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.

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; PA V, proline-alanine-valine; PROP, 6-n-propylthiouracil; PTC, phenylthiocarbamide; TG, triglyceride.

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≥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). 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). These numbers were also higher in Hispanics than their Caucasians and African American equivalents. Almost 90% of obese children and adolescents develop at least one MetS characteristic. In South Asia, nearly one-third of urban-dwelling children and adolescents present MetS characteristics, with 30% of Asian Indians presenting with insulin resistance. 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). 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%). 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%), and obesity (6%). 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. 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%).

Taste sensitivity differs individually based on age, sex, ethnicity, body weight status, taste bud development, taste concentration, and saliva composition. 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 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. Based on 6-α-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). It has been proposed that those individuals identified as super-tasters are more responsive to other taste qualities including fats 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. 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. 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). 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.

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 pre-
sent 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 es-
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 de-
sign but only included studies conducted in humans. The keywords
included “bitter”; “vegetables”; “weight status”; “metabolic pro-
file”, “Asia”; “culture”; and “children”. A two-step search strategy
was adopted with initial searches performed in four electronic da-
tabases (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 Na-
tions regarding global vegetable consumption in 2013 indicated the
highest yearly consumption rate per capita in Asia (176.83 kg), fol-
lowed 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 Braz-
sica 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 mil-
lion tonnes, China was ranked first among the top 10 Brassica-con-
suming 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).

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, were 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 com-
mon across all geographical regions, it was most apparent amongst
South Asians, where 97% and 90% of girls consume fruits and vege-
tables 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 ve-
getable 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 rec-
ommended 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 spe-
cies.62 Around the world, various Brassicaceae vegetable species
are cultivated, which include Brassica oleracea (cabbage, broc-
ccoli, and cauliflower), Brassica rapa (Chinese cabbages, 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 vegeta-
table 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.63 Within Southeast Asia, the Chinese leafy vegetable kai-
lan and choy-sum are the primary crops grown in varying climates,
particularly in Thailand.64 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 cul-
тивars.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 antitumorogenic, anti-oxidant, and anti-inflammatory proper-
ties and they serve as a source of vitamins, minerals, and several
phytochemicals.68 These vegetables, particularly broccoli, contain
high quantities of carotenoids, tocopherol, vitamin C, and folate
and 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 sourc-
es 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 (3.58 mg/kg).73,74
Several other Brassicas, such as Chinese cabbages, white cabbages,
Brussels sprouts, broccoli, and cauliflower also contain substantial
amounts of essential minerals.75 Besides being highly bioavailable
in calcium, this plant family possesses high selenium levels, espe-
cially when cultivated and grown on selenium-rich soils. In vegeta-
bles such as broccoli, selenium is stored as selenocysteine69 before
being relatively quickly absorbed into the systemic circulation. As a
prominent antioxidant, selenium has been associated with a reduc-
tion 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 main-
aining good health via a reduction in the development of reactive oxygen
species. Furthermore, the high polyphenolic content has also been as-
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 caulif-
lower are high in flavonoids, ranging from 148–219 mg/kg. 54

Brassicaceae vegetables have been identified as one of the richest

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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.12,79 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.15

**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 diploptype compared to those from the PAV/AVI and PAV/PAV diploptype,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 associations between consumption of bitter-taste vegetables in Asian culture and metabolic syndrome

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 annuum), curly kale (Brassica oleracea var. sabellica) and orange-fleshed type of sweet potato (Ipomoea batatas).90 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.92 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 atherothrombotic vascular diseases, heart disease, and stroke.21 However, in the meta-analysis of 23 studies by Gan et al., when compared with the

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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, despite Food and Agriculture Organization of the United Nations reporting the highest consumption of vegetables in Asia compared to other parts of the world. 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. 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). 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, 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 revealed an inverse 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.

**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.

**Supporting information**

Supplementary material for this article is available at https://doi.org/10.14218/ERHM.2022.00129.

**Supplementary Table 1.** Systematic search strategy.

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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 methodological 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 R.J.F. 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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