when incorporating cruciferous vegetables into the diet has garnered special attention.[12,75] Several potential mechanisms of action have been associated with these compounds: in particular, changes in insulin sensitivity and glycemic response management, lower blood pressure, and improved endothelial function as well as reduced atherosclerotic plaque development and its progression.[12]

Bitter-taste-related genes and their association with food preference

Differences in taste perception and sensitivity may be explained by genetic variations,[36–38] as polymorphisms of the genes coding for taste are closely linked to the inter-individual differences.[40] In humans, bitter taste perception is controlled by the TAS2R family of genes, which has 25 functional genes. Of all these genes, TAS2R38 has been proven to be the PTC/PROP taste receptor accounting for a quarter of the total phenotypic variance in bitter-taste. Three functional single nucleotide polymorphisms in gene nucleotide positions 145 (rs713598 C/G), 785 (rs126866 C/T) and 886 (rs10246939 G/A) encode amino acids at position 49 (alanine/proline, A49P), 262 (valine/alanine, V262A), and 296 (isoleucine/valine, I296V) explaining the differences between the non-taster allele of PTC genes from the taster allele.[76] The two predominant haplotypes globally are the major taster form [known as Proline-Alanine-Valine (PAV)], and the major non-taster form [Alanine-Valine-Isoleucine (AVI)]. The worldwide variations in non-tasters have been observed in Africa (3%), China (between 6% and 23%), North America (about 30%), and India (as high as 40%).[76]

A systematic review exploring the genetic background of taste perception and preferences and their nutritional implications suggests a significant association exists between TAS2R38 variants (rs713598, rs1726866, rs10246939) and bitter taste preference while fat taste responsiveness is related to rs176667 (CD36).[77] As the AVI/AVI homozygotes possess lesser bitter sensitivity than heterozygous or homozygous PAV carriers, it has been hypothesized that individuals with increased bitter-taste sensitivity might avoid a wide range of bitter compounds such as coffee, brassica vegetables, and spinach.[19] In the adult studies, higher vegetable consumption was reported amongst the AVI/AVI diplotype compared to those from the PAV/AVI and PAV/PAV diplotype,[78] especially regarding the intake of brassica vegetables.[79] However, amongst a sample of preschoolers, PROP taster children demonstrated a greater preference for sweets than non-taster children,[80] highlighting differences between children and adults in their taste sensitivity driven by both genetic and developmental factors. The interaction between bitterness sensitivity and actual food consumption that can predispose to obesity and other health risks in children has yet to be fully understood and calls for more exploration.

Effect of food preference on childhood obesity and metabolic syndrome

At the nexus between hereditary and environmental components, children's food preference is considered an integral factor in the development of childhood obesity. Their preference for discretionary foods (sweet-tasting over bitter/sour-natured fruits and vegetables) may be due to the underlying genetic-environmental determinants such as an inherent evolutionary preference for sweet foods, hereditary genotype markers, and bitter-taste endophenotype *vs* parental feeding practices, food availability, accessibility, and exposure.[10,11,13,18] In some children, an endophenotype sensitivity towards bitter-taste can become a probable cause of their food rejections, including bitter cruciferous vegetables, with a simultaneous preference for sweeter food choices.[10,81]

Children and adolescents require adequate energy intake for optimal growth and development, however, excessive energy intake combined with a decrease in activity can lead to the development of obesity.[14] Moreover, the consumption of ultra-processed and refined diets and sugar-sweetened beverages has been purported to be the contributor to rising obesity prevalence.[37] A recent systematic review of the worldwide consumption of ultra-processed foods concluded high variability in the intake with young people, men, and overweight/obese generally having higher levels of consumption.[16] In turn, environmental changes leading to higher caloric consumption have been accompanied by factors predisposing the young to decreased energy expenditure such as reduced physical activity levels and increased time spent in sedentary activities.[17] Moreover, it has been demonstrated that children's eating habits and the risk of childhood obesity were associated with parental feeding practices.[82–84]

A short-term shift in food type consumption can eventually lead to a chronic increased energy intake, resulting in a subsequent body weight increment over time. Thus, increasing vegetable consumption as a replacement for that of energy-dense foods should be the primary strategy for family food practices and behavioral weight management programs in targeting the obesity epidemic amongst children and adolescents.[85,86] The fundamentals of this weight control concept stem from reduced caloric consumption through the lower energy density and satiety-enhancing properties of water and fiber within the vegetables.[87,88]

Potential associations between consumption of bitter-taste vegetables in Asian culture and clinical outcomes

Increased adiposity is closely associated with increased biomarkers of oxidative stress and inflammation.[89] The phytochemicals found in fruits and vegetables have been shown to have anti-obesity properties due to their possible role in suppressing adiposity-associated metabolic biomarkers.[90,91] To date, the richest sources of vegetables for potential anti-obesity phytochemicals include the red varieties of onion (*Allium cepa*), lettuce (*Lactuca sativa*), capsicum (*Capsicum annum*), curly kale (*Brassica oleracea var sabellica*) and orange-fleshed type of sweet potato (*Ipomoea batatas*).[20] In contrast to the modern diet, which is strong in wheat, processed meat, and fast food, the traditional Chinese diet, which includes a high intake of rice, vegetables, poultry, pork, and fish, was found to be inversely associated with later obesity.[21] This study was conducted in China over 5 years from 2006 to 2011 and followed 489 participants aged 6–14 years.

In a recent narrative review of more than 60 prospective cohorts, most included studies found an inverse or no association between intake of various vegetable groups (green leafy vegetables, cruciferous vegetables, allium vegetables, yellow-orange-red vegetables, and legumes) and risk of developing atherosclerotic vascular diseases, heart disease, and stroke.[22] However, in the meta-analysis of 23 studies by Gan *et al.*, when compared with the lowest consumption levels of total fruits and vegetables, the relative risk of coronary heart disease was 0.84 (95% CI: 0.79–0.90), 0.86 (95% CI: 0.82–0.91), 0.87 (95% CI: 0.81–0.93), respectively. Specifically, the inverse associations between fruit and/or vegetable consumption and risk of coronary heart disease were not observed in Asian populations, contrary to Western populations,[23] despite Food and Agriculture Organization of the United Nations reporting the highest consumption of vegetables in Asia compared to other parts of the world.[52] This valuable finding could be partially explained by the cooking methods and overall intake of fruit and vegetables in Asia. Asian cooking primarily involves the boiling and steaming of vegetables, which may cause the loss of water-soluble, heat-sensitive, and oxygen-labile nutrients while higher salt usage during home cooking may also reduce the benefits of vegetables.[86] More studies are warranted to further investigate the cultural differences in fruit and vegetable intake, and health risks.

The DONALD cohort study compared data on flavonoid intake from vegetables and fruits during adolescence (females: 9–15 years; males: 10–16 years) with fasting blood samples provided in adulthood (18–39 years).[24] Results revealed that a higher flavonoid intake from the consumption of fruits and vegetables was related to higher homeostasis model assessment insulin sensitivity (HOMA-2%S) among females ($p = 0.03$) but not males ($p = 0.05$). The HOMA-2%S is a method used to quantify cellular sensitivity to insulin. The authors concluded that flavonoid intake during adolescence is associated with a favorable risk profile for T2DM in early adulthood,[24] yet data on the relationship between vegetable consumption as an individual dietary component and MetS remain inconsistent. This discrepancy in results may be caused by variations in the amounts and distinct vegetable subgroups employed in different studies. A cohort study that followed 424 Iranian children and adolescents over 3.6 years reported a negative correlation between overall vegetable consumption and the risk of MetS. Among vegetable subgroups and participants with 1 component of MetS, the consumption of green leafy and allium vegetables was negatively related to the risk of MetS, OR = 0.23, 95% CI [0.07–0.71]; OR = 0.29, 95% CI [0.07–0.71], respectively. The associations were observed after accounting for the major potential confounders such as demographic characteristics (age, gender, physical activity, family history of diabetes), total energy and cholesterol intake, and BMI at baseline.[25]

Future directions

Vegetable intake, particularly if it is high in bioactive components yet bitter in taste, might be beneficial for preventing MetS, however, these findings can only be attributed to the associations rather than the cause and effect. Thus, future longitudinal studies investigating taste sensitivity, vegetable acceptance, and the effect of brassicas vegetables on the metabolic syndrome risk in Asian children are warranted. In the ethnically diverse population of children in Asia, in-depth research exploring genetics and taste sensitivity is fundamentally important. The body of evidence can be strengthened by investigating children with differing weight status as weight is a complex phenotype and strong determinant predisposing obese children to chronic diseases including MetS.

Conclusion

Evidently, MetS can be prevented through a healthy lifestyle including active living and a balanced diet. There is supportive evidence showing that an overall increased vegetable intake was negatively associated with the development of MetS in children and adolescents, but the intakes could be influenced by bitter-taste vegetable preference and consumption.

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Conflict of interest

One of the co-authors, Nenad Naumovski, is the Associate Editor of *Exploratory Research and Hypothesis in Medicine*. Other authors declare they have no conflict of interests related to this publication.

Author contributions

WYY conceptualized the manuscript, contributed to the methodology, supervision, project administration, and investigation, conducted the formal analysis and data curation, and prepared the original draft of the manuscript. SHO, KYL, and PLY contributed to the investigation, contributed to the methodology, conducted the formal analysis and data curation, and reviewed and edited the manuscript. NN and RJ: conceptualized, reviewed, and edited the manuscript. All authors read and approved the final version of the manuscript.

Data sharing statement

The data used to support the findings of this study are included in the article.

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