Relationships Between Taste and Food Intake in Adolescents

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Chapter 3

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Abstract

Background and aim: Studies that link taste to specific foods have been conducted; however, an evaluation of how taste associates with overall diet is missing. The aim of this thesis was to investigate associations between dietary tastes of UK and Saudi adolescents and overall diet quality and Body Mass Index (BMI).

Methods: Following a systematic review to report on the impact of taste on adolescents' food intake, a list of foods was generated from adolescents' food records from the National Diet and Nutrition Survey (NDNS). A random sample of adults was asked to identify the main taste for each food. From this, six taste clusters emerged (sweet, salty, savoury, sour, bitter and neutral), which were used to characterise the foods consumed by adolescents in the NDNS by taste. Then, taste patterns were generated, and the diet quality was calculated. Exploring Saudi adolescents' dietary tastes involved adolescents completing a food-taste survey and self-report their food intake using Arabic myfood24 tool (Arabic foods and their compositions were created and integrated into the tool, which showed acceptable level of usability among Saudi adolescents). Survey responses identified five taste clusters (sweet, salty, sour, bitter, and neutral), which were used to characterise the adolescents' foods by taste. Multivariable regression analyses were used in both UK and Saudi studies to explore the associations.

Results: The systematic review identified limited number of studies and an unclear effect of taste on adolescents' food choices and intake. Five taste patterns – *salad-bar, hot-food, takeaway-meal, sweet-snack,* and *beverages* – were generated from the dietary tastes of UK adolescents, with 2/3 of adolescents' diet comprised of sweet- and neutral-tasting foods. The highest impact on energy intake was associated with an increase in the consumption of the takeaway-meal taste pattern by 168 kcal/d (95% CI 139, 197; P < 0.01). However, consumption of the taste pattern was inversely associated with BMI by -0.8 kg/m^2 (95% CI -1.4, -0.1; P = 0.02). S*weet-snack* taste pattern was significantly associated with negative diet quality, while the *hot-food* taste pattern was associated with a better diet quality 2.0% (95% CI 1.0, 3.1; P < 0.01). In contrast, salty foods were most prominent and preferred in Saudi adolescents' diet and contributed the highest impact on energy intake (17 kcal/d; 95% CI 13, 22; P < 0.01). Neutral and bitter foods were linked to positive diet quality scores in Saudi adolescents' diet. However, no relationship with BMI was identified.

Conclusion: For the first time, taste characteristics of adolescents' dietary intake were explored. Sweet foods and salty foods dominated the UK and Saudi adolescents' diets, respectively. Understanding adolescents' dietary tastes could help improve their food choices.

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List of abbreviations

ANCNPAS	Australian National Children’s Nutrition and Physical Activity Survey
BMI	Body Mass Index
BOP	Back-of-pack
CoFID	Composition of Foods Integrated Dataset
COVID-19	Coronavirus disease
CVD	Cardiovascular disease
DQI	Diet Quality Index
DQI-A	Diet Quality Index for Adolescents
DQc	Diet Quality component
DDc	Diet Diversity component
DEc	Diet Equilibrium component
DA	Diet Adequacy
DEx	Diet Excess
DLW	Doubly labelled water
DNFCS	Dutch National Food Consumption Survey
FCDB	Food Composition Database
FBDG	Food-based dietary Guidelines
FFQ	Food Frequency Questionnaire
GPCRs	G-protein coupled receptors
gLMS	generalized Labelled Magnitude Scale
HCA	Hierarchical Cluster Analysis
HEI	Healthy Eating Index
HPFS	Health Professionals
KSA	Kingdom of Saudi Arabia
MSG	Monosodium glutamate
NaCl	Sodium chloride
NCDs	Non-communicable diseases
NDNS	National Diet and Nutrition Survey
NMES	Non-milk extrinsic sugars
NHANES	National Health and Nutrition Examination Survey
NHS	National Health Service
NHS2	Nurses' Health Study 2
NNPAS	National Nutrition and Physical Activity Survey

NQplus	Nutrition Questionnaires plus study
PCA	Principal Component Analysis
PDA	Personal Digital Assistant
PROP	Propylthiouracil
PTC	Phenylthiocarbamide
SSB	Sugar-sweetened beverages
SUS	System Usability Scale
TEE	Total energy expenditure
TNH	Toronto Nutrigenomics and Health
UK	United Kingdom
UNICEF	United Nations Children’s Fund
WHO	World Health Organization

Chapter 1 Overall introduction, thesis aim and objectives

1.1 Introduction

Adolescence, or the transition from childhood to adulthood (World Health Organization, 2020), is a critical phase of human development (Blakemore et al., 2010). Thus, good nutrition and adequate intake of energy and nutrients are important for meeting growth and development requirements. According to the UK National Health Service (NHS), adolescents aged 13 to 18 years old are required an average energy intake of 2414-3155 kcal/day for boys and 2223-2462 kcal/day for girls. However, these are only a guide and energy requirements may increase or decrease depending on other factors such as physically active level (National Health Service, 2021).

Health-related behaviours formed during adolescence can last into adulthood (World Health Organization, 2020). However, because young individuals often assert their independence and autonomy through unhealthy eating behaviours, their eating behaviours and food choices typically worsen as they move from primary to secondary school (Hackett et al., 2002). This may, in turn, negatively affect their dietary intake and health—not only in the short term but also eventually in adulthood (Seddon et al., 2003; World Health Organization, 2020; McKinley et al., 2005). Overnutrition (i.e. excessive energy intake) and undernutrition (i.e. nutrient deficiencies) during adolescence are global health-related issues that can be found in low-income countries because of poverty and in high-income countries because of poor dietary patterns (World Health Organization, 2005).

Individuals during adolescence exhibit unhealthy eating behaviours that may put them at risk of non-communicable diseases (NCDs). Currently, adolescents' typical diet patterns involve an inadequate intake of fruit, vegetables, whole grains and dairy products, along with an increasing frequency of eating out and snacking on low nutrient-dense foods that are high in fat, sugar, and salt (Moreno et al., 2010; Nielsen et al., 2002; Gidding et al., 2005). Studies conducted in several countries have identified dietary patterns among adolescents that range from healthy to unhealthy. Healthy dietary patterns often consist of fruits, vegetables, whole grains and protein sources. Conversely, unhealthy dietary patterns are mostly calorie-dense, processed foods that are associated with a higher intake of saturated fat, sugar, salt and cholesterol, but that are low in most essential nutrients (Hinnig et al., 2018; Man et al., 2020; Martínez Arroyo et al., 2020; McCourt et al., 2014; Neves et al., 2021). Across most countries globally, at least one unhealthy dietary pattern was categorised as high-calorie-dense/low-nutrient-dense foods (e.g. sweet and salty snacks, refined grains, sweetened beverages, fat and processed food products). Moreover, as countries grow economically, adherence to an unhealthy diet becomes greater (Hinnig et al., 2018; Neves et al., 2021).

According to the American National Health and Nutrition Examination Survey (NHANES), the trend of fast-food intake among adolescents (12–19 years) increased in 2017–2018; and more than one-third of children and adolescents in the United States had around 14% of their daily calories coming from fast foods (Fryar et al., 2020). The United Nations Children's Fund (UNICEF) reported that, among adolescents from 18 countries, one-third of dietary intake came from ultra-processed foods, including white processed bread, takeaway meals, sweetened sugar beverages and confectionery. The highest consumption of such foods was found in middle- and high-income countries, such as the United States, Australia, Serbia and Mexico, while their overall consumption of fruits and vegetables was low (Fleming et al., 2020). A study based on the Australian National Nutrition Survey, in turn, demonstrated low fruit and vegetable consumption among children and adolescents and, when fruit juice was excluded, 60% of adolescents aged 16–18 years were found not to consume fruit daily, with their overall fruit and vegetable intake below the recommendation (Magarey et al., 2001). In another instance, a cross-sectional survey conducted in nine European countries showed that participants in Austria, Denmark and Portugal had the highest overall fruit intake, with a mean average intake of 171, 157 and 153 g/d, respectively. Although Portugal (111 g/d), Sweden (109 g/d) and Belgium (105 g/d) had the highest overall vegetable intake, none of the populations met the recommended values (Yngve et al., 2005).

A review based on the early findings of the United Kingdom National Diet and Nutrition Survey (NDNS) reported that 40%–50% of the participants aged 4–18 years old had an intake of fresh vegetables, 40% had cooked leafy vegetables and 60% consumed other types of cooked vegetable (Smithers et al., 2000). However, only 8% of adolescents aged 11–18 years met the five-a-day recommendation (five portions of fruit and vegetables, at 80 g/portion) during the period of 2014–2016 (Public Health England, 2016). More than 80% of the participants had high consumptions of white bread, potatoes, and savoury and sweet snacks (Smithers et al., 2000), while whole grain intake was low among adolescents aged 13–17 years, with a median intake of 15 g/day by only 15% of the adolescents (Mann et al., 2015). A cross-sectional analysis based on data from the NDNS found that only 4% of adolescents aged 11–18 years met the dietary guideline of no more than 5% of non-milk extrinsic sugars (NMES) intake of total energy, which was associated with a higher consumption of pasta, rice, wholemeal, brown bread and fish. However, 79% of the adolescents had more than 10% of NMES intake of the total energy associated with a higher consumption of sweetened drinks, fruit juice, cakes, biscuits, sweet spreads, chocolate confectionery, sugar and sugar confectionery (Lai et al., 2019). Furthermore, recent findings from the NDNS indicated that, from 2016 to 2019, individuals aged 11–18 years had the highest consumption of sugar-sweetened beverages (SSB), with a mean intake of free sugar of 12% of the total energy intake. Similarly, the intake of saturated fats was higher in this age group, with a mean intake of 13% compared to the recommendation of no more than 10% (Public Health England, 2020). Available evidence has shown that the frequent consumption of fast food and takeaway meals is increasing among adolescents, with 24%–37% consuming fast food/takeaway meals ≥ 2–3 days/week, and an increase in the proportion of individuals eating fast food and takeaway meals more often is predicted (Shareck et al., 2018; Taher et al., 2019; d'Angelo et al., 2020).

Nutritional transition in the Kingdom of Saudi Arabia (KSA) is associated with the recent rapid economic growth in the KSA and lifestyle changes introducing more of the Western diet (Musaiger et al., 2012). This nutrition transition has resulted in a malnutrition burden in the form of both undernutrition and overnutrition in children and adolescents (El Mouzan et al., 2012). Findings from a national survey conducted on participants aged 15 years and older showed concerning dietary behaviours, especially for a young population that had increased consumption of SSB and processed foods but low intake of fruits and vegetables (Moradi-Lakeh et al., 2017). Similarly, Al-Hazzaa and colleagues reported that Saudi adolescents aged 14–19 years had high consumption of SSB, sweet foods (e.g. candies, chocolates, cakes, doughnuts, and biscuits), French fries and chips; and that 67%–80% of the participants did not have a daily intake of breakfast, fruit, vegetables and milk (Al-Hazzaa et al., 2011). A cross-sectional study of intermediate-school girls reported a low daily consumption of fruits and vegetables and a higher consumption of cheese sandwiches, chips, chocolate, desserts, fizzy drinks and juice (Al-Muammar et al., 2014). Around 95% of adolescent girls in the capital city of the KSA reported regular fast-food consumption, with 53% consuming fast food once a week and 25% consuming it at least twice a week (Al Faris et al., 2015). Similar findings were found among boys (Al-Hazzaa et al., 2011) . Burgers were reported to be the most popular fast-food choice (70%), and pizza and French fries were the second most popular fast-food choice (33% and 30%, respectively) (Al Faris et al., 2015). A recent study confirmed the increased consumption pattern of fast food, canned juice and sweets (Al Turki et al., 2018). Such a dietary pattern of high calorie-dense but low nutrient-dense foods not only increases the incidence of obesity and its related health issues but also raises the concern of undernutrition due to a lack of nutrients (World Health Organization, 2021).

Therefore, evaluating the quality of individuals' diets is important for assessing adherence to dietary recommendations and guidelines. Several studies from different countries have reported that adolescents usually have poor diet quality (Acar Tek et al., 2011; Llauradó et al., 2016; Taher et al., 2019; Washi and Ageib, 2010; Al-Ghamdi et al., 2012). All these poor diets were generally associated with more frequent consumption of takeaway foods and calorie-dense snacks; a high intake of sodium, fat, saturated fats, and oil; a low intake of whole grains, fruit, vegetable, milk, fibre and protein; as well as a low intake of micronutrients and minerals, including vitamin A, vitamin D, calcium, iron, iodine and zinc. Various Diet Quality Indices (DQIs) have been used to quantify the consumption of foods and nutrients to assess the quality of individuals' diets. However, only a limited number of DQIs have been specified and validated to evaluate adolescents' diets (Dalwood et al., 2020). The Diet Quality Index for Adolescents (DQI-A), a modified validated version of the DQI that was positively associated with nutrient biomarkers, has been suggested as an accurate and reliable tool that can precisely assess adolescents' diet quality (Dalwood et al., 2020; Vyncke et al., 2013). Further details on the DQI-A and its components for evaluating diet quality are provided in both Chapters 5 and 8.

When studying people's dietary intake, it is important to know what factors influence their food choices, intake and diet quality. This can help tailor and enhance people's dietary intake through specifically-designed strategies and interventions. For instance, several factors motivate adolescents' decisions on food choices and intake. Personal factors related to food preferences and food appeal (i.e. taste, food appearance, texture and smell), hunger and food craving, as well as socio-environmental and socio-economic factors (i.e. parents, peers, cultures, beliefs, cost, convenience of food and food availability) are all reported to influence food selections and intake during adolescence. Among these factors, taste has been reported to be the key driver of adolescents' food choices and intake (Fleming et al., 2020).

In daily life, the words "flavour" and "taste" are used interchangeably. Scientifically and biologically, however, flavour refers to the combined sensation that emerges from the gustatory and olfactory systems (Forestell, 2017; Breslin, 2013), while taste—the focus of the current thesis—refers to the detection of the basic tastes in foods (i.e. sweet, salty, sour, bitter and umami/savoury) by the gustatory system (i.e. the process by which chemical components in foods activate the taste receptor cells in the oral cavity) (Breslin, 2013). These components, which are sugar, salt/sodium and fat, play a critical role in food taste and palatability. Thus, taste, as a contributor to food palatability, could affect the quality of the diet. However, the effect of taste on diet quality depends on the type of food and its nutrients content (Cox et al., 2018; Wanich et al., 2020). For example, diets high in sweet-tasting foods (e.g. fruit) are likely to be more nutrient dense than diets high in energy-dense sweet-tasting foods (e.g. cakes, pastries and SSB) that are high in free sugars.

Individuals vary in their sensory attributes (i.e. taste perceptions and preferences), and these variations determine their dietary intake. Available studies on the relationship between taste perceptions/preferences and dietary intake, however, are limited and non-inclusive in terms of the assessed dietary intake (i.e. they study specific foods and nutrients rather than assess the overall dietary intake by taste); and they have revealed inconsistent findings, for reasons that include varying taste and dietary assessment methods (reviewed in Chapters 2 and 3). Researchers have recently taken a new approach to studying a population's dietary taste, which involves a taste classification of the whole diet (van Langeveld et al., 2018; Lease et al., 2016; Martin et al., 2014). But such studies are limited in number, limited to adults, limited in the dietary characteristics studied and they were conducted using mainly highly trained panellists. Although an earlier attempt at taste classification by regular consumers was developed (Cox et al., 1999), it was exclusive to a small number of adults and only studied energy intake in relation to taste. Thus, a comparable study on adolescents is still lacking, despite the critical role of taste as a determinant of this age group's dietary intake.

In order to classify the taste of foods in individuals' diets and to evaluate their dietary taste patterns, there is a need for a comprehensive collection, quantification and assessment of the consumed foods and nutrients. Dietary assessment is a key requirement in nutritional epidemiology and public health, and it is an important measurement to assess people's intake to improve their diet and health (Shim et al., 2014). Adolescents—particularly girls and those with obesity—present a challenge, as they are usually less motivated or sensitive in reporting their food intake, which results in underreporting of foods and misreporting of portion sizes. However, the use of technology-based dietary assessment tools has been observed to be promising in enhancing the process of dietary assessment among adolescents (Foster and Bradley, 2018). This is because technology-based dietary assessment tools are time- and effort-efficient, and they can be integrated with an updated Food Composition Database (FCDB), which is helpful in terms of automatic quantification of the nutrient intake. The current FCDB available for Middle Eastern countries is outdated and limited in foods, and an innovative technology-based dietary assessment tool in the region's native language (i.e. Arabic) has not yet been established. Thus, an updated, comprehensive, nationally-representative FCDB of the included foods and nutrients is essential for reliable assessment (Cade, 2017) and for improving epidemiological studies in this region.

In summary, adolescence is a challenging and critical period of transition from childhood to adulthood, and it corresponds to critical changes in development. At this stage, adolescents need good nutrition and high-quality foods to supply their bodies with adequate nutrients and energy to support their growth—but still meet their taste preferences. Therefore, there is a need for explicit and practical attention to adolescents' eating behaviours and dietary intake from a taste perspective. Adolescents' current dietary taste patterns and the effect of taste on the quality of their diets should be explored.

1.2 Thesis aim

This thesis aimed to explore the dietary tastes of UK and Saudi Arabian adolescents and to examine the association of their dietary tastes with daily energy intake, Body Mass Index (BMI), and overall diet quality. To fulfil this aim, the specific objectives in each chapter are as follows:

1.2.1 Thesis objectives by chapter

Chapter 2: Literature review

- To introduce and briefly review the sense of taste
- To offer a brief review of the current evidence regarding the role of taste in dietary intake
- To briefly review dietary assessment and the development of a food composition table

Chapter 3: Impact of taste on food choices in adolescents: A systematic review and meta-analysis

- To summarise the existing evidence regarding the role of taste in adolescents' food choices
- To combine results from similar studies in order to provide more powerful findings using meta-analysis
- To identify the research gap in this area

Chapter 4: Characterising and assessing UK adolescents' dietary taste: Results from the UK National Diet and Nutrition Survey

- To characterise and assess UK adolescents' food and beverage taste
- To explore the taste contribution to UK adolescents' daily energy intake
- To explore the taste contribution to UK adolescents' daily energy intake by gender
- To explore the taste contribution to UK adolescents' daily energy intake by age group
- To explore the taste contribution to UK adolescents' daily energy intake by BMI
- To explore the taste contribution to UK adolescents' daily energy intake by eating occasion

Chapter 5: Association between UK adolescents' dietary taste patterns and daily energy intake, BMI, and diet quality

- To identify UK adolescents' dietary taste patterns
- To investigate the association between UK adolescents' dietary taste patterns and daily energy intake
- To investigate the association between UK adolescents' dietary taste patterns and BMI
- To investigate the association between UK adolescents' dietary taste patterns and dietary quality scores

Chapter 6: Development of an Arabic food composition database for use in an Arabic online dietary assessment tool (myfood24)

- To build a database of common foods and associated nutrients in Saudi Arabia
- To develop an Arabic online dietary assessment tool, myfood24
- To collect Saudi adolescents' food records to test the usability of the Arabic myfood24 (in Chapter 7) and to study Saudi adolescents' dietary taste (in Chapter 8)

Chapter 7: Exploring the usability and acceptability of the Arabic version of the online dietary assessment tool, myfood24: A pilot study

- To evaluate the usability and acceptability of the Arabic myfood24

Chapter 8: Characterising and assessing Saudi adolescents' dietary intake and diet quality by taste: An exploratory study

- To identify Saudi adolescents' food-taste preferences
- To characterise Saudi adolescents' food and beverage taste
- To explore taste contribution to Saudi adolescents' overall energy intake per day and by gender
- To assess Saudi adolescents' dietary intake by taste

1.3 Thesis framework

Figure 1-1 illustrates the thesis structure by chapter. The thesis starts with a brief introduction to the gaps and limitations in the literature, followed by a general literature review (Chapter 2) and a systematic review and meta-analysis on the available studies on adolescents' taste perceptions/preferences and food choices and intake (Chapter 3). Two chapters are allotted for classifying and assessing UK adolescents' dietary tastes using the UK NDNS (Chapters 4 and 5). The following three chapters are related to Saudi Arabian adolescents' dietary tastes: starting with developing an Arabic FCDB/Arabic myfood24 (Chapter 6), testing its usability (Chapter 7) and move on to quantify and assess Saudi participants' dietary tastes (Chapter 8).

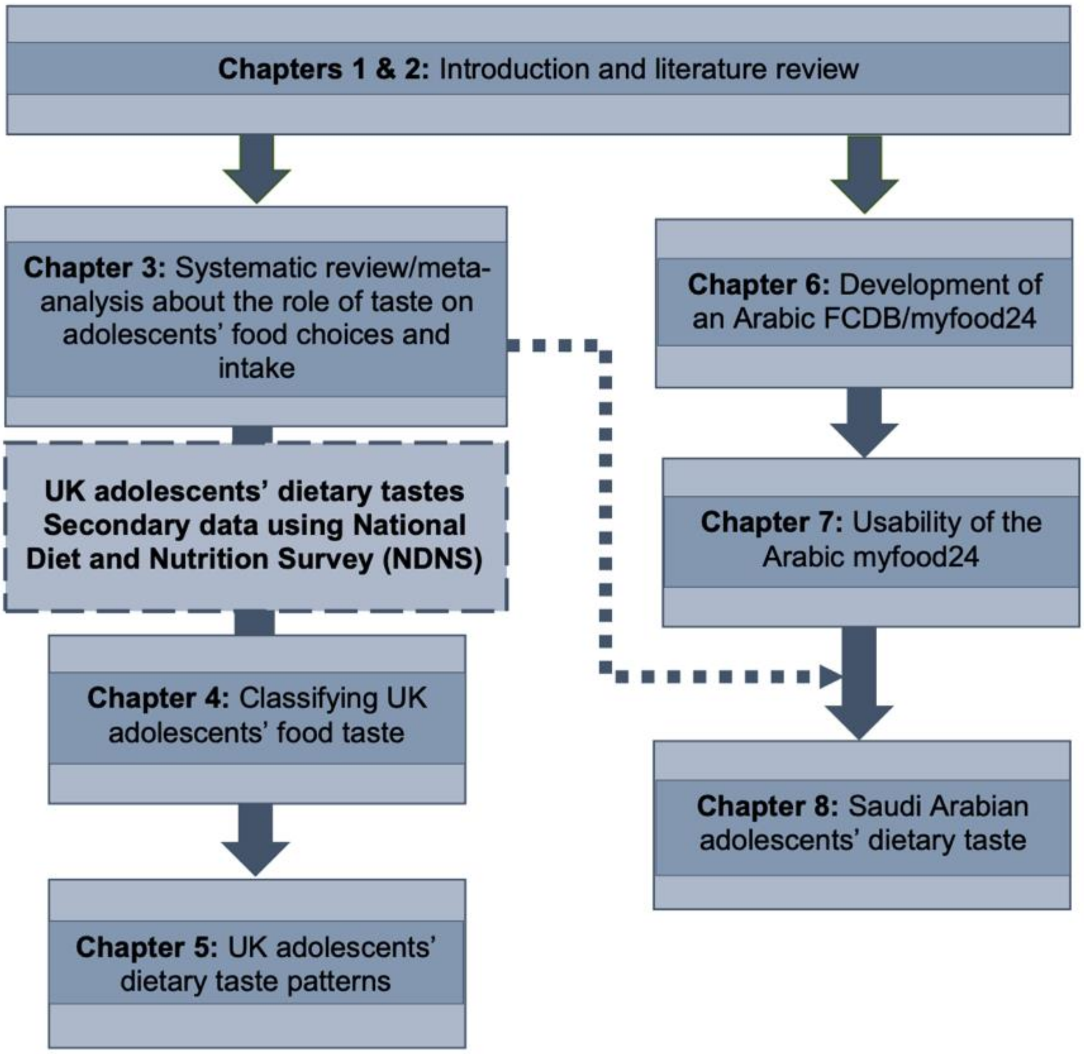

Figure 1-1. Thesis framework

1.4 Conclusion

This chapter provides a brief introduction to the thesis rationale, overall aim, and objectives as well as the thesis framework. The next chapter (Chapter 2) reviews the sections that build the current thesis: human taste, taste assessments, the role of taste on food choices and intake (Chapter 3 concerns adolescents), and dietary assessment methods.

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Chapter 2 Literature review

2.1 The sense of taste

The sense of taste develops early in humans. It is a critical functional modality for evaluating what to eat. Taste perceptions are produced by molecules that stimulate taste buds and taste receptors in the oral cavity. Taste produces an early sense of what is “acceptable” or “unacceptable” to eat. Therefore, the sensation of taste is a gatekeeper that enables the evaluation of and discrimination between foods/nutrients and toxic components, and it prepares the body for metabolism after ingestion. Humans differ in their taste perceptions and preferences throughout life due to distinct factors. This section provides a brief overview of the biology of taste and the determinants of variability in human taste.

2.1.1 The biology of taste and human innate predispositions

The gustatory system consists of taste cells, called taste buds, that reside across the different papillae throughout the tongue. Among taste buds, there are taste receptor cells, which are the first point of the gustatory signals that induce taste sensation. Once food is chewed and dissolved into the saliva, taste stimuli are released and react with the taste receptors, sending taste signals to the brain through intercellular communication with nearby neurons (Breslin, 2013).

The five basic tastes humans can perceive are sweet, salty, sour, bitter, and savoury (umami). Recently, fat has been introduced as a potential sixth taste; however, this has been debatable, as fat perception may involve both taste and olfactory sensations (i.e. flavour release) and the mouthfeel perception (i.e. texture) (Kindleysides et al., 2017; Keast and Costanzo, 2015). Three of the five basic tastes—sweet, bitter and savoury (umami)—are detected by seven-transmembrane G-protein coupled receptors (GPCRs) located within the taste cells. GPCRs have two types of receptor families: type 1 receptor (T1R) and type 2 receptor (T2R). T1R is found in three receptors that interact with sweet taste (T1R2 and T1R3) and umami taste (T1R1 and T1R3), while T2R elicits bitter taste. In contrast to those three tastes, salty and sour tastes are perceived by a direct interaction with ion channels on the taste pores (Breslin and Spector, 2008; Chamoun et al., 2018b; Negri et al., 2012).

Genetic variation in taste perceptions involve a number of single nucleotide polymorphisms (SNPs) in the taste receptor genes. Three nonsynonymous coding SNPs within bitter-related gene, TAS2R38, is responsible for most of the variations in bitter taste perceptions. These are rs713598–Ala49Pro, rs1726866–Val262Ala and rs10246939–Ile296Val, which rise two haplotypes that are common in human, PAV (Proline-Alanine-Valine) AVI (Alanine-Valine-Isoleucine). Individuals carrying PAV are sensitive to the bitterness and known as “tasters”, whereas individuals who carry AVI are insensitive and known as “non-tasters” (Cecati et al., 2022; Bufe et al., 2005). Regarding sweet taste, synonymous noncoding SNP rs12033832 within sweet-related gene TAS1R2 has been linked with differences in sweet taste perceptions with G allele carriers (G/G and G/A) reporting low sensitivity to sweetness compared with A allele carriers (A/A) (Dias et al., 2015). Also within the same gene, two nonsynonymous coding SNPs result in amino acid replacement of isoleucine for valine (rs35874116–Ile19Val) and replacement of serine for cysteine (rs9701796–Ser9Cys) are linked to higher sweet sensitivity (Eny et al., 2010a; Pioltine et al., 2018). Unlike bitter and sweet tastes, less is known around savoury, salty and sour. Amino acid replacement of arginine for cysteine (rs307377–R757C) within the savour-related gene, TAS1R3, results in lowering the sensitivity to the savoury taste (Chen et al., 2009; Raliou et al., 2011). Concerning salty and sour tastes, variation in the salty-related gene, TRPV1 rs8065080, results in low sensitivity to salty taste that is linked to amino acid changes from isoleucine to valine (Ile585Val) (Pilic et al., 2020), and variation in sour-related gene, KCNJ2 rs173135, that is linked to amino acid leucine results in low sensitivity to sour taste (Chamoun et al., 2018a).

Taste sensation begins in the foetus during late gestation, and sweetness is the initial taste that can be detected before birth and continues to develop over time (Forestell, 2017). With this early development, innate taste preferences can be shaped early in life. Newborn infants were found to discriminate between sweet solution and water and to show a preference for sweetness, observed by the increased sucking of the sweet solution compared to water. Also, infants’ preference for sweet taste appeared as a positive reaction, compared to the rejection response to bitter and sour tastes (Ventura and Worobey, 2013). This is due to the transmission of tastes and flavours from the mother's diet to the amniotic fluid during pregnancy and to breast milk during lactation. Thus, infants experience sweet and savoury (umami) tastes in the mother’s milk through breastfeeding (Breslin, 2013). However, infants’ responses to salty taste do not suggest a clear sign of either acceptance or rejection until around the age of 4–

24 months, when signs of acceptance begin to be more pronounced (Ventura and Worobey, 2013). This is probably due to the low saltiness of mothers' milk, and to the introduction of baby formula or solid foods with some level of saltiness. Furthermore, studies have reported that breastfed and formula-fed babies may show preferences for a wider range of tastes and flavours with repeated exposure to tastes that are part of the mother's diet or the unique taste profile of the formula (Ventura and Worobey, 2013). These early taste perceptions and preferences are related to genetic predispositions in the first stage, but several life-related determinants can alter these perceptions and preferences.

2.1.2 Determinants of variability in taste perceptions and preferences

Taste perception occurs as soon as substances react with taste receptors, but individuals vary in taste-related genetic predispositions. This results in inter-individual differences in taste perceptions. Genetic analysis in regard to variations of bitter and sweet tastes has been widely studied, and limited studies of genetic variations in relation to savoury taste perception have been suggested, while genetic variations related to salty and sour tastes are still unclear (Diószegi et al., 2019).

Genetic research has focused on the genetic variations of the bitter taste perception of propylthiouracil (PROP) and phenylthiocarbamide (PTC) as marker compounds to determine individuals' differences in bitter taste. These variations are responsible for differences in people's detection and sensitivity to bitterness. Some individuals who are sensitive to bitter taste can perceive bitterness at low concentrations and are classified as "tasters" or "supertasters" for those who are even incredibly sensitive, whereas individuals who cannot perceive bitterness are classified as "non-tasters" (Smail, 2019). The variations in the sweet and savoury taste receptor genes are responsible for humans' ability to perceive these tastes or to discriminate between various levels. Based on these variations, people are either sensitive and can perceive the taste at very low concentrations (threshold levels) or they are less sensitive and need higher concentrations (suprathreshold levels) (Fushan et al., 2009; Fushan et al., 2010; Kim et al., 2006; Li et al., 2002; Shigemura et al., 2009; Zhao et al., 2003). Moreover, studies have suggested that individuals' sensitivity to bitter taste could be linked to sensitivity to the other remining tastes (Yeomans et al., 2007b; Bartoshuk et al., 1998; Diószegi et al., 2019; Hayes et al., 2010).

The general heritable differences in taste receptors have produced some ethnic variations in taste perceptions. For example, individuals from Asian or African ethnic groups are often more sensitive to bitter taste than white European populations (Guo and Reed, 2001; Sato et al., 1997). Compared to white Europeans and Asians, African Americans are less sensitive to sweet taste, as they require higher concentrations to perceive sweetness (Fushan et al., 2010). Gender differences in taste perceptions are also a factor (Williams et al., 2016). This may refer to the density of taste buds, which are more abundant in females, in addition to genetic and hormonal variations.

Studies have found potential age-related changes in taste perceptions and preferences; as individuals age, taste buds decrease and changes in taste cell membranes occur. While taste identification may not be greatly affected, taste threshold and sensitivity to the taste intensity have been shown to decrease with age, although the degree of the decline varies between taste qualities (Methven et al., 2012; Mojet et al., 2001; Wang et al., 2020; Mojet et al., 2003). Another possibility is that the higher taste perception of younger individuals could be strongly related to the innate genetic predispositions of taste receptors, unlike in adults who have experienced external environmental and other factors that have potentially modified their taste perceptions and preferences (Negri et al., 2015; Mennella et al., 2010).

Thus, humans' preferences and acceptance of tastes are innate at birth (Barragan et al., 2018), but these innate preferences are not stable throughout life. Children appear to grow up having taste preferences similar to what they experienced in their early life, and the preference for higher concentrations of sweetness in foods continues until it decreases during adulthood (De Graaf and Zandstra, 1999). Their natural rejection of other tastes, especially bitter taste, also continues. However, indirect learning—for example, watching adults express enjoyment in eating vegetables through positive and excited comments or facial expressions—has been found to motivate children to overcome rejection (Edwards et al., 2022). Nevertheless, although this approach has proven effective in children up to 10 years old, it may not be as effective in adolescents. In the same context, children can develop taste preferences through their parents giving them healthier food choices, but parents' influence is more limited in adolescents, for whom the influence of their peers and food accessibility outside the home may be more pronounced (Wills et al., 2019).

In summary, genetics, ethnicity, gender, age, parents/peers, and food availability and accessibility are determinants that interact together to shape human taste perceptions and preferences. Since the sense of taste is a key determinant of food choices and preferences, and since individuals' taste preferences are subject to change through behavioural changes, nutritional epidemiological and intervention studies can play a key role in enhancing and improving individuals' taste preferences and dietary intake.

Section summary

- Taste perception is produced when food components touch and activate taste receptors in the oral cavity.
- Humans' taste perceptions are defined by their genetic predispositions.
- Several factors, including age, gender, ethnicity and learning, can modify human taste perceptions and preferences.

2.2 Taste assessment

Sensory studies of taste involve assessing and evaluating humans' taste responses (i.e. perceptions or preferences) to different tastes. Given the several factors that influence the shape of taste sensation, genotype and phenotype methods for taste assessment have been used to identify the characteristics of individuals' taste perceptions or preferences. Thus, the primary purpose of such studies has been to quantify humans' taste perceptions. However, with the increased interest in the link between taste perceptions and dietary intake, the taste characteristics of foods need to be identified and assessed. This section briefly reviews methods commonly used in assessing individuals' taste perceptions and preferences (mainly the phenotype methods), along with the methods and studies conducted to characterise the taste of foods.

2.2.1 Assessing individuals' taste characteristics

Genotype and phenotype methods for taste assessment have been used in identifying individuals' taste characteristics (Shen et al., 2016). The genotyping method involves genomic analysis, which indicates gene variations and predispositions in taste receptors. It aims to identify the characteristics of genes controlling taste receptors (Fay and German, 2008; Laaksonen et al., 2013). Phenotype assessments, in turn, translate individuals' taste traits due to environmental effects on taste perceptions and help identify individuals' perceptions and actual sensations (Armstrong, 2008). Phenotype measurements consist of three aspects: detection and recognition threshold, taste intensity, and hedonic (i.e. preferences and acceptance); these are described in the consecutive points. The relationship between genotype and phenotype methods has been used to provide better evidence and support in identifying individuals' taste perception (Armstrong, 2008; Hayes et al., 2011; Negri et al., 2012). For example, variations in the gene associated with perceived bitterness were related to taste phenotype, with an overall 95% agreement (Negri et al., 2012; Calò et al., 2011). However, this relationship may not always hold, especially in terms of age, where children are more generally sensitive to bitter taste than adults (Mennella et al., 2005).

2.2.1.1 Taste sensitivity (detection and recognition thresholds)

Detection and recognition thresholds emphasise individuals' ability to detect and recognise a taste based on different concentrations. The detection threshold is the lowest concentration of a taste stimulus (e.g. sucrose) that can be detected differently from a control sample. As the concentration of the taste stimulus increases, the quality of the taste can be successfully recognised (e.g. sweet). This is called the recognition threshold (Lawless and Heymann, 2010).

Detection and recognition threshold measurements involve presenting the participants with taste samples at different concentrations and asking them to detect the tastes at the lowest concentration that can be perceived. This can be done through an ascending and descending concentration series (i.e. staircase method) in which the participant is given a sample containing a taste stimulus and another control sample, often water or a less concentrated sample. The participant is asked to identify the stimulus from the control or to identify the sample with a recognisable taste. If the participant cannot identify the stimulus, the subsequent higher concentration is presented. Once the stimulus is correctly identified at a certain concentration, the subsequently-tested concentration decreases. The procedure is repeated until two consecutive correct answers are identified (Pasquet et al., 2006; Leek, 2001).

Another procedure is called ascending forced-choice, in which participants evaluate taste samples at different concentrations, from the lowest to the highest. At each concentration level, the participants are presented with a set of samples containing the taste stimulus (at the target concentration) and one or more other samples containing the control sample (often water) and/or taste stimulus sample at the concentration tested before the target one. The participants are asked to choose the sample they could easily distinguish from the others at each subsequent concentration level. This method can be done using different numbers of target and control samples, for example, a two-alternative forced-choice or a three-alternative forced-choice. As the name indicates, the participants are required to choose a sample from the set of samples, even if they are not able to discriminate between them (Lawless, 2010).

The issue with threshold assessments is that the evaluations are susceptible to selection bias of the detected stimulus, which may be due to fatigue or habituation, or to anticipation of an increase or decrease in concentrations, especially in the staircase method. Moreover, the participants may set a stopping point at the detected threshold differently. Some may be conservative with their answers, while others may report spontaneously or by chance (Lawless and

Heymann, 2010). In the forced-choice method, participants are required to make a choice even if they are uncertain, which is subject to answer bias (Running, 2015).

Generally, at the threshold level, a taste stimulus may elicit considerable differences in inter-individual perceptions. Detection and recognition threshold assessments are, thus, powerful methods of quantifying human taste function and of studying genotype–phenotype association (Genick et al., 2011). However, the low concentrations used in threshold assessments are not comparable to the food context, where taste concentrations in foods are usually above these levels (Keast and Roper, 2007; Low et al., 2016). Therefore, evaluating and exploring individuals' food choices and intake based on threshold methods is inappropriate.

2.2.1.2 **Taste intensity (suprathreshold)**

Taste intensity refers to the perceived intensity of a taste at concentrations above the recognition threshold level (i.e. suprathreshold concentrations). Taste intensity assessment has been used to quantify individuals' taste genotype–phenotype association, along with the detection and recognition thresholds, but it is less powerful due to its higher concentrations (Genick et al., 2011). Conversely, taste intensity assessment effectively evaluates real-life taste experience and can be used to evaluate the link between taste, food choices, and intake and health-related outcomes (Bartoshuk et al., 2004a).

Individuals' perceived taste intensity is assessed using liquid solutions (Webb et al., 2015) and filter paper/taste strips soaked in sample tastes (Manzi and Hummel, 2014) or food/beverage (Hayes et al., 2010). Unlike in the complex threshold methods, participants are presented with each tasting sample independently and given the different concentrations in a random order. The participants are asked to record the perceived intensity on a generalised Labelled Magnitude Scale (gLMS). The gLMS is a labelled scale that allows individuals to rate the perceived intensity of the taste along a line scaled from 0 to 100 and labelled with verbal sensation adjectives (i.e. 0 = no sensation, 100 = strongest imaginable sensation of any kind) (Bartoshuk, 2000; Bartoshuk et al., 2004b).

Taste intensity assessment is more cost- and time-efficient than threshold assessment. Unlike threshold tests that need to be conducted with participants one by one, intensity assessment is feasible for use with a group of people at once (Galindo-Cuspinera et al., 2009; Genick et al., 2011). Therefore, it is considered a better approach than threshold methods to evaluating individuals' taste perception of foods.

2.2.1.3 Hedonic assessment (taste-liking)

Hedonic assessment involves evaluating individuals' liking/disliking of tastes. Similar to taste intensity assessment, concentrations at the suprathreshold level are used in hedonic evaluation. Moreover, samples can be presented to the participants as liquid solutions, real food, or a list of foods survey (Hayes et al., 2010). Similar to the scale used in the intensity assessment, hedonic responses are rated on a hedonic-form gLMS, with "strongest imaginable liking" = 100 and "strongest imaginable disliking" = −100 placed at both ends of the scale, and "neutral" = 0 placed at the centre of the scale (Bartoshuk et al., 2006; Cruickshanks et al., 2009).

Although the gLMS effectively rates perceived intensity and preferences, its use by the public, especially younger individuals, can be misleading. The reason is that the all-inclusive end labels (i.e. strongest imaginable liking/disliking of any kind) may reduce the discrimination power, especially when the extreme labelling is far less than the actual feeling; thus, training in its use is required. To overcome this issue, a nine-point hedonic scale (i.e. a Likert scale) is commonly used in testing food preferences and acceptance among general consumers. This is an odd-point scale (9, 7, or 5), with a "neutral" label at the centre and with various degrees of positive (i.e. "liking") and negative (i.e. "disliking") categories on each side (Lim, 2011). Thus, hedonic testing is time- and effort-effective and is closely related to food intake (Tan and Tucker, 2019; Duffy et al., 2009). It is feasible for it to be commonly used in evaluating food–taste preferences and acceptance among general consumers (Lawless and Heymann, 2010).

The increased evidence regarding taste and dietary intake proposed by intensity and hedonic testing has encouraged researchers to study this relationship. However, it is essential to first classify the taste characteristics of foods as identified by regular consumers of these foods.

2.2.2 Classifying the taste characteristics of foods

The components of food are the source of its unique taste, and different tastes signal the nutrient content of the food. For example, sweetness implies the content of simple sugars and carbohydrates; savoury suggests the presence of amino acids (i.e. amino acid glutamate, aspartate, and selected ribonucleic acids), indicating protein content; and sodium is related to food saltiness. Bioactive compounds, including plant-based phenols, polyphenols, flavonoids, isoflavones, terpenes, glucosinolates, tannin and caffeine elicit bitter taste in vegetables, tea and coffee. The sourness of foods reflects acidity, which could be related to vitamin C, fermentation or unripe fruit (Breslin, 2013; Drewnowski and Gomez-Carneros, 2000). However, this taste-nutrient relationship has been demonstrated with selected nutrients; therefore, not all nutrients in foods are necessarily signalled by tastes, and they are not exclusive to certain foods. The taste-nutrient relationship can be reflected in both healthy (e.g. the sweetness of fruit) and unhealthy foods (e.g. sweetness in sugar-sweetened beverages), as well as in non-nutritive items such as artificial sweeteners. Additionally, in some foods, a nutrient-related taste may not be easily sensed because of its low quantity or its interactions with other tastes, known as taste-taste interactions. Taste interactions play a role in enhancing or suppressing certain tastes. Such an interaction may be naturally occurring (e.g. sweetness and sourness in some fruit) or it may be due to daily life practices (e.g. adding sugar to coffee or salt to broccoli) (Liem and Russell, 2019).

Recently, researchers have begun to study the taste profile of foods (Table 2-1). In most of these studies, trained panellists evaluated the taste intensity of 50 foods as a first attempt (van Dongen et al., 2012), while in others they evaluated a more comprehensive range of foods using food records from national surveys (Lease et al., 2016; van Langeveld et al., 2018; Martin et al., 2014). The principle of this taste evaluation is based on evaluating the taste intensity of foods according to reference solutions at different concentrations for each taste and/or according to food reference modified to different concentrations. Briefly, the panellists first undergo training sessions, which vary among studies, using reference samples and/or food references. Then, the panellists are presented with a certain number of foods for the taste sensory test.

Table 2-1. Studies profiling food taste

Studies	Taste classification procedure				Food taste classification outcomes
	Panellists	Food samples	Training	Taste evaluation	
(van Dongen et al., 2012)	• Nineteen panellists • Mean age 21 years (SD 1·7) • Mean BMI 21·5 (SD 2·0) kg/m^2	• Fifty commonly consumed food items, based on the National Food Consumption Survey 2003	• Two training sessions were provided • Training based on reference solutions in increasing concentrations for each taste (sucrose for sweetness, sodium chloride (NaCl) for saltiness, monosodium glutamate (MSG) for umami, citric acid for sourness, and caffeine for bitterness)	• Taste evaluation took place in one day • Five one-hour sessions were held in total • One hour before the evaluation, panellists were requested to refrain from eating or drinking anything other than water • Panellists were told to put food in their mouths, taste it, and spit it out • Then, they rated the intensity on a scale of 0 to 15 using the reference solutions	• The overall taste profile of the basic tastes for the 50 foods was not made publicly available • Foods were classified and grouped by their taste intensities into: ⇒**Neutral-tasting foods* included**: brown and white rice, macaroni, egg, rice waffle, whole-meal and white bread, cucumber, lettuce, mashed and boiled potatoes, cashew nuts, shrimp, milk, rusk, boiled and raw carrots, peas, crackers, chicken breast filet, peanuts, tomato, tea, and liquorice ⇒**Salty/savoury foods included:** meatballs, vegetable and tomato soup, smoked salmon, potato chips, and cheese ⇒**Sweet/sour foods included:** pineapple, yoghurt, yoghurt drinks, diet coke, apple puree, apple juice ⇒**Sweet-tasting foods included:** banana, custard, chocolate, chocolate milk, toffee, waffle, ginger biscuits, ice cream, cake, and gingerbread

(Martin et al., 2014)	• Twelve panellists (seven women and five men) • Have previous experience in sensory profiling • Mean age 46 years	• 590 foods commonly consumed by the panellists	• Additional training (55 hours over 5 months) • Training based on reference solutions at different concentrations for each taste (sucrose for sweetness, NaCl for saltiness, MSG for umami, citric acid for sourness, and caffeine for bitterness) • Training on samples of foods familiar to the panellists to easily remember the references	• Each panellist was asked to conduct an in-home taste evaluation of at least 75 food items/month • Evaluation lasted 8 months • Then, they rated the intensity on a scale of 0 to 15 based on the reference foods	• The overall taste profile of the basic tastes for the 590 foods was made publicly available • Foods were grouped by their taste intensities into: ⇒**<u>Foods highly intense in salty/umami/fatty included:</u>** cheeses; mixed dishes based on meats, seafood, or processed foods; grain products; and snacks (e.g. crisps) ⇒**<u>Foods highly intense in sweetness included:</u>** pastries, fruits (e.g. fruit juices, dried fruits); bread eaten with jam, honey, or a spread; desserts (e.g. custards and mousses); chocolates; sweets; soft drinks; sweetened tea; sweetened milk chocolate; cookies; and breakfast cereal ⇒**<u>Foods high in sweetness, bitterness, and sourness included:</u>** fresh fruits, fruit juices, and alcoholic drinks (i.e. wine, flavoured beers, some sweet wines) ⇒**<u>Foods mainly bitter included:</u>** unsweetened hot drinks (e.g. coffee and tea), beer, broccoli, cauliflower, and green beans ⇒**<u>Foods highly intense in saltiness, umami, sourness, and bitterness included:</u>** vegetables eaten cold

					with vinaigrette and foods flavoured with lemon ⇒**Foods mainly high in saltiness included:** foods (i.e. vegetables, bread, and potatoes) with added mayonnaise, dressing, salt, or salted butter
(Lease et al., 2016)	• Female panel (sample size not provided) • Mean age 49.81 ± 6.21 years • Previous experience of 5 years in sensory profiling	• 377 out of 3758 food items from the 2007 Australian National Children's Nutrition and Physical Activity Survey	• Additional 3 sessions of training were held • Training based on taste solutions at different concentrations (sucrose 2%–16%, NaCl 0.2%–0.8%, citric acid 0.05%–0.2%, caffeine 0.05%–0.2%, and MSG 0.3%–0.6%) • Food reference for each taste (cola, soaked tea bags, lemon juice, potato chips, and parmesan cheese to represent high levels of sweet, bitter, sour, salty, and umami taste, respectively)	• Panellists evaluated the taste intensity of the 377 food items, and taste profiles were assigned to all the remaining foods (3,758 food items) based on the food groups and the sugar, sodium, or fat content	• The overall taste profile of the basic tastes was not made publicly available • Sweet and salty tastes were the most common • Sour and bitter tastes had a low contribution ⇒**Foods high in sweetness included:** cola soft drinks, milk chocolate, and chocolate cake ⇒**Foods high in saltiness included:** soy sauce and vegemite, salted potato crisps, and cheddar cheese ⇒**'Bland' foods included:** some foods (e.g. rice, bread) that were low in salty, sweet, and any flavour-enhancing effects
(Teo et al., 2018)	• Fifteen Dutch (3 males and 12 females) • Mean age of 33 ± 12 years • 20 Malaysian (3 males and 17 females)	• 469 commonly consumed foods were selected from the Dutch National Food Consumption Surveys	• Six months (56–63 hours) of training • Training on taste intensity based on reference solutions at different concentrations for each taste (sucrose for sweetness, NaCl for	• Panellists evaluated the selected foods (nine samples in a session) by consuming the presented amount of each food (15 ml	• The overall taste profile of the basic tastes for the tested foods was made publicly available • Foods were classified and grouped by their taste intensities into: ⇒ **Sweet and fat:** (23% of the total Dutch foods, 19% of the total

	• Mean age of 21 ± 3 years	(DNFCS 2007–2010) • 423 commonly consumed Malaysian foods were selected from the 2014 Malaysian Adults Nutrition Surveys	saltiness, MSG for umami, citric acid for sourness, and caffeine for bitterness) • Modified food products and commercially available food products	or 15 g) and rated the taste attributes on a 100-point scale	Malaysian foods) included confectionery and pastry ⇒ **<u>Sweet and sour:</u>** (14% of the total Dutch foods, 15% of the total Malaysian foods) included fruits, soft drinks, and yogurt ⇒ **<u>Neutral foods*:</u>** (28% of the total Dutch foods, 14% of the total Malaysian foods) included cereal products, eggs, milk, some vegetables (e.g. carrot, cauliflower, boiled potatoes), rice, and bread ⇒ **<u>Savoury, salty and fat:</u>** (25% of the total Dutch foods, 50% of the total Malaysian foods) included mixed dishes, meats, and cheeses ⇒ **<u>Bitter:</u>** (3% of the total Dutch foods, 2% of the total Malaysian foods) included coffee, beer, and alcoholic beverages ⇒ **<u>Fat:</u>** found only in the Dutch database (7% of the total Dutch foods); included butter, margarine bread spread, cooking fats, and oils
(van Langeveld et al., 2018)	• Fifteen trained adults (3 men and 12 women) • Mean age 33 ±12 years	• 476 foods were chosen from the DNFCS 2007–2010	• Training on taste intensity based on reference solutions at different concentrations for each taste (sucrose for sweetness, NaCl for saltiness, MSG for umami,	• Panellists evaluated the selected foods (nine samples per session)	• The overall taste profile of the basic tastes for the tested foods was made publicly available • Foods were classified and grouped by their taste intensities into: ⇒ **<u>Neutral-tasting foods* included:</u>** 'bread' products, all vegetable food groups, 43% of potatoes, fish

	citric acid for sourness, and caffeine for bitterness) • Three food samples for each taste, modified at different taste concentrations		products, 28% of nuts, seeds, savoury snacks, and 15% of meat/meat products and poultry ⇒ **The fat group included:** fats, oils, and 31% of cheese products ⇒ **The sweet- sour taste:** included 59% of non-alcoholic beverages, fruits, and 33% of milk products ⇒ **The sweet and fat taste included:** sugar, sweets, sweet spreads/sauces, pastry, cakes, biscuits, and 57% of milk/ milk products ⇒ **The bitter taste included:** 28% of non-alcoholic beverages ⇒ **The salt, umami, and fat taste included:** 83% of meat/meat products and poultry, 67% of nuts, seeds, savoury snacks, 63% of cheese products, 57% of potatoes, and 100% of the soup food group

* Neutral-tasting foods defined as foods having no defined/clear one taste or low intensity tastes based on tastes profiling procedure

Panellists are asked to test the taste the foods and evaluate the intensity of the taste qualities (e.g. sweet, sour, salty, bitter and savoury) according to the references (Lease et al., 2016; Martin et al., 2014; van Dongen et al., 2012; van Langeveld et al., 2018). While these attempts are helpful in profiling the taste of foods and creating a food-taste database that can provide a better understanding of the taste characteristics of foods, training panellists can be time-consuming and expensive. Moreover, the day-to-day variability in taste acuity and the differences among individual panellists in tastes can be factors in taste profiling (Rogers, 2002).

In summary, using trained panellists may not capture the perceptions of regular consumers because of the high level of training and exposure to the taste, whereas regular individuals can conduct a real-life evaluation. Therefore, there is a need to adopt an easy and practical way to classify the taste of foods from the perspective of regular consumers and according to their perceptions of the foods they consume, in order to obtain a better understanding of how the taste of foods drives their food choices and intake.

Section summary

- Taste thresholds (detection and recognition) can help quantify the human taste function.
- Taste intensity helps evaluate individuals' real-life taste experiences in food intake and health-related outcomes.
- Hedonic testing (taste liking) effectively examines food-taste preferences and acceptance.
- Classifying the taste characteristics of foods is crucial to studying the relationship between individuals' taste perception/preference and dietary intake.
- The taste of food can signal its nutrients.
- Classifying the taste of food using trained panellists is valuable, but regular individuals can reflect a real-life evaluation.

2.3 Current evidence regarding taste perceptions, food preferences and dietary intake

Studies have reported differences among individuals in taste intensity and preferences for most of the basic tastes (Barragan et al., 2018): bitter (Roura et al., 2015), sour (Tornwall et al., 2012), sweet (Yeomans et al., 2007) , salty (Noh et al., 2013), and umami (Tinoco-Mar et al., 2017). These variations influence people's dietary intake (Feeney et al., 2011; Tepper et al., 2014). The general assumption is that sensitivity to a taste (i.e. capability to perceive the taste) or preference determines food intake. Individuals with high taste sensitivity (i.e. having a low detection or recognition threshold, or the ability to perceive the taste at low concentrations) may avoid consuming certain foods when they perceive the taste, and vice versa. Moreover, a highly preferred taste can indicate more consumption of food that produces a highly perceived concentration of taste. Despite the key role that taste plays in food choices and dietary intake, studies on taste, food preferences, and dietary intake seem unclear.

Studies conducted on adults and children (Table 2-2) and adolescents (Chapter 3) have shown no clear relationships between taste, food-taste preferences and consumption. Adults' sensitivity to bitter taste was found to be associated with less preference for, or consumption of, bitter-tasting foods and with eating behaviours to reduce bitterness (e.g. adding milk to coffee or adding salt to food) (Inoue et al., 2017; Dinehart et al., 2006a; Puputti et al., 2019). Other studies showed no effect on or association between bitter sensitivity and food preferences, frequency of consumption, and energy intake (Leong et al., 2018; Timpson et al., 2005). Similarly with sweet taste, although a liking for higher sweet taste concentrations indicated a higher preference and some evidence of dietary intake, the findings were also inconsistent (Mahar and Duizer, 2007; Mennella et al., 2012; Habberstad et al., 2017). Studies on salty, sour and savoury tastes are limited in number compared to bitter and sweet tastes, and their findings are also unclear (Inoue et al., 2017; Chamoun et al., 2018a; Cattaneo et al., 2019; Pilic et al., 2020; Pilic and Mavrommatis, 2018; Veček et al., 2020; Ferraris et al., 2021). Furthermore, sensitivity to or preference for a particular taste was found to affect sensitivity to other tastes as well as the acceptance and consumption of foods (Cattaneo et al., 2019; Inoue et al., 2017; Leong et al., 2018).

Table 2-2. Current evidence regarding taste and dietary intake in adults and children

Study	Study Sample	Dietary measurements	Taste assessments	Outcomes of the study
		Studies on adults		
		Testing more than one taste		
(Holt et al., 2000)	• Male and female • 17–35 years old	• Food frequency questionnaire (FFQ) of sugar and sweet foods/drinks	• Intensity and liking of sucrose solutions, orange juice, custard, sweet biscuit • Bitter taste intensity (PROP) in filter papers	• Perceived sweet intensity was not associated with the frequency of sweet food/drink intake • Total sweet liking for all the sweet samples was positively associated with the frequency of sweet food/drink intake • Bitter sensitivity influenced sweetness sensitivity
(Dinehart et al., 2006)	• Male and female • 18–60 years old	• FFQ of vegetable intake	• Intensity and hedonic rate of perceived sweetness, sourness, saltiness, and bitterness of vegetables (asparagus, Brussels sprouts, kale) and 4 types of sweet foods (branded chocolate and candy) • Intensity rating of one sample of NaCl, sucrose, citric acid, and quinine • Intensity rating of different concentrations of PROP	• Perceived sweetness in the vegetables predicted the preference for all vegetables • Perceived bitterness predicted the preference for Brussels sprouts and kale but not for asparagus • Sweet sensitivity was related to the frequent consumption of vegetables • PROP, but not quinine, and bitter sensitivity were related to the less frequent consumption of vegetables
(Simpson et al., 2012)	• Male and female • 55–87 years old	• Four-day food diary	• Detection threshold for the basic tastes at different concentrations (sweet: glucose 0.4–0.51, sour: citric acid 0.001–0.39, salty: NaCl 0.006–1.75, and bitter: quinine hydrochloride 0.0001–7.05)	• No significant associations were found between the detection thresholds of all tastes and dietary components

(Martinez-Cordero et al., 2015)	• Male and female • 24–43 years old	• Seven-day food diary	• Taste recognition threshold of saltiness, sweetness, sourness, and bitterness, using two representative compounds for each taste (14 different concentrations)	• Aspartame threshold negatively associated with the energy intake • Caffeine threshold was negatively associated with the percentage of protein intake
(Inoue et al., 2017)	• Female • 20–22 years old	• Three-day weighed dietary record	• Intensity of salty taste using NaCl solutions (10, 100 and 1,000 mm), and bitter taste using PROP solutions (0.032, 0.32, 1, and 3.2 mm)	• Individuals sensitive to bitter taste consumed more salt • Sensitivity to bitter taste was not associated with the total intake of vegetables • Sensitivity to saltiness was not associated with the intake of salt or vegetables
(Leong et al., 2018)	• Male and female • 21–55 years old	• Two 24-hour recalls	• Intensity and liking for basic tastes: sweet (sucrose), salty (NaCl), sour (citric acid), and bitter (PTC and quinine)	• No association between the intensity and liking for all tastes and dietary intake • Weak negative association between perceived saltiness and intake of total sugar and potassium • Weak negative association between perceived sourness and intake of protein and potassium
(Cattaneo et al., 2019)	• Male and female • 18–30 years old	• FFQ • Seven-day food diary	• Detection threshold using different concentrations of sucrose, NaCl, caffeine, and citric acid	• High sensitivity to salty taste was negatively associated with the consumption frequency of bakery and salty baked products, legumes, fats, and soft drinks and the percentage of energy from fat intake • High sensitivity to sweet taste was positively associated with the consumption frequency of legumes and desserts • High sensitivity to bitter was negatively associated with the consumption frequency of oils, while positively associated with energy and carbohydrate intake • High sensitivity to sour taste was associated with the frequency of fish intake noted in individuals with medium sensitivity

(Puputti et al., 2019)	• Male and female • 19–79 years old	• Consumption behaviour questionnaire • Pleasantness of foods and beverages	• Intensity of sour, bitter, sweet, salty, and savoury, using four concentration levels	• Bitter-sensitive subjects had lower consumption of coffee and tended to add milk to coffee • Bitter sensitivity was not related to liking or consumption of vegetables • Sour-sensitive subjects added sugar/honey and soy sauce to tea and meals, respectively • Sour-sensitive subjects had a more frequent consumption of salty and savoury foods • Savoury and sour sensitivity were linked to adding sweetness to tea and to more consumption of vegetables • Salt and sweetness sensitivity were related to the frequency of adding ketchup
(Louro et al., 2021)	• Male and female 20–59 years old	• FFQ • Preferences for fruits and vegetables	• Recognition threshold, intensity, and hedonics assessments for sweet, bitter, sour, and salty, using filter paper	• Higher preferences for sweet and salty foods linked to higher intake of sweets, fast food, protein, and carbohydrates • Higher sensitivity to tastes linked to a higher preference for fruit and vegetables and a higher intake of carbohydrates • Lower sensitivity to sour taste linked to a higher preference for sweet and sour vegetables
			Bitter Taste	
(Yackinous and Guinard, 2002)	• Male and female • 17–36 years	• FFQ	• Intensity of salty taste (NaCl) and bitter (PROP), using five concentrations	• Sensitivity to bitterness of PROP did not affect the daily intake of macronutrients and bitter-tasting foods and beverages
(Timpson et al., 2005)	• Female • 60–79 years old	• FFQ of green vegetables and alcoholic beverage	• Genetic analysis of the bitter-related gene, TAS2R38 (rs713598 and rs1726866)	• No association was found between taster status and consumption of green vegetables or any eating behaviours

(Duffy et al., 2010)	• Male and female • 20–39 years old	• FFQ • Food records	• Genetic analysis of the bitter-related gene, TAS2R38 (rs713598) • Threshold and intensity ratings of quinine and PROP	• Less sensitive subjects (carrying AVI haplotype) reported higher consumption of vegetables compared with sensitive subjects (carrying PAV haplotype).
(Colares-Bento et al., 2012)	• Female • 60 years old or over	• FFQ • Preferences for certain types of foods	• Genetic analysis of the bitter-related gene, TAS2R38 (rs713598) • Bitter sensitivity using filter paper soaked in PTC, sodium benzoate, and thiourea stimulus	• Genotype sensitivity to bitter taste (carrying PAV haplotype) moderately affected the frequent intake of bitter-tasting vegetables • Sensitivity to PTC bitterness did not influence the consumption of cereals, pasta, meat, dairy products, sweets, legumes, fruit, fat, and bread • Sensitivity to PTC bitterness did not show rejection of bitter-tasting vegetables, but frequency was lower
			Sweet taste	
(Mahar and Duizer, 2007)	• Female • 19–50 years old	• FFQ	• Intensity and liking for sweetness, using five orange juice samples in different concentrations of sucrose	• No significant association between sweetness intensity and the consumption of sweetened beverages • Individuals who liked higher concentrations of orange juice had a higher intake of sweetened beverages
(Eny et al., 2010)	• Male and female • 20–29 years old	• FFQ	• Genotype of the sweet-related gene, TAS1R2 (rs9701796 and rs35874116)	• Genetic variation affects the consumption of sugar • No differences were observed in macronutrients consumption for the rs9701796 (Ser9Cys polymorphism) between (Cys) and (Ser) allele carriers • Variations in the rs35874116 (Ile191Val polymorphism) showed significant differences among overweight individuals; those with homozygous major allele (Ile) had a higher intake of sugar and fruits
(Mennella et al., 2012)	• Female • 21–52 years old	• FFQ	• Genotype of the sweet-related gene, TAS1R3 (rs35744813)	• Significant association was found between gene variation and preferences of sweetness in water, but not in pudding

			• Intensity of different sugar concentrations in a pudding sample (without swallowing) • Sweet preferences using different sugar concentrations of five solutions and three puddings	• Significant associations were found between sweetened beverages and the preference for higher sweet concentrations in the solutions and pudding, with T allele carriers (CT and TT) showed higher preference than C allele carriers (CC).
(Dias et al., 2015)	• Male and female • 20–29 years old	• FFQ	• Genotype of the sweet-related gene, TAS1R2 (rs12033832) • Detection threshold using sucrose solutions • Intensity rating using sucrose solutions	• Variations in the sweet-related gene associated with carbohydrate and total sugar intake • The effect varies depending on the BMI, with BMI ≥25, carriers of the (G) allele of the rs12033832 SNP had a higher intake of carbohydrates, total sugars than individuals who were (AA) homozygous.
(Low et al., 2016)	• Male and female • 18–52 years old	• FFQ	• Detection and recognition thresholds • Intensity of glucose, fructose, sucrose, sucralose, erythritol, and rebaudioside A	• No correlation was observed between sweet detection/recognition thresholds and total energy intake or percentage of energy from macronutrients • Significant positive association was observed between sweet intensity of rebaudioside A and sucralose and the total energy intake
(Habberstad et al., 2017)	• Male and female • 46–68 years old	• FFQ • Seven-day food diary	• Genotype of the sweet-related gene, TAS1R2 (rs7534618)	• Modest associations were found between dietary intake and the sweet-related gene variation observed among overweight individuals in the carbohydrate intake, with the major (T) allele carriers consumed more carbohydrates than (G) allele homozygous • No significant association was observed in the sucrose intake
		Salty taste		
(Lucas et al., 2011)	• Male and female • 18–59 years old	• Food record • Free intake of hash browns at different levels of	• Detection and recognition threshold using eight concentrations of NaCl solutions	• No significant relationship was found between the detection/recognition thresholds and the liking or intake of the hash brown samples

		saltiness during lunch for two weeks	• Intensity and preference ranking of the hash browns	• No association was found between morning sodium intake and the liking or intake of hash browns
(Lee et al., 2014)	• Male and female • 31–38 years old	• Dietary habit questionnaire • 24-hour urinary salt	• Detection threshold test by dropping different concentrations of salt solution on the tongue	• No association was found between the detection threshold and salt-eating habit or 24-hour urinary salt excretions
(Pilic and Mavrommatis, 2018)	• Male and female • Median age of 28 years	• FFQ	• Detection and recognition thresholds, using eight different concentrations of NaCl solutions	• No association was found between salt sensitivity using the detection and recognition thresholds and salt intake or adding salt during cooking or at the table
(Martinelli et al., 2020)	• Male and female • 18–59 years	• FFQ • 24-hour food recall	• Recognition threshold for nine different concentrations of NaCl solutions	• Individuals with high salt sensitivity had higher energy and sodium intake
(Pilic et al., 2020)	• Male and female • 18–35 years	• Two 24-hour dietary recalls	• Detection and recognition thresholds, using eight different concentrations of NaCl solutions • Salt intensity and preferences, using tomato soup with different salt concentrations	• No association between detection and recognition thresholds and sodium intake • No association between salt preference in soup and the habit of salt eating • A larger proportion of the participants who preferred high salt content in soups reported eating more salty foods compared to those who eat in moderation or did not eat salty foods
(Veček et al., 2020)	• Male and female • Older than 18 years	• FFQ • Questions about the habit of adding salt before tasting food	• Recognition threshold of salt solutions at different concentrations • Intensity and hedonic tests	• Low sensitivity to saltiness linked to a higher frequency of adding salt to food • Individuals with a high salt threshold had a greater frequency of eating olive oil, legumes, fish, and white meat but fewer fruits and potatoes, whereas those with a low salt threshold were more likely to consume fruits

				• No significant association was found between taste intensity and adding salt or eating frequency • Saltiness liking was positively associated with adding salt
		Sour taste		
(Ferraris et al., 2021)	• Male and female • 65 years and older	• FFQ	• Genotype of the sour-related gene, KCNJ2 (rs236514)	• Carriers of the KCNJ2-rs236514 variant allele (A) had a higher preference for sour taste • The KCNJ2-rs236514 variant allele (A) was associated with a lower intake of energy, total fat, monounsaturated fat, and saturated fat
		Studies on children		
		Bitter taste		
(Keller et al., 2002)	• 4–5 years	• FFQ Preference for raw and cooked broccoli, orange juice, orange-grapefruit juice, semi-sweet and milk chocolate morsels, and American cheese	• Detection of PROP solution	• Significant differences in the liking for raw broccoli and American cheese between bitter-sensitive and non-sensitive • No differences in liking for the other foods between the two groups • No differences in intake between the two groups, except that non-sensitive to bitterness reported greater intake of discretionary fats
(Turnbull and Matisoo-Smith, 2002)	• 3–6 years	• Preference for raw spinach, raw broccoli, cooked broccoli, banana, lemonade, whole milk, and cheddar cheese	• Threshold and intensity, using different concentrations of PROP solutions • Hedonic liking for predominantly sweet or bitter foods	• PROP threshold and intensity did not predict food preference ranking • Those who were bitter-sensitive showed a lower liking rate for raw spinach
(Keller and Tepper, 2004)	• 4–5 years	• FFQ filled out by parents	• Detection of PROP solution	• Subjects not sensitive to bitterness had a higher intake of protein (meat food groups),

				• Subjects who were sensitive had a higher energy intake of sugar (sweet-fat snacks)
(Mennella et al., 2005)	• 5–10 years	• Children's self-report of open-ended questions about their favourite cereals and beverages	• Genotype of the bitter-related gene, TAS2R38 (rs713598) • Threshold testing using PROP and sucrose preferences	• Children who were sensitive to bitterness (PP homozygous allele carrier) preferred higher sucrose concentrations and sweetened cereals, compared to non-sensitive children
(Bell and Tepper, 2006)	• 3.5–4.5 years	• FFQ filled out by parents • Children were asked to eat as much as they want from five types of vegetables (black olives, cucumbers, carrots, red pepper, and raw broccoli)	• Detection of PROP solution • Hedonic rating for the vegetables	• No significant difference was found in the intake of vegetables between bitter sensitivity groups • Children sensitive to bitterness chose fewer bitter vegetables than non-sensitive children • Non-sensitive children liked raw broccoli compared to those who were sensitive • No differences were found in their preferences, as reported by mothers
(Lumeng et al., 2008)	• 3–6 years	• FFQ reported by parents	• Detection of PROP solution	• No difference was found in dietary intake between sensitive and non-sensitive children
(Tsuji et al., 2012)	• 3–6 years	• Three-day diet record	• Detection of PROP solution	• Non-sensitive children to bitter taste had a significantly higher intake of soy foods than those who were sensitive • No significant association was found between vegetable and fruit intake and bitter sensitivity status
(Burd et al., 2013)	• 4–6 years	• Food acceptance questionnaire	• Detection of PROP solution	• No significant correlation was observed between bitter sensitivity status and food acceptance
(Keller et al., 2014)	• 3–6 years	• Intake from a prepared buffet consisting of	• Genotype of the bitter-related gene, TAS2R38 (rs713598)	• Bitter-gene sensitivity did not predict savoury and sweet foods intake

		savoury-fats (e.g. pizza), sweet-fats (e.g. cookies, cakes), and sweets (e.g. juices, candies) • Intake was calculated based on pre- and post-weight consumption	• Threshold using three concentrations of PROP solutions	• Children sensitive to PROP bitterness had more sweet food intake than non-sensitive children
		Sweet Taste		
(Liem and Mennella, 2002)	• 4–7 years	• Questionnaires about children's feeding history, habits, and preferences completed by mothers • Mothers were asked to answer how often they added sugar to their children's diet	• Sweet liking using six apple juice samples with different sugar concentrations • Sour preference assessment by dissolving six different concentrations of citric acid in apple juice samples	• Higher exposure to sweetened foods (e.g. children whose mothers add sugar to their diet) was associated with higher preference for more concentrated sweetened juices • 4–5-year-old children who were fed hydrolysate formulas during infancy preferred more sour juices than 6–7-year-old children who were fed similar formulas • No differences were observed in those who were fed milk-based formulas
(Mennella et al., 2011)	• 5–10 years	• Children's self-report of open-ended questions about their favourite cereals and beverages	• Sweetness preferences of five sucrose solutions	• Sweet preference was positively associated with the sugar content of children's favourite cereals and beverages

(Lanfer et al., 2012)	• 6–9 years	• Frequency of sweet foods	• Sweet preference, using two concentrations of apple juice	• No significant association was found between sweet preference in juice and frequent consumption of sweet foods
(Melo et al., 2017)	• Children evaluated at 1, 3.9, and 7.7 years old	• 24-hour dietary recall: one at 1 year old, and two non-consecutive days at 3.9 and 7.7 years old	• Genotype of the sweet-related, TAS1R2 (rs35874116) and TAS1R3 (rs35744813), gene collected at the age of 3.9 years	• Variation in the sweet-related gene (only TAS1R2) was associated with differences in energy intake from sugar-dense foods and sugar; children with (Val) homozygous had less consumption than those with (Ile) carriers
(Rodrigues et al., 2020)	• 8–9 years	• Lifestyle and food preference questionnaire, answered by children supervised by a teacher and a trained examiner	• Sweet and bitter taste detection thresholds, using different concentrations of sucrose and caffeine	• Boys with low sensitivity to bitterness preferred raw carrots more than those who were highly sensitive • Boys with low sensitivity to sweetness preferred rice more than those who were highly sensitive, while the latter liked fried potatoes more • Girls with low sensitivity to sweetness preferred Brussels sprouts, rape branches, and watercress more than those who were highly sensitive, while the latter liked white milk and chocolate milk more

While still limited, evidence regarding children is possibly more precise than that regarding adults, particularly in the assumption of genetic effects and the limited exposure to external factors that may influence their eating. However, findings regarding adolescents indicated that drawing clear conclusions about the role of taste on dietary intake from the currently existing studies might not be possible (see Chapter 3).

Therefore, the available studies on taste and foods may not clearly suggest the associations between taste perceptions, preferences and dietary intake. The inconsistent findings could be due to the following limitations. Studies varied in sample size, with some studies used a small sample size that could not have drawn clear findings. Some studies were conducted only on females (Colares-Bento et al., 2012; Mahar and Duizer, 2007), even though gender difference was a key determinant of taste intensity perceptions and dietary intake. Additionally, studies used either a narrow or a wide range of ages, which could have affected the results, as individuals differ physiologically at a particular age (Puputti et al., 2019; Duffy et al., 2010). Another limitation is concerning the methods used in assessing taste perceptions, which varied from genetic assessment (genotyping) to sensitivity/intensity (e.g. detections vs. recognition vs. intensity) and hedonic/liking (phenotyping). This could produce different results due to environmental effect associated with phenotyping assessment and that agreements between genotype and phenotype may not always hold (Mennella et al., 2005). Also, taste stimuli (e.g. for bitter taste: PROP vs. PTC vs. quinine vs. caffeine) and the number of samples and concentrations varied between studies, which may affect the findings. Furthermore, some studies assessed tastes using water solutions, other liquids (e.g. juice or soup), specific food samples, or food checklists/questionnaires. The use of liquid solutions to assess taste perceptions may not reflect real food consumption, and the use of certain foods limits the varieties of foods in reality (Mennella et al., 2012). Finally, there were variations in the methods used to assess dietary intake or eating behaviours, where unlike 24-hour recalls that cover more food items, FFQ concerns specific food groups (Timpson et al., 2005; Louro et al., 2021).

Due to the complexity of people’s diets—being consumed in different combinations of foods with different nutrient compositions—researchers have begun to study dietary patterns to gain a comprehensive understanding of people's diets, instead of focusing on individual foods/food groups and/or nutrients (Hu, 2002; McNaughton et al., 2008). Thus, exploring the taste characteristics of entire diets can enable the understanding of how individuals' dietary intake is driven by their taste perceptions. However, limited studies are available in this context (Table 2-3). Unlike the previous studies in Table 2-2 that focused on assessing participants' taste perceptions and examined the association between their tastes and specifically selected foods or their dietary intake, the studies in Table 2-3 focused on classifying the taste of whole diets consumed by the participants and assessed their dietary intake accordingly. However, the studies were still limited, in that they examined the role of taste with energy intake as the main outcome. Furthermore, findings from the studies are not comparable due to the variations in the sample sizes, ages, dietary assessment methods, taste assessments and analytical outcomes. Three of the studies were based on data from a large nationally-representative sample of adults (van Langeveld et al., 2018), children (Nguyen et al., 2021), and a wide range of ages from 2 years and older (Cox et al., 2018). The influence of a taste on dietary intake in the studies was reported as a percentage of the taste contributions to the energy intake or as an association between tastes and energy intake. Furthermore, taste classifications in those studies were evaluated by trained panellists, as previously described in section 2.2.2, which may not properly reflect the taste perceptions of the typical consumer.

Cox and colleagues made an early attempt in which they asked the study participants to identify the predominant taste they perceived when consuming the foods they reported in the food records and to rate the hedonic/liking of the foods/taste (Cox et al., 1999). In a more recent work, Cornelis and colleagues used an online survey to ask the study participants to rate the taste intensity of a list of commonly consumed foods (Cornelis et al., 2017). While both methods are subjective, having typical consumers identify the predominant taste and rate their preferences can provide a meaningful estimate of perceptions and preferences for the tastes that drive their selection of foods and promote their intake. However, the accuracy of the taste classification done by regular consumers may need to be determined. Moreover, studies in this regard were limited to adults, and a comparable study on adolescents remains absent, despite the importance of this age group. Therefore, there is a need to assess and quantify adolescents' dietary intake by taste and to study their dietary taste patterns.

Table 2-3. Studies that classified and assessed individuals' dietary intake by taste

Study	Study Sample	Dietary measurements	Taste assessments	Outcomes of the study
(Cox et al., 1999)	• 76 adults • 18–65 years	• Four-day weighed dietary intake records	• Participants were asked to give each food a predominant taste (salt, savoury, sweet, bitter, or sour) and rate the liking	• Significantly more energy intake from salty-tasting foods, compared to other tastes • Obese individuals had more energy intake from salty-tasting foods than lean individuals • Lean individuals had more energy intake from other tastes, compared to obese individuals
(Cornelis et al., 2017)	• 287 adults were recruited from Toronto Nutrigenomics and Health Study • 20–29 years	• FFQ	• Taste intensity online survey of 120 commonly consumed food items in two phases: • First: a group of Canadian participants, asked to answer the following question: "Please rate the intensity of the [quality] taste in [food name]" • Second: a group of American participants, asked to answer the same question for a subset of food items (20–25 foods) • American participants, asked to rate their liking for a subset of food (77 food items)	• Bitter intensity of foods was negatively associated with the habitual intake of beer, grapefruit juice, liquor, coffee, and Brussel sprouts, but was positively associated with lemonade/punch and dark greens (kale, chard, and mustard greens) • Sweet intensity of foods was negatively associated with the intake of jams and other sweetened carbonated beverages • Saltiness intensity of foods was negatively associated with the intake of most foods, except salt and crackers; only the intake of potato chips was statistically significant • Sourness intensity of foods was negatively associated with the intake of grapefruit/grapefruit juice, red and white wine, and mustard
(Cox et al., 2018)	• 12153 children and adults from Australian National Nutrition and Physical Activity Survey	• 24-hour dietary recall	• The sensory-diet database (only sweet and salty tastes were used), established by Leas et al. (2016) (see Table 2-1)	• Significant positive correlation was found between sweetness and saltiness of foods and the intake of total energy, sugar, and sodium in adults and children • The highest contribution to sweet taste and total energy came from discretionary foods (e.g. cakes, biscuits, chocolate, confectionary, sugar-sweetened beverages, and alcohol)

	(NNPAS) 2011/2012 • 2 years old and older			• Fruits contributed 18% to sweetness and 20% to sugar intake • Dairy contributed 15% to sweetness and 16% to sugar intake • The highest contributions to salty taste and sodium intake were discretionary foods (e.g. fried potatoes), grains, and meat
(van Langeveld et al., 2018)	• 1351 adults aged 19–50 years from the Dutch National Food Consumption Survey (DNFCS) 2007–2010 • 944 adults aged 20–70 years from the Nutrition Questionnaires plus study (NQplus) 2011–2013	• 24-hour dietary recall	• 476 foods were evaluated (see Table 2-1)	• Most of the participants' energy intake came from neutral-tasting foods (36% and 39% in the DNFCS and NQplus studies, respectively), followed by "salt, umami, and fat"-tasting foods (23% and 22%, respectively), "sweet and fat"-tasting foods (14% in both studies), "sweet and sour"-tasting foods (11% in both studies), and "bitter"-tasting foods (5% in both studies)
(Nguyen et al., 2021)	• 3629 children were selected from the ongoing Generation R study, age 1 year • 844 of the children tracked at age 2 years	• Children's dietary intake during the first and second years, obtained using FFQ	• Children's foods from the FFQ were linked to previously established taste databases by Teo et al. (2021) and van Langeveld et al. (2018) (see Table 2-1)	• **During the first year:** • Most of the energy intake obtained from neutral-tasting foods • Children with a higher BMI had more energy obtained from "salt, umami and fat"-tasting foods. • Girls consumed more energy from "fat" foods than boys • **During the second year:** • Most of the energy intake obtained from sweet, salty, and savoury foods • Girls consumed greater energy from "sweet and sour" foods and less from "sweet and fat" foods than boys

Section summary

- Studies on the relationship between taste and dietary intake are limited to bitter and sweet, with fewer studies for the other tastes.
- The methods used in assessing taste perception and dietary intakes varied between studies.
- The relationships between taste and dietary intake are inconsistent.
- Limited studies tested the association based on entire diets, as most studies used a specific individual food or nutrient.
- No study has comprehensively tested the role of taste in adolescents' diets.

2.4 Dietary assessment methods used for adolescents

Assessing dietary intake is fundamental in quantifying the foods and nutrients consumed. It helps assess nutritional status to improve health and to decrease the risk of dietary-related chronic diseases and malnutrition. Traditionally, paper-based dietary assessment methods (i.e. food records, 24-hour recalls, and food frequency questionnaires [FFQs]) have been used in public health and research settings. However, there is an ongoing debate about the accuracy of these methods, compared to objective biomarker methods. Paper-based methods are self-reported (e.g. food records and FFQ) or interview-led (e.g. 24-hour dietary recalls and FFQ). They have advantages and disadvantages, but the major drawbacks associated with respondent and interviewer burdens and with the handling of data have exposed the need for more practical methods (Baghlaf, 2022). Recently, technology has been incorporated into dietary assessment to facilitate the collection and handling of dietary intake data. Nevertheless, challenges related to dietary reporting are still problematic, even with these innovative methods (Amoutzopoulos et al., 2018). Thus, regardless of the method used, it is important to ensure the accuracy of the reported dietary intake. A successful dietary assessment method should be valid, reliable, practical, and appropriate for the target population. Validity and reliability concern evaluating the degree to which a method measures what it is designed to measure and the degree to which it produces the same, or closely similar, results when duplicated. However, because measuring the absolute validity of a dietary assessment method is challenging, relatively validated methods has been the focus of this field. Relative validity is obtained by evaluating the reported dietary intake against outcomes from objective or alternative, universally accepted, gold-standard methods (Gibson, 2005; Walker et al., 2018). Furthermore, the practicality and suitability of an innovative method require testing its usability and acceptability, in order to evaluate user experience regarding the ability and ease of using the tool and its components efficiently (Petrie and Bevan, 2009).

This section briefly reviews traditional (standard) dietary assessment methods and their validity among adolescents, followed by a brief review of innovative technology-based dietary assessment methods. A summary of the strengths and limitations of both methods is presented in Table 2-4. The features of new technology-based tools, with a particular focus on developing an FCDB for a web-based tool, were also reviewed.

2.4.1 Traditional dietary assessment methods

Rapid development and growth during adolescence require increased energy and dietary intake. Therefore, tracking and assessing dietary intake during this period is necessary to quantify and evaluate the quality of the consumed foods and nutrients and the overall eating behaviour, in order to overcome potential nutrient deficiencies or health-related risks. However, conducting and obtaining an accurate assessment of adolescents' dietary intake are challenging compared to that of adults due to limited cognitive abilities and lower motivation associated with a task that may not be interesting for this age group (Pérez-Rodrigo et al., 2015). Many dietary assessment methods have been used for adolescents, including food records, 24-hour recalls, and FFQs, in addition to laboratory methods, which were used mainly in validating other methods (Walker et al., 2018; Ortiz-Andrellucchi et al., 2009).

Laboratory biomarker methods

Laboratory biomarkers are objective methods that overcome self-reporting errors. As they are memory-independent, they are used as reference measurements to estimate the validity and accuracy of dietary assessment methods. The common biomarkers are recovery biomarkers (e.g. doubly labelled water [DLW] and urinary total nitrogen/potassium) and concentration biomarkers (e.g. serum vitamins, blood lipids, and urinary electrolytes) (Jenab et al., 2009).

Recovery biomarkers estimate absolute intake based on the metabolic balance between intake and excretion. For example, the DLW measures total energy expenditure, and urinary total nitrogen estimates protein intake (Westerterp, 2017). Although the DLW is considered the gold standard method of measuring energy intake, it is not practical because it requires a controlled-condition testing calibration before use. Moreover, a repeated collection of urine samples is required for urinary nitrogen biomarkers to measure the usual protein intake. Thus, these methods are costly in terms of technical facilities and expertise (Naska et al., 2017).

Although concentration biomarkers are also used in estimating dietary intake, they do not indicate the absolute intake. Nevertheless, they can estimate the intake of a specific food group or nutrient (e.g. plasma carotenoids are biomarkers of fruit and vegetable intake, plasma fatty acids and blood measures of vitamin C). They are useful in estimating potential health risks. However, it is recommended that they be measured in multiple settings or used in combination with other methods because they are affected by several factors, such as metabolism, genetics, lifestyle, and the manner in which the samples are collected and analysed (Naska et al., 2017; Potischman, 2003).

The standard dietary assessment methods used in nutritional epidemiology studies are categorised into two categories, prospective and retrospective methods, which refer to the time of recording food consumption. Prospective methods involve recording at the time of consumption (real time/current) (e.g. food records), whereas retrospective methods involve recording the foods that have already been consumed (recall) (e.g. 24-hour recalls and FFQs).

Food record (weighed/estimated food records)

A food record (also known as a dietary record) is a self-reported method in which an individual records the foods and beverages at the time of consumption. There are two types of food records: a weighed food record and an estimated food record. Unlike the estimated food record, in which individuals estimate the quantity of consumed items using household measurements, the weighed food record requires eaten or uneaten food and beverage items to be weighed before and after consumption. Therefore, it is considered the gold standard among subjective dietary assessment methods. Details about the preparation methods, the ingredients used, and the brand names of commercial products are also reported (Baghlaf, 2022). This method is practical for use in large groups, such as in national surveys. However, the details for reporting require respondents to be trained and to have a high level of motivation. This method can also be inconvenient when eating outside the home. Moreover, it causes a considerable burden on the respondents, especially when multiple records are required to assess their usual intake (Shim et al., 2014).

Nevertheless, the food record method does not rely on respondents' memory and can eliminate issues associated with portion sizes, particularly in the weight method. This makes it a precise subjective method for use as a reference for validating other dietary assessment methods. This could be the reason for the limited number of available studies validating this method. However, when the energy intake reported by food records was validated against the energy expenditure measured using DLW, there was a general underestimation of energy intake. Accuracy of the estimated energy intake, expressed as a percentage of energy expenditure measured using DLW, ranged from 89 ± 12% to 82 ± 21% among participants ≤ 12 years old and from 58 ± 17% to 78 ± 18% among older adolescents (Rankin et al., 2010). Moreover, energy intake was significantly under-reported among adolescents with obesity, at 41% ±24, compared to non-obese adolescents, at 19 ± 19% (Bandini et al., 1990). The potential factors for the energy intake underestimation associated with this method include forgetting items eaten outside the home, non-compliance with weighing the foods, boredom, or attempts to show good records of eating behaviours. Therefore, food records may not be practical or valid for adolescents.

24-hour recall

The 24-hour recall is similar to the food record in terms of the detailed information required. It is an interview-led method run by a trained nutritionist. In this method, the interviewer asks for detailed information about the foods and beverages consumed over the past 24 hours. Unlike the food record, the 24-hour recall requires 20–30 minutes and is inexpensive (Shim et al., 2014). It can be used for a group of people, such as in research settings and in national nutrition surveys (Amoutzopoulos et al., 2018), but this can be burdensome for the interviewer. The 24-hour recall is less burdensome for the respondents, but it relies on their memory. Therefore, it is liable to a potential bias in recalling or underreporting foods. Similar to the food record, multiple recalls are required to assess the usual intake (Food and Agriculture Organization, 2018).

The dietary intake reported by the 24-hour recall has been validated against the outcomes from food records and biomarker methods. Similar to food records, the intake of energy nutrients was generally underestimated. Compared to the observed food records, the reported energy intake was under-reported by 12% for adolescents aged 10–11 years, and by 8% for older individuals aged 12–14 years. Although most of the nutrients assessed by the 24-hour recall had 15% to 20% equivalence to those from the food records, there was an overall underestimation (Arsenault et al., 2020). When assessment using the 24-hour recall was evaluated against the DLW method, the reported energy intake was 31 ± 110% over-reporting of the estimated energy expenditure. However, at the group level, the results differed. About 46% of adolescents over-reported their energy intake by 140 ± 22%, compared to the estimated energy expenditure using DLW, and 34% of the sample under-reported their energy intake by 102 ± 7% (Fisher et al., 2000). At least 20% reported energy intake that was within 10% of their estimated energy expenditure (Lindquist et al., 2000; Fisher et al., 2000). The 24-hour recall was shown to have good relative validity in estimating energy and nutrient intake, with an acceptable level of misreporting (Arsenault et al., 2020), especially when using multiple non-consecutive days. Additionally, because it is cost- and time-efficient and has a relatively low respondent burden, it is considered the best method for estimating adolescents' dietary intake (Biró et al., 2002).

Food frequency questionnaires (FFQ)

The FFQ is usually self-reported but can be administered by an interviewer. It assesses individuals' dietary intake over a period usually longer than 24 hours (i.e. weeks, months, or years). It is administrated in a questionnaire format that includes a list of food items in the form of a food group/sub-group (e.g. vegetable or leafy vegetables) or as individual food items. Depending on the purpose, the FFQ may ask about the quantity of consumption. Thus, this method is considered the least burdensome, especially when the FFQ is short. It is practical to use in large-scale epidemiological research and when collecting data about habitual intake. However, compared to the 24-hour recall and food record, the FFQ does not provide sufficient information. Therefore, the limited data collected using this method may underestimate dietary variations. Moreover, to be valid and reliable, the FFQ should be developed specifically for the intended population (Naska et al., 2017; Shim et al., 2014).

The FFQ has been widely used and validated among adolescents. For example, two records using the Youth/Adolescent Questionnaire (YAQ) FFQ were validated against three 24-hour recalls within one year among individuals aged 9–18 years. Moderate overestimations of nutrient intake were found, with an overall mean correlation of 0.45 for the energy-adjusted nutrient intake between the two methods. An overestimation of the energy intake reported by the FFQ was found, with a correlation of 0.35 between the two methods (Rockett et al., 1997). When the energy intake obtained by the same FFQ (YAQ) was validated against the DLW method, there was a slight discrepancy between the two methods (0.19 MJ; P = 0.92) at the group level. Energy intake from the FFQ was underestimated by 6.39 MJ/d and overestimated by 6.65 MJ/d at the individual level (Perks et al., 2000). One study found that the FFQ overestimated the reported energy intake by 13% (Burrows et al., 2013), while another found under-reporting by 22% (Zhang et al., 2015). However, the sample for the latter validation was composed of cancer survivors. The energy intake reported by the 24-hour recall showed a more accurate validity of 1% underestimation than the DLW method.

Thus, based on the findings from the literature, the outcomes from validation studies on adolescents are varied. Therefore, generalisations cannot be made. Many factors affect the results, such as sample size, gender proportion, and age. Food reporting is also affected by adolescents' level of knowledge and motivation and by the extent to which they remember the food actually consumed and/or its weight. As adolescents' eating habits usually do not have a regular pattern and change constantly, multiple records seem to be more valid for estimating the usual intake of this age group. However, the standard methods have some limitations, including cost, burden on the respondents/researchers, reporting errors, and the effort required in handling, processing and coding data via food composition tables to estimate the intake. Therefore, there has been a recent attempt to transform dietary assessment methods into technology-based methods to advance and enhance the collection of dietary data, with a positive effect on accuracy, cost, and effort.

2.4.2 Innovative technology-based dietary assessment methods

As adolescents are more inclined to use technology and the internet, innovative technology-based dietary assessment tools can make dietary assessment more efficient and can help overcome the challenges encountered in this age group. However, a successful tool should correctly assess dietary intake and be acceptable and easy to use. The relative validity of technology-based dietary assessment tools can be tested against biomarkers or other more established standard methods, producing reliable and accurate results (Kouvari et al., 2021). In addition, testing the technology's usability and acceptability is also recommended. Testing is carried out at different stages, especially during the development process and when incorporating new features or components (e.g. in the beta version or with a new language version) (Albar et al., 2015; Petrie and

Bevan, 2009a). Innovative technologies include personal digital technologies, mobile-based technologies, interactive computer-based technologies, and web-based technologies. This section provides a brief overview of the different types of innovative technology-based tools, focusing on the web-based tools and their components, features, validity and usability.

Personal digital and mobile-based technologies

A handheld computer allows respondents to record all foods and beverages immediately after consumption. The consumed items can be selected from a drop-down integrated food list, the consumption quantity can be recorded, or the portion size can be selected from portion-size measurement assistance within the system. A more practical personal digital assistant (PDA) is combined with a camera in the form of mobile-based technology. With such a tool, respondents can record their food intake using digital photos or voice recordings instead of selecting from a pre-defined food list (Illner et al., 2012b; Ngo et al., 2009). These tools allow for an immediate short-term assessment of dietary intake. Users do not rely on memory, and they are motivated to record their intake. Moreover, they are less burdened when processing and coding data when linked to databases. Compared to the 24-hour recall, in assessing energy and nutrient intake using a mobile-based tool, there was a significant underestimation of energy, carbohydrates, protein, fat, sodium, and calcium reported by the mobile-based tool (Lee et al., 2017) and an underestimation of energy intake by 29%, relative to the total energy expenditure measured using a SenseWear Armband (Svensson and Larsson, 2015). Recording food intake using mobile-based technologies was acceptable and satisfactory overall (Boushey et al., 2015; Schap et al., 2011). However, training and instructions are usually required before using this tool for the first time (Six et al., 2010) and the capacity for data storage could also be limited (Illner et al., 2012).

Interactive computer-based technologies

Unlike previous devices that allow the recording of “real-time” intake, users of the computer-based tools usually report their consumption retrospectively for the short-term (food record and 24-hour recall) or the long-term (FFQ), depending on the research purpose. These interactive computer-based tools are supported with multimedia attributes (e.g. pictures, animations, audio pop-up functionalities), which makes them attractive and acceptable for children and adolescents. They are programmed to automatically code and calculate the recorded intake and to allow for electronic data transfer in terms of data handling. However, users may need to receive some level of instruction, and some computer skills and literacy may be required. Moreover, due to retrospective recording, recording bias is anticipated (Illner et al., 2012; Amoutzopoulos et al., 2018).

A study on elementary school students tested the accuracy of reporting food intake using a computerised, multiple-pass, 24-hour recall compared to observation assessments during school lunch, and a 24-hour dietary recall conducted by a dietitian. There was a lack of accuracy in the technology-based tool. There were 40% and 56% matches, and 36% and 24% omitted foods, against the observation assessment and 24-hour dietary recall, respectively (Baranowski et al., 2002). Another study reported a reliable estimation of calcium intake using a computerised FFQ against an interview-led 24-hour recall (r= 0.57) (Wong et al., 2008).

Web-based technologies

Web-based technologies are self-administered online dietary assessment tools, such as web-based 24-hour recall, food record, and FFQ. Web-based tools allow users to record their consumption at any time and location convenient to them, overcoming the limitations associated with the use of desktop computer-based tools. Users do not need special training to use web-based dietary assessment tools because they are usually supported with online help features. Users are guided by a set of automated structural questions and instructed prompts to guide them through the food-recording process. Web-based tools allow for easy and practical collection of dietary intake data, especially for large-scale studies. In addition, they are cost-effective and less burdensome for researchers and participants. Web-based dietary assessment tools can improve the efficiency and accuracy of recording and can allow for the automated storage of the recorded data, practical processing and analysis of the data, immediate results and feedback (Illner et al., 2012; Cade, 2017).

However, despite the potential for misreporting found in a self-administered dietary assessment methods, and despite other expected limitations associated with a technology-based tool, web-based tools incorporate features and components that facilitate their purpose (Eldridge et al., 2019). Depending on the tool, reporting can be conducted by searching the consumed food items within an integrated, nationally-representative FCDB (discussed in the next section), thus making these tools easily adaptable to other countries and languages (Koch et al., 2020; Salvesen et al., 2021; Scarpa et al., 2021). Searching for items can be performed directly or through a drop-down food list that can be filtered by food categories, with consideration of misspellings or potential synonyms to facilitate searching (Subar et al., 2012; Carter et al., 2015). Moreover, users can make a list of commonly consumed foods for faster entry, which can overcome the issue of potential misreporting. With some web-based tools, users can create personalised recipes. This feature is also helpful in the case of a missing composite dish (Carter et al., 2015). A number of web-based dietary assessment tools support multiple options for portion size estimations, which help users easily quantify consumed foods. These options include the standard household measurements (spoons and cups), average portion sizes, pack or unit sizes, food photographs and entries of the actual weights (Carter et al., 2015; Forster et al., 2014; Bradley et al., 2016; Kirkpatrick et al., 2014).

The validity of results from web-based 24-hour recall tools against traditional paper-based 24-hour recalls were age-dependent, indicating moderate agreement between the two tools in children and younger adolescents (8 –11 years old) and good agreement in older adolescents (11–18 years old). The Young Adolescent’s Nutrition Assessment on Computer (YANA-C) tool showed a good correlation in energy and nutrient intake of 0.44 – 0.80, compared to the interviewer-led 24-hour recall and food record. There were no significant differences in the estimated nutrient and energy intake between YANA-C and the interviewer-led 24-hour recall, but overestimation was observed in the food record (Vereecken et al., 2005). Similarly, the two tools, myfood24 (Albar et al., 2016a) and INTAKE24 (Bradley et al., 2016), reported no significant difference in estimating the intake of energy, macronutrients and most of the micronutrients, compared to the traditional method.

The Automated Self-Administered 24-hour recall (ASA24) showed acceptable usability, with 50% matches and 19%–23% omissions of reported foods, compared to the interviewer-led 24-hour recall (Baranowski et al., 2012; Diep et al., 2015). Another tool, Children and Adolescents’ Nutrition Assessment and Advice on the Web (CANAA-W), showed outstanding usability among adolescents, with 84%–97% reporting the acceptance of its features, including clarity, comprehensiveness, and ease of completion, and characterising it as an attractive and fun tool; and 71% reporting ease in finding the food items (Vereecken et al., 2014). Similarly, myfood24 obtained a good mean system usability score (SUS) of 75%, with an average completion time of 16 minutes. Adolescents also found the tool easy to use and felt confident in reporting their dietary intake, compared to the interviewer-led method (Albar et al., 2015).

Thus, innovative dietary assessment tools seem promising in enhancing people's dietary evaluation, especially among adolescents, with the increased dependency and use of technologies and the internet. Furthermore, validity and usability measurements of those tools indicated their reliability, acceptability, and efficacity. Moreover, with the rapid pace of change in this area, many of the tools, particularly web-based tools, can undergo ongoing improvements and keep up to date in terms of their features and food databases.

Table 2-4. Summary of traditional (paper-based) and innovative dietary assessment methods used among adolescents

Methods	Traditional	Innovative
Dietary record (food record)	**Strengths:** • No memory reliance • Collects detailed diet information, including quantity, preparation methods, and time of consumption **Limitations:** • Requires motivation and literacy • High participant burden • Requires training before recording • Habitual intake may be changed due to participant fatigue caused by recording • Food eaten away from home is less accurately recalled or may be omitted • Costly and time-consuming in processing and analysing collected data • Multiple records necessary to determine usual intake • Not practical in large epidemiological studies	**Strengths:** • Facilitates real-time data recording • Respondents are motivated • Reduced time delay of recording using technology (e.g. mobile-based) • Faster data collection • Automatic reminder feature is possible • May reduce memory bias **Limitations:** • Requires training • May be expensive and requires effort to develop the technology • Some technologies (e.g. personal digital assistant [PDA]) are restricted to smaller study populations • Challenges in data transfer and storage (e.g. PDA and mobile-based)
24-hour dietary recall	**Strengths:** • Collects detailed diet information, including quantity, preparation methods, and time of consumption • Low participant burden • No literacy requirements **Limitations:** • Requires a skilled interviewer; thus, interviewer bias is a possibility • Relies on the participant’s memory • Multiple 24-hour recalls are necessary to determine the usual intake	**Strengths:** • Less burden on data processing • Good acceptability in young populations (e.g. children, adolescents) • Interactive (e.g. supports portion size images) • Web-based tools allow for completion at any time and location; practical and easily adaptable (e.g. to other languages) **Limitations:** • Requires some level of literacy and computer skills • In computer-based recall, direct coding may impede later data review/editing • Possibility of memory bias • In web-based recall, internet access is required

		• Possibility of non-response bias • Response behaviour may change
Food frequency questionnaire	**Strengths:** • Less burden on respondents • Estimates the usual intake **Limitations**: • Requires literacy • Possibility of incomplete data	**Strengths:** • Cost-effective • Suitable for large population studies • Improved data quality • Interactive **Limitations:** • Requires some level of literacy and computer skills, internet access
Laboratory methods	**Strengths:** • Objective measurements • High accuracy • No subject-associated bias **Limitations:** • Expensive • Needs specialised experts and equipment • Limited to a specific nutrient measured (i.e. doubly labelled water measures only energy intake, while other biomarker measurements are related to a specific nutrient) • Invasive and burdensome sample collection on participants	

2.4.3 Developing a food composition database (FCDB) for a web-based tool

An FCDB is an essential element in the dietary assessment process to quantify the population's nutrient intake. Standard paper-based dietary assessment methods depend on the use of food composition tables that are usually outdated and/or limited in their list of food items (Cade, 2017). An effective web-based dietary assessment tool should incorporate an FCDB that includes a variety of foods and beverages. These databases can be updated to incorporate a more comprehensive range of food items, including branded food products and composite dishes (Carter et al., 2015).

Developing an FCDB could adopt two main approaches: direct and indirect. The direct method is an analytical approach that involves obtaining data based on the laboratory analysis of foods. Although costly and time-consuming, it yields high-quality and reliable values. Used for many years to form food composition data, the method involves sampling and analysis plans, producing food composition data that are used as references. However, this approach is associated with data that are limited and incomplete in terms of the foods and nutrients included. Conversely, the indirect method involves collecting and evaluating already existing food composition data from national food composition tables, scientific literature, and food labelling (Rand et al., 1991a; Greenfield and Southgate, 2003; Westenbrink et al., 2009; Kapsokefalou et al., 2019). Using the indirect method is considered acceptable for developing an FCDB for a country with limited resources and data, or with a food supply that is imported from other countries or regions and whose data and values are already available (Greenfield and Southgate, 2003). Furthermore, the indirect method can overcome the expenses of cost, labour, and time (Rand et al., 1991; Greenfield and Southgate, 2003),

To fulfil the aim of assessing human health and nutritional status, an FCDB should be comprehensive in its included food items and their composition of nutrients. The ideal approach to identifying foods and nutrients to be included in any FCDB is to use a nationally representative study and government health and agricultural statistical data (Greenfield and Southgate, 2003; Kapsokefalou et al., 2019). A comprehensive FCDB should include a wide range of common and less frequently consumed foods and essential nutrients for the intended population/region (Greenfield and Southgate, 2003). Thus, for an FCDB to be representative, it should consist of typical and common food items for the targeted population of different age groups. Furthermore, including foods that consumed by varying levels of socioeconomic and ethnic groups within the region may be necessary to building a comprehensive FCDB. Nutrients, especially those related to common vitamins (e.g. vitamin D) and minerals (e.g. iron), deficiencies, or nutrition-related risks (e.g. cardiovascular disease and diabetes) should also be included (Greenfield and Southgate, 2003).

In most FCDBs, important food items and nutrient data are limited, missing or outdated. For example, reference FCDBs that are limited to raw food items are unsuitable for estimating individuals' dietary intake in which individuals' diet consists of many varieties of foods, including composite dishes (i.e. foods prepared from more than one ingredient), processed foods and branded food products, which are usually excluded. The innovative approach to FCDB development enhances the compilation of missing data by calculating missing values of nutrients from available values through mapping and matching procedures with already-available data. For example, if a specific composite dish is missing or certain nutrient values of a particular food item are missing, data such as ingredients can be generated from other available food items (i.e. recipe calculation) or by matching with similar food items that have complete composition data (see Chapter 6) (Kapsokefalou et al., 2019; Merchant and Dehghan, 2006). Although this approach has become the standard method of developing an FCDB that is comprehensive in its collection of food items and their compositions, it should be completed following a standard quality in order to assure the quality of the data included. Therefore, the European Food Information Resource and the International Network of Food Data Systems (INFOODS) have established quality standards for the production and harmonisation of FCDBs, including food description, component identification, value documentation, recipe calculation and quality evaluation of data (Westenbrink et al., 2016; Food and Agriculture Organization, 2022). This approach has been successfully used to complete existing, limited FCDBs or to produce nationally representative FCDBs worldwide (Hinojosa-Nogueira et al., 2021; Merchant and Dehghan, 2006; Black et al., 2011; Chen et al., 2021; Concina et al., 2015; Scarpa et al., 2021; Sichert-Hellert et al., 2007). Therefore, this approach should be followed to develop an updated Middle Eastern FCDB, especially when it is linked to online dietary assessment tools, to enhance and improve the population’s dietary intake (see Chapter 6).

Section summary

- Standard paper-based dietary assessment methods are valid yet challenging when used with adolescents.
- Innovative technology-based dietary assessment tools are valid and feasible for use with adolescents.
- Innovative technology-based dietary assessment tools cannot eliminate misreporting bias but seem to enhance the accuracy and speed of reporting.
- The usability tests of web-based dietary assessment tools indicate adolescents’ positive attitude.
- The web-based dietary assessment tool is cost-efficient in recording, processing, and analysing data and in keeping them updated.
- The innovative approach to developing an FCDB is effective in updating, completing, and establishing a national-specific FCDB.

2.5 Overall conclusion

This chapter has provided an overview of the sense of taste and of factors affecting taste perceptions and preferences. It describes the methods used in assessing people’s taste perceptions and preferences and indicates the methods that can reflect real-life taste perceptions. Citing the limited studies available, this chapter explains the importance of classifying the taste of foods and suggests the need for an easy and practical method to identify the taste of foods as perceived by regular consumers. The currently available evidence on the role of taste in individuals’ food choices and dietary intake is reviewed, indicating the lack of studies on the role of taste in individuals’ diets, particularly in adolescents. Moreover, this chapter presents an overview of standard and innovative dietary assessment methods that are used among adolescents to quantify their dietary intake and to study their dietary taste patterns and quality. The following chapter systematically reviews the available studies on adolescents’ taste perceptions/preferences, food choices and intake.

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Chapter 3 Impact of Taste on Food Choices in Adolescence-Systematic Review and Meta-analysis

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Abstract

Studies of adults report that perceived taste affects food choices and intake, which in turn may have an impact on health. However, corresponding evidence on adolescents is limited. Our aim was to summarise current evidence of the impact of taste perception on food choice preferences or dietary intakes among adolescents (mean age 10-19.9 years). Systematic searches identified 13 papers, 12 cross-sectional and one cohort study published between 1 January 2000 to 20 February 2020 assessing the impact of taste (using phenotypic and/or genotypic markers) on food choices in adolescents without any disease conditions. Qualitative assessment in the current review indicated that individuals sensitive to bitter taste often have a lower preference of bitter-tasting foods and higher preference for sweet-tasting foods. A meta-analysis of three studies on bitter taste sensitivity revealed no difference in preference for bitter-tasting vegetables between bitter tasters and non-tasters (standardised mean difference (SMD) = 0.04; 95% CI: -0.18, 0.26; *P* = 0.72). Overall, a limited number of studies were available for review. As a result, we report no clear relationship between taste perception and food choices or intake in adolescents. More studies are needed to evaluate the link between adolescents' taste perceptions and dietary intake.

Keywords: taste; sweet; sour; bitter; umami; genetics; genotype; phenotype; adolescents; food choices; food intakes

3.1 Introduction

Taste perceptions differ between individuals due to genetics, culture, ethnicity, personal and environmental factors. The extent to which adults perceive taste has been well defined as a determinant of dietary intake (Chamoun et al., 2018b) and food choices (Chamoun et al., 2018b; Feeney et al., 2011; Tepper et al., 2014).

Studies have reported differences in individual intensity perception and preferences for all tastes (Barragan et al., 2018), bitter (Roura et al., 2015) sour (Tornwall et al., 2012), sweet (Yeomans et al., 2007), salt (Noh et al., 2013) and umami (Tinoco-Mar et al., 2017). Genotype and phenotype methods for taste assessment have been used to identify an individual's taste characteristics (Shen et al., 2016). Human taste phenotype is based on reactions of chemical substances in food with taste receptors located on the tongue (Chamoun et al., 2018b) encoded by different genes (Chamoun et al., 2018b; Keller et al., 2012; Negri et al., 2012). Once those chemical stimuli are mixed with the saliva and digestive enzymes, the taste is detected (Podzimek et al., 2018). Based on that, individuals are classified as tasters (those who can perceive/detect taste at low concentrations) or non-tasters (barely perceive/detect taste or not at all) (Iatridi et al., 2019). Salty and sour tastes are delivered through ion channels, and specific genetic variants within taste receptor genes can also be used to stratify individuals as tasters or non-tasters (Laaksonen et al., 2013). G-coupled protein receptors T1R2, T1R3 and T1R38 encoded by TAS1R2/TAS1R3 and TAS1R1/TAS1R3, are involved in perceiving sweet and umami tastes (Eny et al., 2010; Negri et al., 2012). TAS2R38, is the commonly studied gene responsible for perceiving the bitter taste, and different single-nucleotide polymorphisms (SNPs) within this receptor are responsible for different bitter perceptions (Negri et al., 2012).

The taste of food was reported as an important factor in food choice in adolescence, which is a critical phase of humans' development (Blakemore et al., 2010) transitioning from childhood to adulthood (World Health Organization, 2019). Thus, healthy eating and good nutrition are required during this age to meet growth needs (Washi and Ageib, 2010). However, adolescents' eating habits are often characterised by high consumption of calorie-dense foods primarily sourced from fats and sugars rather than fruit and vegetables (Al Faris et al., 2015; Beck et al., 2019; Vaitkeviciute et al., 2014; Albar et al., 2014).

It has been reported that younger age individuals have a higher preference for high concentrations of sugar and are also more sensitive to the taste of bitter compared to adults (De Graaf and Zandstra, 1999; Negri et al., 2012). This may suggest an association between taste sensitivity and taste preference, where individuals with high bitter taste sensitivity may reflect a low preference for bitter-tasting foods (Chamoun et al., 2018a). In a couple of studies compared taste preference and food consumption between adults and younger individuals, bitter-taster adults reported a higher preference and consumption for bitter-tasting vegetables compared to younger individuals who were bitter tasters (Negri et al., 2012). In contrast, when sweet taste was investigated, the opposite was noted where younger age participants showed higher preference for sweet-tasting food compared to adults (De Graaf and Zandstra, 1999). These differences may be explained by adults' cognitive attitude and awareness of health-benefits of bitter-tasting foods (Chamoun et al., 2018b), differences in hedonistic reward and self-control or due to reduction in sweet taste perception with age.

Links between taste preferences and food intake may be associated with future health (Chamoun et al., 2018b; Feeney et al., 2011). For example, an adult study identified a possible increased risk of colon cancer in bitter-taster men associated with low vegetable consumption (Basson et al., 2005). Concerning adolescents, dietary behaviour of high sugar and low vegetable consumption may be a leading cause of adolescent obesity (Albar et al., 2014), which raises a concern with a projection of 2.7 billion overweight and 1 billion obese adults by 2025 (World Obesity Federation, 2015). Thus, because adolescence is a critical phase of development, transitioning between childhood and adulthood (World Health Organization, 2019), the purpose of this systematic review is to summarise the evidence linking taste perception (genotype and phenotype) to food choices among adolescents.

3.2 Materials and Methods

3.2.1 Search strategy

A protocol was designed and agreed on by all authors, the review protocol was published in PROSPERO with registration number: CRD42019134088 (Bawajeeh et al., 2019).

The following databases were searched: Ovid MEDLINE In-Process, Embase, Web of Science, CINAHL, PsycINFO, and CAB Abstracts. Searching in Medline, Embase, and PsycINFO included combinations of the research question concepts' terms, phrases and Medical Subject Headings (MeSH) as following: (“tast*” or “sweet*” or “sour*” or “salt* “or “bitter*” or “fat*” or “savo?r*” or “cream* “or “PROP” or “PTC” or “pungent*” or “astringent*” or “tast* adj3 fat” or “Taste/ or Taste Threshold/ or Taste Perception/” or “tast* adj3 cream*”) AND (“adolescent*” or “child*” or “young adult*” or “youth*” or “secondary school*” or “high school*” or “Adolescent/”) AND (“gene*” or “genetic*” or “phenotype*” or “ genotype*” or “Genes/” or “Genetics/”) AND (“food preferenc*” or “ food lik*” or “food choic*” or “food intak*” or “FFQ” or “24-hour recall” or “Food Preferences/ “ or “appetite*”).

These keywords and phrases were adapted to be used with other databases when Medical Subject Headings were not available such as in Web of Science.

3.2.2 Inclusion and exclusion criteria

The searches were applied to the period from 1 January 2000 to 1 January 2019, this period is appropriate due to the lack of publication prior to it. All primary-type studies of human subjects published in English were considered. The search was re-run from 1 January 2019 to 20 February 2020 for potential new studies. Studies were included if they were in adolescents without a history of health-related issue or diseases, and aged 13-18 years with a population mean age between 10-19 years. This mean age is based on the WHO definition of adolescents (World Health Organization, 2022), we did not include younger ages of 10-12 years since these studies would often have a mean age below the WHO definition. To be eligible for inclusion, studies needed to include taste assessment for either genotype or phenotype as well as outcomes relating to food choices and intake measurements such as a 24-hour diet recall, food frequency questionnaire (FFQ) or a food preference questionnaire. To be eligible for a quantitative study, studies with more than two results on taste perception and food preference/intake for the same taste and taste test used (phenotype or genotype) were included in a meta-analysis.

3.2.3 Study selection

Titles and abstracts were independently screened in duplicate by four members of the study team (A.B., S.A., M.Z., and J.C.). Any disagreements between screeners were evaluated and decided by the fifth member (C.E.). Full-text articles were also independently screened in duplicate by the members of the study team. Any disagreements were resolved by discussion.

3.2.4 Data extraction

Data were extracted independently in duplicate by two members of the study team (A.B and H.Z.). All data were extracted into Microsoft Excel. Any disagreements were resolved by discussion. Extracted data for the narrative synthesis included demographic information, study design, anthropometric data, methods of testing and measuring taste perception, as well as food intake and studies' results. Only studies on taste perception and preference of bitter-tasting vegetables were able to be meta-analysed, so the effect sizes (means and measures of variance) from these studies were extracted. This was due to the very limited number of studies on other tastes, and it was not possible to include these in a meta-analysis. Bitter-tasting vegetables were classified according to definitions in other studies (Dinehart et al., 2006; Keller and Adise, 2016; Leite et al., 2018; Tepper, 2008).

3.2.5 Quality assessment of studies

Quality assessment of included studies was carried out in duplicate, independently using the Newcastle-Ottawa Scale for observational studies (Ungprasert et al., 2015; Wells et al., 2000). The scale utilizes a 'star system' of points relating to selection of study groups, comparability of groups and ascertainment of exposure and outcome with total a maximum of 10 points. A study with ≥ 5 points was considered a high quality paper (Madhavan et al., 2016).

3.2.6 Statistical analysis

One study reported standard error of the mean (SEM), this was used to calculate the standard deviation (SD). Since two of the studies reported separate results for multiple types of bitter vegetables for tasters and non-tasters, we pooled each study's results into one combined bitter vegetable grouping for both taster groups using Stata software (StataCorp, 2017) to be used in the meta-analysis.

Meta-analysis was carried out using RevMan version 5.3 (The Nordic Cochrane Centre, 2014). Due to anticipated heterogeneity between measures of taste preference and taste phenotype between studies and study populations, a random-effects model was used to evaluate mean effect size. Standardised mean difference (SMD), was calculated by dividing the mean difference in each study by its standard deviation (Higgins and Green, 2011). The SMD was used as preference scales were not directly comparable to estimate differences in bitter-taste vegetable preference between bitter tasters and non-tasters.

3.3 Results

3.3.1 Systematic search

Our search identified a total of 1580 potential articles, including 507 duplicates. The remaining1073 references went through titles and abstracts screening, and of these, 94 potential articles met our criteria for full-text screening. At this stage, 81 studies were removed, which resulted in a final number of 10 studies (9 cross-sectional and 1 follow up study) published in 13 papers. Those 13 papers were included in the qualitative synthesis, of which 3 were included in the quantitative meta-analysis since the measures and outcomes were consistent. The re-running of the searches retrieved no additional relevant papers. The PRISMA flow diagram, with reasons for exclusion, is shown in Figure 3-1, the majority were excluded because they could not be considered adolescent-based studies. The quality of the included papers ranged from 3 to 7 (Table 3-1) with an average of 5.7 points. Two papers had low quality while 11 showed high quality based on the ≥ 5 points categorisation.

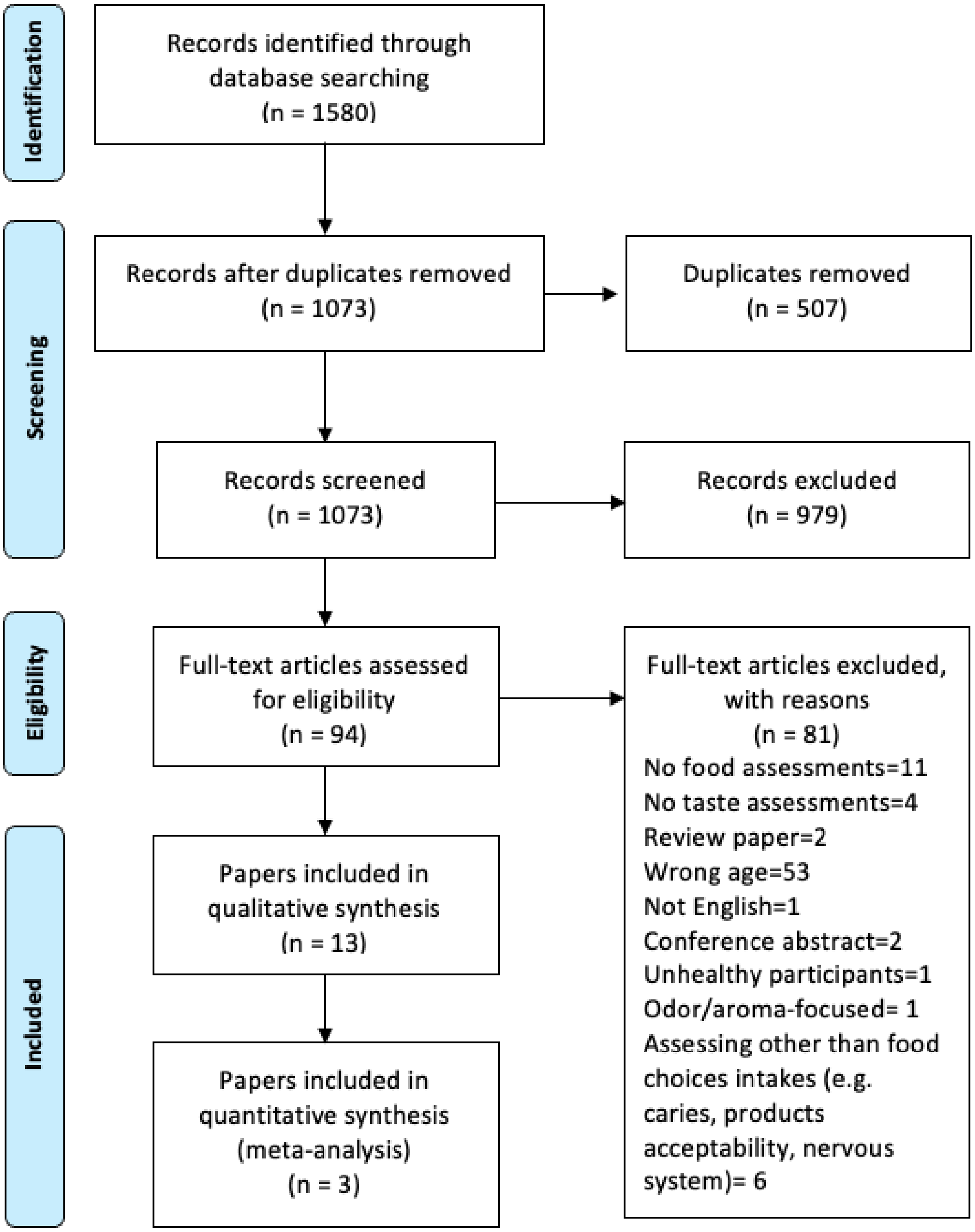

Figure 3-1. Flow diagram indicating number of studies

Table 3-1. Quality assessment of included studies

Criteria/studies	(Borazon et al., 2012)	(Catanzaro et al., 2013)	(Coldwell et al., 2009)	(Feeney et al., 2014)	(Feeney et al., 2017)	(Inoue et al., 2013)	(Joseph et al., 2016)	(Mennella et al., 2017)	(O'Brien et al., 2013)	(Ofted al and Tepper, 2013)	(Pioltine et al., 2017)	(Pioltine et al., 2018b)	(Sharma and Kaur, 2014)
Study design	CS*	CS*	CS*	CS*	CS*	CS*	CS*	CS*	CS*	FU*	CS*	CS*	CS*
Representativeness[1]	1	0	1	1	1	0	1	1	1	1	1	1	0
Sample size [2]	1	0	1	1	1	0	1	0	1	0	0	1	1
Non-respondents [3]	0	1	1	1	1	0	0	0	1	1	0	1	0
Exposure [4]	1	1	0	1	1	1	1	0	1	1	1	1	1
Comparability [5]	1	0	1	1	1	1	1	1	1	1	1	1	1
Outcome [6]	1	1	1	1	1	2	2	0	1	2	1	1	1
Statistical test [7]	0	1	1	1	1	1	1	1	1	1	1	1	1
Total Scores	5	4	6	7	7	5	7	3	7	7	5	7	5

[1] If the sample were representative and wither they were chosen randomly or not

[2] If the sampling was justified and satisfactory (e.g. gender balance, recruitment procedure, adequately powered to detect a difference)

[3] If the non-respondents characteristics and response rate were mentioned and wither the response rate was satisfactory or not (wither or not the non-respondents rate and characteristics were mentioned, comparability between respondents and non-respondents is established and the response rate is satisfactory (50% or higher))

[4] If the exposure tool valid or not (assessing taste perception/preferences)

[5] If confounding factors were controlled

[6] Method of assessing the dietary outcomes

[7] If the statistical test used clearly described and appropriate

[*] CS= Cross-sectional; FU= Follow-up

3.3.2 Study Characteristics

Table 3-2 provides a summary of the descriptive characteristics of the included studies. The total number of participants was 2229 (females= 1281, males=933 and not reported=15), of which 1481 participants had completed taste test measurements (genotype and/or phenotype) and food preference or food intake evaluations. Participants were from different geographic regions, which were the Philippines, India, Japan, Ireland, Brazil and USA.

Taste perception was assessed in all 13 papers: 5 papers conducted taste phenotype measures (Borazon et al., 2012; Catanzaro et al., 2013; Coldwell et al., 2009; Mennella et al., 2017; Sharma and Kaur, 2014), 3 papers conducted taste genotype measures (Inoue et al., 2013; Pioltine et al., 2017; Pioltine et al., 2018b), and 5 papers measures both phenotype and genotype (Feeney et al., 2017; Feeney et al., 2014; Joseph et al., 2016; O'Brien et al., 2013; Oftedal and Tepper, 2013).

Bitter was the most studied taste in nine papers. Six papers used 6-n-propylthiouracil (PROP) (Borazon et al., 2012; Catanzaro et al., 2013; Feeney et al., 2017; Feeney et al., 2014; O'Brien et al., 2013; Oftedal and Tepper, 2013) and one used phenylthiocarbamide (PTC) (Sharma and Kaur, 2014) to test bitter taste, while six papers genotyped the following single nucleotide polymorphisms (SNPs): rs713598, rs1726866 and rs10246939 in the gene TAS2R38 (Feeney et al., 2017; Feeney et al., 2014; Inoue et al., 2013; Joseph et al., 2016; O'Brien et al., 2013; Oftedal and Tepper, 2013).

Five papers studied the sweet-taste phenotype: four used sucrose (Coldwell et al., 2009; Feeney et al., 2017; Feeney et al., 2014; Joseph et al., 2016), one used fructose solution and blueberry fruit (Mennella et al., 2017), and two papers explored genotype for sweet-taste relating to genes TAS1R2 (rs9701796; rs35874116) (Pioltine et al., 2018); TAS1R3 (rs35744813) and GNAT3 (rs7792845) (Joseph et al., 2016). The fat-taste gene, CD36, (rs1761667) was studied in one paper (Pioltine et al., 2017), while no studies reported on savoury (umami) and sour tastes as seen in Appendix A.1 in the Supplementary Materials. Appendix A.2 in the Supplementary Materials illustrates genes and SNPs associated with each taste included in the current review.

Food preference and food intake were assessed in a variety of ways across studies, including food preference and behaviour questionnaires, food record, 24-hour dietary recall and FFQ. The variation of food included (Appendix A.3 in the Supplementary Materials) limited the number of meta-analyses which could be undertaken.

3.3.3 Qualitative summary of findings

3.3.3.1 **Bitter taste**

Generally, the proportion of bitter tasters was higher than non-tasters within the included cohorts. In Filipinos adolescents, 93% were tasters and 7% non-tasters (Borazon et al., 2012); in Indian adolescents, 80% were classified as tasters and 20% non-tasters (Sharma and Kaur, 2014). Around two-third of adolescents from South-eastern USA were tasters (68%) against 32% non-tasters (Catanzaro et al., 2013). White Caucasian and Irish groups were classified as 75% tasters and 25% non-tasters (Feeney et al., 2014; Oftedal and Tepper, 2013).

Perceived bitterness was negatively correlated with preference for bitter-tasting foods such as dark chocolate ($r = -0.155$, $P = 0.03$) and chili peppers ($r = -0.144$, $P = 0.04$) (Catanzaro et al., 2013). A similar association was reported with bitter-tasting vegetables where bitter sensitive individuals (tasters) reported lower preference for cruciferous vegetables such as cabbage (Sharma and Kaur, 2014) and broccoli (Feeney et al., 2014) than individuals who were non-tasters. Similarly, the less sensitive AVI homozygous haplotypes carriers (non-tasters) and PROP non-tasters, had an increased liking for brussels sprouts and cauliflower (Feeney et al., 2014).

Studies also reported that perceived bitterness was associated with other tastes. Joseph et al., 2016 found more added sugar in the diet of individuals carrying the bitter-sensitive genotype in TAS2R38, as well as an increased preference for sweet-tasting foods (Joseph et al., 2016). Likewise, PTC tasters reported a higher preference for sweet-tasting foods (Sharma and Kaur, 2014). Bitter tasters were also observed to have higher preference for salty and sour condiments and high-protein foods known to have savoury (umami) taste (Borazon et al., 2012). Appendix A.4 in the Supplementary Materials illustrates the liked and disliked foods based on bitter taste sensitivity as reported in the included studies.

Table 3-2. Characteristics of the studies using phenotype and genotypes taste tests (separately and in combination) included in the current systematic review/meta-analysis

Studies	Location/ Ethnicity	Population characteristics		Study Measurements			Study outcomes
		Sample	Age (yrs.)	Taste	Taste-test	Dietary assessments	
				Phenotype taste test			
*(Borazon et al., 2012)	Philippine/ Filipino	120 F= 60 M= 60	13-17 Mean=15	Bitter	3-PROP/3 NaCl	3-day food record & Food preferences	Significant high preference in supertasters for the condiments** (*P*<0.05). Positive correlation between PROP tasters and bacon, fried chicken, dried herring, muscles, boiled pork, shrimps and rice Tasters had higher energy intake than non-tasters
*(Catanzaro et al., 2013)	South-eastern USA/ Ethnicity NR	139 F= 76 M= 48 NR= 15	18-37 Mean=19	Bitter	3-PROP/3 NaCl	Food preference questionnaire	Negative correlations between PROP tasters and dark chocolate, r = -.155 (*P* =.035); chili peppers, r = -.144 (*P* =.046), but not bitter vegetables r = .062 (*P* =.235)
(Sharma and Kaur, 2014)	India/Indian	210 F	11–18	Bitter	14 PTC solutions	Unstructured questionnaire for last 24-h	Negative correlations between PTC threshold and preference of bitter tasting foods (r= -0.13, P=0.05; raw cabbage r= -0.15, *P* =0.03) Significant positive correlation of PTC TSN with sweet tasting food (r= 0.13, *P* =0.05)

(Coldwell et al., 2009)	USA/ 2 Alaskan Native, 4 American Indian, 14 Asian/Pacific Islander, 31 Black, Non-Hispanic, 11 Hispanic, 73 White, Non-Hispanic,8 others	143 F= 65 M= 78	11-15 Mean=13	Sweet	6-sucrose solutions 4 orange Kool-Aid® in different concentrations	Dutch Eating Behaviours Questionnaire	No impact found in eating behaviour based on the hedonic of sucrose High sugar preference individuals ranked Kool-Aid® with the most sugar concentration (30% sucrose) as best, while low sugar preference individuals ranked the same concentration of Kool-Aid® as the worst
(Mennella et al., 2017)	USA diverse ethnicity	49 F= 28 M= 21	6-16 Mean=11	Sweet	3 different harvest blueberries 5-fructose solutions	Automated Self-administered 24-h recall system	Significant preference for the sweatiest-taste blueberry (Keecrisp) during the 1st harvest. Preference changed to the other blueberry types (Arcadia and Kestrel) as being the sweeter than Keecrisp for the 2nd harvest
				Genotype taste test			
(Inoue et al., 2013)	Japan/ Japanese	F=87	18-22	Bitter	TAS2R38 rs713598 & rs10246939	3-day food recording	Higher intake of energy (*P* = 0.02) and carbohydrate (*P* =0.01) in AI/AI carriers comparing to PV/PV and PV/AI carriers. Vegetable and dairy products intake did not differ among the three groups
(Pioltine et al., 2017)	Brazil/ Brazilian	580	7-18 (Mean=12. 2) obese (Mean=10. 4) normal weight	Fat	CD36 rs1761667	2 24-h food recalls	Significant decreased intake of total fat (*P* = 0.01), polyunsaturated and monounsaturated fatty acids, total sugars (*P* = 0.01), fatty foods (*P* < 0.001), and vegetable oils (*P* = 0.02) in obese subjects carrying A allele of rs1761667 in CD36 gene

(Pioltine et al., 2018)	Brazil/ Brazilian	648 F= 303 M= 345	7-18 (Mean=12.2) obese and (Mean=10.4) normal weight	Sweet	TAS1R2 rs9701796 and rs35874116	2 24-h food recalls	Significant high intake of the sweet chocolate powder in obese with different allele carriers *P* = 0.04 Significant high intake of MUFA (g and %) *P* =0.04 in obese carrying serine allele in rs9701796 in TAS1R2 gene Significant low intake of dietary fibre *P* =0.002 in obese carrying valine allele in rs35874116 in TAS1R2 gene
				Phenotypes and genotypes taste tests			
*(Feeney et al., 2014)	Dublin/ White Caucasian	525 F= 300 M= 225	7-13 Mean=10	Bitter Sweet	TAS2R38 (rs713598, rs1726866 and rs10246939 PROP/ NaCl 2-sugar solutions	3-day diet history Vegetable hedonic ratings	Significant higher liking scores for cauliflower in PAV/AVI heterozygous girls compared to PAV/PAV or AVI/AVI girls *P* = 0.04 Significant higher liking for cauliflower in NTs boys compared to MTs and STs *P* =0.03 Significant lower liking for broccoli in NTs girls compared to MTs and STs *P* =0.02 NTs boys had a higher liking for cauliflower, while NTs girls had lower preference for broccoli Cruciferous vegetable intakes did not differ between TAS2R38 genotype or PROP taster groups
(Feeney et al., 2017)	Dublin/ White Caucasian	525 F= 300 M= 225	7-13 Mean=10	Bitter Sweet	TAS2R38 rs713598, rs1726866 and rs10246939 PROP/ NaCl	3-day diet history	No difference in diet quality between taster groups No significant correlations between sweet, salt or bitter taste intensity and intake *P* > 0.05

					2-sugar solutions		
(Joseph et al., 2016)	USA/ 136 Black, 46 White Caucasian, 2 Asians, 51 more than one ethnicity, 219 non-Hispanic	235 F= 124 M= 111	7-14 Mean=10	Bitter Sweet	TAS2R38 rs713598, rs1726866 and rs10246939 TAS1R3 rs35744813, GNAT3 rs7792845 17-sucrose solution	Automated Self-Administered 24-h recall system	Sucrose threshold associated with bitter-sensitive Bitter-sensitive genotype had more 6% of their kcal as added sugars
(O'Brien et al., 2013)	Dublin/ White Caucasian	525 F= 300 M= 225	7-13 Mean=10	Bitter	TAS2R38 rs713598, rs1726866 and rs10246939 PROP/NaCl	3-day diet history & Frequency of eaten food	No significant differences for all nutrients or food group intakes between genotypes and phenotypes taster groups No significant difference between the proportions of taster types across “more healthful” and “less healthful” clusters of food intake, *P* = 0.06 and 0.74 for TAS2R38 genotype and PROP taster status, respectively
(Oftedal and Tepper, 2013)	USA 86% white Caucasian	73 F= 28 M= 45	7-13 Mean=10	Bitter	TAS2R38 (rs713598 and rs172866) PROP/NaCl	3 24-hour recalls Dutch Eating Behaviour Questionnaire	No differences in eating attitude, and the energy intake did not vary among taster groups

F= females; M= males; NT= non-tasters; MT= medium tasters; ST= supertasters; T=tasters; HP=high preference; LP=low preference; H. =high; W. weight; NW=normal weight; FFM= fat free mass; N/A= not applicable; NR=not reported. (*) Indicates studies included in the meta-analysis
** Condiments refers to sauces such as (Shrimp paste, fish paste, fish sauce, vinegar, tomato catsup, soy sauce)

As for nutrient intakes, a higher mean intake of energy was found in PROP medium tasters (1952 ±666 kcal) and supertasters (1851 ±656 kcal) compared to non-tasters (1620 ±364 kcal), ($P < 0.05$) in a study of 120 Filipino adolescents (Borazon et al., 2012). However, Inoue et.al, 2013, found the opposite in a smaller study (n = 47) of Japanese, reporting significantly higher intakes of energy in AI/AI haplotype carriers (non-tasters) comparing to PV/PV and PV/AI haplotype carriers (tasters) (AI/AI carriers = 1742 ±216 kcal; PV/PV and PV/AI = 1512 ±259 kcal, $P = 0.02$). The same pattern was noted with carbohydrate intakes (AI/AI carriers = 254.7 ±34.4 kcal; PV/PV and PV/AI = 217.3 ±37.4 kcal, $P = 0.01$) (Inoue et al., 2013).

3.3.3.2 **Sweet taste**

Concerning sweet taste, participants with a high sweet threshold were found to prefer food items with higher sugar content. In one study, researchers examined sweet-taste preference using blueberries at different harvest times, which has an impact on the sugar content of fruits. This influenced participant liking and preference where they preferred the sweetest berries (Mennella et al., 2017). Similarly, participants in another study were asked to taste a flavoured beverage (orange Kool-Aid® drink) with four different sugar concentrations where participants with a high sweet threshold reported a higher preference for the drink with the highest sugar concentration compared to other concentrations (Coldwell et al., 2009).

Regarding sweet-taste genotype, obese individuals with an allelic variant in the SNP rs9701796 in the sweet-related gene, TAS1R2, reported a higher intake of sweetened chocolate powder (Pioltine et al., 2018). In contrast, in another sweet-related gene, TAS1R3, and GNAT3 genes were not associated with sucrose taste threshold or intake of sugar (Joseph et al., 2016).

3.3.3.3 **Fatty taste**

Although not traditionally recognised as a primary taste (Mattes, 2010), there was one cross-sectional study exploring fat-related gene included in this review, the researchers studied the effect of the genetic variation in the CD36 gene on food intake in both obese and normal-weight adolescents. Statistical differences in dietary intakes were noted in the obese participants but not for normal- weight participants. Obese participants with an allelic variant in rs1761667 of the CD36 gene had a significantly lower intake of fatty food (266.0 g/d) compared to those with homozygous alleles (343.2 g/d) ($P < 0.01$), which also translated to a lower intake of total fat (49.2 versus 62.4 g/d; $P = 0.01$). More specifically, the total intake of monounsaturated and polyunsaturated fatty acids was significantly less ($P = 0.01$) but not that of saturated fatty acids. Additionally, genetic variation in the CD36 gene was found to impact sugar intake, where obese participants with the allelic variant also had lower intake of sugar compared to the homozygous group ($P = 0.01$) (Pioltine et al., 2017).

3.3.3.4 **Other tastes**

There were no papers on the perception of salty, sour, and umami tastes and food choices and intakes in adolescents.

3.3.4 Meta analysis

Three studies identifying the bitter-taste phenotype in relation to preference for bitter-tasting vegetables were included in the meta-analysis, one of the studies reported females and males separately, providing four effect sizes. Bitter-tasting vegetables included broccoli, cauliflower, sprouts, cabbage and bitter gourd. The use of different food preference scales (i.e. five-points (Catanzaro et al., 2013; Feeney et al., 2014) and 9-points (Borazon et al., 2012) required the use of the standardised mean difference (SMD).

The meta-analysis (Figure 3-2) shows no clear difference in adolescents' mean score of preference for bitter-tasting vegetables between bitter tasters and non-tasters (SMD = 0.04; 95% CI: −0.18, 0.26; $P = 0.72$). A low level of heterogeneity was observed in our analysis denoted by I-squared (0%) and chi-squared ($P = 0.98$). With only four effect sizes, we also ran a fixed-effects model, also with low I-squared (0%), and reporting the same effect size.

	Tasters			Non-tasters				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Borazon et al. 2012	4.32	4.67	41	3.9	4.3	8	8.2%	0.09 [-0.67, 0.85]
Catanzaro et al. 2013	2.66	0.89	40	2.63	0.89	44	25.6%	0.03 [-0.39, 0.46]
Feeney et al. 2014 Females	3.18	1.62	50	2.82	2.64	73	36.2%	0.16 [-0.20, 0.52]
Feeney et al. 2014 Males	2.66	2.57	46	2.92	2.11	53	30.1%	-0.11 [-0.51, 0.28]
Total (95% CI)			**177**			**178**	**100.0%**	**0.04 [-0.18, 0.26]**

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.98$, df = 3 (P = 0.81); $I^2 = 0\%$
Test for overall effect: Z = 0.36 (P = 0.72)

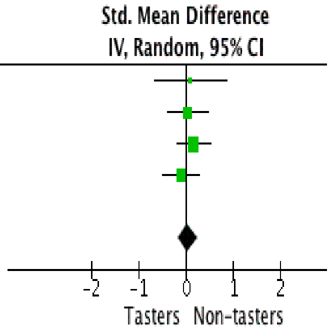

Figure 3-2. Pooled estimate of bitter-taste vegetables preference between tasters and non-tasters

3.4 Discussion

This is the first systematic review and meta-analysis in adolescents to investigate the impact of taste perception on food choices. A number of studies on adolescents dietary behaviour observed a calorie-dense diet full of sweet-source foods (Al-Hazzaa et al., 2011; Ashi et al., 2017; Al-Muammar et al., 2014) and low in vegetables (Smith et al., 2016; Al-Hazzaa et al., 2011). The taste of foods was reported as an important factor in adolescents’ food choices (Al Faris et al., 2015; Elbel et al., 2011; Ensaff et al., 2015; Hallstrom et al., 2011). Previous reviews in adults have reported potential effects of taste perceptions (genotype and phenotype) on food choices (Chamoun et al., 2018b; Feeney et al., 2011). However, given the fact that taste perceptions change with age (Barragan et al., 2018), this suggests that evidence obtained from adult studies linking perceived taste, food choices, and intakes, may not directly translate to younger populations. Thus, taste may have an impact on adolescent eating and food choices, however, the evidence base is limited and more studies to understand adolescences’ taste perceptions and dietary pattern are needed in order to overcome any prediction of increased health risk in adulthood.

Bitter taste was the most studied for its impact on food preference and intake (Borazon et al., 2012; Catanzaro et al., 2013; Feeney et al., 2017; Feeney et al., 2014; Inoue et al., 2013; Joseph et al., 2016; O'Brien et al., 2013; Oftedal and Tepper, 2013; Sharma and Kaur, 2014); followed by sweet taste (Coldwell et al., 2009; Feeney et al., 2017; Feeney et al., 2014; Joseph et al., 2016; Mennella et al., 2017; Pioltine et al., 2018). Only one study reported on fat taste (Pioltine et al., 2017), while no studies in adolescents reported on umami and sour tastes. Taste testing approaches varied across studies in terms of components used:

with PROP (Borazon et al., 2012; Catanzaro et al., 2013; Feeney et al., 2017; Feeney et al., 2014; O'Brien et al., 2013; Oftedal and Tepper, 2013) and PTC (Sharma and Kaur, 2014) for bitter taste; and sucrose (Coldwell et al., 2009; Feeney et al., 2017; Feeney et al., 2014; Joseph et al., 2016), fructose solutions, and real food using blueberries for sweet taste (Mennella et al., 2017). Furthermore, taste phenotyping methods and assessment for dietary preference and intake also differed between studies as did the food examined (Appendix A.3). Food studied was either based on food being commonly consumed for the population studied (Sharma and Kaur, 2014; Borazon et al., 2012), or as reported by participants through a 24-hour diet recall (O'Brien et al., 2013; Pioltine et al., 2018). Furthermore, some foods were studied because they are often avoided for their bitterness such as cruciferous vegetables (e.g. broccoli, cauliflower, and cabbage) (Beck et al., 2014; Drewnowski and Gomez-Carneros, 2000; Chamoun et al., 2018b). While researchers have focused on studying single food items in relation to taste, questions may arise regarding composite food and complex dishes which involve multiple combined tastes (Keast and Breslin, 2003). There is a need for understanding taste profiles based on dietary intakes at national and global levels to support our interpretation of relationships between food choices and health outcomes (van Langeveld et al., 2018).

Humans' PROP/PTC bitter sensitivity has been widely studied, and the sensitivity to these thiourea compounds' bitterness may be reflected in dietary behaviour (Keller and Adise, 2016; Tepper et al., 2014; Leite et al., 2018; Armstrong, 2008). It has been observed that increased sensitivity could result in dietary behaviour which is low in vegetables (Armstrong, 2008), especially, bitter-tasting vegetables like cruciferous vegetables known for their content of health-related bioactive compounds [53,56]. However, findings are inconsistent (Keller and Adise, 2016; Turner-McGrievy et al., 2013). In adults, an inverse relationship was reported between bitter sensitivity and preference of bitter-tasting foods such as coffee, dark chocolate, green tea and Brassica vegetables (Chamoun et al., 2018b; Tepper et al., 2014). Likewise as found in our qualitative assessment, perceived bitterness among PROP and PTC adolescent tasters were reported to be negatively, albeit weakly associated with the preference of bitter-tasting foods (Catanzaro et al., 2013; Sharma and Kaur, 2014), while individuals who were less sensitive to PROP and carrying AVI/AVI haplotypes known as non-tasters, reported higher preference for bitter-tasting vegetable (Feeney et al., 2014).

However, our meta-analysis with only three studies did not show any significant association between bitter-tasting phenotype and bitter vegetable preferences, which may be due to the limited number of studies and sample sizes available for inclusion.

Even though TAS1R3 and GNAT3 were not related to sweet perception (Joseph et al., 2016) in this review, a third sweet-related gene, TAS1R2, has been observed to be linked with sweet taste threshold and consumption of sweet-tasting foods in individuals with obesity compared to individuals with normal weight. This difference in sweet detection and consumption is thought to be related to the leptin level, which increases the threshold to sweet taste in individuals with obesity (Pioltine et al., 2018). Different results in sweet perception in relation to sweet-related genes may depend on the different genes studied, which would support the need for more studies in this area.

Concerning the concordance between phenotype-genotype classifications, this was only mentioned in two studies (Joseph et al., 2016; Feeney et al., 2014). Regarding bitter taste, individuals who were classified as less sensitive based on both phenotype and genotype (r = 0.17, P = 0.035) had a higher preference for bitter-tasting vegetables than those who were more sensitive (Feeney et al., 2014). This phenotype-genotype relationship has also been shown in studies with adults (Calò et al., 2011; Negri et al., 2012). On the other hand, sucrose thresholds were reported to be linked with two SNPs, rs1726866 and rs10246939, in the bitter-related gene, TAS2R38, (P = 0.01; P = 0.05) rather than in the sweet-related gene TAS1R3 (P = 0.36) confirmed by observing more added sugar in the diets of adolescents with high bitter sensitivity (Joseph et al., 2016). Thus, phenotype-genotype relationship in terms of sweet taste may not be consistent. This is probably emphasising the difficulty of separating tastes. For instance, sweet has been described to have a "masking effect" on bitter perception (Beck et al., 2014) and suppressing its perception (Keast and Breslin, 2003). Another point is the examined gene/SNPs as different results were reported with TAS1R3 and TAS1R2 (Pioltine et al., 2018; Joseph et al., 2016).

Perception of one taste appears to be related to other tastes. Bitter and sweet tastes were found to be interrelated (Chamoun et al., 2018b; Beck et al., 2014). This was noted as adolescents sensitive to the bitter taste reported lower preference for bitter-tasting vegetables but had a higher preference for sweet-tasting foods (Joseph et al., 2016). This was found in children but not in adults (Mennella et al., 2005), which may in part be explained by the impact of age and cognitive behaviours in adults' taste perception and food intake (Mennella et al., 2005; Chamoun et al., 2018b). In one study in this review, bitter tasters reported their preference for sour, salty and savoury (umami) tastes (Borazon et al., 2012). This is probably due to a taste-taste interaction and the effect of enhancing/suppressing of taste receptors when compounds in foods interact (Beck et al., 2014; Keast and Breslin, 2003), where salt and sour were found to have a suppressive effect on perceiving bitterness (Keast and Breslin, 2003). However, more research is needed to understand these interactions of tastes in adolescents affecting their dietary behaviour and eating pattern rather than just measuring their taste perception and food preference.

The association between taste and nutrient intakes was inconsistent. In one study, PROP tasters were reported to consume more energy-dense foods and have higher daily intake of total energy and carbohydrate (Borazon et al., 2012). While another study reported the opposite, where the bitter-related genotype AI homozygous (non-taster) individuals had a higher intake of total energy and carbohydrate than other taster groups (Inoue et al., 2013). This variation may be related to the different ethnic groups in the two studies where variations in factors such as genetic predispositions, environmental and culture in relation to food exposure and beliefs may all influence intake (Smith et al., 2016; Wardle and Cooke, 2008; Williams et al., 2016). Additionally, results may be inconsistent due to the different approaches to testing taste with phenotype versus genotype, or participants' age (Mennella et al., 2005), where participants recruited by Inoue et al (2013) were older by an average of 4-5 years.

The present review study has strengths and limitations. This review is the first to study the associations between taste and food choices in adolescents. The protocol was published in PROSPERO (Bawajeeh et al., 2019). Additionally, we included both phenotype and genotype measurements for all taste qualities. The search strategy focused on searching for adolescents 13–18 years of age, so we may have missed studies that focused on 10–12-year-olds, who are also defined as adolescents by the WHO. However, we did not include this age group as the mean age would likely be below our inclusion criteria. Methods for measuring exposures and outcomes as well as the food items studied varied between the studies. As a result, this limited the studies suitable for meta-analysis. Moreover, types of studies were limited to cross-sectional studies and one follow-up study, and the sample size in some of the included studies was small, which could influence the validity of results.

3.5 Conclusions

Differences in phenotype or genotype may affect taste perceptions and influence food intake preferences in adolescents. Our qualitative assessment of previous studies indicated that bitter- sensitive individuals may have a lower preference for bitter-tasting food and higher preference for sweet-tasting food, though findings were inconsistent. Meta-analysis showed no association between bitter-taste phenotype and preference of bitter-tasting vegetables. However, this lack of association may be due to the limited number of studies included, rather than demonstrating a true lack of association. Thus, more studies are needed to understand (i) how taste perceptions and dietary habits develop in adolescence, and (ii) how strongly these habits predict health and disease risk in adulthood. More evidence will help in understanding the strength of the relationship between taste perception and food choices. Understanding how tastes affect adolescents' food choices can help the food industry and care providers to offer healthier food options.

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Chapter 4 Characterising adolescents’ dietary intake by taste: results from the UK National Diet and Nutrition Survey

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Abstract

The taste of foods is a key factor for adolescents' food choices and intakes, yet, exploring taste characteristics of adolescents' diet is limited. Using food records for 284 adolescents (10-19 years old) from the National Diet and Nutrition Survey (NDNS), year 9 (2016-2017), we classified diets according to taste. Tastes for each food consumed were generated from a previous survey that asked participants to allocate one main taste to each food. Responses from that survey were processed and included in a Hierarchical Cluster Analysis (HCA) to identify taste clusters. The resulting tastes were then applied to the adolescents’ food records in the NDNS. For each individual, the total weight of food per day for each taste was calculated. A linear regression model was used to explore dietary intakes from each taste. Findings reveal that adolescents' daily energy intake was highest (34%) from foods that taste sweet. Sweet foods were the main calorie contributors at breakfast and daytime snacking, while energy intake from neutral-tasting foods was higher at lunch and dinner. Sweet food intake was significantly positively associated with higher energy, sugar and fat intakes. For each percentage increase in sweet foods, energy increased by 10 kcal/d (95% CI 6, 15; $P < 0.01$). Savoury food intake was lower in carbohydrates and sugars; with neutral food consumption inversely associated with energy, carbohydrate, sugars, saturated and total fat. Higher salty food intake was linked to higher saturated fat as well as sodium consumption. Sweet and neutral foods dominate the UK adolescent diet, followed by savoury tastes. Balancing the contributions of different tasting foods could assist in improving adolescent diet quality.

Keywords: taste, dietary taste, NDNS, adolescents, taste perception

4.1 Introduction

The taste of foods has been reported to be an important predictor in food choice decisions, independently of a range of factors, such as cost, availability, food appearance, hunger, socio-environmental and socio-economic characteristics that influence food choices and intake (Connors et al., 2001; Kearney et al., 2000; Kourouniotis et al., 2016). Individual variations in taste perception may lead to differences in dietary intake which in turn influences nutritional status (Garcia-Bailo et al., 2009; Hayes et al., 2013). The sense of taste (i.e. gustation) is a sensory modality that allows humans to perceive the basic tastes in foods (sweet, salty, sour, bitter and savoury/umami) when the substances in foods interact and stimulate taste receptor cells on the tongue (Gravina et al., 2013). Early sweet taste preferences in humans are innate; with salty taste preference starting during the first few months after birth, while bitter and sour tastes are less attractive (Barragán et al., 2018). However, these innate preferences are not stable throughout life. Children are likely to have taste preferences that are comparable to those they experienced in their early life (Sobek et al., 2020); however, observing adults' pleasure in eating vegetables through enjoyable comments and facial expressions can motivate a young child's curiosity and overcome their refusal of bitter vegetables, like broccoli (Edwards et al., 2022). As the child enters adolescence, parental influences on their child's taste preferences in relation to food choices and intake is less effective (Edwards et al., 2022; Wills et al., 2019).

In sensory studies, individuals' taste perception can be assessed by subjectively nominating the perceived taste quality and/or intensity (Douglas et al., 2018). This is known as phenotype assessment and has been widely used in sensory studies aiming to identify individuals' perceptions and classify their actual experience of tastes. A number of sensory studies (i.e. taste perception and/or preference studies) have been conducted in relation to food choice and dietary intake in different age groups (Bawajeeh et al., 2020; Appleton et al., 2018; Liem, 2017; Tan et al., 2021; Tan and Tucker, 2019; Cornelis et al., 2017). Sweet, salty and savoury tastes have been shown to influence energy intake (Forde and de Graaf, 2022). In our previous systematic review of adolescents' taste perception and food choices, we found that perceived bitterness in cruciferous vegetables (i.e. broccoli, cabbage, Brussels sprouts and cauliflower) was negatively associated with intake and preferences and positively associated with energy intake. However, this was not consistent due to variations in the taste assessment among the studies(Bawajeeh et al., 2020); likewise in adults (Cattaneo et al., 2019; Inoue et al., 2017; Puputti et al., 2019). This inconsistency may be due to variations in the taste assessment where studies have tested this relationship using liquid solutions of taste samples and/or limited individual food items as references to evaluate the influence of individuals' taste perceptions and/or preferences on selected dietary outcomes.

Studies assessing the taste perceptions of foods consumed in a real-world context integrated with food composition data are limited to a small number of studies (Cox et al., 1999; Lease et al., 2016; Martin et al., 2014; van Dongen et al., 2012; van Langeveld et al., 2018). An innovative “in-home” method was used to create a food-taste database for foods that were frequently consumed by the study participants (Martin et al., 2014). Another study quantified the taste intensity of fifty frequently consumed Dutch foods (van Dongen et al., 2012), while an Australian study quantified a sensory profile of a wider range of food intake data from a national survey (Lease et al., 2016). None of these studies assessed how taste influenced their populations’ dietary intake. van Langeveld et al. studied Dutch adults’ dietary taste patterns using a taste profile generated for food intake data reported in the Dutch National Food Consumption Survey (van Langeveld et al., 2018). However, the authors only assessed taste contributions to energy intake. In an earlier small study, researchers studied the association between taste characteristics of foods and dietary intake of 41 UK adults. The study used dietary intake records of participants who were asked to assign one predominant taste for the reported consumed foods (Cox et al., 1999). This study also only focused on energy intake by taste, identifying differences between obese and non-obese adults, but such a study is absent in adolescents. Findings from the existing literature indicate that taste is not just a sense that motivates people's food choices and consumption, but it can imply and signal calories and nutrients in foods. Since adolescents have indicated taste as an important factor when selecting and consuming foods, how taste links to intakes needs to be explored.

Adolescence is a critical phase of growth and development transitioning from childhood to adulthood (World Health Organization, 2019). Thus, healthy eating and good nutrition are required during this period to meet growth needs; however, one way in which adolescents assert their independence and autonomy is in relation to food choices (Vaitkeviciute et al., 2014), which may not always be healthy. Food choices among adolescents have been found to be predominantly based on food taste, with a greater consumption associated with foods that satisfy their preferences (Fitzgerald et al., 2010; Noble et al., 2003; Stevenson et al., 2007; Warren et al., 2008). They often consume more sweetened drinks and fast foods but lower intakes of fruits and vegetables (Beal et al., 2019). This may be because the sugar, salt and fat content of these drinks and foods provide pleasant tastes (Mouritsen, 2016) while vegetables are often related to unpleasant bitterness and sourness (Krølner et al., 2011). Dietary intake that is driven by individuals' taste preference may be related to future health risks (Chamoun et al., 2018c), especially, during adolescence as a critical period of development. Therefore, it is important to understand the relationships between taste, dietary habits, and nutritional intakes in this age group (Bawajeeh et al., 2020). Thus, the purpose of this study was to characterize the taste of foods using adolescents' food records from the National Diet and Nutrition Survey (NDNS) and to assess the taste characteristics in relation to food and nutrient intakes of UK adolescents.

4.2 Methods

This study used food intake data from 284 adolescents (girls =144 and boys=140) aged 10-19 years old in the UK National Diet and Nutrition Survey (NDNS) rolling program, year 9 (2016/2017). The NDNS is an annual cross-sectional survey assessing dietary intake and nutritional status of a UK representative sample aged 1.5 + years who are randomly recruited based on postcode. The dietary data are collected using the estimated food record method. Parents/carers of adolescents aged ≤ 12 years are asked to help their children to complete the diary, while those who are ≥13 years completed their diary themselves. Participants are asked to keep a record of everything they consumed with estimated quantities of consumption for four consecutive days. A check-up visit by trained interviewers is arranged to review the diary for any clarification needed. Food items are then categorized into main and sub food groups and assigned a food code and name. In the current study, the detailed food record dataset "Food Level Dietary Data" was used for grouping foods to support food taste classification. Survey details and methodology of the NDNS have been reported elsewhere (Public Health England, 2019b). Figure 4-1 illustrates the steps undertaken in the current study.

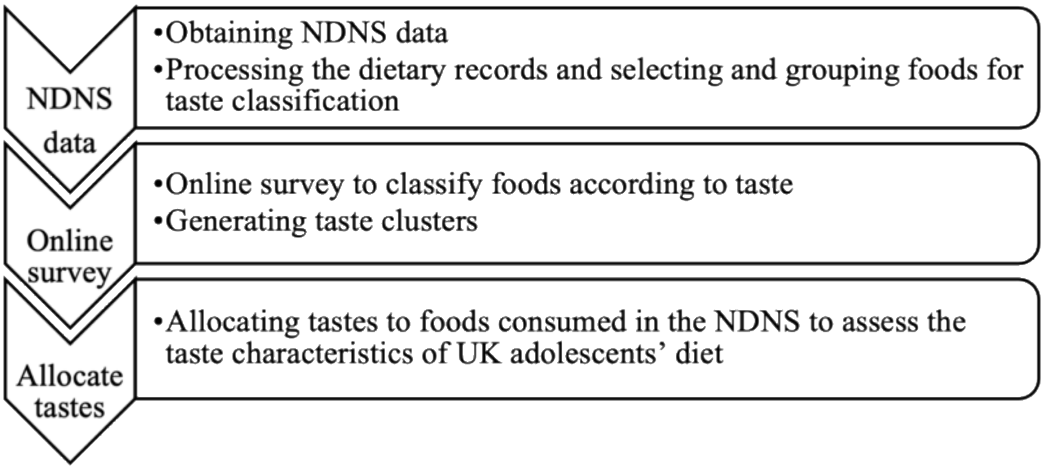

Figure 4-1. Study outline to classify food tastes in UK adolescents

4.2.1 Processing dietary data and selecting foods for taste classification survey

Foods in the NDNS diaries were grouped according to how foods may be consumed. This step was necessary to harmonize the data since some composite dishes had been coded as separate ingredients and some coded as single composite items. To do this we used the following approach:

1- Food items that were ingredients of composite foods and were linked together with one code for that composite dish. For example, ingredients of "Chicken curry" (e.g. chicken, curry sauce, onion… etc.) were linked under one new code.

2- Dry/powdered items (e.g. instant coffee, drinking chocolate) and concentrated juices where water or another diluent was listed for the same reported mealtime were also combined.

3- Where the food items could be eaten separately, they were allocated tastes individually and not combined with one coded composite item. For example, a cheese and bacon sandwich was retained as bread, cheese and bacon separately.

More than 1743 different food items were identified as having been consumed by the adolescents in the NDNS records. These food items were grouped with similar items to create a manageable list of foods for inclusion in the online questionnaire, limiting the burden on participants.

For inclusion in the questionnaire, foods were identified based on consumption frequency, contribution to energy, and contribution to taste (e.g. salad dressing, ketchup). Foods were grouped into food groups using the NDNS main and subsidiary food groups with further considerations such as sugar/salt content (e.g. sweet biscuits or salty biscuits were kept separate) and fruit and vegetable types known to be sweet, sour or bitter. Appendix B.1 in the Supplementary Materials shows examples of the grouped food list under the main and subsidiary food groups. These were checked and agreed by the members of the research team.

4.2.2 Developing an online food-taste classification survey

The list of foods was used in an online survey asking a sample of regular consumers to classify the taste of the foods. Ethics approval for the online survey was obtained from the University of Leeds MEEC 19-039.

Participants were asked to assign one main taste to each food. Taste choices given were sweet, salty, sour, bitter, savoury/umami, neutral or never tried, with an explanation provided for each taste (Appendix B.2). An initial list of 239 food items was piloted with 19 individuals to identify foods where everyone allocated the same taste to further limit the list. Following this pilot test, 55 foods were removed (Appendix B.3) which had a very high level of agreement on taste classification. For example, cakes, fruit yogurt and unsweetened apple juice were allocated by all in the pilot test as sweet tasting. A final list of 184 food items to be rated for taste was generated. A convenience sample was used, distributing the survey online via Facebook and Twitter platforms as well as to individuals known to the researchers. Due to ethical considerations, only respondents aged 18 years and above were allowed to complete the survey. Whilst it is possible that there are some taste changes between adolescence and adulthood, these are likely to be in terms of taste intensity and concentration preference, rather than detection or sensation of taste (Petty et al., 2020; De Graaf and Zandstra, 1999). To minimize participant burden, the food lists were divided into three parts (Adigüzel and Wedel, 2008) and participants were asked to complete one part with an option to voluntarily complete the rest.

Taste classification of our participants was tested through concurrent validity with trained panel data by checking responses from the taste classification survey against taste profiles developed by trained panellists from previous publications in the literature (Teo et al., 2018; van Langeveld et al., 2018; Mars et al., 2020). A total of 123 food items were available for comparison checking. As illustrated in Appendix B.4, there was 84% agreement (n=103), 7% disagreement and 9% neutral.

4.2.3 Data analysis

Following survey completion, for each food item, the percentage of respondents choosing each taste was included in a Hierarchical Cluster Analysis (HCA) using Python Software Foundation version 3.9 to identify taste clusters. The “never tried” responses were excluded from the analysis. The number of clusters was determined based on the dendrogram and assessment of the scree plot (Bertin and Atanassova, 2017). The identified tastes were allocated to individual food items in the NDNS. For example, all cake types that were reported in the NDNS were grouped as "cakes" in our grouped food list used in the online questionnaire. Then from the HCA, "cakes" were classified under the sweet taste cluster. Thus, all individual codes for cakes in the NDNS were allocated a sweet taste.

A specific taste was allocated to each food consumed in the NDNS. Then for each individual, foods contributing to each taste group were summed and the proportion of the weight of the food consumed per day was then calculated for each taste by dividing the weight of foods in each taste group by the total weight of food consumed.

Linear regression modelling was used to compare the mean differences of daily energy intake from each taste cluster by gender, age group (younger adolescents aged 10-14 years and older adolescents aged 15-19 years), and BMI categories (normal weight, overweight and obese). Repeated measures ANOVA, with Bonferroni post-hoc test, was used to compare the mean difference of energy intake from each taste cluster between eating occasions during the day. Eating occasions were chosen according to the time of day as in a previous study using the NDNS data. Time frames are 06.00 to 08.59 am (breakfast), 12.00 noon to 1.59 pm (lunch) and 17.00 pm to 19.59 pm (dinner). Snacking is defined as eating occasions outside meal times (Llauradó et al., 2016).

The final analysis explored characteristics of the adolescents’ dietary intakes by taste. A test for trend was conducted using the percentage of foods from each taste group (exposure) as continuous variables by food and nutrient intakes (outcomes) in linear regression modelling. The percentage of food weight for each taste was split into quintiles to illustrate the direction of effect. The sour taste cluster was presented as only two categories (consumers and non-consumers) due to the high proportion of non-consumers of sour foods.

Weighting to adjust for non-response in the NDNS was applied in all analyses using weights provided for the NDNS (Public Health England, 2019). Statistical significance was assigned to a P-value < 0.05 for all tests. The statistical analysis was performed using STATA statistical software version 16.1.

4.3 Results

4.3.1 Online food-taste classification survey

In total 209 responses (162 females, 44 males & 3 not known) were obtained. Around 90% of the survey respondents were British/white European, and their age ranged from 20 to 70 years, with the majority being between 40 and 59 years old. The HCA grouped the 184 foods/food groups in the questionnaire into six main taste clusters (sweet, salty, sour, bitter, savoury, and neutral). Applying these tastes to the 1743 individual food codes in the diaries resulted in the following: 40% of foods (n= 703) were sweet, 27% (n= 463) were neutral, 20% (n= 346) were savoury, 7% (n= 115) were salty, 4% (n= 77) were bitter and 2% (n= 39) were sour.

Foods that mostly contributed to the sweet taste cluster were sweet snacks (e.g. sweet biscuits, chocolates & candies), desserts (e.g. cakes, sweet pastries and pies) sweetened beverages, dairy products and fruit. Foods characterised as neutral tasting included potatoes, bread, white fish and some vegetables. Savoury tastes included meats and poultry products and flavoured/spiced foods. Foods with a high salt content were, as expected, included in the salty taste, with the top contribution coming from snacks (e.g. crisps, salty biscuits & crackers). Most of the foods contributing to bitter taste came from vegetables known for their bitter taste, such as Brussel sprouts, cabbage, coffee and tea. Some fruits (e.g. kiwi and other fruit that have some sourness) and salad dressing were characterised as sour-tasting items. Appendix B.5 in the Supplementary Materials illustrates common examples of foods items contributed to each taste.

4.3.2 Contribution of the identified tastes to the UK adolescents' daily energy intake from the NDNS

Table 4-1 illustrates adolescents' energy intake from each taste stratified by sample characteristics and eating occasions. The major contributions to adolescents' daily energy intakes were from sweet-tasting foods (34%) 558kcal/d (95%CI 516, 599), neutral-tasting foods (34%) 556kcal/d (95%CI 521, 592), and savoury-tasting foods (21%) 334 kcal (95%CI 307, 362), salty, bitter and sour tasting foods provided much smaller energy contributions.

There was no statistically significant difference in the percentage of energy from each taste between boys and girls. However, younger adolescents (10-14 years) had higher energy intake from sweet-tasting foods by 6% (95%CI 1, 9; $P < 0.01$), and higher salty-tasting foods by 3% (95%CI 1, 5; $P < 0.01$) compared with older adolescents (15-19 years). Older adolescents had significantly higher energy intakes from savoury-tasting foods by 5% (95%CI 2, 7; $P < 0.01$), and bitter-tasting foods by 1% (95%CI 0.2, 1; $P < 0.01$) compared to younger individuals. In relation to BMI categories, normal-weight individuals had a borderline significant difference in the energy intake from sweet-tasting foods compared to obese individuals by 6% (95%CI 0.03, 10; $P = 0.05$).

At breakfast, most of the energy intake was obtained from sweet-tasting foods (38%) while energy intakes from neutral-tasting foods were higher at lunch (37%) and dinner (34%). Across main meals, adolescents had significantly higher energy intake from sweet-tasting foods at breakfast compared to lunch-time by 15% (95%CI 7, 19; $P < 0.01$) and at dinner by 19% (95%CI 11, 23; $P < 0.01$). Energy intake from savoury-tasting foods at dinner was higher by 13% (95%CI 6, 18; $P < 0.01$) than at lunch. Energy intake from neutral-tasting foods at lunch and dinner was significantly higher than at breakfast.

For snacks, adolescents had a higher energy intake from sweet-tasting foods in the morning (31%). In the afternoon, sweet-tasting foods and savoury-tasting foods were the major contributors to the energy intake by 27% each. Savoury-tasting foods were also the main source of energy intake for snacking in the evening (34%) and for late snacking (33%). However, no significant differences in energy intake were observed across the different snacking times.

Table 4-1. Adolescents' energy intake (kcal/d) as a total and from each taste stratified by sample characteristics and eating occasions

		Energy intake (kcal/ day) Mean (95%CI)	Taste contribution to energy intake (kcal/d) Mean (95%CI) & (% of total energy)					
			Sweet	Neutral	Savoury	Salty	Bitter	Sour
Total sample (n= 284)		1626 (1565, 1688)	558 (516, 599) (34%)	556 (521, 592) (34%)	334 (307, 362) (21%)	163 (146, 181) (10%)	10 (6, 13) (1%)	5 (2, 7) (<1%)
Gender	Boys (n= 140)	1729 (1651, 1808)	614 (551, 677) (36%)	581 (540, 623) (34%)	349 (309, 389) (20%)	171 (148, 195) (10%)	10 (5, 16) (1%)	3 (1, 5) (<1%)
	Girls (n= 144)	1523 (1427, 1616)	501 (450, 552) (33%)	531 (473, 590) (35%)	320 (282, 357) (21%)	155 (129, 181) (10%)	8 (4, 13) (1%)	6 (2, 11) (<1%)
Age group	10-14 years (n=174)	1596 (1516, 1675)	586 (530, 643) (37%)	538 (477, 579) (34%)	293 (263, 323) (18%)	181 (156, 205) (11%)	4 (1, 7) (<1%)	3 (2, 5) (<1%)
	15-19 years (n=110)	1667 (1570, 1763)	520 (459, 581) (31%)	594 (548, 640) (36%)	389 (344, 434) (23%)	140 (117, 163) (8%)	16 (9, 24) (1%)	9 (1, 12) (1%)
BMI categories *	Normal (n=170) 18.5 to <25 kg/m^2	1679 (1599, 1759)	602 (546, 657) (36%)	563 (514, 612) (34%)	332 (299, 366) (20%)	168 (144, 192) (10%)	10 (5, 15) (1%)	4 (2, 6) (<1%)
	Overweight (n=37) 25 to <30 kg/m^2	1555 (1387, 1722)	517 (425, 610) (33%)	545 (454, 616) (35%)	329 (246, 411) (21%)	159 (108, 210) (10%)	4 (<1, 7) (<1%)	11 (-2, 24) (1%)
	Obese (n=61) ≥30 kg/m^2	1513 (1383, 1643)	461 (377, 546) (30%)	529 (460, 598) (35%)	351 (277, 424) (23%)	160 (130, 190) (11%)	9 (1, 16) (1%)	3 (1, 5) (<1%)
Main meals	Breakfast (n= 235) ^	297 (234, 376)	114 (99, 128) (38%)	73 (61, 86) (25%)	47 (19, 75) (16%)	57 (37, 77) (19%)	2 (-0.1, 5) (1%)	4 (-1, 10) (1%)

	Lunch (n=275) ^	451 (407, 470)	103 (91, 115) (23%)	165 (145, 185) (37%)	87 (76, 99) (19%)	83 (69, 97) (18%)	2 (1, 3) (<1%)	12 (5, 17) (3%)
	Dinner (n=284)	533 (498, 555)	100 (91, 115) (19%)	179 (162, 196) (34%)	170 (152, 188) (32%)	66 (56, 76) (12%)	8 (4, 13) (2%)	9 (5, 13) (2%)
Snacks^	Morning snack (n=266)	338 (243, 395)	106 (92, 121) (31%)	77 (65, 89) (23%)	70 (53, 87) (21%)	55 (45, 64) (16%)	8 (<1, 16) (2%)	22 (-8, 52) (7%)
	Afternoon snack (n=273)	370 (290, 396)	99 (87, 112) (27%)	91 (72, 111) (25%)	90 (80, 117) (27%)	57 (48, 66) (15%)	4 (1, 6) (1%)	20 (-0.3, 41) (5%)
	Evening snack (n=252)	366 (286, 376)	93 (79, 106) (25%)	76 (52, 99) (21%)	123 (101, 146) (34%)	55 (40, 71) (15%)	11 (1, 21) (3%)	8 (1, 16) (2%)
	Late evening snack (n=130)	274 (242, 298)	68 (48, 89) (25%)	39 (22, 55) (14%)	89 (51, 127) (33%)	56 (18, 95) (21%)	9 (<1, 20) (3%)	13 (-82, 107) (5%)

* Indicates missing data for 16 participants; ^ Not all adolescents had consumption during the stated meals
When the total exceeds 100%, this is due to rounding of values.

4.3.3 Assessment of the UK adolescents' dietary taste based on their food records from the NDNS

Table 4-2 illustrates the nutrient and food intake by taste. Taste is characterised as a percentage of the total food weight presented by quintile.

4.3.3.1 Sweet-tasting foods

Energy, carbohydrate, sugars, and saturated fat all showed significant positive linear trends with increasing sweet-tasting foods. Energy intake increased by 20% from the lowest quintile (Q1) to the highest quintile (Q5) and there was a statistically significant positive trend of higher energy intake by 10 kcal/d (95% CI 6, 15; $P < 0.01$) for each percentage increase in sweet food consumption. Carbohydrate intake also showed a positive overall trend of higher intakes with higher sweet foods. Individuals who had the highest proportion of sweet-tasting foods (Q5) had higher total sugar (115%) and free sugar (147%) intakes compared to those in the lowest quintile (Q1). Total fat intake was 9% higher between the lowest quintile (Q1) to the highest quintile (Q5) of sweet-tasting foods with an overall significant trend ($P = 0.02$).

Fruit intake was 60% higher and fruit juice was 161% higher in the highest quintile (Q5) compared to the lowest quintile (Q1) of sweet-tasting foods with overall significant trends for both. Meat and poultry intakes were 38% lower between the lowest and highest quintile (Q5) with an overall significant trend ($P = 0.03$).

4.3.3.2 Neutral-tasting foods

Energy, carbohydrate, sugars, total fat and saturated fats all showed significant negative linear trends with increasing neutral-tasting foods. Energy intake decreased by 19% from the lowest to the highest quintile and there was a statistically significant negative trend of lower energy intake by 10 kcal/d (95% CI -15, -5; $P < 0.001$) for each increase in the proportion of neutral-tasting foods. Individuals in the highest quintile of neutral-tasting foods had lower carbohydrate (21%), total sugars (47%) and free sugars (54%) compared to those in the lowest quintile. Total fat and saturated fats intakes also showed negative overall trends of lower intakes with higher consumption of neutral-tasting foods. Processed meats consumption was 44% less in the highest compared to the lowest quintile of neutral-tasting foods; with an overall significant trend ($P < 0.01$) per each percentage increase in neutral-tasting foods.

4.3.3.3 Savoury-tasting foods

Protein intake showed a borderline significant positive linear trend while carbohydrate and sugars intakes showed inverse linear trends with higher consumption of savoury-tasting foods. Individuals in the highest quintile of savoury-tasting foods had 14% higher protein intake compared with those in the lowest quintile. Carbohydrate intake decreased by 14% from the lowest to the highest quintiles. Also, total sugars intake was (30%) lower and free sugars intake was (32%) lower between the lowest and highest quintiles.

Fruit intake was inversely associated with higher amounts of savoury-tasting foods; with a 47% lower intake between the highest and lowest quintile and overall decrease per each percentage increase in savoury foods by 3 g/d (95% CI -5, -1; P < 0.001). However, non-Brassica vegetable intake was higher with increasing amounts of savoury foods. Meat and poultry intakes increased by 90% from the lowest to the highest quintile and there was a statistically significant positive trend of higher meat intake by 2 g/d (95% CI 0.4, 3; P = 0.01) with each percentage increase in savoury-tasting foods. Processed meats intake increased by 67% from the lowest to the highest quintile.

4.3.3.4 Salty-tasting foods

Individuals with the lowest proportion of salty foods (Q1) had 19% less sodium, 1771 mg/d (95% CI 1545, 1996) compared to individuals with the highest proportion of salty foods (Q5) 2101mg/d (95% CI 1893, 2309). Overall sodium intake was higher by 22 mg/d (95% CI 5, 40; P = 0.01) for each percentage increase in salty foods. Saturated fats intake increased by 14% from the lowest quintile (Q1) to the highest quintile (Q5) and there was a statistically significant positive trend of higher intake by 0.3 g/d (95% CI 0.02, 1.00; P = 0.03) for each percentage increase in salty foods. Processed meat consumption was 186% higher and cheese intake 230% higher between the lowest to the highest quintile. Non-processed meat and poultry showed an overall negative trend of 2 g/d (95% CI 3, 1; P = 0.02) lower for each percentage increase in salty foods consumed. Similarly, higher intakes of both fruit and Brassica vegetables were associated with lower intakes of salty foods.

Table 4-2. Characteristics of adolescents' dietary intakes by the quintiles (Q) weight of foods consumed as a percentage of the total food weight

	Quintiles of sweet-tasting foods as percentage of the total food weight (%)							
	Q1 (n=57) 7- 31%	**Q2 (n=57) 31- 37%**	**Q3 (n=57) 37- 43%**	**Q4 (n=57) 43- 50%**	**Q5 (n=56) 50-73%**	**%Diff Q1&Q5**	**Coeff. (95%CI)[*]**	***P*-trend**
Energy (kcal/d)	1449 (1330, 1569)	1574 (1428, 1721)	1696 (1564, 1828)	1750 (1620, 1879)	1738 (1619, 1858)	20%	10 (6, 15)	<0.01
Carbohydrate (g/d)	183 (169, 198)	208 (186, 231)	223 (209, 237)	234 (216, 253)	250 (235, 266)	37%	2 (1.5, 3)	<0.01
Protein (g/d)	62 (56, 67)	62 (56, 68)	65 (59, 72)	69 (6276)	58 (53, 64)	-6%	0.02 (-0.2, 0.2)	0.83
Fat (g/d)	57 (51, 63)	60 (54, 66)	66 (59, 74)	65 (59, 71)	62 (56, 68)	9%	0.3 (0.03, 0.5)	0.02
Total sugars (g/d)	54 (48, 61)	71 (62, 80)	89 (80, 99)	96 (87, 105)	116 (105, 127)	115%	2 (1.5, 2)	<0.01
Free sugars (g/d)	34 (28, 40)	47 (40, 54)	61 (51, 72)	63 (51, 74)	84 (72, 97)	147%	1.5 (1, 2)	<0.01
Fibre (g/d)	14 (13, 15)	16 (14, 18)	15 (13, 16)	16 (14, 17)	15 (14, 17)	7%	0.04 (-0.01, 0.1)	0.14
Saturated fat (g/d)	19 (17, 21)	22 (19, 25)	24 (21, 28)	26 (23, 28)	25 (22, 28)	32%	0.2 (0.1, 0.3)	<0.01
Sodium (mg/d)	1791 (1580, 2003)	1772 (1584, 1961)	1983 (1771, 2195)	1942 (1769, 2114)	1651 (1456, 1846)	-8%	1 (-7, 8)	0.86
Fruit (g/d)	55 (37, 73)	52 (33, 72)	69 (50, 88)	71 (42, 100)	88 (58, 118)	60%	1.2 (0.3, 2)	<0.01
Fruit Juice (g/d)	57 (25, 89)	72 (32, 112)	88 (60, 117)	82 (44, 120)	149 (73, 225)	161%	2 (0.3, 4)	0.02
Brassica vegetables (g/d)	12 (6, 19)	12 (7, 17)	16 (7, 24)	10 (4, 16)	10 (5, 15)	-17%	-0.04 (-0.2, 0.2)	0.66
Other vegetables (g/d)	87 (69, 105)	97 (77, 117)	73 (62, 84)	106 (83, 130)	73 (57, 90)	-16%	-0.3 (-1, 0.4)	0.42
Meat & poultry (g/d)	72 (56, 89)	55 (44, 65)	72 (51, 93)	59 (47, 72)	45 (35, 55)	-38%	-0.5 (-1, -0.3)	0.03

Processed meats (g/d)	25 (17, 33)	26 (17, 35)	29 (21, 36)	28 (19, 36)	18 (11, 26)	-28%	-0.1 (-0.4, 0.3)	0.66
Cheese (g/d)	18 (12, 24)	22 (15, 28)	16 (11, 22)	17(12, 23)	18 (13, 23)	0%	-0.1 (-0.3, 0.1)	0.55

	Quintiles of neutral-tasting foods as percentage of the total food weight (%)							
	Q1 (n=57) 9- 26%	**Q2 (n=57) 26-33%**	**Q3 (n=57) 33- 38%**	**Q4 (n=57) 38-46%**	**Q5 (n=56) 46-78%**	**%Diff Q1&Q5**	**Coeff. (95%CI)** *	***P*-trend**
Energy (kcal/d)	1772 (1647, 1898)	1721 (1580, 1863	1644 (1537, 1751)	1601 (1445, 1757)	1436 (1317, 1555)	-19%	-10 (-15, -5)	<0.01
Carbohydrate (g/d)	243 (225, 261)	228 (210, 247)	218 (204, 233)	211 (190, 233)	191 (173, 209)	-21%	-2 (-2, -1)	<0.01
Protein (g/d)	60 (54, 65)	69 (62, 76)	66 (60, 72)	63 (56, 70)	58 (53, 63)	-3%	-0.1 (-0.4, 0.1)	0.25
Fat (g/d)	69 (61, 76)	64 (56, 71)	61 (57, 66)	62 (55, 69)	55 (49, 60)	-20%	-0.4 (-1, -0.1)	0.02
Total sugars (g/d)	111 (98, 124)	93 (83, 103)	80 (72, 87)	77 (66, 87)	59 (52, 67)	-47%	-1 (-2, -1)	<0.01
Free sugars (g/d)	82 (69, 95)	63 (52, 74)	52 (44, 59)	51 (41, 60)	38 (31, 44)	-54%	-1 (-2, -1)	<0.01
Fibre (g/d)	15 (13, 16)	16 (14, 17)	16 (14, 17)	15 (13, 17)	14 (13, 16)	-7%	-0.02 (-0.1,0.03)	0.48
Saturated fat (g/d)	28 (24, 32)	25 (21, 28)	22 (21, 24)	22 (19, 25)	18 (16, 20)	-36%	-0.3 (-0.4, -0.2)	<0.01
Sodium (mg/d)	1845 (1605, 2085)	2013 (1848, 2178)	1841 (1611, 2072)	1801 (1604, 1997)	1648 (1473, 1823)	-11%	-7 (-15, 1)	0.07
Fruit (g/d)	64 (39, 89)	72 (50, 93)	68 (40, 95)	64 (45, 84)	60 (42, 79)	-6%	-0.1 (-1, 1)	0.73
Fruit Juice (g/d)	131 (56, 206)	90 (44, 137)	86 (53, 118)	67 (34, 100)	66 (32, 101)	-50%	-1 (-4, 1)	0.19
Brassica vegetables (g/d)	10 (5, 15)	13 (7, 20)	12 (5, 20)	12 (6, 17)	12 (6, 19)	20%	0.01 (-0.2, 0.2)	0.94
Other vegetables (g/d)	77 (60, 94)	106 (80, 132)	84 (73, 95)	82 (64, 100)	89 (69, 108)	16%	-0.1 (-1, 1)	0.81
Meat & poultry (g/d)	44 (34, 53)	63 (51, 75)	66 (45, 86)	70 (53, 86)	62 (49, 76)	41%	0.4 (-0.1, 1)	0.13

Processed meats (g/d)	32 (22, 43)	32 (24, 40)	20 (14, 26)	25 (17, 32)	18 (11, 25)	-44%	-0.4 (-1, -0.1)	<0.01
Cheese (g/d)	23 (16, 30)	18 (13, 23)	20 (13, 26)	17 (12, 22)	16 (10, 21)	-30%	-0.2 (-0.4, 0.03)	0.10

	Quintiles of savoury-tasting foods as percentage of the total food weight (%)							
	Q1 (n=57) 0- 7%	**Q2 (n=57) 7- 10%**	**Q3 (n=57) 10- 12%**	**Q4 (n=57) 12-16%**	**Q5 (n=56) 16-27%**	**%Diff Q1&Q5**	**Coeff. (95%CI)***	***P*-trend**
Energy (kcal/d)	1678 (1565, 1791)	1698 (1566, 1831)	1609 (1476, 1741)	1584 (1443, 1725)	1581 (1433, 1730)	-6%	-9 (-19, 0.4)	0.06
Carbohydrate (g/d)	233 (216, 249)	231 (213, 249)	220 (201, 240)	207 (188, 227)	200 (181, 220)	-14%	-3 (-4, -1)	<0.01
Protein (g/d)	58 (53, 62)	63 (58, 69)	61 (56, 66)	65 (58, 72)	66 (59, 73)	14%	0.4 (-0.01, 1)	0.05
Fat (g/d)	63 (57, 69)	64 (57, 70)	60 (53, 66)	60 (54, 66)	63 (55, 70)	0%	-0.2 (-1, 1)	0.92
Total sugars (g/d)	100 (88, 113)	89 (78, 100)	89 (76, 102)	71 (62, 80)	70 (61, 79)	-30%	-2 (-3, -1)	<0.01
Free sugars (g/d)	69 (57, 82)	59 (50, 69)	65 (52, 77)	45 (37, 53)	47 (37, 57)	-32%	-2 (-2, -1)	<0.01
Fibre (g/d)	16 (14, 17)	16 (15, 18)	13 (12, 15)	15 (14, 17)	14 (12, 16)	-13%	-0.1 (-0.2, 0.01)	0.07
Saturated fat (g/d)	25 (21, 28)	24 (21, 26)	23 (20, 25)	21 (19, 24)	22 (19, 26)	-12%	-0.1 (-0.4, 0.2)	0.42
Sodium (mg/d)	1762 (1637, 1888)	1810 (1639, 1981)	1734 (1553, 1915)	1925 (1690, 2160)	1840 (1600, 2080)	4%	7 (-9, 23)	0.37
Fruit (g/d)	100 (70, 129)	85 (61, 109)	50 (33, 66)	48 (35, 60)	53 (30, 75)	-47%	-3 (-5, -1)	<0.01
Fruit Juice (g/d)	97 (53, 140)	133 (65, 202)	77 (50, 104)	53 (33, 73)	84 (31, 136)	-13%	-3 (-7, 1)	0.12
Brassica vegetables (g/d)	7 (3, 11)	17 (8, 25)	8 (3, 12)	13 (6, 21)	13 (8, 19)	86%	0.2 (-0.2, 1)	0.39
Other vegetables (g/d)	65 (51, 80)	91 (69, 112)	82 (63, 101)	97 (81, 113)	97 (76, 118)	49%	2 (0.2, 3)	0.03
Meat & poultry (g/d)	38 (29, 46)	59 (48, 71)	60 (48, 71)	71 (54, 88)	72 (54, 90)	90%	2 (0.4, 3)	0.01
Processed meats (g/d)	21 (14, 27)	26 (17, 35)	20 (14, 26)	22 (15, 29)	35 (25, 44)	67%	1 (0.2, 2)	0.01

Cheese (g/d)	18 (13, 23)	21 (15, 27)	19 (15, 24)	15 (9, 20)	20 (13, 27)	11%	0.1 (-1, 1)	0.85
	Quintiles of salty-tasting foods as percentage of the total food weight (%)							
	Q1 (n=57) 0- 3%	**Q2 (n=57) 3- 6%**	**Q3 (n=57) 6- 8%**	**Q4 (n=57) 8- 11%**	**Q5 (n=56) 11-31%**	**%Diff Q1&Q5**	**Coeff. (95%CI)***	***P*-trend**
Energy (kcal/d)	1617 (1474, 1760)	1655 (1493, 1816)	1579 (1439, 1720)	1649 (1536, 1762)	1621 (1499, 1742)	0%	2 (-9, 12)	0.72
Carbohydrate (g/d)	214 (195, 234)	226 (201, 250)	210 (194, 227)	226 (209, 244)	206 (191, 220)	-4%	-0.4 (-2, 1)	0.50
Protein (g/d)	67 (59, 74)	66 (60, 73)	61 (55, 67)	59 (54, 63)	63 (57, 68)	-6%	-0.3 (-1,.2)	0.26
Fat (g/d)	60 (54, 67)	61 (54, 67)	60 (52, 68)	62 (57, 68)	66 (59, 73)	10%	1 (-0.1, 1)	0.07
Total sugars (g/d)	83 (72, 94)	84 (72, 96)	87 (74, 100)	89 (77, 101)	69 (61, 77)	-17%	-0.7 (-2, 0.1)	0.08
Free sugars (g/d)	53 (42, 64)	53 (42, 63)	63 (51, 75)	64 (52, 75)	47 (40, 54)	-11%	-0.2 (-1, 1)	0.65
Fibre (g/d)	15 (14, 17)	15 (13, 17)	14 (13, 16)	15 (13, 16)	15 (14, 17)	0%	-0.02 (-0.1, 0.1)	0.80
Saturated fat (g/d)	22 (19, 25)	22 (19, 25)	22 (19, 26)	23 (21, 25)	25 (22, 29)	14%	0.3 (0.02, 1)	0.03
Sodium (mg/d)	1770 (1545, 1996)	1717 (1511, 1923)	1711 (1523, 1898)	1825 (1642, 2008)	2101 (1893, 2309)	19%	22 (4.5, 40)	0.01
Fruit (g/d)	66 (49, 83)	92 (62, 122)	64 (43, 85)	66 (44, 89)	35 (23, 47)	-47%	-2 (-4, -1)	<0.01
Fruit Juice (g/d)	70 (35, 104)	66 (35, 98)	111 (50, 172)	126 (67, 184)	60 (31, 89)	-14%	-0.5 (-3, 2)	0.73
Brassica vegetables (g/d)	19 (10, 28)	11 (6, 15)	12 (6, 19)	10 (6, 15)	7 (3, 11)	-63%	-1 (-1, -0.2)	<0.01
Other vegetables (g/d)	101 (81, 120)	91 (71, 111)	91 (74, 107)	78 (56, 100)	77 (62, 92)	-24%	-2 (-3, -0.3)	0.01
Meat & poultry (g/d)	75 (53, 96)	72 (57, 87)	56 (46, 66)	57 (47, 67)	42 (33, 52)	-44%	-2 (-3, -1)	<0.01
Processed meats (g/d)	14 (8, 21)	22 (14, 31)	22 (15, 28)	28 (22, 35)	40 (30, 49)	186%	2 (1, 2)	<0.01
Cheese (g/d)	10 (6, 14)	15 (10, 19)	18 (14, 22)	19 (14, 24)	33 (26, 41)	230%	1 (1, 2)	<0.01
	Quintiles of bitter-tasting foods as percentage of the total food weight (%)							
	Q1 (n=88) 0%	**Q2 (n=26) <1- 1%**	**Q3 (n=57) 1- 4%**	**Q4 (n=57) 4- 7%**	**Q5 (n=56) 7-27%**	**%Diff Q1&Q5**	**Coeff. (95%CI)***	***P*-trend**

Energy (kcal/d)	1570 (1454, 1686)	1808 (1584, 2032)	1607 (1501, 1713)	1673 (1517, 1828)	1585 (1475, 1696)	1%	-3 (-15, 9)	0.62
Carbohydrate (g/d)	213 (196, 231)	245 (211, 278)	219 (207, 231)	215 (195, 235)	210 (192, 228)	-1%	-1 (-3, 1)	0.30
Protein (g/d)	58 (54, 62)	73 (62, 84)	60 (53, 67)	67 (61, 74)	63 (57, 69)	9%	0.2 (-0.4, 1)	0.41
Fat (g/d)	60 (55, 65)	67 (59, 75)	61 (55, 66)	66 (58, 74)	58 (54, 63)	-3%	-0.3 (-1, 0.2)	0.28
Total sugars (g/d)	81 (70, 93)	91 (75, 107)	86 (76, 97)	78 (67, 89)	82 (72, 93)	1%	-0.2 (-1, 1)	0.77
Free sugars (g/d)	57 (47, 67)	57 (44, 71)	58 (47, 69)	54 (44, 64)	54 (43, 65)	-5%	-0.3 (-1, 1)	0.59
Fibre (g/d)	14 (13, 15)	18 (15, 21)	15 (14, 16)	15 (14, 17)	15 (13, 16)	7%	-0.02 (-0.2, 0.2)	0.86
Saturated fat (g/d)	23 (20, 25)	26 (22, 30)	21 (20, 23)	25 (21, 28)	21 (19, 23)	-9%	-0.2 (-0.4, 0.1)	0.15
Sodium (mg/d)	1722 (1590, 1855)	2036 (1763, 2309)	1779 (1535, 2023)	1906 (1660, 2152)	1803 (1664, 1941)	5%	1 (-15, 18)	0.86
Fruit (g/d)	69 (50, 89)	85 (38, 132)	72 (49, 96)	54 (36, 72)	59 (39, 79)	-14%	-1 (-4, 1)	0.34
Fruit Juice (g/d)	86 (56, 115)	118 (60, 176)	120 (50, 190)	69 (41, 97)	61 (21, 102)	-29%	-4 (-8, 1)	0.11
Brassica vegetables (g/d)	6 (2, 10)	8 (2, 13)	17 (10, 25)	12 (6, 18)	15 (9, 21)	150%	1 (-0.1, 1)	0.07
Other vegetables (g/d)	63 (51, 74)	112 (73, 151)	97 (78, 115)	84 (68, 100)	104 (85, 124)	65%	3 (1, 5)	0.01
Meat & poultry (g/d)	53 (42, 65)	55 (37, 73)	64 (45, 84)	65 (53, 76)	66 (51, 81)	25%	1 (-1, 2)	0.41
Processed meats (g/d)	21 (16, 26)	43 (28, 58)	20 (14, 26)	30 (21, 39)	22 (16, 29)	5%	-0.1 (-1, 1)	0.81
Cheese (g/d)	17 (13, 22)	23 (15, 32)	15 (9, 20)	25 (18, 31)	15 (11, 19)	-12%	-0.2 (-1, 0.3)	0.51

* Change in nutrient/food per % increase in taste
Q1-Q5= quintiles 1 (lowest quintile)- quintiles 5 (highest quintile). Each quintile represents: 1) number of adolescents (n); although they are in the same size it is different individuals; 2) proportion of food tastes (%)

4.3.3.5 Bitter-tasting foods

The proportion of bitter-tasting foods was not shown to have a statistically significant association with dietary intakes, except with vegetables. The intake of non-Brassica vegetables increased by 65% from the lowest to the highest quintile and there was a significant positive trend of higher non-Brassica vegetable intake by 3 g/d (95% CI 1, 5; $P < 0.01$) with each percentage increase in bitter-tasting foods. Brassica vegetables also increased by 150% from the lowest quintile (Q1) to the highest quintile (Q5); with a borderline significant positive trend of higher Brassica vegetables intake by 1 g/d per percentage increase in bitter foods (95% CI -0.1, 1.0; $P = 0.07$).

4.3.3.6 Sour-tasting foods

As seen in Appendix B.6 in Supplementary Materials, only 70 adolescents (25%) had any intake from sour-tasting foods. There was no statistically significant association between any of the nutrients explored and the sour-tasting foods. Individuals who consumed sour-tasting foods had higher intakes of Brassica vegetables 16 g/d (95% CI 10, 23) compared with non-consumers 10 g/d (95% CI 7, 13) and there was a significantly higher intake by 2 g/d (95% CI 0.5, 4; $P = 0.01$) for each percentage increase in sour foods. Meat & poultry intakes were also higher among consumers of sour-tasting foods.

4.4 Discussion

The present study aimed to characterize the taste of UK adolescents' overall food and nutrient intakes using food records from the UK National Diet and Nutrition Survey, NDNS (2016-2017). Our approach of characterizing the food taste of the whole diet is novel in this age group. Findings revealed that taste contributions to daily energy intake differed based on sample characteristics and eating occasions. Findings have also shown different trends in the intake of nutrients and foods according to the contribution of each taste to the overall diet.

Comparing the taste classification from our work against previous published work using trained panellists showed a good level of agreement for foods which were available; suggesting that taste classification by regular consumers could be reliable. The small number of disagreements between our survey and trained panellists may be due to a range of factors including variations in ingredients, food preparation and other factors that could affect the taste of the crops including ripeness, seasonality, and different types of tested items (e.g. there are sweet tomatoes, while others are sour savoury or neutral).

About two-thirds of adolescents' dietary intakes were from both sweet-tasting and neutral-tasting foods, and around one third were from both savoury and salty-tasting foods. However, taste contributions to daily energy intake differed by age group. Young individuals have been shown to have greater preference and consumption of sweet-tasting foods than adults (De Graaf and Zandstra, 1999; Petty et al., 2020). Adults may consume more bitter-tasting foods due to their awareness of potential health benefits (Chamoun et al., 2018). This may explain our findings of higher energy intake from sweet foods among younger adolescents compared with older adolescents whose highest energy intake was from neutral-tasting foods. Also, older adolescents were observed to have a higher energy intake from bitter-tasting foods compared with younger individuals. This was linked to higher consumption of coffee, tea and alcoholic beverages where the bitterness in those items was found to be acceptable (Drewnowski and Gomez-Carneros, 2000). Concerning savoury and salty foods, older adolescents had slightly higher energy intake from these tastes compared to younger adolescents. A study on adolescents' frequent consumption of takeaway foods at age 12 and followed-up at age 17 found increasing consumption by age (Gopinath et al., 2016). Takeaway foods alongside other items (e.g. crisps and nuts), were classified as salty or savoury tastes in the current work.

Sweet-tasting foods dominated breakfast-times, which may be due to the intake of milk, breakfast cereals, white bread, sugar preserves, sweet spreads and/or fruit which have been reported as popular foods consumed by the UK population at breakfast (Gaal et al., 2018). Sweet tasting foods also contributed the most energy for daytime snacking. An earlier study comparing adolescents snacking showed that sugar-sweetened beverages, caloric-dense foods (e.g. biscuits, cakes and pastries), and fruit were the most commonly consumed snacks (Kerr et al., 2008). However, we found that later on the day, at lunch and dinner as well as evening and late evening snacking, foods tasting neutral, and savoury were the highest sources of the adolescents' energy intake. This could be explained by the common consumption of core foods at lunch and dinner (composite dishes like meat and poultry-based foods and some vegetables) and savoury snacks.

Evidence on the relationship between BMI and taste is contradictory. Studies on adults have shown a positive association between higher BMI and preference for savoury and salty foods (Matsushita et al., 2009; Deglaire et al., 2015; Cox et al., 1999) and sweet foods (Matsushita et al., 2009; Deglaire et al., 2015), while others observed no association (Pepino et al., 2010). Normal-weight adults have reported preferring sweet foods more than adults with obesity (Cox et al., 1999). A study characterising adolescent tastes by genotype observed a higher intake of chocolate among individuals with obesity than normal weight (Pioltine et al., 2018) while in another study, a higher preference for salty foods was reported by overweight and obese adolescents (Santos et al., 2017). In our study, normal-weight individuals had higher energy intake from sweet foods compared with those with obesity who had the highest energy intake from neutral-tasting foods and both of savoury and salty tasting foods. A similar result has also been shown in adults (van Langeveld et al., 2018). However, inconsistent findings may be attributed to a number of possible reasons. First, the methods used in assessing taste are varied which may influence the outcome (Tan and Tucker, 2019; Webb et al., 2015). Second, whether bodyweight is measured or self-reported may have an effect. Differences between self-reported and measured body weight were associated with differences in taste perception (Simchen et al., 2006). Third, potential misreporting of certain foods in food records may affect the outcome association between taste and BMI (Forrestal, 2011; Heitmann and Lissner, 1995). Fourth, the relationship between taste and body weight may depend on age and gender. Older individuals and girls identified tastes better than younger individuals and boys (Overberg et al., 2012; Simchen et al., 2006). Fifth, leptin, which is associated with higher body weight, has been found to decrease sweetness perception which could drive individuals to consume higher concentrated sweet taste foods. This could affect the taste buds causing taste impairment associated with obesity (Rohde et al., 2020). Furthermore, tastes, and contributing components such as sugar and salt increase food palatability and hedonic responses that could be linked with increased consumption (Harnischfeger and Dando, 2021). This could cause potential health risks, especially with the presence of obesity.

Regarding the overall characteristic of adolescents' dietary intake by taste, we found that higher consumption of sweet-tasting foods was linked to a higher intake of energy, carbohydrate, sugars, fibre and saturated fats. Previous studies have also identified a strong association between sweetness and sugar content in foods (Lease et al., 2016; van Dongen et al., 2012b; Martin et al., 2014), and liking for higher concentrations of sweet taste was positively associated with total energy, carbohydrate and total sugar intake in adults (Jayasinghe et al., 2017). Adolescents' eating is often categorised by high calorie-dense food with a high proportion of calories coming from fat and sugar (Beck et al., 2019; Ensaff et al., 2013; Vaitkeviciute et al., 2014). It has been reported that children and adolescents have the highest intake of free sugars; at least three times the recommended level. This high consumption of added sugars has been a public health concern due to the potential of free sugars increasing the risk of obesity and consequently other non-communicable diseases (Public Health England, 2015). In our study, we observed adolescents' intake of free sugars exceeded the dietary recommendations of less than 5% (Public Health England, 2015). This could be explained by the consumption of sweet snacks and sweet baked products which highly contributed to the sweet taste in the present study. This was the opposite of the observations from adults who had low consumption of sweet-tasting foods and drinks and sucrose intake associated with increased intensity of the sweetness (Jayasinghe et al., 2017). However, another study on adults reported higher intake of sweetened beverages and high energy intake from sugar-sweetened beverages among those who reported higher preference for sweetness compared with others who showed less or neutral liking (Garneau et al., 2018). In the current study, it was noted by the food records that adolescents had frequent consumption of sweet beverages, especially, with meals. A review has reported that approximately 75% of calorie-dense beverage consumption (e.g. carbonated soft drinks) occurs with meals (McKiernan et al., 2008). Moreover, the addition of sugar to coffee and tea could be contributed to the high level of sugar intake where sweetness modulates the acceptance of the bitterness of these beverages (Low et al., 2014). Nevertheless, as sweet taste is related to the calorie content in food and energy intake, the increased consumption of sweet-tasting foods among adolescents may indicate the increased need for calories during this period of growth (Das et al., 2017). However, healthier choices of sweet foods and beverages are recommended.

Adolescents had a higher protein intake associated with a higher intake of savoury-tasting foods compared with the other tastes. This may be related to the higher consumption of meats and processed meats. Previous work has reported moderate (Lease et al., 2016) to strong correlation between savoury-tasting foods and protein content (van Dongen et al., 2012). Protein and sodium contents were found to have positive associations with saltiness (van Dongen et al., 2012). Whilst studies on adults reported that individuals with higher preference for salty taste had a higher intake of fast-foods, protein (Louro et al., 2021) and protein-source foods (e.g. legumes and white meats) (Veček et al., 2020), our findings confirmed the positive association between sodium intake and the higher intake of salty-tasting foods, but protein intake did not increase with saltiness. This could be explained by the observed higher intake of sodium sources (e.g. cheese and processed meats) and the lower intake of protein sources (e.g. meat and poultry) within the higher intake of salty-tasting foods. Whilst these findings indicate a link between sodium intake and saltiness (van Dongen et al., 2012; Martin et al., 2014), this has not always been found to be true (Lease et al., 2016). Interestingly, processed meats were found to correlate with both savoury and salty tastes, which may refer to a potential connection between these tastes. This is because processed products (e.g. some type of cheese and processed meats) are high in salt and other taste enhancing items including monosodium glutamate (MSG). MSG is known for its savoury taste, which can also enhance the saltiness in the foods (Zanfirescu et al., 2019; Onuma et al., 2018; Hayabuchi et al., 2020). However, some foods (e.g. meats, mushroom) also naturally produce savoury taste due to the presence of the amino aide, glutamate (Maluly et al., 2017). Regarding the findings in relation to neutral-tasting foods, the high consumption was negatively associated with the intake of energy and most of the nutrients. This could be due to the relatively low taste intensity in the foods classified as neutral (Nguyen et al., 2021), which failed to demonstrate taste-nutrient relationships.

The UK dietary guidelines recommend at least five portions of fruit and vegetables a day (Public Health England, 2018). Adolescents' intake of fruit and vegetables has been reported to be low (Beal et al., 2019). The Health Survey for England (HSE) found that young adults (aged 16 to 24 years) did not meet the recommendation of fruit and vegetable portion size; and that <18% of UK children aged 5 –15 years ate five portions of fruits and vegetables (NHS Digital, 2022). Our findings showed that a higher intake of fruit was associated with the higher intake from sweet-tasting foods, while a higher vegetable intake was observed with higher intakes of bitter-, savoury- and neutral-tasting foods;

although, the guideline of five-a-day was typically not met (about 3 portions of fruits and vegetables were consumed/day). The current results indicated a positive association between vegetable consumption and bitter taste. In our earlier systematic review, we reported findings from genotype and phenotype studies on adolescents linking to bitter taste. Perceived bitterness was negatively associated with the preference of foods with bitter taste including Brassica vegetables (Bawajeeh et al., 2020). Likewise lower intakes of coffee (Cornelis et al., 2017; Puputti et al., 2019), beer and Brussel sprouts have been observed in highly bitter sensitive adults compared with those who are less sensitive (Cornelis et al., 2017); yet, this is not always true in adults due to cognitive control. However, adolescents were found to eat vegetables as part of composite foods, and rarely consumed vegetables on their own (Chawner et al., 2021; O'Brien et al., 2003). There may be a role of saltiness (Keast et al., 2001; Keast and Breslin, 2003; Sharafi et al., 2013), savoury/umami taste (Kim et al., 2015; Keast and Breslin, 2003), and fats (Homma et al., 2012; Mattes, 2007) in meals which suppress the bitterness. This may explain our results of higher consumption of meats, and vegetables among adolescents in association with the higher intake of bitter-and savoury-tasting foods.

To our knowledge, this is the first study to assess adolescents' dietary intakes from a taste perspective using nationally representative food intake data. While our approach of using regular consumers was subjective, this is true for all phenotype methods used in sensory studies. Moreover, there is no universally agreed or standard method to assess taste patterns, but we still found agreement with other studies. Additionally, the significant associations between taste (e.g. higher intake of sweet, salty or savoury tasting foods) and nutrient intake (e.g. intake of sugar, sodium or protein, respectively) that we observed agrees with previous work using trained panellists (Lease et al., 2016; Martin et al., 2014; van Dongen et al., 2012b). However, some limitations are worth mentioning. The first limitation is related to the use of NDNS, which is a cross-sectional survey that involves a high level of participant burden and potentially leads to overrepresentation of health conscious individuals taking part. This could lead to the sample obtained being non-representative of the general population. Weighting to take into account this non-representativeness has been used in the analysis. Although we applied the sampling weight in the analysis for a more representative set of results, it may not be suitable to generalize the findings.

Another limitation is related to the dietary records and food diary method that was used for collecting the dietary data, which is subject to potential recording bias, omission of foods and misreporting of some foods or portion sizes. Also altering dietary behaviours is a potential problem as a result of a lack of motivation, the burden of recording or to demonstrate good dietary habits. Moreover, under-reporting is expected with dietary measurements, especially with multiple recording days (Whybrow et al., 2020), which potentially has an impact on estimations of food and nutrient intakes (Jones et al., 2021a). Additionally, under-reporting some foods could have affected the taste classification of foods, proportion of foods in taste groups and taste contribution to energy intake and its influence on dietary intake in general. Likewise, meal timings applied in the study may not be suitable for adolescents, where adolescents' eating habits usually do not have a regular pattern (i.e. irregular meal timings and meal skipping). This may affect the findings about the tastes’ contributions to food intakes during eating occasions. Another limitation is our use of adults to characterize food tastes which was due to the COVID 19 situation and ethical constraints which limited us approaching adolescents. It is worth mentioning that responses to the online taste survey was dominated by females, which may not be truly representative of the general population and could have biased the obtained results. Whilst we have no definite explanation for this preponderance of female respondents, it may be due to females' interest towards foods and their eager to participate in such surveys compared to males. However, authors would like to clarify that, unlike the perception and assessment of foods' taste intensity that may differ among individuals of different age and gender, taste classification in the current study was based on defining a predominate taste of foods. Thus, variations on taste perceptions between adults (males and/or females) and adolescents are likely to be in terms of taste intensity level and concentrations, rather than defining the taste (Petty et al., 2020; De Graaf and Zandstra, 1999). However, future studies including more representative sample of adults and adolescents from both genders are needed, which could produce better taste classifications of the consumed foods. Although we considered including varieties of representative foods to be matched to the entire foods in the NDNS, some variations in taste and/or intensity may differ due to the use of different ingredients, herbs, or spices. This leads to another limitation that our approach of classifying the main taste for each food may not take the taste profile of food and tastes interactions into consideration. We only used one year of adolescents' data from the NDNS, thus, future work may use additional years of adolescents' data from the UK national survey, which would also allow a wider range of foods to be classified by taste.

The current work characterized adolescents' food intake by taste as a first step in understanding the effect of taste on this age group's dietary intake. However, since foods are often eaten in combination involving different tastes, it would be more valuable to study the role of taste on their dietary patterns by exploring their dietary taste patterns. Also, while taste may have an influence on the diet quality, a limited number of studies have explored that and the studies are limited to specific tastes (Ferraris et al., 2021; Sharafi et al., 2018). Furthermore, others only reported that participants who rated taste as a very important factor had poor diet quality, although they did not study the association between dietary taste and diet quality directly (Kourouniotis et al., 2016; Aggarwal et al., 2016). In a recent study, authors have reported poor diet quality associated with sweet foods other than fruit (e.g. ice cream, biscuits, chocolate, sweetened beverages) and salty foods (e.g. crisps, chips, fast foods) (Wanich et al., 2020). In contrast, a study by Cox and colleagues reported good diet quality associated with sweet and bitter foods but not salty foods (Cox et al., 2018). However, sweet foods in the latter were generally healthy core foods (e.g. fruit, vegetables, and dairy). Similar work concerning dietary taste patterns and diet quality needs exploring in adolescents. This could help in understanding adolescents' dietary choices and behaviours in relation to their taste preferences, which could aid in designing interventions or educational programs tailoring adolescents' food choices by their taste preferences. Also, findings could help food producers (e.g. school canteens, caregivers, food industries) in promoting more varieties of foods and tastes.

4.5 Conclusion

Our findings have characterized diets of UK adolescents by taste, a key factor influencing food choice. We found that energy intake was dominated by sweet tasting and neutral foods. Protein and vegetable intakes were linked to an increased intake of savoury-tasting foods. Individuals in this cohort had limited intakes of foods with a sour taste. Adolescents' dietary intakes may be driven by their taste preferences which may, in turn, be important determinants of later health as they grow into adulthood.

4.6 References for Chapter 4

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Chapter 5 Association between UK adolescents' dietary taste patterns and daily energy intake, BMI, and diet quality

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Abstract

Despite increasing evidence that taste is critical in determining adolescents' dietary intake, no study has explored adolescents' dietary patterns from a taste perspective. This study generated UK adolescents' taste patterns using data for 284 adolescents (aged 10–19 years) from the National Diet and Nutrition Survey (NDNS) (2016–2017), and examined the associations between taste patterns and daily energy intake, Body Mass Index (BMI), and diet quality using multivariable regression analysis. The dietary taste patterns were generated using Principal Component Analysis (PCA). Adolescents' diet quality was assessed using the Diet Quality Index for Adolescents (DQI-A). The PCA identified five dietary taste patterns: salad-bar, hot-food, takeaway-meal, sweet-snack, and beverages. All taste patterns except hot-food had significantly positive association with energy intake, with highest impact seen in the takeaway-meal and sweet-snack patterns, where each unit increase resulted in an additional 168 kcal/d (95% CI 139, 197; $P < 0.01$) and 89 kcal/d (95% CI 47, 130: $P < 0.01$), respectively. The takeaway-meal taste pattern was, however, inversely associated with BMI – 0.8 kg/m2 (95% CI – 1.4, – 0.1; $P = 0.02$). Sweet-snack taste pattern was associated with a poor diet quality, while a higher intake of hot-food taste pattern was associated with a better diet quality 2.0% (95% CI 1.0, 3.1; $P < 0.01$). The taste patterns identified reflect adolescents' eating habits. Taste patterns relatively low in sugar, salt, and fat showed better diet quality compared with those high in sugar and fat. Findings could improve adolescents' food choices, taking their taste preferences into consideration.

Keywords: taste, dietary taste, NDNS, adolescent, taste perception, dietary pattern

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5.1 Introduction

Adolescence is considered an important period in the human lifecycle (Viner et al., 2015), representing the transition from childhood to adulthood, with various changes in physiology, lifestyle, and behaviour, including those related to dietary intake (Winpenny et al., 2018). This development is associated with a critical need for good nutrition and increased levels of energy and nutrient intake (World Health Organization, 2022). However, given the accessibility of highly processed and calorie-dense foods (Liem and Russell, 2019; Crino et al., 2015), adolescents' dietary patterns have been reported to be high in sugar, salt and fat

(Moreno et al., 2010), substances widely used in the food industry to enhance the tastiness of foods (Crino et al., 2015).

Individuals differ in their taste perceptions and preferences, and these differences influence their dietary intake. Therefore, the tastes of various foods are among the main determinants of food choices and intake (Boesveldt et al., 2018). Individuals’ taste perceptions and preferences and food palatability, that is, the hedonic appraisal of the sensory characteristics of the food, such as taste (Yeomans, 1998), may lead to overconsumption and, therefore, overweight and obesity (Liem and Russell, 2019; Sobek et al., 2020). The incidence of overweight and obesity has been found to rise during the transition from adolescence to adulthood (Johnson et al., 2015). According to the Health Survey for England (2019), the prevalence of overweight/obesity increases over time in both genders. The rate increases from around 20% in children under 10 years old to 35% to 40% in children between the ages of 11 and 15, and it continues to increase to 55% to 70% between the mid-twenties and early forties (NHS Digital, 2020).

Because dietary behaviour during adolescence can be an indicator of later health consequences (Viner et al., 2015), establishing healthy dietary patterns during this age period is important (Mikkilä et al., 2005). A number of studies concerning adolescents’ dietary patterns have been performed based on the commonly understood food groups (Martínez Arroyo et al., 2020; Richter et al., 2012), establishing knowledge about adolescents’ eating behaviours from a food-and-nutrition perspective. However, despite the increasing evidence that taste is a critical factor in determining adolescents’ dietary intake (Fleming et al., 2020), explorations of adolescents’ dietary patterns from a taste perspective remain rare, and such studies may offer a better understanding of the role of taste in dietary intake (van Langeveld et al., 2018). Unhealthy foods have been reported to have acceptable taste and are considered more palatable than healthy foods (e.g. vegetables) (Zorbas et al., 2018). A savoury (umami) taste (Nasser, 2001), sweetness, saltiness and fat content in foods (Chamoun et al., 2018) contribute to the taste of foods and promote higher food intake (Chamoun et al., 2018; Nasser, 2001). Thus, taste, as a contributor to food palatability, could affect the quality of one’s diet (Bawajeeh et al., 2022).

The developmental period of adolescence affects food choices and diet quality (Story et al., 2002), with many adolescents not meeting dietary guidelines

(Smithers et al., 2000; Story et al., 2002; Lytle et al., 2000; Lien et al., 2001). Thus, typically, diet quality declines throughout adolescence (Demory-Luce et al., 2004). Diet quality (DQ) is a measure of eating patterns in terms of the quality and variety of one's diet, as well as adherence to dietary recommendations (Marshall et al., 2014). The quality of an individual's dietary intake can be measured using a range of methods (Wirt and Collins, 2009) that provide links with nutrition-related health (Dalwood et al., 2020; Marshall et al., 2014; Wirt and Collins, 2009) and identify the barriers to adhering to dietary guidelines (de Mestral et al., 2020; Gu and Tucker, 2017; Haack and Byker, 2014). The taste of foods has been reported to be one such barrier (de Mestral et al., 2020; Raghunathan et al., 2006; Zorbas et al., 2018). A study based on the National Health and Nutrition Examination Survey (NHANES) revealed that 77% of adults rated taste as "very important" in buying foods, which was negatively associated with the of their diet (Aggarwal et al., 2016). A study on adolescents using data from the UK National Diet and Nutrition Survey (NDNS) 2008–2011 reported that 40% of adolescents' energy intake was obtained from calorie-dense foods (e.g. soft drinks, crisps and chocolate) (Toumpakari et al., 2016). In our recent work, we characterised UK adolescents' diet in terms of taste and observed that sweet-tasting foods comprised most of their diet. Moreover, the foods that most contributed to sweet and salty tastes were calorie-dense (Bawajeeh et al., 2022), which may explain the poor diet quality of UK adolescents (Taher et al., 2019) as compared to other European adolescents (Ortega et al., 2014; Vyncke et al., 2013).

Because the taste of foods determines adolescents' intake (Heary et al., 2010), it is concerning that only a minority of young people's diets meet the recommended dietary guidelines (Chawner et al., 2021; NHS Digital, 2022; Banfield et al., 2016). Because foods are often eaten in combination, studying dietary patterns — rather than examining food groups or nutrients — may be a better approach to understanding individuals' eating habits and preferences, as well as the relationships between diet, taste and health (Northstone et al., 2014; van Langeveld et al., 2018), and it may help to explain individuals' lack of adherence to dietary guidelines and recommendations (Cox et al., 2018a). Thus, the objective of this study was to generate the dietary taste patterns of UK adolescents and explore any associations between taste patterns and energy intake, Body Mass Index (BMI), and diet quality.

5.2 Methods

5.2.1 The National Diet and Nutrition Survey (NDNS)

The NDNS is an annual cross-sectional survey assessing dietary intake and nutritional status of a representative sample, aged 1.5+ years, from all four countries of the UK. The sample is randomly recruited based on postcode. The NDNS provides data on the dietary intake of the UK population. The survey design and data collection methods are described in detail elsewhere (Public Health England, 2019). For the present study, we used the NDNS rolling programme year 9, with data collection conducted from April 2016 through August 2017. We selected data from adolescents aged 10 –19 years, which is the definition of adolescence used by the World Health Organisation (WHO) (World Health Organization, 2022).

5.2.1.1 **Dietary data**

In the NDNS, dietary data were collected based on 4-day dietary records. Participants were asked to keep records of everything they ate or drank for four consecutive days. Foods were coded and categorised into main and sub food groups. Parents and carers of adolescents aged ≤ 12 years were asked to help their children to complete the diaries, while those who were ≥ 13 years old completed their diaries themselves. For this paper, the detailed food record dataset “Food Level Dietary Data” was used to create a food list for taste allocation purposes; this process is described elsewhere (Bawajeeh et al., 2022).

5.2.2 Taste patterns

Each food reported in the food diaries and consumed by adolescents from the NDNS year 9 was allocated to a specific taste; the food taste classification is described in detail elsewhere (Bawajeeh et al., 2022). Briefly, a reference list of foods was identified from the adolescents’ food records in the NDNS and was allocated to a particular taste recognised by regular consumers using an online survey. This was followed by Hierarchical Cluster Analysis (HCA) which identified six taste clusters (sweet, salty, sour, bitter, savoury, and neutral).

To identify taste patterns, we grouped foods within each taste cluster into different food groups. For example, for sweet-tasting foods, we created separate food groups including sweet beverages, fruit, cakes and pastries, cereals, vegetables and beans, milk and cream, dairy desserts, sauces and sweet snacks. The same was done for each remaining taste cluster, resulting in a total of 32 food groups under the six primary taste clusters (Appendix C.1). Principal Components Analysis (PCA) with orthogonal rotation was applied to the average weight per day from the 32 food groups (Newby and Tucker, 2004). The number of retained components was determined by eigenvalues (> 1.0), scree plots and component interpretability. Within each component, food groups with loading scores ≥ 0.3 were considered to contribute significantly to the taste pattern (de Souza et al., 2016). Kaiser-Meyer-Olkin (KMO) and Bartlett's tests were checked to indicate whether applying PCA was appropriate (Santos et al., 2019).

5.2.3 Diet quality

Diet quality was measured using the Diet Quality Index for Adolescents (DQI-A). The DQI-A is a validated tool for assessing adolescents' degree of adherence to food-based dietary guidelines (FBDG) based on three main components: the diet quality component (DQc), the diet diversity component (DDc), and the diet equilibrium component (DEc), which is, in turn, comprised of two sub-components: diet adequacy (DA) and diet excess (DEx). The DQI-A score is calculated as a percentage; each of the DDc and DEc ranges from 0% to 100%, while the range of the DQc is –100% to 100%. Thus, to compute the DQI-A, the mean percentage of those three components is calculated and the results in a DQI-A score range from –33% to 100% (Vyncke et al., 2013).

In the current paper, we calculated the DQI-A according to a previous work done on UK adolescents that relied on NDNS data (Taher et al., 2019) and used the recently published UK food-based dietary guidelines (FBDG) for foods included in the Eatwell Guide (Public Health England, 2018) and the recommended food portion sizes from the British Dietetic Association (British Dietetic Association, 2021). Both food groups and portion sizes used in the current work were based on the originally validated tool from the Flemish FBDG (Vyncke et al., 2013).

5.2.3.1 Diet Quality component (DQc)

The DQc assesses food quality to determine whether adolescents had optimal consumption within food groups. To calculate the DQ scores, the daily amounts of foods consumed from each food group were multiplied by different factors: "1" for "preference group" (e.g. cereal/brown bread, fresh fruit, fish), "0" for "intermediate group" (e.g. white bread, minced meat) and "-1" for "low-nutrient, energy-dense group" (e.g. soft drinks, sweet snacks, chicken nuggets). Appendix

C.2, presents the classification by “preference,” “intermediate,” and “low-nutrient or energy-dense” food groups. Then, the final score of this component is calculated using the equation $\sum(DQ)/\sum m \times 100\%$, where “m” is the amount of food consumed (Vyncke et al., 2013b).

5.2.3.2 **Diet Diversity component (DDc)**

The DDc assesses the variation in an adolescent diet on a scale of 0 to 9 points, where consumption of at least one serving from the nine recommended food groups adds a point. Then, the final score is calculated using the equation $\sum(DD)/9 \times 100\%$ (Vyncke et al., 2013b). The serving sizes of the nine recommended food groups were as follows: (1) water, 200 ml; (2) bread and cereal, 35 g; (3) potatoes and grains, 175 g; (4) vegetables, 80 g; (5) fruit, 80 g; (6) milk products, 200 g; (7) cheese, 30 g; (8) meat, fish, and substitutes, 100 g; and (9) fat and oils, 4g.

5.2.3.3 **Diet Equilibrium component (DEc)**

The DEc assesses an adolescent’s adherence to the minimum and maximum intakes based on the DEc sub-components: 1) diet adequacy (DA), calculated as percentage of the minimum recommended intake from the nine food groups, shortened to 1; and 2) diet excess (DEx), calculated as percentage of intake exceeding the upper limit of the recommendations of eleven food groups (the previous nine recommended and two non-recommended, to include snacks and sugary drinks), converted to “1” if greater than 1 and converted to “0” if below 0. Then, the diet equilibrium component (DEc) is calculated by subtracting DEx from DA, and the final DEc score is divided by 11, which is the total number of food groups, and multiplied by 100 ($\sum (DE) / 11 \times 100\%$) (Vyncke et al., 2013).

5.2.4 Data analysis

Descriptive statistics were used to describe the study population age, BMI, and DQI score. Multivariable regression analysis was used to explore relationships between taste patterns and daily energy intake, BMI, and dietary quality score. All taste patterns (being orthogonal) were entered into the model together. The results for the regression analysis are presented as unadjusted values and as adjusted values. The minimal sufficient adjustment set of confounders was age, gender, ethnicity and income, as determined by Directed Acyclic Graph (DAG) using the online DAGitty tool (http://www.dagitty.net) (VanderWeele et al., 2008).

Daily energy intake misreporting was calculated by determining the basal metabolic rate (BMR) according to participants' body weights and using the standard equations of Schofield Cut-off points based on multiples of BMR with minimum (1.39 and 1.30) and maximum (2.24 and 2.10) for both genders, respectively, to identify under-reporters and over-reporters (Albar et al., 2014).

Weighting to adjust for non-response in the NDNS was applied in all analyses using weights provided for the NDNS (Public Health England, 2019). Statistical significance was assigned to a *P*-value < 0.05 for all tests. The statistical analysis was performed using STATA statistical software version 16.1.

5.3 Results

5.3.1 NDNS Sample characteristics

As shows in Table 5-1, a total of 284 adolescents (49% males and 51% females) were included in the NDNS rolling programme, year 9 (2016–2017), with a mean age of 13.9 years. The mean body mass index (BMI) was 21.3 kg/m2; BMI measurements were available for 268 participants. Adolescents completed at least three food diaries (98% completed 4 records; 2% completed 3 records). The mean daily energy intake was 1626 kcal/day and the overall DQI-A mean score was 19.4% (95% CI 17.4, 21.4) (the results of the diet quality components can be seen in Appendix C.3).

Table 5-1. Characteristics of adolescents from the National Diet and Nutrition Survey (NDNS) rolling programme, year 9 (2016–2017)

	Total sample (n = 284)	**Boys (n = 140)**	**Girls (n = 144)**
Age (years) (mean, 95%CI)	14 (13.5, 14.4)	14 (13, 14.3)	14 (13.5, 15)
BMI (kg/m^2) (mean, 95%CI) *	21.3 (20.5, 22.1)	20.8 (19.5, 22.1)	21.8 (20.7, 22.8)
Ethnicity (n, %)			
White	238 (78%)	119 (80%)	119 (76%)
Mixed ethnic group	7 (2%)	4 (4%)	3(1%)
Black/ Black British	7 (4%)	1(1%)	6 (7%)
Asian/ Asian British	29 (14%)	14 (14%)	15 (14%)
Any other group	3 (2%)	2 (1%)	1 (2%)
Income (n, %) ^			
Under £ 5,000	1 (0.4%)	1 (1%)	0
£ 5,000 - £ 9,999	9 (4%)	5 (4%)	4 (3%)
£ 10,000 - £ 14,999	16 (6%)	8 (6%)	8 (6%)
£ 15,000 - £ 19,999	41 (16%)	18 (15%)	23 (18%)

£ 20,000 - £ 24,999	17 (7%)	8 (6%)	9 (7%)
£ 25,000 - £ 29,999	11 (4%)	6 (5%)	5 (4%)
£ 30,000 - £ 34,999	21 (8%)	7 (6%)	14 (11%)
£ 35,000 - £ 39,999	18 (7%)	9 (7%)	9 (7%)
£ 40,000 - £ 44,999	8 (3%)	6 (5%)	2 (2%)
£ 45,000 - £ 49,999	30 (12%)	13 (10%)	17 (13%)
£ 50,000 - £ 74,999	39 (15%)	22 (18%)	17 (13%)
£ 75,000 - £ 99,999	20 (8%)	14 (11%)	6 (5%)
£ 100,000 or more	21 (8%)	7 (6%)	14 (11%)
Energy (kcal/d) (mean, 95%CI)	1626 (1565, 1688)	1729 (1651, 1808)	1523 (1427, 1616)
Energy intake misreporting (n, %)			
Under-reporting	225 (79%)	113 (81%)	112 (78%)
Plausible	57 (20%)	27 (19%)	30 (21%)
Over-reporting	2 (1%)	0 (0%)	2 (1%)
DQI-A%	19.4 (17.4, 21.4)	19.5 (16.6, 22.4)	19.3 (16.4, 22.1)

[*] 16 participants had missing data; ^32 participants had missing data

5.3.2 Taste patterns

The PCA identified five orthogonal taste patterns with eigenvalues of 2.64, 1.99, 1.88, 1.76 and 1.65, which collectively explained 31% of the variance. Results of the Kaiser-Meyer-Olkin (KMO) and the Bartlett tests were 0.56 and P = 0.04, respectively, indicating that the correlations among the taste clusters were sufficient and appropriate for applying PCA. The taste patterns were labelled as follows: salad-bar, consisting of a combination of savoury-sour-salty-bitter foods and including leafy vegetables, cheese, savoury pastries, nuts, salad dressing and pickles; hot-food, consisting mainly of neutral-tasting foods and including bread, plain rice and pasta, vegetables (e.g. boiled and steamed cauliflower, stir fry vegetables, potatoes and vegetables soup), beans, eggs, white fish, oil/butter and white/cheese sauces; takeaway-meal, consisting of a combination of savoury-sweet items and including takeaway foods and sweetened beverages; sweet-snack, consisting mainly of sweet-tasting foods and including fruit, chocolates, candies, cakes, sweet pastries and dairy desserts; and beverages taste pattern, consisting of a combination of sweet-bitter items and including coffee, tea, alcoholic beverages, milk and sugar. Table (Appendix C.4) presents component loadings for each taste pattern, highlighting the factor loading ≥ 0.3.

Energy intake according to the quintiles of taste patterns showed overall significant positive trends. The takeaway meals taste pattern was associated with the highest energy intake compared with the other taste patterns, with the highest difference increase by 37% from the lowest (Q1) to the highest (Q5) quintiles.

However, BMI showed a significant negative trend only with the takeaway meals taste pattern with 3% difference decrease from the lowest to the highest quintiles (*P* for trend < 0.01). Diet quality score showed strong positive significant linear trends with the hot-food taste pattern and takeaway meals taste pattern; a weaker positive significant linear trend with the sweet-bitter beverages taste pattern; and a negative significant linear trend with the sweet snacks taste pattern (Appendix C.5).

5.3.3 Associations between daily energy intake, BMI and diet quality and the taste patterns

Table 5-2 illustrates results from the multiple regression analysis. There were significant positive associations between daily energy intake and all taste patterns except the neutral hot-food taste pattern. The largest effect on the energy intake was associated with the savoury-sweet takeaway-meals taste pattern. For each additional unit in the takeaway-meal pattern, energy intake was 168 kcal/day (95% CI 139, 197; *P* < 0.01) higher. However, the takeaway-meal taste pattern was associated with lower BMI showing that, for each additional unit in the pattern score, BMI was lower by 0.8 kg/m2 (95% CI 1.4, 0.1; *P* = 0.02). Diet quality was positively associated with the hot-food taste pattern, whereas the sweet-snack taste pattern was inversely associated with diet quality.

Table 5-2. Association between energy intake, BMI and diet quality score and the taste patterns

	Energy intake (kcal/d)			
	Unadjusted model		Adjusted model	
Taste patterns	**Coeff. (95%CI)***	***P*- value**	**Coeff. (95%CI)***	***P*- value**
Salad-bar Savoury-sour-salty-bitter	53 (21, 84)	<0.01	45 (16, 73)	<0.01
Hot-food Neutral	11 (-25, 49)	0.054	18 (-13, 49)	0.25
Takeaway-meal Savoury-sweet	130 (99, 161)	<0.01	168 (139, 197)	<0.01
Sweet-snack Sweet	95 (60, 132)	<0.01	116 (78, 154)	<0.01
Beverages Sweet-bitter	60 (32, 89)	<0.01	58 (20, 96)	<0.01
	BMI (kg/m^2)			
	Unadjusted model		**Adjusted model**	
	Coeff. (95%CI)*	***P*- value**	**Coeff. (95%CI)***	***P*- value**
Salad-bar Savoury-sour-salty-bitter	0.4 (-0.3, 1.0)	0.32	0.3 (-0.2, 0.7)	0.26

Hot-food Neutral	-0.04 (-0.5, 0.4)	0.85	0.1 (-0.3, 0.5)	0.69
Takeaway-meal Savoury-sweet	-1.3 (-1.9, -0.6)	<0.01	-0.8 (-1.4, -0.1)	0.02
Sweet-snack Sweet	0.3 (-0.1, 0.7)	0.16	0.2 (-0.2, 0.7)	0.38
Beverages Sweet-bitter	-0.2 (-0.6, 0.1)	0.18	-0.3 (-0.8, 0.1)	0.15
	Diet quality (%)			
	Unadjusted model		**Adjusted model**	
	Coeff. (95%CI) *	***P*- value**	**Coeff. (95%CI)** *	***P*- value**
Salad-bar Savoury-sour-salty-bitter	0.1 (-0.6, 1.0)	0.83	0.2 (-0.5, 1.1)	0.56
Hot-food Neutral	2.2 (1.1, 3.4)	<0.01	2.0 (1.0, 3.1)	<0.01
Takeaway-meal Savoury-sweet	2.0 (1.0, 3.2)	<0.01	1.0 (-0.3, 2.1)	0.16
Sweet-snack Sweet	-4.5 (-5.7, -3.2)	<0.01	-4.4 (-5.6, -3.1)	<0.01
Beverages Sweet-bitter	1.0 (-0.4, 2.0)	0.18	1.0 (-0.6, 2.0)	0.32

* Change in energy intake, BMI and diet quality
Models were adjusted for age, gender, ethnicity, and income

5.4 Discussion

We identified five dietary taste patterns among UK adolescents: salad-bar, which consists of a combination of savoury-sour-salty-bitter foods; hot-food, consisting of mainly neutral-tasting foods; takeaway meals, which consists of a combination of savoury-sweet foods and beverages; sweet snacks, consisting of mainly sweet-tasting snacks; and beverages, consisting of a combination of sweet-bitter items. We studied the association of those taste patterns with daily energy intake, BMI and diet quality. Findings indicated that, while energy intake was positively associated with all taste patterns, the largest effect on energy intake was associated with the takeaway-meals taste pattern, despite it being inversely associated with BMI in this analysis of cross-sectional data. Positive diet quality was associated with the hot-food pattern and it was negative with the sweet-snack taste pattern.

Using PCA, we identified correlations of taste within our dataset and distinctive taste patterns (Newby and Tucker, 2004) that offer insight into taste interactions (Keast and Breslin, 2003; Wilkie and Capaldi Phillips, 2014). One of the common taste interactions in young individuals is related to the sweet and bitter tastes (Wilkie and Capaldi Phillips, 2014), in that sweetness has the effect of suppressing unpleasant bitterness. This may explain the currently identified sweet-bitter taste pattern (e.g. coffee/tea with milk and sugar), compared to adults where bitter taste typically stands by itself in their dietary taste patterns (van Langeveld et al., 2018). It was similar for the salad-bar taste pattern, while bitter and sour are often unpleasant tastes when consumed by themselves (Nasser, 2001), savoury and salty tastes were found to mask this unpleasantness and increase food palatability (Mouritsen, 2012). It could also be that sour-tasting foods included in this pattern (e.g. pickles and salad dressing) and cheese, which was characterised as salty, are used as toppings to leafy vegetable salads or eaten with savoury pastries, which in this data were classified as bitter and savoury foods. The possible explanation for the identified savoury-sweet taste pattern is that takeaway/fast foods associated with this taste pattern are often high in sodium. Sodium content in these foods was found to be linked to the sweetened beverages for children and adolescents (He et al., 2008; Grimes et al., 2013), probably as a reaction to sodium-induced thirst. It may also be due to the accessibility, availability and sweetness preferences of these beverages.

A recent review reported that sweet and salty tasting foods are major contributors to overall energy intake (McCrickerd and Forde, 2016). In an Australian study, significant positive correlations were seen between sweet and salty tastes and energy intakes among children (sweet = 0.635 & salty = 0.749; $P < 0.01$) and adults (sweet = 0.517 & salty = 0.623; $P < 0.01$) (Cox et al., 2018b). This supports the strong significant linear trends we observed in this study between energy intake and salty and sweet taste patterns. The highest increase in energy intake was associated with the savoury-sweet takeaway meals and sweet snacks, with the highest contributions coming from takeaway foods, sweetened beverages and sweet snacks that typically have a high content of fats and sugars (Cox et al., 2018b).

Some taste profiles contribute to the increased palatability of foods (McCrickerd and Forde, 2016; Sørensen et al., 2003), which could promote overconsumption (Mela, 2006; Yeomans, 2010; McCrickerd and Forde, 2016; Sørensen et al., 2003), cause excess energy intake, and increase the likelihood of obesity. Although the current work found indications of a significant increase in the energy intake associated with the savoury-sweet takeaway meals taste pattern, this pattern was negatively associated with BMI. This may be related to the suggestion that sweetness (Lavin et al., 2002a; Lavin et al., 2002b) and saltiness (Bolhuis et al., 2011) have a role in satiety and in regulating intake by decreasing the desire to eat . Additionally, the potential misreporting of foods could result in an energy under-reporting (Forrestal, 2011), which could affect the relationship between dietary taste patterns and BMI. However, in the present study, the proportion of non-obese adolescents (63%) was higher than of obese individuals (37%), and those classified as non-obese had the higher frequency of takeaway/meal-out foods, which may explain the negative association. This may suggest that non-obese adolescents feel greater liberty to consume fast food and that they experience less stigma when they do, which can lead to continuous health concerns during adulthood.

Adolescents' mean dietary quality score in the present study (19.4%) was comparable to a recently published score of 20.4% in UK adolescents (Taher et al., 2019), but it was poor compared to adolescents in mainland Europe (Ortega et al., 2014; Vyncke et al., 2013). Taste as a contributor to food palatability plays an important role in individuals' food liking and intake; consequently, it was suggested that it affects the quality of the diet. However, the influence of taste on diet quality was found to depend on the type of food and its nutrient content (Cox et al., 2018a; Wanich et al., 2020). To illustrate this relationship, a high-score diet quality suggests an optimal dietary intake and better adherence to dietary guidelines (Wirt and Collins, 2009); thus, a diet high in nutrient-dense foods and low in calorie-dense foods is believed to be of good quality. The taste-nutrient relationships have been studied and links between sweet taste and sugar, salty taste and sodium and savoury (umami) taste and protein have been suggested (Teo et al., 2021). Hence, the role of taste in diet quality may be suggested by the correlations between taste and nutrients in the foods.

In the current work, the neutral taste pattern 'hot-food' was significantly associated with good diet quality. This might be because foods associated with this taste pattern were vegetables, beans and bread, which are unprocessed or minimally processed (Teo et al., 2021). Both the savoury-sweet and sweet-bitter foods showed a significant positive linear trend in association with diet quality score. This may be because of the protein content in the savoury foods and the milk as a sweet item; however, none of the taste patterns were significant in the adjusted model. In contrast, the negative association of the sweet taste pattern with diet quality is due to the type of foods that are high in sugar (cakes, pastries, chocolate, and candies). Our finding that poor diet quality is linked to sweet taste pattern is consistent with one study of Australian young adults (Wanich et al., 2020a), although diet quality was positively associated with a sweet taste in another Australian study (Cox et al., 2018a). In that study, healthy foods (e.g. fruit, vegetables, grains and dairy products) were the greater contributors to the sweet taste compared with calorie-dense foods (e.g. sweet snacks and sugar-sweetened beverages). Although, in our study, fruit is loaded to the sweet taste pattern, we have previously found that calorie-dense foods (e.g. chocolates, biscuits and cakes) were the greater contributors to the sweet taste in our current sample diet (Bawajeeh et al., 2022).

There were a number of strengths to this study. The use of the national survey is a strength of this work in exploring the effect of taste using adolescents' food records, as this was noted to be limited in the literature (Cox et al., 2018a). Also, our approach of studying the role of taste in terms of dietary taste patterns—rather than studying the effect of each taste separately—provides an overview of the adolescents' dietary taste intake and assesses their diet pattern from a taste perspective, which may offer more insight than assessing food choices in relation to taste preference or liking. However, the nature of the cross-sectional data and the potential misreporting and underreporting of foods (Albar et al., 2014) are limitations of this study that could influence the identification of dietary taste patterns, measured dietary quality score, daily energy intake, and BMI, and that could, consequently, affect the association. Another limitation is that sorting foods into food groups could be challenging (Chawner et al., 2021) when some foods may fit into one group or another. This could also affect the generated taste patterns.

The findings from this work suggest that adolescents' dietary and energy intakes could be driven by their taste preferences, which may affect the quality of their diet and make them vulnerable to health risks in the future if unhealthy eating behaviours continue. Food-Based Dietary Guidelines (FBDG) worldwide recommend limiting the consumption of sugar, salt, and fat and encourage consuming fruits and vegetables (Herforth et al., 2019). While individuals may find it challenging to follow the dietary recommendations (Cox et al., 2018a) when it comes to taste and food palatability, studies have suggested that taste perception and preferences can be improved through learning and exposure (Wanich et al., 2020; Cox et al., 2016; Cox et al., 2018a) and that taste preference could be achieved by substituting unhealthy food choices with healthy options (Cox et al., 2018b). Thus, understanding adolescents' dietary taste patterns may help design programmes and interventions to improve their taste preferences and help them adopt healthier food choices that would satisfy their taste preference levels. Additionally, these findings can help people in the industries and in school canteens in producing and introducing higher quality food choices that meet individuals' taste preferences.

5.5 Conclusions

Studying adolescents' dietary taste patterns could reflect dietary behaviours and food-taste preferences of this age group. Better diet quality was linked to the neutral dietary taste pattern that is low in calorie-dense foods compared to the sweet taste pattern, which had bad diet quality. Findings from this work could help improve adolescents' food intake and dietary quality while still considering taste preferences.

5.6 References for Chapter 5

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Chapter 6 Development of an Arabic Food Composition Database for use in an Arabic online dietary assessment tool (myfood24)

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Abstract:

A comprehensive food composition database (FCDB) is essential for assessing dietary intake of nutrients. However, currently available food composition data for Gulf Cooperation Council countries (GCC) is limited. The aim was to develop an Arabic FCDB of foods commonly available in the GCC (initial focus on Saudi Arabia and Kuwait), which will be integrated into an Arabic version of an online dietary assessment tool, myfood24. The Arabic FCDB was built using a standardised approach identifying currently available foods from existing food composition tables (FCTs), research articles and back-of-pack (BOP) nutrient labels on food products, with additional generic food items from the UK Composition of Foods Integrated Database (CoFID). The development of the FCDB used a 6-step approach: food identification, cleaning, mapping, translation, allocating portion sizes and quality checking. The database includes a total of 2016 food items, 30% of which have standard portion size images in addition to other options for portion size estimation. The database and myfood24 have been translated into Arabic to be suitable for native Arabic users. These tools will help to assess dietary intake for 51 million people in the GCC. Future work will cover more foods from other Middle Eastern countries to serve over 400 million Arabic speakers in the region.

Keywords: food composition table, food composition database, myfood24, composite food, Middle East, Arabic, dietary assessment tool

6.1 Introduction

Accurate food composition databases support the quantification of nutrients consumed to evaluate nutritional intakes (Foster et al., 2014). Food Composition Tables (FCTs) for Middle Eastern foods are limited in terms of foods and nutrients (Al-Faris, 2017; Musayqar, 2006; Sawaya et al., 1998; Pellet and Shadarevian, 1970). Researchers in Gulf Cooperation Council (GCC) countries have used food composition databases (FCDB) from non-representative populations/countries including the USDA (Alkazemi and Saleh, 2019; Al-Daghri et al., 2013), but there is a need to develop a representative food database for these countries. An FCDB should include a wide range of local and commonly consumed foods with a comprehensive nutrient profile (Greenfield and Southgate, 2003). While the analysis of foods in a laboratory is costly and time-consuming, the use of existing nutritional data is cost-effective to develop an FCDB for countries with limited resources and data (Greenfield and Southgate, 2003).

Traditionally, interviewer-led, paper-based food frequency questionnaires (FFQ), food diaries, dietary records and 24-hour dietary recalls were used to collect food intakes (Carter et al., 2016; Thompson and Subar, 2017). However, these methods are becoming outdated with limitations: they are time-consuming and burdensome for both participants and interviewers and experience potential under-reporting, measurement error and expense due to coding and processing requirements (Touvier et al., 2010; Conrad et al., 2018; Thompson and Subar, 2017). While large population-based studies have often favoured FFQs (Thompson et al., 2015), 24-hour dietary recalls may be more accurate (Freedman et al., 2014). Furthermore, new web-based systems offer advantages over traditional time-consuming techniques, allowing for self-administered recalls (Foster et al., 2014; Zenun Franco et al., 2018; Cade, 2017; Eldridge et al., 2018), without compromising on accuracy (Park et al., 2018; Wark et al., 2018; Koch et al., 2020; Conrad et al., 2018).

The online dietary assessment tool, myfood24, is a validated tool, initially developed for the UK population (Carter et al., 2015; Albar et al., 2016; Wark et al., 2018). The system is supported by a comprehensive UK FCDB (~60k food items), which facilitates its use as a self-reported 24-hour dietary recall or dietary record (Carter et al., 2016). The myfood24 system has been adapted to different languages in terms of food database and its functions and layout and there are currently Danish, Norwegian, French and German versions. There are more than 400 million Arabic speakers in the Middle East region (Boudad et al., 2018), yet there is no Arabic web-based dietary assessment tool incorporating common foods for this population. Therefore, we aimed to develop a FCDB of GCC foods, with a focus on Saudi Arabia and Kuwait, to be incorporated into an Arabic version of myfood24. This paper illustrates the methods and techniques used to develop the FCDB, which has been included in an Arabic version of myfood24.

6.2 Materials and Methods

The development of the Arabic FCDB was undertaken in the following steps: food identification, cleaning and processing of data, mapping procedure and quality checking. Then, additional steps were undertaken to enable the inclusion of the database in the Arabic myfood24 as seen in Figure 6-1.

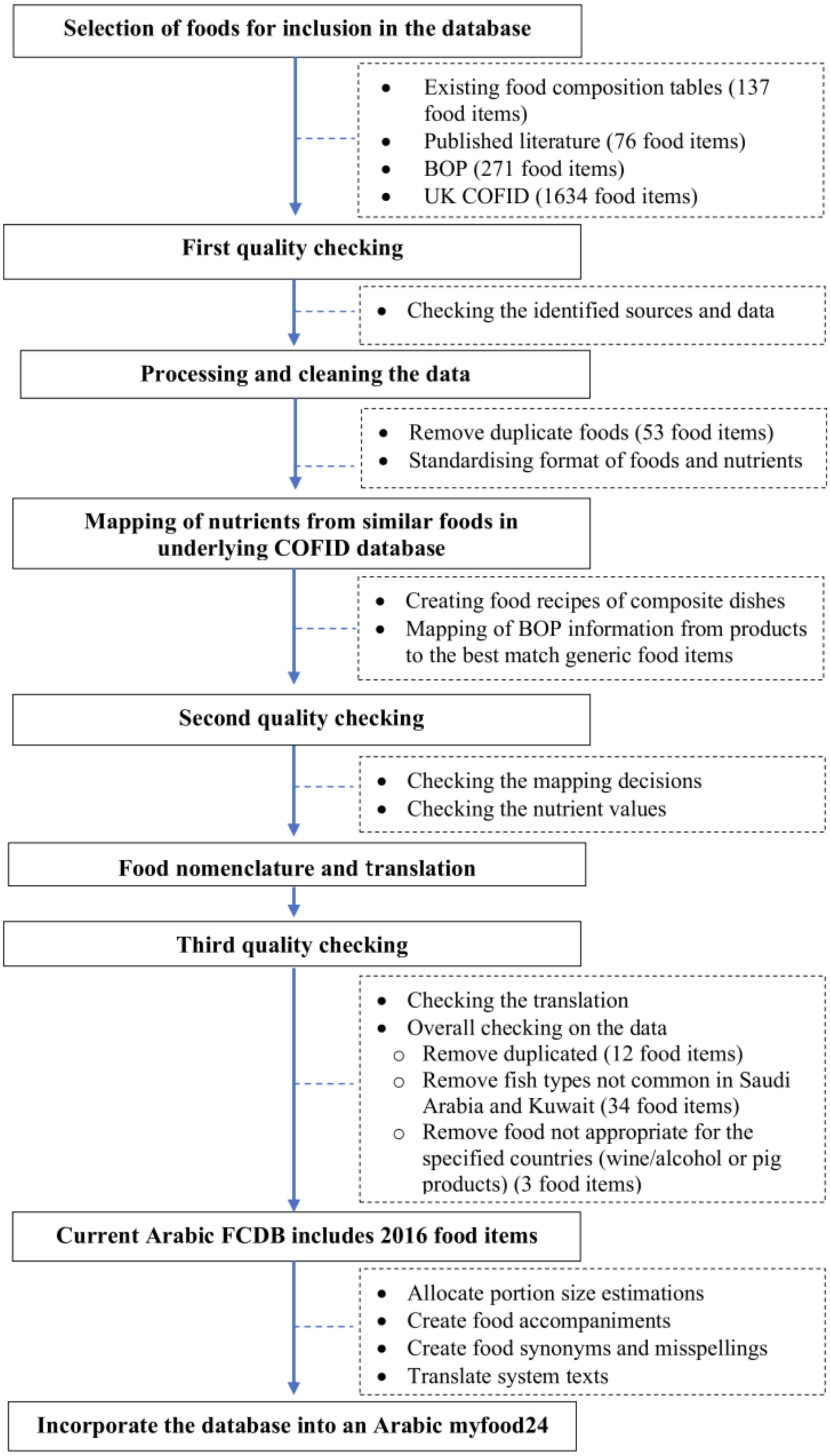

Figure 6-1. A flow chart of developing the Arabic FCDB

6.2.1 Identification of foods for inclusion in the food composition database

A literature search of Arabic and Middle Eastern foods and composition data was conducted using: Medline, Web of Science, Saudi Digital Library (SDL), and Google Scholar using different combinations of the keywords: "Arabic/Middle Eastern food composition table/database". Searching involved both electronic and printed research articles and existing FCTs. Most of the academic literature was freely available online, whereas FCTs were hard copies obtained upon request.

Branded food products with back of pack (BOP) nutrition labels were identified for foods frequently reported in national studies (Adam et al., 2014; Almajwal et al., 2018; Alsufiani et al., 2015; Gosadi et al., 2017) and were available in local food stores. For example, dairy products were frequently reported in national surveys; and we searched for these food products on the websites and in-store of local retailers. To ensure a comprehensive database of foods and complete nutritional information, we included generic foods (e.g. fruits, vegetables, spices, etc.) from the UK food database (Public Health England, 2019).

The following sources were identified: (1) three existing FCTs (“Kuwaiti’s Composite Food Table” (Sawaya et al., 1998); “Food Composition Tables for Arab Gulf Countries” (Musayqar, 2006) and “Food Composition for Use in the Middle East” (Pellet and Shadarevian, 1970); (2) food composition from 9 published research articles (Al-Kanhal et al., 1998; Al-Kanhal et al., 1999; Assirey, 2015; Al-Faris, 2017; Dashti et al., 2004; Dashti et al., 2003a; Dashti et al., 2003b; Dashti et al., 2001; Al Jasser, 2015; Al-Bahrany, 2002); (3) back-of-pack (BOP) label information; (4) generic food items from the UK Composition of Foods Integrated Dataset (CoFID) (Public Health England, 2019a).

Food identification was based on food names, synonyms, description, and ingredients known to the target countries by local bilingual researchers (authors AB & SK). We included foods relevant to the local population by including core commonly consumed foods (e.g. dairy products, grain products, meats and poultry), composite foods and other less commonly consumed items (e.g. regional types of fruit, vegetables, seafood, etc).

6.2.2 Cleaning and processing of the data

The creation of the database followed the procedure and standards for creation of FCDB in myfood24, and nutrients were defined in accordance with the requirements of myfood24 which is based on the UK database (CoFID). Identified data were extracted from the original identified sources into an Excel sheet for processing as follows: (1) Removing duplicate foods with identical ingredients, cooking methods and macronutrients. Where duplicates were identified, foods with the most complete nutrient analysis were included (53 duplicate food items were removed). If differences in ingredients or method of cooking were found, both food items were kept (e.g. Dulmah and stuffed grape leaves are similar but differ in some ingredients; Kofta (meatball) was included as both grilled and fried). (2) Reformatting of units for some nutrients from existing tables/literature was undertaken to match the formats in myfood24; for example, vitamin D was converted from IU to µg. Also, some BOP values were presented by portion size rather than per 100mL or per 100g, so values per 100mL or per 100g were generated. (3) Missing values for some nutrients were calculated from other existing nutrients. Total nitrogen was calculated by dividing protein from the original source by the nitrogen conversion factor (6.25) (Greenfield and Southgate, 2003). Where carbohydrate was missing, it was calculated by difference, subtracting the calories obtained from protein (4kcal/g) and fat (9kcal/g) from the total calories. The calories provided by carbohydrate were then divided by 4 to obtain a value in grams. For the fruit, dates, a staple item in the Middle East, values of carbohydrate and calories were missing from local FCT. Carbohydrates were estimated from the sugar values for dates obtained from an existing FCT (Greenfield and Southgate, 2003), then total calories were calculated through the myfood24 system. The definitions of nutrients in the current work are based on those stated in the UK FCDB (CoFID) (Pinchen et al., 2021). For example, carbohydrate values were based on values for total carbohydrate from the sum of analysed values for components of available carbohydrate not including fibre. However, in case of missing data, they were calculated as explained above for carbohydrate and energy.

Initial cleaning processes were applied to the 429 food items from the existing FCTs, publications and BOP, while generic food items from the UK CoFID were already in the required format and of appropriate quality.

6.2.3 Mapping procedure to generate nutrient values

The mapping process was based on the approach used to create the UK food table underlying myfood24 (Carter et al., 2016). The purpose was to assign available nutrients to the foods in the database from existing published FCT/FCDB, and to generate values for missing nutrients (mostly micronutrients) by matching to similar items from the UK FCDB (CoFID) (Public Health England, 2019a) using the myfood24 system.

Mapping was carried out using Microsoft Access. The mapping process generated nutrient values for all nutrients, including those already available from the original sources, which allowed us to ensure that our matching for nutrients was similar to the original. Mapping involved matching foods, and the matching criteria was compliant to the FAO/INFOODS guidelines for food matching (Stadlmayr et al., 2012). During the mapping process, the programme used (Carter et al., 2015) suggested a range of generic food items (available from the built-in food database (CoFID)), and the researchers were able to select the most appropriate match. We ensured the results from mapping provided values close (no more than 10% difference) the original source values for water content, total calories and macronutrients (grams of carbohydrate, protein and fat).

In order to calculate missing nutrients for composite foods using the mapping technique, we used standard recipes from local recipe sources (Sawaya et al., 1998; Al-Qassar, 2012; Al-Qassar, 2016; AL-Turky, 2013; Musali et al., 1990). To allocate nutrient values where these were missing, we mapped recipes to cooked ingredients since the available nutrient data for the composite foods we identified were for cooked foods . In order to get accurate quantities of cooked ingredients, we applied yield factors from “*McCance and Widdowson's The Composition of Foods*” (Finglas et al., 2015) from the raw ingredients (Rand et al., 1991; Finglas et al., 2015). Water, as an ingredient had volumes adjusted to take into account the evaporation and/or absorption while cooking (Bognar, 2002; Greenfield and Southgate, 2003). Each ingredient was allocated a percentage contribution to the total recipe to enable generation of missing nutrient values using the myfood24 system. To illustrate an example, Marag Laham is a composite food that identified from the searched FCT, which had some missing nutrients. Thus, to generate values for these missing nutrients, we obtained the recipe (raw ingredients in grams). However, to ensure matching with the existing nutrient values from the identified FCT which were for the cooked item, with the values resulting from the mapping process, we mapped to cooked ingredients as seen in Figure 6-2. Since we mapped to cooked items, the water content was already taken into account with the tomato juice/sauce.

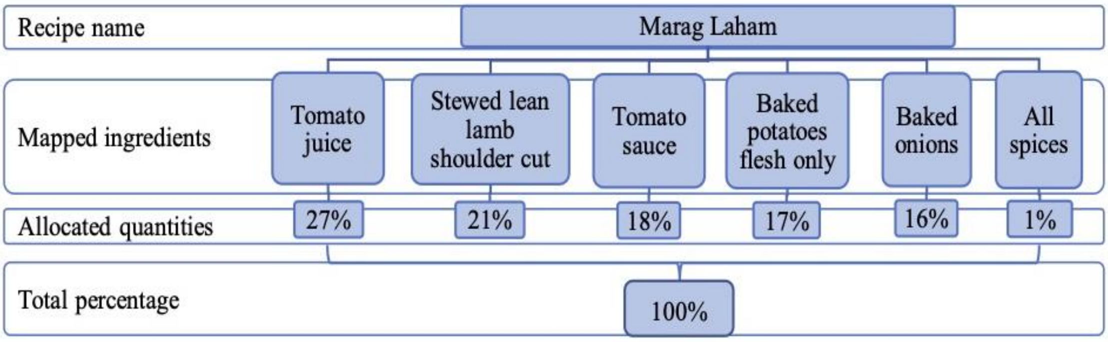

Figure 6-2. Example of mapping for the composite food "Marag Laham" with the allocated percentages of each ingredient

In circumstances where a particular ingredient was not available within the existing UK myfood24 FCDB, a nearest sensible alternative item from the same food group similar in term of nutrient content was selected (e.g. Molokhiya, a local green leafy vegetable, was mapped to curly Kale). For some food items, we matched a combination of more than one item within the same food group to obtain the missing values (e.g. Akawi cheese was mapped to 70% Mozzarella and 30% Halloumi cheeses).

Branded products with declared BOP nutrient information for energy, carbohydrate, sugar, protein, fat, saturated fat, trans fat and sodium were matched with similar generic food items to obtain a comprehensive set of nutrient values. For example, BOP values from a branded milk product were mapped to a milk item within the UK FCDB using the myfood24 system. Table 6-1 highlights some of the mapping decisions undertaken.

Table 6-1. Examples of mapping decisions for local foods and recipes to generate complete nutritional information

Food Item	Closest matched foods
Tannouri bread	100% nan bread
Molokhiya	100% curly Kale
Marag bamiah	44% Okra boiled in unsalted water, 9% onion fried in sunflower oil, 21% tomato puree, 1% Allspice ground, 1% tamarind pulp, 16% lean stewed lamb, 2% reduced fat tomato base, 1% puree garlic and 1% salt, 4% water

Makbos/Kabsa laham	63% basmati rice boiled, 5% chickpeas boiled, 3% raisin, 1% ground allspice, 19% grilled lamb chops, 8% sunflower oil &1% salt
Balila	80% canned chickpeas, 1% cumin, 3% vinegar, 1% salt and 15% distilled water
Akawi cheese	70% Mozzarella and 30% Halloumi cheeses
Labnah	10% Yogurt powder and 90% Greek yogurt

6.2.4 Food nomenclature and translation

The Arabic FCDB was initially developed in English and then translated into Arabic. The translation was done in duplicate by two bilingual researchers (AB, SK), independently. All foods identified were given a food name, a detailed description (e.g. source, processing type, fat content, etc) and a unique numerical food identifier for inclusion in the database.

6.2.5 The Arabic myfood24 system

The myfood24 system was established in its original English version for the UK population in 2015 (Carter et al., 2015) with the option to create additional country-/language-specific versions of the tool. In order to create the Arabic version, an appropriate FCDB and some additional features such as portion size estimation support and food accompaniments were developed, which are described in this section. The next step involved translating the whole database alongside the translation of the original text within myfood24, including the administration side where projects are set up and the instructions for using the food diary, into Arabic. The entire Arabic files were then returned to the myfood24 developer team for construction of the Arabic version of myfood24.

6.2.5.1 Portion size estimations

We used multiple options for portion size estimations: portion size images, standard household measurements (in cups and spoons), serving sizes of products from BOP labels and average portion sizes. We used 50 food images (each with 7 different portion sizes) from the "*Young Person's Food Atlas*" (Foster et al., 2010) within the current database. These ranges of portions had previously been shown to cover all adult and adolescent portion sizes for the UK (Carter et al., 2015). The previous UK food atlas (Nelson et al., 1997) has been used in the Abu Dhabi Photographic Atlas of Food Portions (Al Marzooqi et al., 2015) and in other studies of Middle Eastern populations (Ahmed et al., 2012; Dehghan et al., 2005), suggesting that portion sizes are likely to be similar. Food portion images for a few additional items relevant to foods in the current database were photographed (Figure 6-3) following training by a food photography specialist based on standard guidelines (Abu Dhabi Food Control Authority., 2014; Foster et al., 2010). The weights of the portion sizes for these items were based on the Abu Dhabi Photographic Atlas of Food Portions (Abu Dhabi Food Control Authority., 2014). Some images were used multiple times by allocating them to food items similar in terms of appearance and/or composition (Al Marzooqi et al., 2015; Carter et al., 2016). For example, white rice portion images were assigned to all rice dishes; stuffed grape leaves images were assigned to dolma and stuffed cabbage.

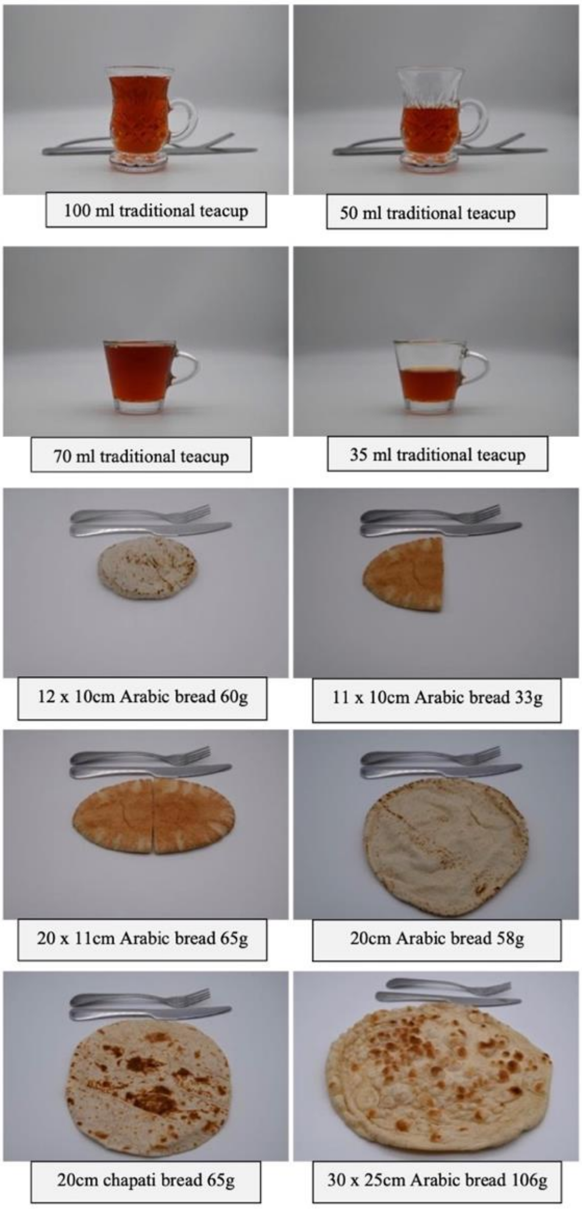

Figure 6-3. Examples of food portion images created based on local foods

6.2.5.2 Food accompaniments

Prompting for any missing food accompaniments where a food item is commonly consumed with another food is one of the features of myfood24. Thus, we created a list of food accompaniments as seen in Table 6-2. For example, if dates were selected, prompts to add Arabic coffee, yogurt and laban would occur automatically.

Table 6-2. Examples of food accompaniments

Food logged in as being consumed	Common food accompaniment prompts
Rice	Stewed dishes (e.g. stewed meats, vegetables and stuffed vegetables)
Bread	Peanut butter and jam, egg (e.g. omelette, boiled), and humus
Coffee and tea	Milk and sugar
Dates	Arabic coffee, yogurt and laban (kefir)

EANs (European Article Numbers) were used as unique identifiers in the myfood24 database to uniquely identify foods and to prevent over-stamping (i.e. one item replacing another). The Arabic database was given a unique EAN range, specific to this regional database. This allows portions and accompaniment information to be linked to the correct foods.

6.2.5.3 Food synonyms and misspellings and system translation

To facilitate searching for foods within the myfood24, synonyms of food names based on different dialects existing in Kuwait and Saudi Arabia (e.g. rice called "aish عيش" and "ruz رز") were added. Also, we included potential misspellings (e.g. potential misspellings of the word rice like رز، أرز، ارز).

6.2.6 Quality checking

Quality checking procedures, compliant to FAO/INFOODS guidelines on checking data for inclusion in FCDB (Charrondiere et al., 2012), were applied throughout the process. Here we present the checking procedures applied in three stages.

6.2.6.1 First quality checking stage

The first stage of quality checking was conducted on the identified sources and foods ensuring appropriateness and sufficiency of the data. For each source, data were extracted and documented in an Excel sheet originally designed by the myfood24 team. Data required for each food was the food name, synonyms, food descriptions, food category and nutrients. The extracted data were checked against the original source to ensure that values were combined and matched; nutrients and values (units and denominators) had been included in the database correctly. Also, data was checked for any missing values requiring generation of nutrients by mapping.

6.2.6.2 Second quality checking stage

The second stage of quality checking was conducted after the mapping procedure. This involved 1) checking the quantities and description of matched ingredients and decisions relating to volume changes with cooked foods (e.g. pasta); 2) Checking and confirming matched food selection for missing foods (e.g. Molokhiya); and 3) Checking all the nutrient values resulting from the mapping. This stage was carried out by a nutritionist (SB), an expert in food analysis (MR) and the local researchers. The local researchers independently calculated the recipes and mapped foods to generate complete nutrient information. Subsequently, results were checked with the nutritionist (SB), to ensure plausible nutrient values.

6.2.6.3 Third quality checking stage

The final stage was performed after the translation by the native researchers to ensure all translations (e.g. translation of food names, descriptions and components) were accurate. This stage also involved checking that the synonyms and misspellings were sufficient to cover any potential search terms within the Arabic myfood24 as well as checking the translations of portion size units, system text, prompts and user instructions.

6.3 Results

The Arabic FCDB is comprised of food items consumed in Saudi Arabia and Kuwait. The database includes in total, 2016 food items with their macronutrient and micronutrient data (120 nutrients available for all foods). A full list of nutrients can be seen in Appendix D.1 in the Supplementary Materials. All data included are in either 100g or 100 mL edible proportion. About 30% of the food items in the Arabic FCDB were assigned portion size images in addition to standard household measurements or serving sizes from BOP labels.

As shown in Figure 6-4, the majority, 79% (n=1585) of the data in the Arabic FCDB, were generic items from the UK CoFID. The large percentage of foods included from the UK database is due to the addition of generic food items such as meats, poultry, fruits and vegetables in addition to some commercial food items (e.g. nuts, biscuits and puddings) and condiments (e.g. spices, dressings and sauces). These foods were chosen from the CoFID since that database already has a complete set of nutrient information and whilst there may be some regional variations, we wanted to include quality assessed standard information. Foods with BOP label information for local and regional branded products in Saudi Arabia and Kuwait comprised 13% (n=271) of the food items. Food items from existing FCTs and research articles contributed 8% (n=160) of the final database items. Out of these 160 items, 141 were composite foods and 19 items were local fruits (mostly dates), local dairy products and Arabic coffee drinks.

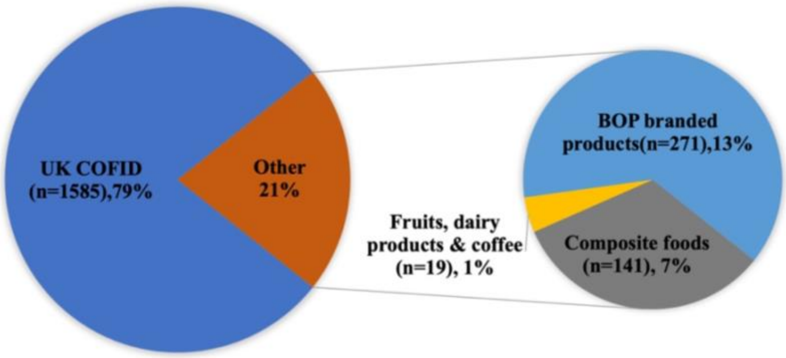

Figure 6-4. Sources of data for the new FCDB

Meat-based composite dishes represented the majority of the food items obtained from the existing FCTs and research publications followed by desserts and cereal-based foods, while most of the fruits included were dates (e.g. Ajwa, Sukkari, Khodari and Suqaey). The highest number of branded products included were dairy products. The majority of the branded products were from the largest dairy, bakery and confectionery and fast-food producers in the region. Appendix D.2 in the Supplementary Materials shows the number and source of food items in the Arabic myfood24 FCDB.

In total, as seen in Figure 6-5, the whole database included 14% of items from both meat products and dishes (n= 286) and vegetables and vegetable-based dishes (n=278); 11% of items were cereal products and associated dishes (n=230); 9% sweet-tasting foods (e.g. desserts and chocolate) (n=187); and 8%

were fruits (n=171), seafood (n= 166) and dairy products (n=166). There were only 5% poultry products and associated dishes (n=99), 5% beverages (n=93) and 3% bean-based dishes (n=68), while 13% come from miscellaneous foods including spices (n=81), savoury snacks (n=53), sauces (n=52), ready-to-eat products (n=39) and oils (n=24).

Figure 6-5. Total number of foods included in the Arabic FCDB

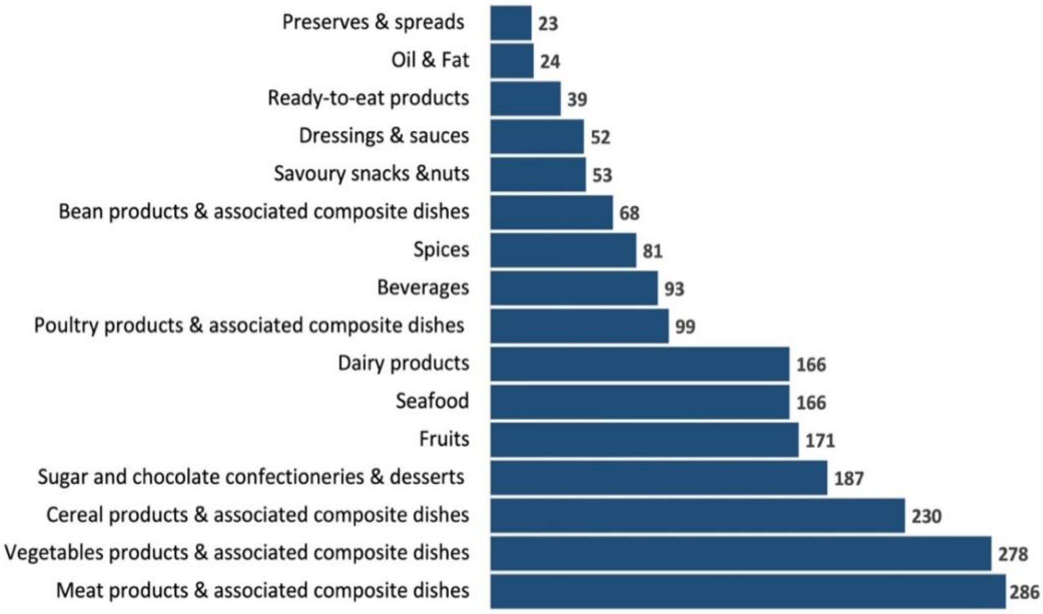

Table 6-3 displays selected nutritional information for some of the most commonly consumed foods. It can be seen from the examples in the table that the highest source of energy/100g comes from high sugar foods like Basbousah (a dessert), dates, and cakes. The composite savoury dishes illustrated are mostly eaten for lunch/dinner (e.g. Marag Laham, Margook and Mandi) and are higher in protein and also sodium. Coffee and dairy products, mainly milk and laban, are typically consumed on a daily basis. These items provide the lowest energy.

Sources of included data were scientific articles, existing regional FCTs, UK FCDB and BOP food labels. Some missing data was found in the national and regional sources. Nutrients to replace this missing data were estimated through the mapping procedure using the UK database. The format of the data included a description, definition of components, units and denominator in accordance with the UK database (CoFID) included in myfood24, which we used for mapping and matching food items to complete missing values.

Table 6-3. Examples of nutritional composition of chosen Middle Eastern foods included in the database

Food name	Nutrients/100g											
	Water (g)	Energy (kJ)	Protein (g)	Total fat (g)	CHO[1] (g)	Fibre (AOAC)[2] (g)	Vitamin C (mg)	Vitamin E (mg)	Vitamin B12 (µg)	Ca[1] (mg)	Na[1] (mg)	Iron (mg)
Composite foods												
Marag laham (مرق لحم)	82.2	338	6.4	3.7	5.4	0.8	3.1	1.0	0.6	30	126	0.8
Margook (مرقوق)	75.9	422	5.1	2.8	12.9	1.5	2.4	0.3	0.4	22	90	1.0
Mandi rice & chicken (رز مندي بالدجاج)	56.6	556	8.2	4.6	15.4	0.4	0	0.5	0.0*	11	22	0.2
Basbousah (بسبوسة)	22.5	1401	3.9	6.9	64.4	1.4	0	1.0	0	17	7	0.9
Fruits (dates) and Arabic coffee drinks												
Sukkari date (تمر سكري)	14.2	1394	2.7	0.4	79.7	0	0	0	0	38	8	1.1
Coffee husk (قهوة قشر)	98.8	8	0.2	0	0.3	0	0	0.0*	0	2	0.0*	0.0*
BOP food products												
Laban full fat (لبن كامل الدسم)	88.14	251	3	3.3	4.7	0	0.6	0.5	0.1	120	48	0.1
Milk long life (حليب طويل الاجل)	87.6	259	3.2	3.2	5.4	0	2	0.0*	0.9	120	42	0.0*
Chocolate cake (كيك بالشوكولاته)	17.6	1644	6.5	18.5	49.4	1.6	0	0.6	0.5	51	430	1.2

* Trace values

[1] CHO= Carbohydrate; Ca= Calcium; Na= Sodium

[2] "AOAC determinations include resistant starch and lignin in the estimation of total fibre, rather than only the non-starch polysaccharides"

Results of the quality checking identified differences in the values of some micronutrients (e.g. sodium, potassium, magnesium and phosphorus) as a result of the mapping using items from the UK CoFID database when compared with values reported in the identified sources for some composite dishes. Since the availability of nutrient values was variable or missing from the local sources, we included values from UK database through the mapping procedure to ensure a consistent and complete set of nutrient value data. For food where a BOP food label was available, we matched the values of calories and macronutrients from the label to matched items within the UK database, which resulted in similar matched values. During the final quality checking, we identified and removed 12 duplicate foods and 3 food items that included wine in its description (not suitable for the population of this version of the FCDB). Also with a further search during translation, 34 types of fish unavailable locally were removed.

6.4 Discussion

This work describes the creation of an Arabic FCDB containing 2016 foods and its integration into the online dietary assessment tool, myfood24, producing a unique Arabic online dietary assessment tool.

Traditionally, creating a FCDB uses laboratory analysis providing high quality, reliable data; however, this process is costly and time-consuming. Furthermore, analysing a wide range of food items and composite dishes may not be possible (Marconi et al., 2018), and local tables often present a limited number of nutrients (Merchant and Dehghan, 2006; Puwastien, 2002). In our work, we used existing data and generated missing data using a recipe calculation method and mapping to generic items with complete nutrient data using the UK CoFID. To ensure accurate values of nutrient content, we applied yield factors to raw ingredients in recipes since we mapped to cooked ingredients (Reinivuo et al., 2009; Greenfield and Southgate, 2003a). Estimating nutrients based on recipe calculations has been done in European FCDBs within the European Food Information Resource (EuroFIR) (Reinivuo et al., 2009) and is approved as an alternative way of creating FCDB (Marconi et al., 2018; Machackova et al., 2018; Rand et al., 1991b; Greenfield and Southgate, 2003a). A comparison of recipe calculation with laboratory analysis, showed good agreement between the techniques for total calories and macronutrients (Vasilopoulou et al., 2003); however, discrepancies in micronutrient values were reported (Machackova et al., 2018; Marconi et al., 2018; Puwastien, 2002; Vasilopoulou et al., 2003). Differences in these nutrients may be due to natural regional differences in agricultural factors (e.g. crops breeding, soils, weather and water) (Greenfield and Southgate, 2003a; Elobeid et al., 2014; Marconi et al., 2018) or variations in food recipes and ingredients (particularly sodium values due to using sodium phosphates rather than sodium chloride or due reformulation of salt in products) (Jacobson et al., 2013; Kapsokefalou et al., 2019; Machackova et al., 2018; Adam et al., 2014; Elobeid et al., 2014). Further differences may be due to methodological or procedural differences between databases (Cromwell et al., 1999; Puwastien, 2002; Marconi et al., 2018). These limitations can be generalised across all FCDBs. Developing an FCDB based on existing FCTs substituting missing data using similar foods or more comprehensive FCDBs/FCTs of other countries has been suggested as a method to use in enhancing food composition databases (Leclercq et al., 2001). Using this approach, allowed us to have a complete set of nutrients for each food item in our FCDB.

A representative FCDB in terms of the foods to be included is essential to obtain reliable information, especially, to assess dietary intakes for a specific population (Leclercq et al., 2001). The current work presents a national-level FCDB that contains composite dishes and branded products that are commonly consumed by the populations of Saudi Arabia and Kuwait. For example, rice dishes are the main food consume in the region on a daily basis with red meat or chicken (Adam et al., 2014; Al-Mssallem, 2014). Wheat is also used as the main ingredient in traditional desserts (Alfaris, 2018; Al-Mssallem, 2014); however, dates remain the main dessert item that are commonly consumed with Laban (kefir) or Arabic coffee (Al-Mssallem, 2014). The majority of the BOP data in the Arabic FCDB was for dairy products, popular in Saudi Arabia and Kuwait (Adam et al., 2014; Alkazemi and Saleh, 2019; Adam et al., 2019). Dairy products in Saudi Arabia are produced locally (Adam et al., 2014), and are exported to Africa and the other Middle Eastern countries (Almarai, 2017). Our database also includes a variety of products (e.g. snacks, confectionery and frozen foods) from one of the largest fast-food businesses in the Middle East with around 48% and 41% of its products in the Kuwaiti and Saudi Arabian markets, respectively (Mehta and Lulla, 2016). However, there are other common branded products missing in our database where BOP information was not available. This is a common problem as it is not possible to include all foods made available in the markets in an FCDB as new products are continually being produced (Leclercq et al., 2001). Thus, it will be important for researchers to build trust with food companies and retailers to support food surveys through providing access to new products and BOP nutritional information (Harrington et al., 2019; Kapsokefalou et al., 2019b).

Branded products are updated regularly when regulations and formulation are changed (e.g. reductions in sugar, salt or fat) (Kapsokefalou et al., 2019b; Concina et al., 2016), or new products are introduced (Black, 2017). This results in changes in nutrient content requiring the FCDB to be kept up-to-date (Kapsokefalou et al., 2019; Harrington et al., 2019). Today's usage of technology such as web-scraping, undertaken to create FoodDB in the UK (Harrington et al., 2019), allows regular collection of data for a large number of local food products. This provides up-to-date BOP data for branded products, overcoming limitations using traditional methods that rely on contacting food suppliers, or visits to supermarkets (Harrington et al., 2019). Since this technique was not available for our work, we obtained branded products' data by hand from companies' websites and product BOP labels.

The current work created the Arabic FCDB containing Arabic composite dishes and branded products available for Saudi Arabia and Kuwait, which has been integrated into an Arabic version of the online dietary assessment tool, myfood24. This development was based on the existing food databases available for these two countries following the same standard approach used to create the food composition data for myfood24.

Our approach of mapping foods to items which had complete nutrient data from CoFID allowed the missing nutritional information to be imputed. However, some nutrient values, especially for micronutrients such as sodium, potassium, and calcium, may not accurately reflect the composition of any single food. Thus, results should be considered with some caution. Whilst the aim for our database was to include all relevant foods consumed in the region, due to limited national consumption data, limited pre-existing tables and unavailability of data (e.g. other branded foods, fast food and local restaurants) it is possible that some foods have been missed. These will be incorporated with future updates to include more composite dishes and branded foods and expand it for other Gulf and Middle Eastern countries.

6.5 Conclusions

The Arabic FCDB has been developed which includes 2016 items consisting of composite foods, branded products, and generic foods that are commonly consumed in Saudi Arabia and Kuwait. The database includes data on 120 nutrients for all foods and these have been linked to multiple portion size options. The current work has been integrated into the fully Arabic version of the online dietary assessment tool, myfood24; the first comprehensive online tool designed to facilitate nutritional epidemiological studies and help in measuring dietary intake of Arabic-speaking populations. Regular updates and expansion of the database are planned to offer more food items from a wider range of Middle Eastern countries.

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Chapter 7 Usability and acceptability of the Arabic version of the online dietary assessment tool, myfood24

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Abstract

Innovative dietary assessment tools are found to enhance the process of dietary intake collection and handling data. This work aims to determine the usability and acceptability of an online dietary assessment tool, Arabic myfood24 among 46 Saudi Arabian adolescents aged 12-19 years old. Participants were asked to self-report two non-consecutive 24-hour dietary recalls using the Arabic myfood24. Then, they were directed to complete an online questionnaire including the user's experience and usability of the Arabic myfood24 using the System Usability Scale (SUS). The majority of the participants (80%) had not used technology-based food recording tools. The completion time (10-30 minutes) was reported to be reasonable. The mean score of the SUS was 62 (95%CI 58, 65); however, users reported that they would like more food items added to reflect their intakes. The usability of the Arabic myfood24 among Saudi Arabian adolescents is promising. A more detailed food database is needed.

Keywords: Dietary assessment, innovative tool, usability, adolescents

7.1 Introduction

Collecting information on individuals' usual intake is important to monitor dietary recommendations over time and helps assess the dietary intakes and the association between diet and health (Boushey et al., 2009). Measuring adolescents' dietary intakes is challenging and reporting errors may occur (Boushey et al., 2009; Livingstone et al., 2004). However, the use of technology may improve the accuracy of the dietary records (Boushey et al., 2009; Khanna et al., 2010).

As adolescents are often enthusiastic and eager to use the internet and new technologies, using innovative technology-based dietary assessment tools is reported to be easy to use, more appealing and motivating to adolescents over the traditional paper-based or interview-led techniques (Cade, 2017; Khanna et al., 2010). Web-based 24-hour food recalls and food records are promising, facilitating dietary assessment by providing sensible estimates of dietary intakes with effective cost and minimal user effort (Park et al., 2018). Moreover, web-based tools can be effectively adapted to country-specific food databases and languages, which allows their use across nations (Koch et al., 2020; Amoutzopoulos et al., 2018).

myfood24 is a self-administered online dietary assessment tool that was initially developed for the UK population. The tool was built to ease the process of dietary recording for the users and collecting the data for the researchers (Carter et al., 2015). It is a valid tool for use with adolescents (Albar et al., 2016) and testing its usability and acceptability on British adolescents indicated it is suitable for adolescents reporting their dietary intakes (Albar et al., 2015). The Arabic version of myfood24, to our knowledge, is the only available self-administered online dietary assessment tool that is fully in the Arabic language (Bawajeeh et al., 2021). Assessing the usability and acceptability of a new tool is required to evaluate the user experience of utilising the tool and its components efficiently (Petrie and Bevan, 2009). These tests should be undertaken during the development process and when incorporating new features or components (e.g. a new language version) identify potential tool improvements (Albar et al., 2015; Petrie and Bevan, 2009). The System Usability Scale (SUS) is a validated usability metric tool. It is a quick, easy and cost-effective tool to assess various technological components of electronic systems(Albar et al., 2015). Even with relatively small sample sizes, it can produce reliable results (Lewis, 2018). This study aimed to explore the usability and acceptability of the Arabic myfood24 as a tool used among a convenience sample of Saudi Arabian adolescents.

7.2 Method

7.2.1 Recruitment

The study involved Saudi adolescents of secondary and high school age (12-18 years old). Due to COVID 19-related challenges in recruitment, schools were not available, so participants were approached through families and friends via text messages. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the University of Leeds ethics committee MEEC 19-003, including an approval letter from the Ministry of Education in Saudi Arabia permitting this study to proceed. Written informed consent was obtained from all subjects.

7.2.2 Dietary records using Arabic myfood24

Dietary record data were obtained using an online dietary assessment tool, Arabic myfood24 (Bawajeeh et al., 2021). Participants were asked to complete two non-consecutive 24-hour recalls. For the first record, participants were emailed with a unique individualised link for each participant through the myfood24 system. Reminder emails were sent to participants every week for a month to remind them about logging their food intake. Emails with a unique individualised link for the second record were sent to all participants (whether they had completed the first record or not). This was to provide additional time and opportunity for those who did not respond to the first record request. Reminder emails were also sent to participants every week for a month. If a participant completed the second record but did not do the first one, the link for the first record was re-sent to be completed. Participants were not provided with any training or special instructions on using the tool.

7.2.3 The Arabic myfood24 usability and acceptability online survey

After completing the food record, participants were emailed a link to an online questionnaire. The questionnaire included questions about participants' experience using technology and food diaries, questions about the experience of using the Arabic myfood24 and questions about the usability of the tool using the System Usability Scale (SUS). The SUS asks participants to rate their level of agreement for 10 statements using a 5-point scale (1 = strongly agree and 5 = strongly disagree). The total score ranges from 0 to 100, where scores below 50 are unsatisfactory, 50 to 70 are marginal (i.e. acceptable) and above 70 are good (Brooke, 1995; Bangor et al., 2009). Additionally, open-ended questions asked participants to comment on food availability and overall experience about the tool usage and the likelihood of re-using the tool.

7.2.4 Data analysis

Descriptive statistics were used to describe participants' characteristics. The overall SUS score ranged from 0-100 (Bangor et al., 2009). Independent t-test was used for comparison of the SUS score between genders. Analyses were performed using STATA statistical software version 16.1.

7.3 Results

7.3.1 Characteristics of participants

A total of 76 adolescents aged 12-19 years were recruited. Forty-eight completed the food records; two did not return the usability questionnaire were excluded from further analysis. Thus, 46 adolescents (girls=25; boys=21) completed the study with two 24-hour recalls and the usability questionnaire. The mean age of participants was 16 years old. The participants' mean BMI was 22.8 (95% CI 21, 24.5) kg/m2 and the mean energy intake was 5.3 MJ/d (95% CI 4.6, 6.0). Most of the adolescents had not previously completed food records (67%) nor used any App or websites to record their foods (80%). However, the majority (89%) rated themselves excellent at using technology (Table 7-1).

Table 7-1. Summary description of the participants

	Total sample (n= 46)	Girls (n= 25)	Boys (n=21)
Age (mean, 95% CI)	16 (15.6, 16.8)	16 (15.6, 17)	16 (15, 16.9)
BMI (mean, 95% CI)	22.8 (21, 24.5)	21.3 (19, 23.3)	24.6 (21.6, 27.5)
Dietary intake (mean, 95% CI)			
Energy (MJ/d)	5.3 (4.6, 6.0)	4.2 (3.4, 5.1)	6.6 (5.7, 7.4)
Energy (Kcal/d)	1276 (1115, 1436)	1025 (831, 1219)	1574 (1362, 1787)
Carbohydrate (g/d)	157 (136, 178)	124 (98, 149)	196 (168, 224)
Total sugar (g/d)	52 (42, 63)	38 (27, 50)	69 (53, 86)
Protein (g/d)	57 (49, 66)	46 (36, 56)	71 (58, 85)
Fat (g/d)	50 (43, 57)	40 (32, 49)	61 (52, 71)
Saturated fat (g/d)	26 (8, 45)	15 (-5, 35)	40 (7, 74)
Sodium (mg/d)	1463 (1237, 1688)	1144 (894, 1393)	1842 (1495, 2190)
Has previously done food record (n, %)			
Yes	15 (33%)	8 (32%)	7 (33%)
No	31 (67%)	17 (68%)	14 (67%)
Has previously used App/Internet to record your eating (n, %)			
Yes	9 (20%)	3 (12%)	6 (29%)
No	37 (80%)	22 (88%)	15 (71%)
Confident in using technology and internet (n, %)			
Excellent	41 (89%)	24 (96%)	17 (81%)
Very good	4 (9%)	1 (4%)	3 (14%)
Good	1 (2%)	0	1 (5%)
How often use internet (n, %)			
Every day	46 (100%)	25 (100%)	21 (100%)

7.3.2 Usability and acceptability of the Arabic myfood24

The majority (39%) completed the records in 10-15 minutes; and more than half of the participants reported the completion time of the record was between 10-30 minutes.

Most of the participants (80%) found the completion time was reasonable. The terminology of the whole tool and foods were reported to be clear by 87% and more than half found food searching and selecting portion size was simple and efficient. Only 33% (n=15) of those who used the recipe feature found it easy although 26% (n=12) of the participants did not use the feature. The overall mean score of the System Usability Scale (SUS) was 62 (95%CI 58, 65) and there was a significant difference between boys and girls 7.5 (0.5, 14; *P* =0.03), with girls scoring lower (Table 7-2). The majority (76%) found the foods for which they searched, and a total of 39% of participants said they would re-use the tool.

Table 7-2. Participants' responses on the Arabic myfood24's acceptability

	Total sample (n= 46)	Girls (n= 25)	Boys (n=21)
Completion time to finish food record using the Arabic myfood24 (n, %)			
Less than 10 minutes	10 (22%)	7 (28%)	3 (14%)
10-15 min	18 (39%)	12 (48%)	6 (29%)
15-30 min	16 (35%)	5 (20%)	11 (52%)
30-60 min	2 (4%)	1 (4%)	1 (5%)
Time for completion was reasonable (n, %)			
Agree	37 (80%)	21 (84%)	16 (76%)
Disagree	0	0	0
Neither/Nor	9 (20%)	4 (16%)	5 (24%)
Did not use it	0	0	0
Terminology used was easy (n, %)			
Agree	40 (87%)	23 (92%)	17 (81%)
Disagree	1 (2%)	(-)	1 (5%)
Neither/Nor	5 (11%)	2 (8%)	3 (14%)
Did not use it	0	0	0
Food searching was simple and efficient (n, %)			
Agree	27 (59%)	16 (64%)	11 (52%)
Disagree	4 (9%)	3 (12%)	1 (5%)
Neither/Nor	15 (33%)	6 (24%)	9 (43%)
Did not use it	0	0	(0
Selecting food portion size was easy (n, %)			
Agree	25 (54%)	13 (52%)	12 (57%)
Disagree	3 (7%)	2 (8%)	1 (5%)
Neither/Nor	18 (39%)	10 (40%)	8 (38%)

Did not use it	0	0	0
Add home cooked recipe was straight forward (n, %)			
Agree	15 (33%)	10 (40%)	5 (24%)
Disagree	3 (7%)	1 (4%)	2 (10%)
Neither/Nor	16 (35%)	9 (36%)	7 (33%)
Did not use it	12 (26%)	5 (20%)	7 (33%)
Correcting my mistakes was easy (n, %)			
Agree	23 (50%)	14 (56%)	9 (43%)
Disagree	1 (2%)	1 (4%)	0
Neither/Nor	17 (37%)	8 (32%)	9 (43%)
Did not use it	5 (11%)	2 (8%)	3 (14%)
The output of my food records was easy to understand (n, %)			
Agree	28 (61%)	15 (60%)	13 (62%)
Disagree	0	0	0
Neither/Nor	15 (33%)	8 (32%)	7 (33%)
Did not use it	3 (7%)	2 (8%)	1 (5%)
SUS (mean, 95%CI)	62 (58, 65)	58 (54, 62)	66 (59, 72)

A total of sixteen food items were named as missing food in the search. Four of the missing items were added as recipes by the participants using the recipe features. The given feedback also emphasised the need for adding more food choices (Table 7-3).

Table 7-3. List of missing foods when searched for and feedback provided by the participants

<table>
<tr><th colspan="2">Missing foods</th></tr>
<tr><td>• Indonesian foods (added as recipe)
• Molokai with chicken (added as recipe)
• Tahini sauce (added as recipe)
• Banana milkshake (added as recipe)
• Some types of soup (not specified by the participant)
• More types of edam (i.e. stew)
• Fired fish (Hamour/Shaour/Najel)
• Drinks of all kinds (not specified by the participant)</td><td>• Hot drinks (not specified by the participant)
• Nespresso coffee
• Cold coffee drinks
• More commercial products like crisps
• Ready-made pies
• Nutritional supplements
• Galaxy
• Granola</td></tr>
<tr><th colspan="2">Feedback</th></tr>
<tr><td colspan="2">• Add tablespoon choice as portion size instead of grams
• Add more food choices
• Some standard foods missing (not specified by the participant)
• ‘I like the website’
• ‘I really enjoyed entering the foods, first time I do it’
• ‘I like it, I am following a diet trying to add more protein and this help’
• ‘I tried to use the recipe builder to create my breakfast meal, but did not find granola’</td></tr>
</table>

7.4 Discussion

This study has explored the feasibility of the usability and acceptability of the recently developed Arabic myfood24 as the first web-based dietary assessment tool fully in Arabic among Saudi Arabian adolescents. However, due to the nature of convenience sampling which may be nonrepresentative, results should be interpreted cautiously.

The finding from the current food records indicated relatively low-calorie intake for both girls and boys compared to recommendations (Public Health England, 2016), This may suggest misreporting of foods or portion sizes. However, BMI, particularly for the girls was also relatively low potentially supporting a lower intake. However, the distribution of macronutrients (carbohydrates, fat and protein) based on their current reported calories was appropriate.

The SUS score obtained in the current study was 62 out of 100, which is a satisfactory usability score. This was close to the score obtained when evaluating the beta-version of the original tool among UK adolescents (Albar et al., 2015), given the case that this is the first usability testing for the Arabic version with no instructions or help (other than instructions already included in the system) were given to the users. However, we observed that 26% to 59% of participants chose “neutral” as an answer to the SUS questions, which could affect the results. Respondents have been reported to often choose the midpoint option when they are completing a survey either when it is not of interest to them or as a choice that is recognised to be socially accepted. However, eliminating the midpoint option (e.g. neutral) would force respondents to choose an explicit positive or negative option, which could lower the validity (Chyung et al., 2017).

As expected, most of the adolescents found themselves confident using technology and the internet in general; however, only 20% of them had previous use of technology to record their food intake. This may suggest that recording dietary intake is less of interest in this age group, although adolescents still prefer the use of technology-based dietary assessment over the traditional paper based dietary assessment (Albar et al., 2015). Regarding the completion time for reporting diet, 22% of the participants completed the records in less than 10 minutes. Whilst this may indicate the ease and mastering the use of technology by adolescents, misreporting or underreporting of foods could suggest the quick reporting. However, completion time of food recording ranged from 10-30 minutes by 74% of the participants. This time range has been reported with other web-based tools (Lindroos et al., 2019; Albar et al., 2015). While the traditional methods take also around 30 minutes on average to be completed, additional time is required to further complete data processing, coding and analysing (Thompson and Subar, 2017). Thus, the use of a technology-based tool is more valuable and practical.

Adolescents in the present study did not report difficulties using the tool; however, some food items were reported as missing. This was noted as a limitation during the development (Bawajeeh et al., 2021). Regarding the portion sizes, although the Arabic myfood24 has different portion size options (weight, and standard household measurements e.g. spoons and cups) (Bawajeeh et al., 2021), one of the feedback comments was to “add tablespoon choice as portion size”. This may indicate potential difficulties in describing portion sizes.

The current work has a number of strengths and limitations. A new online dietary assessment tool that included foods familiar to this study population and fully in their native language (Arabic) has been tested. A strength of this testing is that the participants were not given a prior training or introduction to the tool to obtain evaluation based on naive person usage. Although the sample size achieved is considered acceptable for a pilot study (In, 2017), it may limit us from getting a broader evaluation. Another limitation is that recruitment was based on convenience sampling (families and friends). This was due to COVID19 restrictions and the inability to travel and recruit participants. Additionally, with schools being switched to a virtual system (online), thus, approaching participants through teachers during classes was not possible. Also, we only evaluated the usability through a quantitative method; however, it may be useful to conduct a qualitative method (e.g. focus group) to get further insight into the usability of the tool. Furthermore, comparing the self-reported foods with interview-led assessment could allow inspection of misreporting of foods and/or portion sizes.

7.5 Conclusion

The usability testing of the Arabic myfood24 identified promising usability and acceptability; however, the inclusion of more food items is required. Such a tool is widely accepted, particularly among adolescents. Using this technology in dietary assessment allowed data collection from a wider geography and eased handling and analysis of the data. Further research may be needed to determine the validity of the results against standard biochemical marker methods.

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Chapter 8 Characterising Saudi adolescents' dietary intake by taste: links to food-taste liking and diet quality _ Exploratory study

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Abstract

Taste perceptions and preferences are key factors influencing adolescents' dietary intake. This exploratory study characterised Saudi adolescents' dietary intake by taste and explored the associations between dietary tastes and food-taste liking, BMI and overall diet quality. Forty-six Saudi adolescents (girls = 25; boys = 21), mean age of 16 years, completed an online food-taste survey and self-report their food intake using the online Arabic myfood24 tool. Participants were divided into two groups based on median consumption by taste to describe their dietary tastes. Multivariable regression analyses were used to explore the relationship between dietary intake by taste and the food-taste liking, energy intake, BMI and diet quality. High consumers of sweet-tasting foods had higher total sugar intake by 20g/d (95% CI -0.3, 40; P = 0.05) and free sugar intake by 9g/d (95% CI 1, 17; P = 0.03) compared to low consumers. Protein intake was higher by 23 g/d (95% CI 7, 40; P < 0.01) among high consumers of salty-tasting foods compared to low consumers. Liking for salty-tasting foods was significantly associated with increased intake of bitter-tasting foods by 30 g/d (95% CI 9, 50; P < 0.01), and liking for bitter-tasting foods was associated with increased intake of sour-tasting foods by 6 g/d (95% CI 0.2, 13; P = 0. 04). Salty-tasting foods had the highest influence on energy intake, at 17 kcal/d (95% CI 13, 22; P < 0.01) for every 10g/d of increased intake; however, there was no significant association with BMI. Neutral- and bitter-tasting foods were significantly linked to a positive diet quality score. Salty foods are dominant in Saudi adolescents' diet. Taste preferences may reflect food choices and intakes and may affect diet quality.

Keywords: taste, dietary taste, Saudi, adolescents, diet quality

8.1 Introduction

During adolescence, young people assert themselves to become independent in various aspects of life, which includes the desire to make independent food-related decisions. This attitude, along with their food and taste preferences, is a strong predictor of adolescents' food choices (Banna et al., 2016; Brug et al., 2008; Di Noia and Byrd-Bredbenner, 2013).

Adolescents often like sweet and salty foods more than they like sour and bitter foods. Sweet and salty foods are often palatable due to their content of sugar, salt, and fat (McCrickerd and Forde, 2016). While these tastes can be perceived in healthy food options like fruits, some vegetables, and home-cooked foods that normally are moderately salted, adolescents consume less of these options than of sweetened beverages, sweet and salty snacks (e.g. candies, chocolates, and crisps), and takeaway/fast foods (Lachat et al., 2012). This may contribute to the development of a number of nutrition-related problems that may have lasting effects throughout the lifespan (Dwyer, 2006).

As in many parts of the world, the eating behaviours of Saudi adolescents have been reported to be less than optimal. The prevalence of Saudi adolescents' consumption of fast foods is up to 80%, while their intake of fruit and vegetables is insufficient (Alasqah et al., 2021). Studies have indicated that socioeconomic factors, the role of media, adolescents' knowledge, sleeping patterns, parental effect, food availability, and taste all influence Saudi adolescents' dietary intake and nutritional status (Al-Almaie, 2005; Al-Disi et al., 2010; AL-Jaaly, 2012; ALFaris et al., 2015). The increased intake of foods high in sugar and salt is linked to increased risk of obesity, diabetes, and cardiovascular diseases (CVD), all of which are health concerns among Saudi adolescents and adults (Al-Rubeaan et al., 2018; Alowfi et al., 2021; DeNicola et al., 2015; Kalaf et al., 2016). Despite the importance of taste as a key predictor of food intake and, thus, as a potential indicator of future health, we are aware of only one study conducted on Saudi adolescents concerning taste preference and intake (Ashi et al., 2017), and that study focused specifically on the impact of sweet taste preference and intake on dental health.

Taste preference is learned over time with repeated exposure (Eertmans et al., 2001), studying dietary intakes from a taste perspective could help improve adolescents' eating behaviours and help establish interventions and policies concerning taste and foods. Therefore, this exploratory study aimed to characterise and assess the dietary intake of Saudi adolescents by taste, and to explore the associations between their dietary intake from each taste and food-taste liking, daily energy intake, BMI and diet quality.

8.2 Method

8.2.1 Study Design and Data Collection

The study involved a sample of adolescents in Saudi Arabia aged 12–19. Due to recruitment challenges related to COVID-19, participants were approached through families and friends via text messages. Informed consent was obtained from adolescents and their parents. Ethical approval for the study was obtained from the University of Leeds MEEC 19-003, including an approval letter from the Ministry of Education in Saudi Arabia permitting this study to proceed. Data collection involved two steps: a food-taste online survey, followed by two self-reported non-consecutive 24-hour dietary recalls obtained through an online dietary assessment tool, Arabic myfood24 (Bawajeeh et al., 2021).

8.2.1.1 **Food-taste online survey**

The online survey asked the following: 1) demographic questions such as age, gender, weight, height, health, and income, as well as general dietary questions on taste preferences when hungry and snacking; 2) food liking (i.e. food preference) questions—with food items representing the basic tastes (sweet, salty, sour, bitter) adapted from the previous food preferences questionnaires (Borazon et al., 2012; Catanzaro et al., 2013)—on a 5-point Likert scale (1 = Don't like it at all and 5 = Like it a lot; a “0” category to represent food items that were "never tried" was also added); and 3) food taste classification questions adapted from our previous work on UK adolescents (Bawajeeh et al., 2022b), where participants were asked to assign one main taste (sweet, salty, sour, bitter, savoury (umami), or neutral) to a list of foods. The neutral taste was given as an option for food that may be light in taste or may have an unclear main taste (Nguyen et al., 2020), and a “never tried” option was also given. Food items included in both the food preference questions and the food taste classification list were chosen based on national studies of what is typical for Saudi adolescents (Adam et al., 2014; Almajwal et al., 2018; Alsufiani et al., 2015; Gosadi et al., 2017).

The initially developed survey was tested with a sample of 10 adolescents to check its accuracy, acceptability, and clarity. Because the results from the tested survey indicated its length that resulted in boredom, the survey was shortened and modified as follows: 1) in the food liking questions, an item was removed if the result was “never tried” by > 50% (e.g. Helium); 2) in the food taste classification, an item with > 50% taste agreement was accepted as the final classified taste to be used and was removed from the final survey (85 food items get > 50% taste agreement). In addition to the demographic questions, thus, the final survey included a total of 16 items (4 for each taste) in the food liking questions and a total of 86 food items in the food taste classification list. All survey components were in the Arabic language.

To check the accuracy of the adolescents' taste classification, responses from the taste classification survey were checked against taste profile database conducted by trained panellists from previous works in the literature (Teo et al., 2018; van Langeveld et al., 2018; Mars et al., 2020). A total of 101 food items were available for checking There was 85% agreement (n= 86), 8% disagreement (n=8), 5% differed between savoury and salty tastes (n=5) and 2% neutral (n=2) (Appendix E.1 in the Supplementary Materials).

8.2.2 Diet quality

The Diet Quality Index for Adolescents (DQI-A) was used to calculate participants' diet quality scores. It is a validated tool that assesses the degree of adherence to food-based dietary guidelines (FBDG) based on three main components: the diet quality component (DQc), the diet diversity component (DDc), and the diet equilibrium component (DEc), which in turn is comprised of two sub-components: diet adequacy (DAx) and diet excess (DEx). The DQI-A score is computed as a percentage; the DDc and DEc each range from 0% to 100%, while the range of the DQc is –100% to 100%. Thus, the DQI-A is the mean percentage of those three components, and the DQI-A score ranges from –33% to 100% (Vyncke et al., 2013).

Since food groups and portion sizes of the Saudi Arabian food-based dietary guidelines (FBDG) (Saudi Arabia Ministry of Health, 2022) are similar to the UK food-based dietary guidelines (FBDG) (Public Health England, 2018a), we calculated the diet quality components and the overall score according to our previous work on UK adolescents (Taher et al., 2019; Bawajeeh et al., 2022a). Briefly, the DQc was calculated by multiplying the daily amounts of foods consumed from each food group by different factors: 1 for "preference group", 0 for "intermediate group", and -1 for "low-nutrient, energy-dense group". Appendix E.2 in the Supplementary Materials presents the classification by "preference", "intermediate", and "low-nutrient, energy-dense" food groups. The DDc measures the variation in the adolescent diet on a scale of 0 to 9 based on nine recommended food groups, where consumption of at least one serving from the nine recommended food groups adds a point. The serving sizes of the nine recommended food groups were as follows: (1) water, 200 ml; (2) bread and cereal, 35 g; (3) potatoes and grains, 175 g; (4) vegetables, 80 g; (5) fruit, 80 g; (6) milk products, 200 g; (7) cheese, 30 g; (8) meat, fish, and substitutes, 100 g; and (9) fat and oils, 4g. The DEc assesses the adherence of adolescents to the minimum and maximum intakes calculated based on its two sub-components DA (the minimum recommended intake from the nine food groups) and DEx (the intake exceeds the upper limit of the recommendations of eleven food groups, which are the previous nine recommended groups and two non-recommended groups that include snacks and sugary drinks) (Vyncke et al., 2013).

8.2.3 Data analysis

Descriptive statistics were used to describe participants' characteristics. For the food liking questions, Cronbach's alpha was used to determine internal consistency and reliability (Gliem and Gliem, 2003). Mean food liking scores for each taste group (sweet, salty, sour, and bitter) were calculated. For example, the scores of the four sweet-tasting foods obtained from the Likert questions in the survey were added together before the mean score was calculated (Joshi et al., 2015).

Responses from the food-taste classification questions were included in a Hierarchical Cluster Analysis (HCA) using Python Software Foundation version 3.9. to decide on the number of taste clusters based on the dendrogram and assessment of the scree plot. A specific taste was then allocated to each food reported as consumed in the food records (Bawajeeh et al., 2022b). Then, for each individual, the total weight of food from each taste was calculated to generate an average amount of food consumed by taste per day. Likewise, the total weight of food groups (vegetables, fruit, sweet snacks, salty snacks, and takeaway foods) was calculated to generate an average amount consumed by taste per day.

To describe adolescents' dietary intake by taste, individuals were divided into two groups—low and high consumers—based on the median percentage of foods consumed for each taste identified (sweet, salty, neutral and bitter). For the sour taste, due to the high number of non-consumers, participants were divided into consumers and non-consumers. An independent sample t-test was used to compare the two groups of consumption.

Multivariable regression analyses were carried out to examine the relationship between the intakes from each taste (g/d) (outcome) and food-taste liking scores (predictors). Further multivariable regression analyses were carried out to explore the relationship between the intakes by taste and the daily energy intake, BMI, and diet quality. The daily energy intake, BMI, and diet quality were each treated as the outcome variable, and the amounts of food consumed per taste (scaled by 10) were treated as predictors.

Daily energy intake misreporting was calculated by determining the basal metabolic rate (BMR) according to participants' body weights and using the standard equations of Schofield Cut-off points based on multiples of BMR with minimum (1.39 and 1.30) and maximum (2.24 and 2.10) for both genders, respectively, to identify under-reporters and over-reporters (Albar et al., 2014).

All models are presented as unadjusted and adjusted (multivariable regression models were adjusted for age, gender, and monthly income). Analyses were performed using STATA statistical software version 16.1.

8.3 Results

8.3.1 Characteristics of the participants

Table 8-1 provides a descriptive summary of the participants. A total of 76 adolescents aged 12–19 participated in the first stage and answered the food-taste survey; however, only 46 adolescents completed the study. Thus, the current work represents findings of dietary taste for those remaining 46 adolescents (girls = 25; boys = 21), a relatively small sample size. The mean age of participants was 16, with a mean BMI of 22.8 kg/m2. Seven of the participants reported health issues of iron deficiency and one had vitamin B deficiency. The mean daily energy intake was 1276 kcal/d, and 96% (n = 44) of participants under-reported the energy intake. The mean diet quality score (DQI-A) was 17.9% (95% CI 7.6, 28.2). Salty foods were preferred when hungry by 46% of the participants (n = 21). More than half of the boys (57%) answered that they would prefer salty foods when hungry, whereas most of the girls (40%) reported no taste preference. However, sweet foods were preferred as snacks by 48% (n = 22) of the participants.

The Cronbach's alpha value ranged between 0.53 and 0.62 (Appendix E.3). The results of the Likert scale indicated a higher mean liking score for salty-tasting foods, at 17.3 (95% CI 16.8, 17.9), and for sweet-tasting foods, at 16.8 (95% CI

16.2, 17.4). The mean Likert score for each item is illustrated in Appendix E.4 and the frequency answers are shown in Appendix E.5.

Table 8-1. Summary description of the participants

	Total sample (n= 46)	Girls (n= 25)	Boys (n=21)
Age (mean, 95%CI)	16 (15.6, 16.8)	16 (15.6, 17)	16 (15, 16.9)
BMI (mean, 95%CI)	22.8 (21, 24.5)	21.3 (19, 23.3)	24.6 (21.6, 27.5)
BMI categories (n, %)			
Underweight	11 (24%)	5 (20%)	6 (29%)
Normal	25 (54%)	17 (68%)	8 (38%)
Overweight	6 (13%)	2 (8%)	4 (19%)
Obese	4 (9%)	1 (4%)	3 (14%)
Health issue (n, %)			
None	28 (61%)	13 (52%)	15 (71%)
Iron deficiency	7 (15%)	6 (24%)	1 (5%)
Vitamin B deficiency	1 (2%)	1 (4%)	0
Not sure	10 (22%)	5 (20)	5 (24%)
Dietary intake (mean, 95%CI)			
Energy (Kcal/d)	1276 (1115, 1436)	1025 (831, 1219)	1574 (1362, 1787)
Carbohydrate (g/d)	157 (136, 178)	124 (98, 149)	196 (168, 224)
Protein (g/d)	57 (49, 66)	46 (36, 56)	71 (58, 85)
Fat (g/d)	50 (43, 57)	40 (32, 49)	61 (52, 71)
Total sugar (g/d)	52 (42, 63)	38 (27, 50)	69 (53, 86)
Sodium (mg/d)	1463 (1237, 1688)	144 (894, 1393)	1842 (1495, 2190)
Energy intake misreporting (n, %)			
Under-report	44 (96%)	24 (96%)	20 (95%)
Plausible	2 (4%)	1 (4%)	1 (5%)
Diet quality score (%)(mean, 95%CI)	17.9 (7.6, 28.2)	18.4 (4.5, 32.3)	17.4 (1.0, 34.1)
Preferred foods when hungry (n, %)			
Sweet	10 (22%)	5 (20%)	5 (24%)
Salty	21 (46%)	9 (36%)	12 (57%)
Sour	1 (2%)	1 (4%)	0
Bitter	0	0	0
No preference	4 (30%)	10 (40%)	4 (19%)
Preferred foods when snacking (n, %)			
Sweet	22 (48%)	12 (48%)	10 (48%)
Salty	12 (26%)	5 (20%)	7 (33%)
Sour	5 (11%)	4 (16%)	1 (5%)
Bitter	0	0	0
No preference	7 (15%)	4 (16%)	3 (14%)
Food liking scores (mean, 95%CI)			
Sweet	16.8 (16.2, 17.4)	16.8 (16.0, 17.5)	16.8 (15.8, 17.8)

Salty	17.3 (16.8, 17.9)	17.5 (16.9, 18.1)	17.1 (16.2, 18.0)
Sour	14.9 (13.9, 15.8)	15.7 (14.5, 16.9)	13.9 (12.4, 15.3)
Bitter	10.9 (9.7, 12.0)	11.0 (9.4, 12.6)	10.7 (8.9, ,12.4)

8.3.2 Classification of food intake by taste

The HCA of the 87 foods resulted in six potential taste clusters: sweet, salty, sour, bitter, neutral, and sweet-sour, with examples of foods in each taste presented in Appendix E.6. However, when allocating the tastes to the participants' actual food records, there were no foods consumed to be categorised as sweet-sour. Thus, foods in the sweet-sour cluster were merged with the sweet cluster, as it was the closest cluster distance according to the dendrogram (Appendix E.7). Therefore, the final taste clusters retained and applied to the adolescents' foods in the present work are sweet, salty, sour, bitter, and neutral.

Applying the identified predominant tastes to the individual food codes in the diaries resulted in 46% salty-tasting foods (n = 105), 34% sweet-tasting foods (n = 77), 9% neutral-tasting foods (n= 20), 6% sour-tasting foods (n = 15), and 5% bitter-tasting foods (n = 12). Foods that mainly contributed to the salty taste were composite dishes (e.g. rice-based with meat, poultry, fish, and/or vegetables), takeaway/fast foods, chips (e.g. French fries), noodles, snacks (e.g. crisps, popcorn, and nuts), pastries, eggs, and spreadable cheese. Foods characterised as sweet-tasting included snacks (e.g. biscuits, chocolates, and candies), desserts (e.g. cakes, Middle Eastern desserts, doughnuts, and cheesecakes), sweetened beverages, dairy products (e.g. milk, dairy desserts, and ice cream), and fruit (e.g. dates, fruit salad, banana). Neutral tasting foods included bread, plain pasta, boiled eggs, and some vegetables. Foods that contributed to the sour taste were dairy products (e.g. yoghurt, buttermilk, and labneh, which is thicker than Greek yoghurt and is commonly spread on bread), fruits (e.g. lemons, green olives), and some Middle Eastern foods that are known for their sourness (e.g. stuffed grape leaves and Tabouleh and Fattoush, which are types of salads). Foods that contributed to the bitter taste were coffee and tea.

8.3.3 Characteristics of adolescents' dietary taste

More than half (60%) of the participants' daily energy intake came from salty-tasting foods, at 763 kcal/d (95% CI 641, 884), and a quarter of the daily energy intake came from sweet-tasting foods, at 316 kcal/d (95% CI 248, 384) (see Figure 8-1).

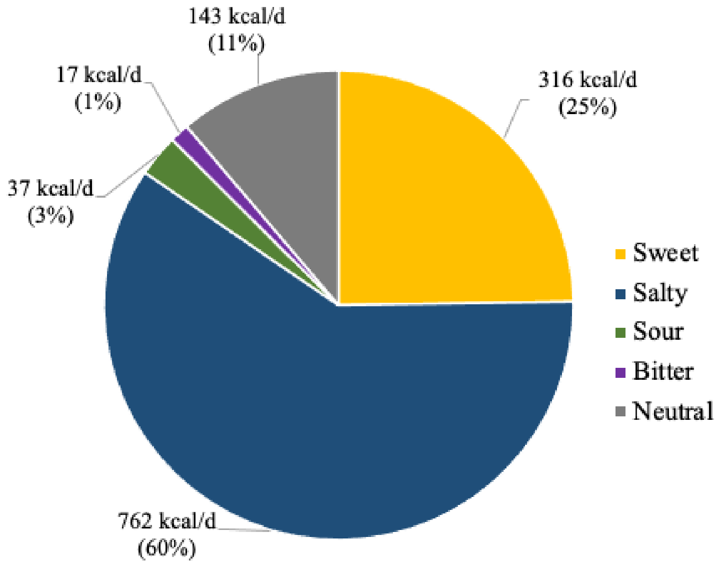

Figure 8-1. Energy intake (kcal/d) from food taste clusters

Table 8-2 illustrates characteristics of adolescents' dietary intake by taste. High vs low consumers, or consumers vs non-consumers, had higher energy intake; however, no significant mean differences were detected. Individuals who had a higher consumption of salty-tasting foods had a significantly higher protein intake, by 23 g/d (95% CI 7, 40; $P < 0.01$), and higher sodium intake, by 288 mg/d (95% CI 281, 1094; $P < 0.01$), compared with those with low consumption. Total and free sugars intakes were significantly higher within the high consumption of sweet-tasting foods compared to those who had low consumption, with a mean difference of 20 g/d (95% CI -0.3, 40; $P = 0.05$) for total sugar and 9 g/d (95% CI 1, 17; $P = 0.03$) for free sugars. High consumption of neutral-tasting foods was associated with a lower intake of protein, saturated fat, sodium, and iron, although in comparison with low consumers these differences were not statistically significant. Those who consumed sour-tasting foods had a higher significant intake of takeaway foods compared with non-consumers, with a mean difference of 103 g/d (95% CI 20, 186; $P = 0.01$).

Table 8-2. Characteristics of adolescents' dietary intakes by high vs low taste consumers

	Salty-tasting foods		
	Low consumers (n=23) Consumption= 22-40%	**High consumers (n=23) Consumption= 41-76%**	***P*-value***
Energy (kcal/d)	1182 (963, 1401)	1369 (1124, 1614)	0.24
Carbohydrate (g/d)	157 (124, 190)	157 (128, 186)	0.99
Protein (g/d)	46 (34, 57)	69 (57, 81)	**<0.01**

Fat (g/d)	45 (37, 54)	55 (44, 65)	0.16
Total sugar (g/d)	61 (43, 78)	44 (32, 56)	0.10
Free sugar (g/d)	19 (13, 25)	18 (12, 25)	0.90
Saturated fatty acid (g/d)	15 (12, 17)	17 (12, 21)	0.57
Sodium (mg/d)	1119 (896, 1341)	1807 (1452, 2161)	**<0.01**
Iron (mg/d)	6 (4, 8)	9 (7, 11)	0.07
Vegetables (g/d)	61 (31, 91)	33 (15, 51)	0.10
Fruit (g/d)	57 (13, 101)	71 (45, 97)	0.58
Sweet snacks (g/d)	44 (24, 64)	53 (28, 77)	0.57
Salty snacks (g/d)	26 (10, 41)	19 (6, 32)	0.51
Takeaway foods (g/d)	112 (59, 165)	152 (83, 221)	0.34
	Sweet-tasting foods		
	Low consumers (n=23) Consumption= 0-24%	**High consumers (n=23) Consumption= 25-57%**	***P*-value***
Energy (kcal/d)	1235 (977, 1493)	1316 (1106, 1527)	0.61
Carbohydrate (g/d)	146 (114, 178)	168 (138, 197)	0.31
Protein (g/d)	57 (42, 72)	58 (47, 68)	0.94
Fat (g/d)	49 (38, 60)	51 (42, 59)	0.84
Total sugar (g/d)	42 (28, 57)	62 (47, 77)	**0.05**
Free sugar (g/d)	14 (8, 21)	23 (18, 29)	**0.03**
Saturated fatty acid (g/d)	17 (12, 21)	15 (12, 17)	0.32
Sodium (mg/d)	1404 (1053, 1755)	1521 (1210, 1832)	0.60
Iron (mg/d)	7 (5, 9)	8 (6, 11)	0.33
Vegetables (g/d)	57 (28, 86)	37 (17, 57)	0.23
Fruit (g/d)	49 (10, 89)	79 (47, 110)	0.23
Sweet snacks (g/d)	48 (26, 69)	49 (26, 72)	0.93
Salty snacks (g/d)	26 (10, 41)	19 (6, 32)	0.51
Takeaway foods (g/d)	122 (55, 189)	142 (85, 199)	0.65
	Neutral-tasting foods		
	Low consumers (n=23) Consumption= 0-15%	**High consumers (n=23) Consumption= 16-78%**	***P*-value***
Energy (kcal/d)	1229 (1013, 1445)	1322 (1069, 1575)	0.56
Carbohydrate (g/d)	145 (118, 172)	169 (135, 203)	0.25
Protein (g/d)	60 (49, 73)	54 (40, 67)	0.42
Fat (g/d)	48 (39, 57)	52 (41, 63)	0.54
Total sugar (g/d)	47 (35, 59)	57 (40, 75)	0.33
Free sugar (g/d)	17 (12, 21)	21 (13, 28)	0.32
Saturated fatty acid (g/d)	14 (11, 16)	18 (13, 22)	0.14
Sodium (mg/d)	1568 (1256, 1880)	1358 (1012, 1703)	0.35
Iron (mg/d)	8 (7, 10)	7 (5, 10)	0.51
Vegetables (g/d)	38 (19, 57)	56 (26, 86)	0.29
Fruit (g/d)	70 (43, 97)	57 (14, 101)	0.60
Sweet snacks (g/d)	61 (34, 87)	36 (20, 52)	0.10
Salty snacks (g/d)	27 (13, 41)	18 (3, 32)	0.34
Takeaway foods (g/d)	163 (101, 225)	100 (42, 160)	0.14
	Bitter-tasting foods		
	Low consumers (n=23) Consumption= 0-9%	**High consumers (n=23) Consumption= 10-50%**	***P*-value***
Energy (kcal/d)	1256 (999, 1513)	1295 (1082, 1508)	0.80

Carbohydrate (g/d)	154 (120, 189)	159 (133, 186)	0.82
Protein (g/d)	54 (42, 66)	60 (47, 74)	0.45
Fat (g/d)	50 (39, 60)	50 (40, 60)	0.94
Total sugar (g/d)	52 (35, 70)	53 (40, 65)	0.97
Free sugar (g/d)	19 (12, 26)	18 (13, 24)	0.95
Saturated fatty acid (g/d)	15 (11, 19)	16 (13, 19)	0.72
Sodium (mg/d)	1506 (1149, 1864)	1419 (1115, 1724)	0.70
Iron (mg/d)	8 (6, 11)	7 (6, 8)	0.40
Vegetables (g/d)	48 (23, 73)	46 (21, 72)	0.93
Fruit (g/d)	57 (30, 85)	71 (27, 114)	0.59
Sweet snacks (g/d)	41 (22, 61)	55 (31, 80)	0.35
Salty snacks (g/d)	17 (5, 29)	28 (11, 44)	0.28
Takeaway foods (g/d)	111 (48, 174)	153 (92, 213)	0.31
	Sour-tasting foods		
	Non consumers (n=29) Consumption= 0%	**Consumers (n=17) Consumption= <1-49%**	***P*-value***
Energy (kcal/d)	1216 (1039, 1393)	1378 (1043, 1712)	0.33
Carbohydrate (g/d)	150 (128, 173)	168 (123, 213)	0.43
Protein (g/d)	56 (44, 67)	61 (45, 76)	0.58
Fat (g/d)	47 (39, 55)	55 (41, 69)	0.25
Total sugar (g/d)	46 (36, 56)	63 (40, 86)	0.12
Free sugar (g/d)	17 (12, 21)	22 (13, 31)	0.21
Saturated fatty acid (g/d)	14 (12, 17)	18 (12, 24)	0.13
Sodium (mg/d)	1316 (1071, 1561)	1713 (1255, 2171)	0.08
Iron (mg/d)	7 (6, 8)	9 (6, 13)	0.07
Vegetables (g/d)	49 (28, 70)	43 (10, 76)	0.72
Fruit (g/d)	68 (34, 102)	58 (20, 95)	0.69
Sweet snacks (g/d)	55 (34, 76)	37 (15, 58)	0.24
Salty snacks (g/d)	18 (5, 31)	30 (14, 46)	0.23
Takeaway foods (g/d)	94 (47, 141)	197 (119, 275)	**0.01**

*Differences were assessed by an independent sample t-test

8.3.4 Association between food-taste liking scores and dietary intake from taste groups

There was no significant association between the overall food liking score from the Likert-scale and the intake of foods tasting sweet, salty, and neutral. Overall liking score of salty foods was significantly associated with an increased intake of bitter-tasting foods by 28 g/d (95% CI 7, 50; *P* = 0.01), and the association became stronger after adjusting the model with an increase in the intake of bitter-tasting foods by 30 g/d (95% CI 9, 50; *P* < 0.01). Overall liking score of bitter foods was associated with an increased intake of sour-tasting foods, by 6 g/d (95% CI 0.2, 13; *P* = 0.04) (Table 8-3).

Table 8-3. Association between taste liking and food intake from each taste

Food intake by taste (g/d)			Food liking scores			
			Sweet	**Salty**	**Bitter**	**Sour**
Salty foods	**Unadjusted**	Coeff. (95%CI) *	20 (-11, 51)	3 (-35, 42)	1 (-15, 17)	-1 (-22, 19)
		P- value	0.20	0.85	0.91	0.90
	Adjusted ^	Coeff. (95%CI) *	12 (-15, 41)	5 (-29, 40)	1 (-13, 17)	7 (-12, 27)
		P- value	0.37	0.77	0.79	0.43
Sweet foods	**Unadjusted**	Coeff. (95%CI) *	-1 (-26, 23)	-7 (-38, 23)	-3 (-16, 9)	-6 (-23, 9)
		P- value	0.90	0.60	0.57	0.40
	Adjusted ^	Coeff. (95%CI) *	-4 (-26, 16)	-6 (-32, 20)	-2 (-14, 8)	2 (-12, 17)
		P- value	0.65	0.64	0.63	0.78
Neutral foods	**Unadjusted**	Coeff. (95%CI) *	-14 (-56, 26)	-17 (-68, 33)	-10 (-32, 11)	-3 (-30, 24)
		P- value	0.46	0.49	0.33	0.81
	Adjusted ^	Coeff. (95%CI) *	-18 (-60, 23)	-15 (-66, 35)	-12 (-35, 9)	4 (-24, 33)
		P- value	0.36	0.54	0.26	0.76
Bitter foods	**Unadjusted**	Coeff. (95%CI) *	6 (-11, 23)	28 (7, 50)	7 (-2, 16)	-10 (-22, 1)
		P- value	0.49	0.01	0.13	0.6
	Adjusted ^	Coeff. (95%CI) *	4 (-12, 21)	30 (9, 50)	4 (-4, 13)	-7 (-19, 3)
		P- value	0.60	**<0.01**	0.27	0.17
Sour foods	**Unadjusted**	Coeff. (95%CI) *	-7 (-19, 4)	9 (-4, 23)	6 (-0.1, 12)	1 (-6, 9)
		P- value	0.20	0.19	0.05	0.71
	Adjusted ^	Coeff. (95%CI) *	-8 (-20, 3)	9 (-5, 23)	6 (0.2, 13)	1 (-6, 10)
		P- value	0.14	0.21	**0.04**	0.69

* Coeff. Indicates the increased intake of foods in each taste (g/d) for every increase in the liking score; ^ Models adjusted for age, gender and monthly income

8.3.5 Associations between the dietary intake from taste groups and energy intake, BMI, and diet quality

Salty, sweet, and neutral-tasting foods were significantly associated with energy intake. The greatest effect in energy intake was associated with salty-tasting foods at 17 kcal/d (95% CI 13, 22; *P* < 0.01) for every 10g/d increase in intake. Energy intake increased by 9 kcal/d (95% CI 3, 15; *P* < 0.01) and by 7 kcal/d (95% CI 4, 10; *P* < 0.01) for every 10g/d increase in the intake of sweet-tasting and neutral-tasting foods, respectively. There was no significant association between BMI and any of the food taste groups. In relation to diet quality, neutral- and bitter-tasting foods were significantly associated with positive diet quality score, of 1.0% (95% CI 0.1, 1.1; *P* < 0.01) and 1.1% (95% CI 0.1, 2.1; *P* = 0.03), respectively (Table 8-4).

Table 8-4. Association between food taste groups and the daily energy intake, BMI, and diet quality

Food intake by taste (10g/d)	Unadjusted		Adjusted ^	
	Coeff.[1] (95%CI)	***P*-value**	**Coeff. [1] (95%CI)**	***P*-value**
	Energy intake (kcal/d)			
Sweet-tasting foods	10 (4, 15)	<0.01	9 (3, 15)	**<0.01**
Salty-tasting foods	17 (13, 21)	<0.01	17 (13, 22)	**<0.01**
Neutral-tasting foods	7 (4, 9)	<0.01	7 (4, 10)	**<0.01**
Bitter-tasting foods	1 (-5, 7)	0.76	2 (-4, 9)	0.47
Sour-tasting foods *	33 (-122, 188)	0.67	29 (-130, 187)	0.71
	BMI (Kg/m²)			
Sweet-tasting foods	-0.03 (-0.1, 0.1)	0.55	-0.09 (-0.2, 0.04)	0.18
Salty-tasting foods	0.1 (0.004, 0.2)	0.04	0.1 (-0.02, 0.2)	0.11
Neutral-tasting foods	<0.01 (-0.05, 0.1)	0.80	-<0.01 (-0.07, 0.1)	0.91
Bitter-tasting foods	0.04 (-0.1, 0.2)	0.55	0.01 (-0.1, 0.2)	0.84
Sour-tasting foods *	0.1 (-3.5, 3.6)	0.96	0.1 (-3.5, 3.7)	0.96
	Diet quality (%)			
Sweet-tasting foods	0.2 (-0.4, 1.0)	0.41	0.4 (-0.2, 1.2)	0.16
Salty-tasting foods	-0.4 (-1.0, 0.1)	0.10	-0.3 (-0.8, 0.1)	0.19
Neutral-tasting foods	0.5 (0.1, 1.0)	0.01	1.0 (0.3, 1.1)	**<0.01**
Bitter-tasting foods	0.2 (-0.5, 1.0)	0.56	1.0 (0.1, 2.1)	**0.03**
Sour-tasting foods *	5.9 (-14.7, 26.7)	0.56	5.0 (-13.0, 23.0)	0.61

*Consumers of sour-tasting foods.
^ Models adjusted for age, gender and monthly income.
[1] Coeff. indicates the increase intake of energy intake (kcal/d)/ BMI (kg/m2), diet quality (%) for every 10 (g/d) increase in the food intake from each taste group

8.4 Discussion

Adolescents are in a critical period of growth and development associated with a number of behavioural changes. Because perceived taste and preferences were suggested to determine their food selections and dietary intake, the current study aimed to characterise Saudi adolescents' dietary intakes by taste, as perceived and classified by the participants themselves. Despite the relatively small sample size achieved, findings indicated that adolescents as typical consumers could provide a potentially effective food taste classification, reflecting how they perceive the taste of foods they choose to eat and how that affects their dietary intake and diet quality.

In comparison to food taste classifications conducted by trained panellists, the classification done by our participants showed a good level of agreement. However, variations in taste perceptions are expected due to genetics and environmental factors. Therefore, although the disagreement observed in our work against the work done by the trained panellists was minor, a couple of explanations could be provided. First, the ingredients used in the foods may differ, resulting in some taste differences. Second, in the case of raw food items like fruit and vegetables, a number of factors may impact the perceived taste, including the crops' level of ripeness, seasonality, the water and soil used, and the type of the crop itself (e.g. some tomatoes are sweeter than others, some lettuce can be bitter while others can have a sweet taste). Moreover, the two populations' different ages, ethnicities, and cultural backgrounds could have impacted the classifications (Wang et al., 2020; Williams et al., 2016).

Salty-tasting foods were the highest contributors (60%) to our participants' daily energy intake. In comparison to our previous work on British adolescents, sweet- and neutral-tasting foods were equally major contributors to the daily energy intake (Bawajeeh et al., 2022b). While this is similar to the findings observed in Dutch adults who had most of their energy intake from "salt, umami, and fat" eating foods (van Langeveld et al., 2018), variations between the present work and our previous work on UK adolescents could be attributed to a couple of potential reasons. The differences could indicate the cultural and environmental effects on taste as a key element in food selection (Jeong and Lee, 2021). It may also indicate a taste preference, which can be explained by the current findings of a high preference for salty-tasting foods reported by our participants. Moreover, the recruitment bias, small sample size, and potential underreporting of foods may have affected the outcome (Jones et al., 2021). Interestingly, although the savoury taste option was given as a potential response in our taste classification survey, very few of the foods were categorised by this taste by only a few adolescents, which consequently was not appropriate for forming a savoury taste cluster in the HCA. This suggests that the savoury taste may be unfamiliar to our population, or that they perceive it as a salty taste (Overberg et al., 2012; Mouritsen, 2012; Hartley et al., 2019).

Only a few differences in the nutrient intakes were observed between those who had higher and lower consumption of each taste; however, as we have noted earlier, this may be affected by the potential underreporting of some foods. Nevertheless, findings showed that a higher intake of salty-tasting foods was linked to a higher protein and sodium intake. This has been reported to indicate a taste-nutrient relationship (van Dongen et al., 2012). Although in our previous work on UK adolescents no significant association was obtained between protein intake and the increased intake of salty-tasting foods (Bawajeeh et al., 2022b), the currently observed association is due to the salty taste here including foods that were previously classified as savoury (e.g. meat and poultry), which signals protein content. In contrast, similar to the findings from the UK work, as expected, a higher intake of sweet-tasting foods was linked with a higher intake of sugars compared with those who had less intake. Interestingly, consumers of sour-tasting foods had a significantly higher intake of takeaway foods than did non-consumers. This may suggest an association between the sour and salty tastes (Keast and Breslin, 2003), which could be explained by the sourness produced from sauces and additives added to foods and the saltiness that is dominantly perceived in takeaway foods.

In exploring the relationship between food-taste liking scores and food intake from taste groups, we found one association between the liking score of salty foods and the intake of bitter-tasting foods, and another significant association between the liking score of bitter foods and the intake of sour-tasting foods. While there is no clear explanation for these associations, this may be due to a few possible reasons. First, it may be that the type and number of foods included in the food liking questions were unsatisfactory. This could be explained by the values of Cronbach's alpha obtained, although the same values have been considered acceptable and reliable in some studies (Taber, 2018). Second, foods included in the Likert-scale questions may not, per se, suggest inclusive liking. For example, while 44% of the participants said they did "like/like a lot" black coffee or tea, this does not mean they liked all bitter tastes in general. Also, preference for a certain taste, for example sweet, may not mean a generalisable preference or intake of all sweet-tasting foods. For example, a higher intake of sweet-tasting items, including sugar-sweetened drinks, sweets snacks, and cake/doughnuts, compared to the consumption of fruit was reported among Saudi adolescents (Al-Hazzaa et al., 2012). Nevertheless, a potential correlation between salty and bitter tastes has been reported (Cui et al., 2019), which may be due to the role of the salty taste in supressing bitterness (Keast and Breslin, 2003). Moreover, the obtained association between bitter and sour tastes may refer to a common confusion between them (Doty et al., 2017). Nevertheless, mixed or undefined associations between food-taste liking and intake have been noted previously, and small sample size has been suggested as a possible explanation for the findings (Feeney et al., 2021).

All tastes, except bitter and sour, showed a positive significant association with energy intake. However, the greatest effect was observed with the salty-tasting foods, which is probably due to the high consumption of these foods. Foods classified as salty were mainly composite dishes that are rice-based with meat, poultry, fish, or vegetables. These foods are commonly consumed at lunch and dinner in Saudi culture (Al-Mssallem, 2018; Mohamed et al., 2019), which was also observed in the present work's food records. Moreover, takeaway foods included in the salty taste are often highly consumed by Saudis at dinner. A review study reported that the prevalence of fast-food (takeaway foods) consumption among Saudi adolescents is 25%–80% (Alasqah et al., 2021). These foods are high in fat in addition to carbohydrates and protein as calorie derivatives. Saltiness plays a role in the palatability and pleasantness of the foods (Bolhuis et al., 2016); however, the excessive amount of salt in foods commonly consumed by adolescents and young adults (e.g. fast foods, processed foods, and snacks) (Kazi et al., 2020) is a public-health concern in Saudi Arabia in relation to the increased prevalence of hypertension and cardiovascular disease (CVD) among adolescents and adults (Musaiger, 2002; Almahmoud et al., 2022; Al-Rubeaan et al., 2018).

As in many other parts of the world, the diet of Saudi adolescents is high in fat, sugar, and salt and is inadequate in nutrient-dense foods (Alasqah et al., 2021). This has been a concern because it has increased the prevalence of abnormal body weight (underweight or overweight/obesity) (Abahussain et al., 1999) that is linked to poor diet quality (Alkhaldy et al., 2019; Washi and Ageib, 2010). Because, in the present work, anthropometric measurements (weight and height) were self-reported by participants, there is potential for reporting errors. This could be the reason in observing no significant associations were observed between the intake from all taste groups and the BMI (Sherry et al., 2007).

In regard to diet quality, similar to our previous finding in UK adolescents (Bawajeeh et al., 2022a), neutral-tasting foods are linked to better diet quality among Saudi adolescents. This could be because these foods are plain rice and pasta, bread and vegetables that are low in sugar and salt. Moreover, nutrient-dense foods are often low in taste intensity (Liem and Russell, 2019a). It is similar for the positive diet quality associated with the bitter taste that includes tea and coffee, which may be due to the tea flavonoids-rich component that is good for the health (Vieux et al., 2019), even if the evidence around coffee and health is controversial (Thomas and Hodges, 2019). However, the positive diet quality score we observed here was based on tea and coffee as individual items in the bitter-taste cluster but without considering any added sugar as part of the diet pattern, which may change the outcome association. However, generating dietary taste patterns in the present work was not feasible due to sample inadequacy (Santos et al., 2019).

This study has a number of strengths as well as limitations. The main strength is related to the taste classification. Although the classified foods were based on a list of commonly consumed foods as per national studies, most of these foods were reported in the food records. Thus, foods were classified as perceived by the actual consumers. Also, we obtained adolescents' food and taste preferences to get a better sense of the role of taste in their dietary intakes and preferences. We used a new online dietary assessment tool that included foods familiar to this study population and fully in their native language, Arabic. Although innovative dietary assessment tools were suggested to enhance dietary records, reporting errors—including potential underreporting of some food or misreporting of portion sizes due to literacy skills, reliance on memory associated with 24-hour recalls and cognitive aspects of reporting diet among adolescents—are expected. Moreover, although dietary data of the current study was collected after lifting COVID-19 lockdown, general COVID-related restrictions, including restaurants and eating out, were still applied. Thus, the period when data was collected may associate with changes in adolescents' usual dietary intake that could have been affected during that time. Therefore, this limitation should be minded concerning the identified associations between dietary intakes and taste in this study. Thus, all that could have affected the results of the identified dietary tastes and associations in this study. Potential errors related to self-reported weight and height may obstruct obtaining a significant association between BMI and food intake. Although the sample size achieved was small, the size achieved is considered acceptable for a pilot study (In, 2017). However, we suspect it may have limited the quantity and type of classified food taste and may have limited the observed associations between food liking and food intake. Moreover, due to the small sample size and the potential for multiple testing as a result of exploring tastes in relation to a range of nutrients some of the statistically significant associations could have occurred by chance (i.e. potential false positive associations). The size of the sample was due to COVID-19 restrictions and the inability to travel and recruit participants. Additionally, with schools being switched to a virtual system (online), it was not possible to approach participants through teachers during classes. For the Likert-scale survey, the low Cronbach's alpha values obtained may be due to the types or number of foods. Thus, it may be worth testing the items included in the Likert-scale questions and calculating Cronbach's alpha for internal reliability before the actual use. This exploratory study may suggest an intercorrelation between taste perceptions, food-taste preferences, and food intake. A wider exploration of adolescents' food preferences from a taste perspective, alongside studying the taste characteristics of their dietary intakes, could lead to a better understanding of their eating behaviours.

8.5 Conclusion

The salty taste was dominant in our participants' dietary intake. Food tastes could influence adolescents' eating behaviours and their diet quality. Taste classification of foods by typical consumers seems to be reliable. Food-cultural backgrounds, familiarity, and preferences influence individuals' dietary tastes. Such findings could help improve perceived taste preferences and enhance people's dietary intake.

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Chapter 9 Overall discussion and conclusion

9.1 Introduction

Adolescents between 10 and 19 years old comprise over 16% of the world's population, and they play a key role in future sustainability (World Health Organization, 2022). As a unique phase of human development, adolescence is the period when habits and behaviours, such as those related to diet, are established and can potentially persist into adulthood. There is a critical need for good nutrition during adolescence, which could be associated with increased levels of energy and nutrients intake. However, many adolescents adopt unhealthy diet behaviours (i.e. consumptions of high calorie-dense foods but low intake of vegetables) that compromise their health (Public Health England, 2017). While several factors affecting adolescents' food choices and intake, the sensory taste of foods is reported to be the key driver of food choices in this age group (Fleming et al., 2020).

Many unhealthy diet behaviours are changeable, and many potential health-related risks are preventable; however, the first step towards effective changes is to establish an evidence-based understanding of the current situation. Although various factors that influence adolescents' dietary intake have been studied from a nutritional viewpoint, no study has comprehensively considered the sense of taste, despite its potential importance in guiding food choices. To remedy this gap in published research, the present thesis has studied adolescents' dietary intake from the perspective of taste.

Following the detailed discussions offered in each chapter of the present thesis, this chapter aims to summarise its main findings and discuss the factors that may impact its overall results. The overall strengths and limitations of the thesis, along with its implications and potential future work, will also be discussed.

9.2 Summary of findings

9.2.1 Current evidence on the role of taste in adolescents' food choices and dietary intake

As reviewed in Chapter 2, individuals differ in their taste perceptions: some people can perceive a particular taste at a very low level, while others need a higher threshold level to perceive a specific taste such as bitterness. These variations in taste perceptions are based on individuals' genetic predispositions and other effects. Generally, humans have an innate preference for sweet and salty tastes, while sour and bitter tastes are perceived as unpleasant. Even though the aversion to bitter taste may continue beyond adolescence, adults tend to select their foods based on their cognitive awareness of health and nutrition benefits and, as parents or caregivers, they can also positively influence children in this matter. This influence of parents, however, has less effect on adolescents as they try to be more independent in choosing their food.

Although taste perceptions and preferences play a crucial role in adolescents' decisions in terms of food choices and intake, the existing evidence is limited and does not reflect the entire range of eating patterns. As systematically reviewed in Chapter 3, a limited number of studies has investigated the relationship between adolescents' taste perceptions and preferences, on the one hand, and their food choices and intake, on the other. Studies were limited to bitter and sweet tastes and focused on testing specific food items. Overall, most adolescents seemed to be sensitive to bitter taste. This could follow the same pattern as children's perceptions and preferences, where the aversion is still innate, and where the genetic predisposition may not be greatly affected by external exposures or cognitive awareness, as it is in adults. However, the meta-analysis conducted on the bitter sensitivity and bitter-tasting vegetables in Chapter 3 showed no clear differences between sensitive and less sensitive adolescents. We assume that was due to the small number of studies that qualified to be included in the meta-analysis. Therefore, more studies with standardised methods of taste assessment are needed in this age group to confirm these findings.

In addition, the effect of taste sensitivity and preferences showed different effect patterns in terms of energy and nutrient intakes. Moreover, findings have identified that adolescents' sensitivity to bitter taste could affect preferences for other tastes. For example, higher sensitivity to bitterness was associated with a higher preference for sweetness (i.e. more added sugar in the diet), sour-tasting additives, and salty or savoury-tasting foods. Although this was reported by one study in our review study (in Chapter 3), similar findings with regard to other tastes have been reported and discussed in our analysis in Chapters 4, 5 and 8, referring to the role of taste-taste interactions.

In summary, the findings based on the available evidence indicate the need for more comprehensive studies on the impact of taste on adolescents' dietary intake.

9.2.2 Food taste classification

Humans can perceive five basic tastes through the gustatory sensory system: sweet, salty, sour, bitter and savoury. Although the word "flavour" is used to describe foods in daily life, flavour is often beyond the gustatory sensory system and the five basic tastes. It involves both gustatory and olfactory sensations due to the odour in some foods or the smells produced by the use of flavour-enhancers, such as spices. For example, fruit juice is known for its sweet taste, but it has a fruity or tropical flavour; likewise, the taste of orange or chocolate cake is often described as sweet, but such a cake has an orange or chocolate flavour. The sense of taste, as opposed to flavour, involves the perception of the basic tastes when taste receptors in the oral cavity react to stimulation (Feeney et al., 2021; Institute of Medicine, 2010).

Thus, taste is often the principal and predominant form of the sensory modalities that facilitate the classification of particular foods as, for example, sweet, salty or bitter (Cox et al., 2016). In Section 2.1.1 of Chapter 2, this thesis has reviewed the standard approaches to assessing individuals' taste perceptions and sensitivity towards tastes. Those approaches have enriched the basic knowledge about the variations in taste perception among people and have helped build an understanding of how those variations may affect people's food choices and intake. However, the evidence is inadequate and does not encompass the whole diet.

Such gaps in the available evidence have inspired researchers to study individuals' dietary tastes by classifying the taste of foods, as reviewed in Section 2.2.2 (Table 2-1) of Chapter 2. While using trained panellists for this purpose may be valid, it is costly and time-consuming. It may also result in misclassifications due to repeated procedures or to the use of tastant references (i.e. taste stimuli in water), where responsiveness to tastes in water cannot reflect taste perception in foods. Moreover, bias in panellists' characteristics—including gender, age, BMI or potential day-to-day variations—could affect their perceptions, and their extensive training may not precisely reflect actual perceptions of typical people.

Therefore, this thesis has added to the existing body of literature on normal people's classifications of food tastes, as described in Chapters 4 and 8.

In Chapter 4, the taste of foods consumed by adolescents, as reported in their food records from the NDNS, was classified. Food data in the NDNS were collected using the standard (paper-based) estimated food record method, and taste classification was performed by adults due to ethical considerations, in part related to the recruitment of UK adolescent participants during the COVID-19 pandemic (this was autumn 2020). However, as the situation of COVID-19 slightly improved during autumn 2021, adolescents' food intake in Chapter 8 was collected by self-reported 24-hour recalls using the online dietary assessment tool, Arabic myfood24. The tool was developed entirely in the Arabic language and integrated with a common Middle Eastern food database and its food compositions, as described in Chapter 6. The use of technology-based dietary assessment tools is promising in enhancing the process of dietary assessment, especially among adolescents who are eager to use technology and the internet. The Arabic myfood24 showed good usability and accessibility, as reported in Chapter 7. The taste classification was then reported by Saudi Arabian adolescents.

In order to identify and group foods in participants' food records by taste, the Hierarchical Cluster Analysis (HCA) was used. The HCA allowed similar food items to be grouped according to participants' responses into prominent taste clusters (Tullis and Albert, 2013). Findings from the HCA and taste classification surveys in Chapters 4 and 8 showed an overall similar classification for the taste of foods by the two populations—British adults and Saudi adolescents—except for some differences in classifying foods as salty or savoury. These differences involved a higher proportion of foods classified as salty in the Saudi study compared to the UK study, where foods classified as savoury in the UK study were categorised as salty in the Saudi study (Appendices B.4 and E.1). For example, meat and poultry, meat-based dishes and fast food were classified as salty by the Saudi population, while in the UK they were reported as savoury. Differences in the classification may have two explanations. First, the correlation between salty and savoury tastes suggested by the study may result in an overlap between these two tastes, as discussed in Chapter 4. Second, the potential variation in perceiving the savoury taste as salty may be due to differences in ethnicity and cultural background (Cecchini et al., 2019; Shu-Fen et al., 2018). However, it may be worth noting that although some of those food items were identified as savoury by a few Saudi participants, the HCA could not group these foods into a separate savoury taste group due to inadequate data (Tullis and Albert, 2013).

When savoury and salty tastes were combined in the UK study, 27% of foods were categorised as a savoury/salty taste comprising the second-largest proportion alongside neutral-tasting foods. Thus, these differences may reflect variations in food-cultural backgrounds and familiarity in relation to taste perceptions and preferences (Jeong and Lee, 2021). However, the smaller convenience sample of participants in the Saudi study could have resulted in bias in food reporting and classification. Additionally, the procedures used for collecting food intake information could have impacted the proportion of foods classified within each taste. In the UK study, food intake data were collected through the standard estimated food record method as part of the national diet and nutrition survey (NDNS), whereas in the Saudi study, food intake data were collected by 24-hour recalls using the innovative online dietary assessment tool, Arabic myfood24. Although both approaches are associated with the misreporting of foods, food intake recorded by participants in the NDNS was reviewed by nutritionists to fill in any potential missing foods (Public Health England, 2019) and, thus, reduce the level of misreporting. Because this kind of review did not take place in the Saudi study, food misreporting is expected to be higher there, affecting the proportion of foods within each taste.

The salty/savoury variations between the two populations notwithstanding, however, when the overall taste classifications in both studies were checked against taste classifications conducted by trained panellists in a more systematic method (van Langeveld et al., 2018; Mars et al., 2020; Teo et al., 2018), the number of respondents per taste for the food items from our studies showed a similar pattern as the mean taste intensity values and good agreement for the same foods classified by trained panellists, as discussed in Chapters 4 and 8. For example, if a certain food obtained the highest respondent rating of sweet from our taste classification survey, the mean sweet intensity of the same food was the highest among the mean intensity of the other tastes as evaluated by trained panellists as illustrated in Appendices B.4 and E.1. At the same time, some differences in the taste characteristics of foods are expected due to seasonality, plant varieties and the soil used, which affect the taste of crops. Variations in food preparation methods, ingredients and additives, moreover, can result in different taste perceptions. This can indicate that recruiting a typical population to classify the predominant taste of their food intake is promising and can be more efficient for linking people’s taste perceptions to their dietary intake.

The outcomes of the HCA depended on the taste characteristics of the foods, which helped us construct the predominant taste clusters of the foods. For example, foods that were mainly classified as sweet were grouped together, foods that were mainly classified as salty were grouped together, and so on. Five typical taste clusters (i.e. sweet, salty, sour, bitter and neutral) were obtained from the UK and Saudi studies, with an additional savoury taste obtained only in the UK study because Saudis did not recognise the savoury taste. Similar taste clusters were constructed in previous studies (van Langeveld et al., 2018; Nguyen et al., 2021), except that, in those studies, savoury and salty formed one taste cluster, and sweet and sour formed another. This may be because of the number of observations (i.e. the number and characteristics of the foods) entered into the HCA. Thus, the outcomes of the HCA differ based on the data entered.

9.2.3 Characteristics of adolescents’ dietary intake by taste

Studies reviewed concerning the role of taste in dietary intake among adults, children (Table 2-2 in Chapter 2) and adolescents (Table 3-2 in Chapter 3) lack evidence due to the limited number of studies and heterogeneity involved in measuring taste and dietary intake., where most of these studies examined the influence of taste on specifically chosen food items. Moreover, they assessed relationships based on stimuli solution measurements, which are unrepresentative of tastes in real food consumption. In contrast to that selective approach, studies reviewed in Table 2-3 in Chapter 2 explored the link between taste and dietary intake based on taste classification for the whole food consumed. While these are more comprehensive in using the measures of dietary intake, they only studied the influence of taste on energy intake. Furthermore, taste classifications assessed by highly trained panellists could be questionable compared to typical consumers’ points of view, as discussed previously. Thus, this thesis filled the gap identified in the literature by studying the influence of taste, as classified by regular consumers, on the nutritional characteristics of adolescents' dietary intake, as no such study on this age group existed.

As reported in Chapter 4 and Chapter 8, respectively, the UK adolescents obtained most of their energy intake from sweet- and neutral-tasting foods equally, at 34% each, while Saudi adolescents obtained most of their energy intake from salty-tasting foods (60%) and sweet-tasting foods (25%). The differences in the taste contribution to the daily energy intake may be a consequence of what has been explained in the prior section concerning the food-taste classifications and potential misreporting. However, the intake disparities could also reflect the participants' individual preferences and food-cultural backgrounds. For example, Saudi adolescents reported a preference for salty-tasting foods when hungry. Inspecting the participants' food records, we observed that about 96% of the Saudi adolescents' energy intake at lunch and dinner, combined, came from salty-tasting foods. Foods that contributed to the salty taste were mostly composite dishes based on rice with meat, poultry, fish and/or vegetables. As discussed in Chapters 6 and 8, these foods are typical and frequently consumed by Saudis at lunch and dinner. A recent review reported that rice and bread (often eaten in combination with a protein source) were the most often consumed items among Saudi adolescents, with about 60%–96% reporting consumption of rice at least once daily (Al-Jawaldeh et al., 2020). Unfortunately, the link between taste preferences and intake could not be made for the UK adolescents, as no data on food preferences were available in the NDNS.

Univariate analysis was used to derive and describe the dietary intake by tastes. This made it possible to study the influence of taste on the variables of interest in dietary intake each by itself and to obtain an overall understanding of the existing relationship. In the UK study (Chapter 4), the assessment was conducted by quintile of food tastes consumed, whereas the Saudi study (Chapter 8) used the central tendency of median consumption, due to the smaller sample size. Overall, the findings indicated that a higher intake of sweet-tasting foods was, unsurprisingly, associated with a higher intake of sugar, suggesting that sweet taste signals sugar content in foods (Kochem, 2017). Although the higher intake of sweet-tasting foods in the UK study was significantly associated with the intake of energy, carbohydrates and fruit, the higher intake in the Saudi study was not significant, which could be due to food underreporting (Jones et al., 2021). However, food records for both populations revealed that sweet-tasting foods were mostly calorie-dense sources, while the intake of fruit as a source of sweetness was below the recommended levels.

Regarding savoury- and salty-tasting foods, a higher intake of savoury-tasting foods by the UK adolescents—but not of salty-tasting foods—was significantly associated with a higher intake of protein, while only a higher intake of salty-tasting foods was significantly associated with sodium intake. In the Saudi study, however, the high consumption of salty-tasting foods was significantly associated with both protein and sodium intake. The likely explanation is that the salty taste in the Saudi study included foods that could have been classified as savoury, which is reported to signal protein content (Lease et al., 2016; Hartley et al., 2019; van Dongen et al., 2012). Moreover, the correlation between salty and savoury tastes makes it challenging to distinguish between these tastes, especially in composite dishes and processed foods, in which the addition of salts, spices, and other flavour-enhancers produces intercorrelation in the tastes perceived (Onuma et al., 2018).

The intake of neutral-tasting foods among the UK adolescents showed a significant negative association with the intake of calories and nutrients, while no significant associations were noted in the Saudi study. In either study, moreover, no significant associations were observed between the intake of bitter- or sour-tasting foods and dietary intake—except that the UK adolescents had a significantly higher intake of vegetables associated with a higher intake of bitter-tasting foods. This can be expected because some vegetables were identified as having a bitter taste (Drewnowski and Gomez-Carneros, 2000). The Saudi adolescents, in contrast, had a significantly higher intake of takeaway foods, associated with the higher intake of sour-tasting foods, which could be related to the use of additives like sauces and dressings, identified to produce sourness. Nevertheless, the misreporting of foods plays a critical role in the assessments.

9.2.4 Associations between tastes and energy intake, BMI, and diet quality

HCA groups similar observations into distinct clusters that, unlike the Principle Component Analysis (PCA), do not necessarily describe dietary patterns (Smith et al., 2011). Therefore, in Chapters 4 and 8, HCA was used first to identify taste clusters that describe food items in the participants' food records. The reference food items used in the online taste classification surveys were grouped by the HCA into dominant tastes. PCA was then used to generate dietary taste patterns, as described in Chapter 5. However, due to the small sample size in the Saudi study, PCA returned with unsuitable results for generating the patterns (the Kaiser-Meyer-Olkin [KMO] test was 0.50 and Bartlett's test was greater than 0.05 (P=0.87)) (Santos et al., 2019). Thus, the generated dietary taste patterns in Chapter 5 and the weight of foods from each taste in Chapter 8 were examined for their association with energy intake, BMI and diet quality. This has added to the growing body of literature on 1) the PCA-generated dietary taste patterns and 2) the overall associations between taste and the outcome variables among adolescents.

A number of studies on adolescents' dietary patterns have been performed. Since the patterns in those studies were based on common food groups (Ambrosini et al., 2009; Richter et al., 2012; Martínez Arroyo et al., 2020), however, those studies have established knowledge of adolescents' eating behaviours from a food and nutritional perspective. To our knowledge, no study has yet explored adolescents' dietary patterns from a taste perspective—despite increasing evidence that taste is a critical factor determining adolescents' dietary intake. Adolescents are often reported to have a higher consumption of calorie-dense foods, including fast food and takeaway food, sweet and savoury snacks and sweetened beverages. In Chapter 5, two of the identified dietary taste patterns fall into the calorie-dense categories of the 'takeaway meals' taste pattern, which combines savoury and sweet foods and beverages, and the 'sweet snacks' taste pattern, which mainly included sweet-tasting snacks. Compared to other dietary taste patterns, these two had the highest impact on increased energy intake. However, only the 'takeaway meals' taste pattern showed a significant association with BMI, albeit in an inverse direction. Although this could be due to the large amount of potential underreporting (79%), non-obese adolescents comprised the greater proportion of this cohort and had a higher frequency of takeaway meals. This would raise health concerns if non-obese adolescents feel greater liberty and less concern when consuming fast foods.

Foods within the 'takeaway meals' and 'sweet snacks' taste patterns (i.e. fast foods, cakes, cookies, confectionery and sweetened beverages), or those in the so-called Western diet, are high in salt, sugar and fat. These components are known to enhance taste, increase palatability and encourage consumers' hedonic behaviours towards the foods (Liem and Russell, 2019). The fact that adolescents' attitudes towards the increased Western diet consumption are related to their pre-existing taste perceptions. Generally, a high proportion of adolescents are sensitive to bitter taste, as reported in Chapter 3, and that the perceived bitterness could result in a lower intake of vegetables. In the context of a Western-style diet, which could apply to the 'takeaway meals' and 'sweet snacks' taste patterns identified in the current thesis, a study found that frequent consumption of a Western diet that involves processed foods high in sugar, salt and fat was associated with greater bitter sensitivity. Moreover, repeated exposure to these foods may increase the preference for higher concentrations of the associated tastes (Stevenson et al., 2016). The increased and repeated consumption of such foods is a public health concern, with health risks including obesity and Noncommunicable diseases (NCDs).

Sweet taste seemed to be the main component in three of the UK cohort's dietary taste patterns, which could reflect the participants' general preference for sweet taste. Only one of those taste patterns, 'sweet snacks', inversely impacted the quality of the diet, which may be due to the greater quantity of sugar and fat in the foods that comprise this taste pattern. In contrast to sweet-tasting foods, neutral-tasting foods were associated with a positive diet quality in both the UK and Saudi cohorts. Foods within this taste are low in taste intensity (e.g. plain white rice, pasta, bread, potatoes, white fish and some vegetables), as indicated in Chapters 4, 5 and 8. In the Saudi study, bitter-tasting items were likewise found to be linked with a positive diet quality, which could be due to the nutritional composition of the food items that comprised the taste. Therefore, the impact of taste on diet quality depends on the type of food and its composition (Cox et al., 2018; Wanich et al., 2020). To illustrate this relationship, since a high score in diet quality suggests an optimal dietary intake and better adherence to dietary guidelines (Wirt and Collins, 2009), a diet high in nutrient-dense foods and low in calorie-dense foods is believed to be of good quality. Studies of taste-nutrient relationships have suggested links between sweet taste and sugar, salty taste and sodium, and savoury/umami taste and protein (Teo et al., 2021). The correlations between taste and nutrients in the foods, thus, suggest that taste plays a role in diet quality.

Although more than two-thirds of the Saudi adolescents' energy intake was obtained from salty- and sweet-tasting foods, no significant associations were observed between the food-taste groups and BMI or diet quality. This could imply a bias in reporting weight and height, due to self-reporting. Additionally, given that more than half of the participants had not experienced food recording before, the results may have been affected by potential underreporting—some foods went unreported and portion sizes were misreported—all of which are major dietary assessment problems among adolescents. Using innovative technology-based dietary assessment tools has the potential to enhance food reporting (Illner et al., 2012). However, despite the use of the innovative tool Arabic myfood24 and despite positive evaluations of its features, usability and overall acceptability, a lack of motivation or interest (data collection took place during COVID-19 and virtual schooling) may have influenced the accuracy of the reported food intake.

Food intake is positively linked with food liking or preference, which implies taste liking (Rogers and Hardman, 2015). Studies concerning the associations between taste liking and food intake have yielded inconsistent results. The author of the present thesis reported some unexpected associations between food intakes from taste groups and the liking score of foods/tastes in Chapter 8. The findings revealed a significant positive association between the mean liking score of salty-tasting foods and the intake of bitter-tasting foods. Salty taste liking could determine the intake of salty-tasting foods. This was affirmed by the generally high preference for salty-tasting foods (Table 8-1, Appendices E.3 and E.4) and the high proportion of salty-tasting foods as the main contributor to Saudi adolescent's daily energy intake (Figure 8-1). However, in relation to bitter taste, a clinical study on hypertensive patients showed that repeated consumption of high levels of salt was linked to a lower bitter perception (Cui et al., 2019), which could, consequently, increase the intake of bitter-tasting food. This increase, moreover, may be because the salty taste suppresses bitterness (Keast and Breslin, 2003). Thus, given the high liking and intake of salty-tasting foods among the Saudi population, this phenomenon may create a general feedback suppression of bitter taste, resulting in an increased intake of bitter-tasting foods. The other significant association found was between the mean liking score of bitter-tasting foods and the intake of sour-tasting foods. This may be due to either a confusion between sour and bitter tastes (Doty et al., 2017), a possible correlation between these tastes (Pagliarini et al., 2021) or the hint that two tastes exists in the foods. For example, some foods can produce some level of bitterness and sourness—coffee (Portela et al., 2022), some vegetables (e.g. lemon), and fruit (e.g. grapefruit)—and that sourness and bitterness can heighten each other (Keast and Breslin, 2003). As discussed in Chapter 8, however, there may be a false positive association resulting from the small sample size or from a false representation of foods in the Likert questions (Feeney et al., 2021; Gorroochurn et al., 2007). In addition, the influence of a taste on liking and intake varies from one food to another (Feeney et al., 2021). For example, bitterness in coffee, tea and alcoholic beverages is accepted over the perceived bitterness in vegetables.

9.3 Thesis overall strengths and limitations

The strengths and limitations have been discussed in each chapter; however, this section summarises the general strengths and limitations of the overall work.

9.3.1 Thesis strengths

- To the extent of the author's knowledge, this is the first work that considers adolescents' dietary intake from a taste perspective based on the whole diet (that is, actual reported dietary intakes combined with food composition) rather than based on selected foods.
- One of the main strengths of the thesis is that it considers adolescents as the age group between 10 and 18, as defined by the WHO (World Health Organization, 2022), whilst many of the studies in this age group include 10–year-olds in the younger age group, merge adolescents up to 16 years of age with the children's group (7–16 years) or consider 17 and 18 year-old adolescents to be adults. This may result in an incomplete picture when assessing eating behaviours, dietary intake and health-related effects among adolescents.
- This thesis is novel in characterising the UK adolescents' dietary intake by taste using the NDNS, which provides nationally representative data on food consumption. It is also the first to study the taste characteristics of Middle Eastern, specifically Saudi Arabian, adolescents' dietary intake.
- The taste classification of foods was done by typical consumers rather than by trained panellists, which provided insight into the taste perceptions of people in general as a driver of food intake. Moreover, the outcomes

were shown to be reliable when checked against the classification conducted by trained panellists.

- This thesis has established the first online dietary assessment tool that contains Middle Eastern food items and is entirely in the Arabic language. This has helped collect and study the food data of Saudi adolescents. Moreover, because such an online dietary assessment tool that is designed to be nationally-representative is superior to standard, paper-based dietary assessment methods or the use of other countries' food composition data, it will help enhance dietary assessments and epidemiological studies in the region.
- The usability and accessibility of the online dietary assessment tool (the Arabic myfood24) were determined using the System Usability Scale (SUS), which provides reliable results even with a small sample size (Lewis, 2018; McLellan et al., 2011; Brooke, 2013). Adolescents' feedback regarding the tool was also obtained.
- This thesis is novel in generating UK adolescents' dietary taste patterns using PCA, a procedure widely used for generating dietary patterns.
- This thesis is the first to examine the associations between dietary tastes and overall daily energy intake, BMI and diet quality. Additionally, it explored the association between dietary tastes and food-taste liking among Saudi adolescents.

9.3.2 Thesis limitations

- The age and definition of "adolescents" have varied in the literature. For example, some papers merged adolescents, especially younger adolescents aged 10 to 13, with children, while others merged those aged 18 and 19 with adults. Some researchers, moreover, have referred to them as "children" instead of "adolescents". As a result, the systematic review and meta-analysis in Chapter 3 may have missed some relevant papers.
- The NDNS is a cross-sectional survey, meaning that causality cannot be established over time. Thus, the findings from this thesis indicate associations between dietary tastes and outcome variables rather than cause-effect relationships.
- Potential bias regarding participants includes bias in sample size and representativeness. The Saudi study may have been limited by a sampling

bias in recruiting Saudi adolescents due to COVID-19 challenges and participants were recruited based on snowball sampling within families and friends. Thus, bias related to relatives and friendships could have influenced the participations and responses. Moreover, bias concerning participants non-representativeness and/or overrepresentations of health awareness are potential in both NDNS and Saudi studies due to the nature of the studies (i.e. cross-sectional surveys), and that findings cannot be generalised.

- Bias on food reporting and altering eating behaviours, particularly among females and overweight/obese individuals, that can result in misreporting or underreporting of foods and nutrients intakes and, consequently, the identified dietary tastes. Moreover, in the NDNS, food intakes of younger adolescents were reported by a parent/caregiver, and this could associate with misreporting of foods, especially, when those adolescents were not home (e.g. schools) where reporters may not be aware about the details of the food consumed.
- Potential bias related to participants' responses and reporting. This includes responses to the taste classification survey and potential misunderstandings of the taste definitions provided in the taste classification survey, particularly for savoury taste, may have affected the classification. Another potential bias is related to responses to to taste preferences questions, where participants may display better or healthier choices. Also, the self-reported weights and heights in the Saudi study are prone to reporting errors, which could be the reason of no significant associations were obtained between dietary tastes and BMI.
- Food intake data in the NDNS were collected based on 4-day estimated diary method. This method is prone to recording errors because it is burdensome to participants. Inaccurate portion size estimations and food underreporting may have affected the outcomes as well. Likewise, in the Saudi study, although the use of an innovative dietary assessment tool enhances the procedure, 24-hour recall relies on memory, which may result in misreporting, either by underreporting or forgetting items. Errors associated with dietary measurements can affect the outcomes when studying the link between taste liking and intake.

- There are high levels of underreporting in both UK and Saudi studies. A ratio of energy intake (EI) to Basal metabolic rate (BMR) <1.3 is defined as underreporting (Mirmiran et al., 2006; Zainuddin et al., 2019). In both studies of the current thesis, the ration of EI:BMR = 1.1 (UK study, Chapter 5) and 1.0 (Saudi study, Chapter 8), indicating underreporting by an average of 255 kcal/day (95% CI 245-265) and 200 kcal/day (95% CI 188-219), respectively. The high proportion of under-reporters could be due to the used dietary assessments methods including fatigue and burdensome associated with food diaries method used in the NDNS, reliance on memory associated with 24-hour recall used with the Saudi study, general literacy skills and cognitive aspects of reporting diet among adolescents, which require understanding of the information requested (i.e. details of foods/ingredients, preparations and estimation of portions). Also, adolescents are often less motivated in reporting their dietary intake that can result in underreporting.
- While the usability testing of the Arabic myfood24 is considered good, the low level of interest or motivation associated with the dietary assessment method among adolescents may have affected the results. Therefore, conducting a focus group to discuss the tool may support the quantitative outcome.

9.4 Implications and future research

Individuals' dietary tastes could have potential implications for health. Thus, understanding the taste characteristics of people's dietary intake can help enhance the quality of foods and implement effective interventions and guidelines that can improve people's dietary intake and overall health. The current thesis has highlighted the influence of the sense of taste on dietary intake among adolescents. From a public-health perspective, findings from the thesis could specifically emphasise the importance of special attention to adolescents' taste perceptions and preferences as fundamental factors in their food choices and intake. A number of prominent findings (including the use of an innovative technology-based dietary assessment tool to self-report dietary intake, reporting the taste of foods and taste preferences during the self-reporting of the food consumptions and findings about dietary tastes) may help researchers and policymakers focus on effective collection of the dietary intake and influential factors (taste in the case of the current thesis) and improve the population's taste perceptions, preferences and overall dietary taste.

An accurate dietary assessment is essential for effective dietary taste evaluations. However, particularly with adolescents, dietary intake measurements are challenging and can result in measurement errors that could bias or attenuate the outcome association between taste indicators and dietary intake. For instance, the NDNS data used in Chapter 4 is a national survey that relies on 4-day paper-based food records, which could place a massive burden on the participants in reporting food intake and, thus, lead to misreporting. Using a web-based dietary assessment tool can enhance these measurements. However, misreporting can still be an issue in dietary assessment among adolescents, especially when self-reported, as found by the high proportion of under-reporters in Chapter 8. Therefore, future research could provide direction on appropriate knowledge and training for adolescents regarding dietary measurements through intervention-based studies. Moreover, the findings from such studies may propose the implementation of dietary measurements knowledge and practice as part of a health and sciences school curriculum.

Concerning the relationship between taste and individuals' food intake, technology-based dietary assessment tools could enhance the study of this relationship by implementing a taste-category reporting feature as part of the food reporting process. An implication of this inclusion is taste classification based on consumers' perceptions as a motive for food consumption, especially with the promising findings obtained from taste classification in Chapters 4 and 8. However, further validity and reliability studies may be required on a broader population of different age groups. A better knowledge of food taste properties and their relationship with dietary intake may provide insight into the possible drivers of food choice and dietary patterns, and it may increase our understanding of one of the possible causes of obesity and NCDs.

Further to the knowledge of the relationship between food taste and dietary intake, identifying food-taste preferences as a driver of food intake and a determinant of obesity and NCDs could help design interventions that aim at altering taste preferences or that develop novel food options for healthier dietary patterns. For instance, our findings from Chapter 8 could not identify the expected relationships (e.g. an association between sweet-tasting food intake and sweet foods liking); however, the unexpected association that was identified may give insight into the effect of taste-taste interactions. In Chapter 4, our analysis showed that higher vegetable intake was linked with salty-savoury taste, and in Chapter 5, the dietary taste pattern labelled 'salad bar' consisted of savoury, salty, bitter and sour tastes. These findings suggest that vegetable intake, particularly in adolescents, is not their desire or liking, especially since bitterness can be easily perceived in some vegetables. Thus, programmes concerned with reformulating and reproducing novel foods provided in restaurants, schools and homes may do so by mixing and combining less desired foods with other, better-liked foods, which may be promising (i.e. unpleasant vegetables may be blended with other ingredients, such as tomato sauce used in pizza, pasta, or soups). Therefore, future population-based research may benefit from collecting and developing data on food-taste preferences.

The WHO has suggested regulating and restricting the availability of foods high in sugar, salt and fat in regular gathering settings for young people. Moreover, the WHO dietary recommendations to the Member States encourage adolescents to decrease the consumption of food rich in calories, fats, free sugars or salt and to increase the intake of fruit, vegetables and dietary fibre (World Health Organization, 2016). Furthermore, governments, including those in the UK and Saudi Arabia, have been taking action to implement public health guidance, including reformulating and reducing added sugar and salt in food (Bin Sunaid et al., 2021; Public Health England, 2021). While these actions may be effective for new generations who will grow up with the experience of low sweetness and saltiness, they are likely to be ineffective for the immediate generation. This has been observed in our analysis with a higher intake of sweet and salty-tasting foods that were linked with sugar and salt intakes that exceed recommendations. An implication of this is that dietary guidelines and recommendations may need to consider additional factors, including the taste characteristics of the diet and taste preferences of the population, rather than focus only on the nutritional composition of the diet.

As discussed earlier in chapter 2 of this thesis, taste perceptions and preferences are determined by several factors including genetics and environmental factors; however, genetic predisposition of taste could be override by environmental factors leading to differences in the primary perceptions and preferences. For example, the price of foods and individuals'' socioeconomic status may define the chosen foods and taste preferences. Energy-dense foods that are high in added sugar, salt and fat, typically cost less compared to nutrient-dense foods. It has been reported that individuals from low socioeconomic status often tend to choose energy-dense food options (Lim et al., 2020). Moreover, economic constraints influence low-income families' food decisions in terms of purchasing calorie-dense foods that are familiar and preferred to their children as they cannot afford to risk providing healthier options that may not be eaten. In contrast, high-income families would tend to reintroduce initially rejected foods to their children to develop their taste for healthy options (Daniel, 2016); thus parental affect and their modelling of food consumption (i.e. consumption of bitter-tasting vegetables) can have a powerful effect on building and developing their children's taste preferences and food intakes; however, peers effect, particularly among adolescents, could shape a preference of less healthy foods that are high in sweet and salt. This may be linked to food availability and accessibility such as fast-foods and takeaway food outlets that are often affordable and display attractive marketing targeting young individuals through multiple digital media channels (i.e. computers, tablets and smartphone) (Sina et al., 2021). Different cultures, believes are also key determine in taste preferences and food intake, and this is confirmed from our findings of differences in taste characterisation and taste contributions to UK and Saudi adolescents' diets indicated that there are potential cultural variations in food and taste preferences. This implies that it could be effective to consider taste when regulating dietary guidelines and recommendations that are population-based. Altogether, future research is needed to investigate the influence of those different environmental factors in developing and shaping tastes preferences and food intake, and innovative approach of integrating questions about food-taste preferences and perceptions into national nutrition surveys can help build such knowledge.

Overall, interventions and strategies to enhance adolescents' taste preferences and dietary intake are recommended. Although studies have reported that adolescents' body images, particularly in girls, could affect their food choices and eating behaviours (Bibiloni et al., 2013; Fleming et al., 2020), taste is identified as the most important factor in choosing what to eat (Fleming et al., 2020). Despite some knowledge of the health consequences, this age group often likes nutrient-poor and taste-rich foods (e.g. takeaway meals). Studies have indicated that consumers concerned with taste rather than health often select unhealthier food choices. Moreover, trying to steer those consumers toward healthy food options is ineffective (Liem and Russell, 2019). Thus, it was suggested to emphasise the taste properties of healthy foods rather than highlight the health advantages. Also, involving adolescents in the strategies established toward healthy eating may enhance their behaviours and build some sense of awareness and responsibility. Moreover, this approach could build more effective and reliable strategies that can be adopted by people.

9.5 Conclusion

This chapter has discussed the overall findings of the thesis, as well as its overall strengths and limitations. The implications of its findings and suggestions for future work have also been discussed. The taste characteristics of the UK and Saudi adolescents' diets have been explored and assessed, and the associations between each of the dietary taste patterns among UK adolescents and dietary tastes among Saudi adolescents with the daily energy intake, BMI, and diet quality were examined. The fact that measuring adolescents' dietary intake is challenging could influence the findings. The web-based dietary assessment tools seem promising in enhancing dietary assessment, as well as in data collection across countries when a direct connection is challenging. Our use of the Arabic myfood24 helped us obtain data from Saudi adolescents in an efficient way. However, further improvements, in terms of expanding the foods and a broader evaluation of usability and validity are required. The current thesis provides insight into the importance of considering the taste characteristics of people's diets and the food served to them. In order to be effective, dietary guidelines and recommendations, including action plans for enhancing population foods and overall diet, should consider taste alongside the nutritional aspects of foods. More research is needed to help design population- and culture-based strategies, guidelines and interventions aimed at reformulating food, producing novel food production and improving people's taste preferences.

9.6 References for Chapter 9

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Appendices

Appendix A: Supplementary Materials for Chapter 3

Appendix A.1. Number of papers for each taste based on phenotype or genotype classification

Taste	Phenotype	Genotype
Bitter	5 cohorts in 7 papers	4 cohort in 6 papers
Sweet	4 cohorts in 5 papers	2 studies
Fat	0	1 study
Salty	0	0
Sour	0	0
Umami	0	0

Appendix A.2. Genes and SNPs associated with each taste

Taste	Gene	SNPs
Bitter	TAS2R38	rs713598
		rs10246939
		rs1726866
Sweet	TAS1R2	rs9701796
		rs35874116
	TAS1R3	rs35744813
	GNAT3	rs7792845
Fat	CD36	rs1761667

Appendix A.3. Most frequently reported food based on taste qualities

Food categories/ Taste		Bitter		Sweet		Fatty	
		Pheno.	Geno.	Pheno.	Geno.	Pheno.	Geno.
Total Brassica vegetables	Pref.	0	0	0	0	0	0
	intake	0	1	0	0	0	0
Bitter green vegetables.	Pref.	0	0	0	0	0	0
	intake	1	1	0	0	0	0
Cauliflower	Pref.	2	1	0	0	0	0
	intake	0	0	0	0	0	0
Bitter gourd	Pref.	1	0	0	0	0	0
	intake	0	0	0	0	0	0
Cabbage	Pref.	3	1	0	0	0	0
	intake	0	0	0	0	0	0
Brussels sprouts	Pref.	2	1	0	0	0	0
	intake	0	0	0	0	0	0
Broccoli	Pref.	2	1	0	0	0	0
	intake	0	0	0	0	0	0
Other vegetables	Pref.	1	0	0	0	0	0
	intake	0	1	0	0	0	0
Coffee	Pref.	3	0	0	0	0	0
	intake	0	0	0	0	0	0
Dark chocolate	Pref.	1	0	0	0	0	0
	intake	0	0	0	0	0	0
Fruit	Pref.	1	0	1	0	0	0
	intake	0	1	0	0	0	0
Meats	Pref.	1	0	0	0	0	0
	intake	0	1	0	0	0	0
Cake	Pref.	1	0	0	0	0	0
	intake	0	1	0	0	0	0
Candy	Pref.	1	0	0	0	0	0
	intake	0	0	0	0	0	0
Donut	Pref.	1	0	0	0	0	0
	intake	0	0	0	0	0	0
Honey	Pref.	1	0	0	0	0	0
	intake	0	0	0	0	0	0
Ice cream	Pref.	1	0	0	0	0	0
	intake	0	1	0	0	0	0

Margarine	Pref.	1	0	0	0	0	0
	intake	0	0	0	0	0	0
Butter	Pref.	0	0	0	0	0	0
	intake	1	1	0	0	0	0
Fat/oil	Pref.	0	0	0	0	0	1
	intake	0	0	0	0	0	0
Mayonnaise	Pref.	2	0	0	0	0	0
	intake	0	0	0	0	0	0
Milks	Pref.	1	0	0	0	0	0
	intake	0	2	0	0	0	0
Sugar	Pref.	1	1	1	0	0	0
	intake	1	1	0	2	0	1
Salty food	Pref.	1	0	0	0	0	0
	intake	0	0	0	0	0	0
Sour food	Pref.	1	0	0	0	0	0
	intake	0	0	0	0	0	0
Chilli/spicy	Pref.	1	0	0	0	0	0
	intake	0	0	0	0	0	0

Pheno.= phenotype; Geno.= genotype

Appendix A.4. Food likes and dislikes based on taste

		Food-liked	**Food-disliked**
Bitter	**Taster**	* Sweet-tasting food (e.g. Sugar) * Salty and sour food (e.g. condiments and sauces) * Umami and fried food (meat products and fried chicken)	* Black coffee * Dark chocolate * Chilli peppers * Cruciferous vegetables (e.g. cabbage and broccoli)
		Food-liked	**Food-disliked**
	Non-tasters	* Cruciferous vegetables (e.g. brussels sprouts and cauliflower)	Nothing reported

Appendix B: Supplementary Materials for Chapter 4

Appendix B.1. Examples of the grouped food list under the main and subsidiary food groups

Main food groups	Sub food groups	Examples
Cereals and cereal products	Breakfast cereals, bread, pasta, rice, and pizza	Breakfast cereals, Plain pasta/rice, White bread
	Buns cakes, pastries, and puddings	Plain scones, Eclairs, doughnuts, Lemon meringue pie
	Biscuits	Chocolate biscuits, Digestives, cheese flavoured biscuits
Vegetables, beans, and seeds	Root vegetables	Carrots, potato, radish
	Leafy type vegetables	Mixed leaf salad, lettuce, rocket, cabbage, spinach
	Other vegetables	Cucumber, aubergine, mushrooms
	Vegetable based dishes, and salads	Vegetable samosa, pakora, cauliflower cheese, guacamole
	Beans, lentils, and seeds	Canned baked beans, hummus, seeds (e.g. sunflower, pumpkin)
Fruit	Fruit	Banana, kiwi, grapefruit
Meats, poultry, eggs and seafoods	Meats/chicken	Beef, chicken (grilled, roasted), processed meat (e.g. sausages)
	Meats/chicken meals, pastry, and eggs	Burgers, kebab, fried egg, boiled eggs/poached
	Seafood	White fish, sushi, tinned fish (e.g. tuna canned in oil)
Dairy products and fats	Milk, milk products and alternatives	Whole milk, plain yogurt, alternatives milk (e.g. almond, soy)
	Cheese	Feta cheese, cheddar cheese, cheese spreads
Beverages	Juices and fizzy drinks	Ready to drink fruit juice (carton/can), Lemon juice sweetened,
	Wine, beer, and alcoholic drinks	White wine, Beer, lager, Liqueurs
	Coffee and tea	Coffee drinks with milk (e.g. latte, cappuccino), Black coffee, tea
	Dry weight beverages	Drinks made from powder (e.g. sweetened drinking chocolate)
Miscellaneous	Sugar, sugar confectionery and chocolate confectionery	Boiled sweets and gums, Milk chocolate, Dark chocolate (70% cocoa)
	Preserves, and spreads	Honey, jam, chocolate spread, Peanut butter smooth/crunchy with added sugar, Peanut butter no added sugar
	Savoury snacks (e.g. crisps and nuts)	Crisps, Unsalted nuts, Honey roasted peanuts
	Soups	Tomato soup, Chicken soup, Vegetable soup
	Salt, herbs, spices, pickles, pastes, and sauces	Chinese sweet & sour sauce, White sauce, Gravy

Appendix B.2. Explanation for each taste as provided in the online foods taste classification survey

Taste	Definition explained
Sweet	the sense of sweetness of sugar on your tongue
Salty	the sense of saltiness from salt on your tongue
Sour	the sense of sourness of lemon on your tongue
Bitter	the sense of a sharp, potentially disagreeable taste like the bitterness of caffeine
Savoury	often described as ‘broth-like’ or ‘meaty’. It is like the taste found in Japanese food and soy sauce
Neutral	the sense of little or no specific taste

Appendix B.3. Removed foods after the pilot

Sweet-tasting foods	
Cereals and cereal products	**Fruit**
Breakfast cereal with chocolate or honey or fruit High fibre breakfast cereal with chocolate or honey or fruit Sweet pastries and breads e.g. currant bun, Danish pastry, scotch pancake Eclairs, doughnuts, cream, or iced bun Puddings e.g. sponge, trifle, bread, and butter pudding Cakes and sweet muffins Custard, mousse, dairy desserts, rice pudding, jelly Custard, mousse, dairy desserts, rice pudding, jelly Chocolate biscuits, chocolate chip cookies Cream, jam filled or iced biscuits Biscuits with fruits or currants Cereal bar with fruit Cereal bars (e.g. Kellogg's rice Krispy, coco pops, Frosties), cereal bars with oats	Apples, pears Peaches, nectarines, plums, apricots Mango, papaya Banana Melon Strawberries, raspberries Cherries Grapes Pineapple Dried mixed fruit Mixed fruit puree, compote, canned fruit Fruit bars, sticks Desiccated coconut sweetened Condensed milk, coffee creamer liquid Condensed milk, coffee creamer liquid Fruit yogurt and fromage frais **Vegetables** Carrots Sweet potatoes Sweetcorn Peppers (red, green, yellow
***Dairy* products**	**Beverages**
Ice cream Condensed milk, coffee creamer liquid Milkshake, hot chocolate, flavoured milk Fruit yogurt and fromage frais ***Mi*scellaneous** Sugar, syrups, sweeteners Boiled sweets and gums Milk chocolate Honey, jam, chocolate spread	Mixed fruit smoothie, sweetened Ready to drink fruit juice (carton/can) Apple juice unsweetened Concentrated soft drinks/squash (e.g. Ribena) Fizzy drinks (e.g. lemonade) Alcoholic fruit drinks (e.g. cocktails) Drinks made with powder (e.g. drinking chocolate, mocha, milkshake)
Salty-tasting foods	
Cereals and cereal products	**Miscellaneous**
Salted biscuits e.g. Tuc, Ritz	Crisps and savoury snacks (e.g., tortilla chips), Bombay mix / chevda Salted popcorn, salted nuts Salt
Bitter-tasting foods	
Beverages	
Beer, lager Black coffee & Black tea	
Savoury/Umami	
Meats, poultry, eggs and seafoods	
Meat or chicken-based dishes e.g. Lasagne, cottage pie, hotpot	
Neutral-tasting foods	
Cereals and cereal products: Plain pasta, noodles, rice	

Appendix B.4. Validity checking of the taste classification

Food	Our work (Values= respondents)						Others' work (Values= mean intensity)					Validity outcome
	Sweet	Salty	Sour	Bitter	Savoury	Neutral	Sweet	Salty	Sour	Bitter	Savoury	
Fruit yogurt and fromage frais	15	0	3	0	1	0	34	3	27	1	1	Agreed
Breakfast cereal (e.g. cornflakes, multigrain) without honey, chocolate, fruit	50	4	1	1	6	38	14	9	2	1	2	
Pasta with tomato or cheese sauces	16	31	2	1	42	8	9	29	11	0	25	
Pot noodle	2	65	0	0	31	1	9	45	3	1	37	
Rice or risotto dishes (e.g. fried rice with chicken or egg)	2	35	0	0	55	9	6	39	2	1	27	
Pizza	12	48	1	1	32	5	12	32	11	1	29	
Plain scones	52	7	1	1	8	31	44	12	1	1	1	
Fruit pies and crumbles	98	0	2	0	0	0	54	11	14	1	2	
Beef	2	10	0	0	84	4	4	27	3	2	35	
Lamb	6	8	1	1	78	5	11	38	5	2	36	
Chicken, duck	4	8	0	0	75	12	5	28	2	1	28	
salami	3	68	0	1	26	1	3	51	19	1	21	
corned beef	3	68	0	1	26	1	4	43	8	1	23	
Processed meat e.g. sausages, pastrami	3	68	0	1	26	1	5	46	10	1	23	
Smoked bacon	3	70	1	1	25	0	6	67	6	0	15	
Unsmoked bacon	1	69	1	1	26	2	6	67	6	0	15	
Burgers, kebab	2	34	0	0	62	2	10	31	11	1	27	
Chicken kebab	8	41	1	0	42	9	4	37	6	1	17	

nuggets	8	41	1	0	42	9	7	35	3	1	21
Meat or chicken based spicy dishes e.g. curry, biryani	4	25	4	5	61	1	6	37	2	2	32
Cheese quiche, souffle, scotch egg, vegetable and cheese pie	7	46	0	2	39	6	6	54	10	1	23
Eggs boiled, poached	6	9	0	0	33	52	5	10	2	1	8
White fish steamed, grilled, baked, fried	6	16	1	0	28	51	2	13	3	2	12
Fish curry, prawn curry	7	32	5	3	49	5	6	37	2	2	32
Oily fish meals e.g. salmon, herring, mackerel, fresh tuna	5	33	0	2	52	8	3	29	10	1	26
Tinned fish e.g. tuna canned in oil	5	37	1	5	39	13	3	37	19	2	31
Tinned fish canned in water	5	34	1	4	37	20	4	25	16	2	22
Mackerel in tomato sauce	17	32	5	5	34	7	3	42	8	1	44
Whole milk	57	1	4	1	3	34	12	3	4	1	1
Semi-skimmed milk	48	0	3	1	3	45	12	3	4	1	1
Skimmed milk	31	0	8	0	2	60	14	2	5	1	1
Plain yogurt, sour cream, buttermilk	11	1	67	4	6	12	4	4	54	2	2
Mozzarella	26	26	6	1	16	26	2	9	7	1	3
Radish	6	4	14	54	8	14	5	1	6	7	3
Celeriac	27	7	11	13	18	24	12	3	3	3	3
Mixed leaf salad, lettuce, rocket	9	1	4	50	14	23	7	1	2	6	1
Spring onions, chives, leeks	16	5	14	29	26	10	5	2	3	11	2
Spinach	7	3	7	44	12	27	7	4	4	8	3

Cabbage, Chinese leaves	16	3	4	33	13	31	3	1	3	6	1
Brussels sprouts	7	2	7	58	16	10	8	5	2	19	9
Courgette	31	2	2	16	10	39	7	2	1	2	4
Carrots	15	0	0	0	2	2	15	2	2	1	7
Crispy seaweed, seaweed wakame dried	8	42	2	13	29	6	6	22	3	1	40
Mushrooms	9	5	0	4	57	25	7	5	3	2	18
Peas	74	1	0	4	6	15	15	4	2	1	5
Potato chips/waffles or roast	16	47	0	0	17	20	9	15	3	0	7
Vegetable soup	15	42	1	2	29	11	19	32	16	1	27
Clear soup (e.g. consommé, stock cubes)	3	63	0	2	25	7	10	39	6	3	21
Plain biscuits e.g. digestives, shortbread	83	9	0	0	4	5	51	11	0	3	2
Cheese straws, cheese flavoured biscuits	7	69	1	0	18	5	6	41	2	0	8
Prawn crackers, papadums	17	48	0	0	27	9	12	29	1	0	26
Olives	2	44	8	30	13	2	4	31	6	4	18
Red wine	13	1	29	34	15	8	8	1	46	38	2
White wine	38	1	29	20	4	8	12	1	45	21	1
70% proof spirits e.g. whisky	13	1	13	44	13	14	22	2	12	25	1
Coffee drinks with milk, unsweetened (e.g. latte, cappuccino)	30	1	4	48	8	10	8	2	9	44	1
Twiglets, pretzels	0	62	1	6	28	3	6	45	1	0	4
Unsalted nuts	9	6	3	3	50	30	7	8	1	6	9
Honey roasted peanuts	88	5	0	2	5	0	42	11	1	4	2

Curry sauce/ curry paste	18	21	4	7	48	3	31	33	22	1	22
Pesto	14	31	4	9	36	7	5	57	12	2	23
Marmite	0	46	2	17	32	2	11	62	23	23	46
Mustard	2	7	17	47	23	4	6	37	47	10	5
French salad dressing	22	16	41	6	9	6	10	41	56	2	11
Eclairs, doughnuts, cream or iced bun	19	0	0	0	0	0	44	10	1	1	2
Crisps and savoury snacks (e.g. tortilla chips), Bombay mix / chevda	1	15	1	0	2	0	9	45	5	2	13
Apples, pears	17	0	1	1	0	0	27	1	17	1	1
Banana	19	0	0	0	0	0	29	1	2	1	1
Grapes	18	0	0	1	0	0	30	1	25	2	0
Meat or chicken-based dishes e.g. Lasagne, cottage pie, hotpot	1	2	0	0	15	1	12	42	8	1	32
Biscuits with fruits or currants	17	0	1	0	1	0	30	7	5	1	1
Milkshake, hot chocolate, flavoured milk	18	0	0	0	0	0	37	6	2	7	0
Custard, mousse, dairy desserts, rice pudding, jelly	18	0	0	0	1	0	43	4	5	5	1
Ice cream	19	0	0	0	0	0	46	6	2	3	1
Breakfast cereal with chocolate or honey or fruit	19	0	0	0	0	0	41	12	1	5	0
High fibre breakfast cereal with chocolate or honey or fruit	17	0	0	0	0	1	23	9	3	1	1
Black coffee	0	0	0	17	2	0	2	1	9	63	1
Black tea	0	0	0	17	2	0	4	1	5	20	1

Ready to drink fruit juice (carton/can)	19	0	0	0	0	0	50	2	33	7	0
Fizzy drinks (e.g. lemonade)	17	0	2	0	0	0	41	1	23	5	0
Beer, lager	1	0	1	15	2	0	7	1	17	55	1
Cakes and sweet muffins	19	0	0	0	0	0	47	10	2	4	1
Chocolate biscuits, chocolate chip cookies	19	0	0	0	0	0	59	13	1	4	1
Sweet peppers	15	0	0	3	0	1	11	2	8	11	4
Boiled sweets and gums	17	0	0	0	0	0	46	2	19	2	0
Jam	19	0	0	0	0	0	74	3	19	1	0
Honey	19	0	0	0	0	0	76	4	1	3	0
Marmite flavour rice cakes	0	51	0	14	28	7	11	62	23	23	46
Sushi	9	20	2	2	57	10	/	/	/	/	28
Tomato juice	36	18	20	8	12	6	10	32	23	1	33
Oyster, black bean, plum, satay sauce	32	22	3	3	36	3	26	24	4	2	32
Cheese spreads	24	37	3	0	12	24	6	55	22	5	18
Cottage cheese, ricotta, feta cheese	8	51	20	2	7	12	9	37	22	2	24
Vegetable samosa, pakora, pancake roll, bhaji	13	34	2	2	46	4	16	24	1	1	12
Fried plantain	62	11	2	5	13	8	32	10	8	2	1
Mango	15	0	0	2	0	1	42	0	15	2	0
Papaya	15	0	0	2	0	1	31	1	2	2	2
Sweetcorn	19	0	0	0	0	0	15	2	0	0	0
Coconut milk or cream	82	0	4	0	2	12	25	4	9	1	1
Coleslaw, Tzatziki, raita	15	14	31	7	18	14	15	24	32	1	7

Meats quiche, pastry and pies	4	37	0	0	53	6	7	45	4	1	17	
Salted nuts	2	17	0	0	0	0	12	32	1	4	11	
Egg fried, omelette, scrambled egg	5	22	0	0	41	33	1	12	0	0	17	
Croissant plain	72	6	0	0	7	14	13	19	2	1	1	Disagreed
Tomatoes	66	2	17	4	5	6	10	3	19	3	12	
Onions	25	4	20	20	24	7	9	3	8	31	3	
Mashed potato	28	17	1	0	13	41	7	44	3	1	15	
Baked potato	26	11	2	0	17	45	15	44	8	1	18	
Canned baked beans	74	11	0	1	10	4	18	28	6	1	16	
Canned tomatoes, pasta-tomato sauce, cook-in tomato sauce, tomato puree	58	6	17	2	15	4	20	39	24	1	33	
Tomato ketchup	73	8	8	0	10	0	28	29	42	1	22	
Mayonnaise, salad cream, Caesar salad dressing	34	13	12	4	13	24	10	25	33	1	8	
White boiled rice	0	2	0	0	0	17	3	2	2	2	4	Neutral
Plain pasta	0	2	0	0	0	17	3	3	2	1	1	
High fibre breakfast cereal (e.g. Weetabix, multigrain, bran)	22	3	1	1	15	58	6	6	1	2	1	
White bread	40	13	0	0	5	41	5	11	2	2	0	
Wholemeal bread	20	11	2	2	28	38	4	11	2	2	0	
Brown, granary, wheatgerm bread	17	13	3	2	36	29	4	12	2	2	0	
Broccoli	22	4	2	27	20	26	6	4	5	4	6	
Cauliflower	17	2	3	19	18	40	6	3	4	3	4	

Cucumber	28	2	5	6	1	58	6	1	4	4	1
Seeds (e.g. mixed seeds, sesame, sunflower, pumpkin, poppy, linseeds)	15	13	1	10	28	33	6	3	2	3	2
Unflavoured rice cakes, ice-cream wafer	34	5	0	2	7	52	3	7	0	1	1

Appendix B.5. Main foods contributing to each taste cluster

Taste clusters	Products	Quantity and %Contribution
Sweet-tasting foods	Snacks (biscuits, chocolates & candies)	118 (17%)
	Desserts (cakes, sweet pastries& pies)	113 (16%)
	Beverages (fizzy drinks, juices & alcoholic drinks)	111 (16%)
	Dairy products (fruit yogurt, ice cream & milk)	100 (14%)
	Fruits	84 (12%)
Neutral-tasting foods	Potatoes	60 (13%)
	Bread	58 (13%)
	Unsalted butter & oils	44 (10%)
	Seafoods (white fish, shellfish & crab)	37 (8%)
	Vegetables	31 (7%)
Savoury-tasting foods	Meats and poultry	107 (31%)
	Meat-based dishes & curries	68 (20%)
	Burgers & meat-based pastries	64 (18%)
	Vegetables and cheese-based foods	45 (13%)
	Seafoods (oily fish & sushi)	16 (5%)
Salty-tasting foods	Snacks (crisps, biscuits & crackers)	42 (37%)
	Processed meat	33 (29%)
	Cheese	22 (19%)
	Canned/ready soups & pot noodle	5 (4%)
	Garlic bread	3 (3%)
Bitter-tasting foods	Vegetables	35 (45%)
	Alcoholic drinks	17 (22%)
	Coffee & tea	17 (22)
	Dark chocolate & cocoa powder	4 (5%)
	Mustard & chilli papers	4 (5%)
Sour-tasting foods	Fruits	12 (31%)
	Dipping and dressing	12 (31%)
	Plain yogurt, sour cream & buttermilk	9 (23%)
	Pickles + Viner	5 (13%)
	White wine	1 (3%)

Appendix B.6. Characteristics of the adolescents' dietary intakes as consumers and non-consumers of sour-tasting foods

	Weight of sour-tasting food consumed as percentage of the total food weight				
	Non-consumers (n=214) Mean (95% CI)	Consumers(n=70)	% Diff	Coeff. * (95%CI)	*P value*
Energy (kcal/d)	1592 (1527, 1657)	1713 (1575, 1850)	8%	32 (-9, 72)	0.12
Carbohydrate (g/d)	214 (204, 224)	224 (206, 242)	5%	2 (-2, 7)	0.37
Protein (g/d)	61 (58, 65)	67 (61, 73)	10%	2 (-0.2, 3)	0.08
Fat (g/d)	60 (57, 63)	67 (60, 74)	12%	2 (-0.3, 4)	0.09
Total sugars (g/d)	82 (76, 88)	84 (75, 94)	2%	1 (-2, 3)	0.59
Free sugars (g/d)	56 (50, 62)	56 (8, 64)	0%	0.2 (-2, 3)	0.84
Fibre (g/d)	15 (14, 15)	16 (15, 18)	7%	0.2 (-0.2, 1)	0.24
Saturated fat (g/d)	22 (21, 24)	24 (21, 28)	9%	1 (-0.5, 2)	0.27
Sodium (mg/d)	1795 (1690, 1900)	1890 (1691, 2088)	5%	25 (-34, 83)	0.40
Fruit (g/d)	61 (49, 73)	76 (57, 95)	25%	5 (-0.3, 10)	0.06
Fruit Juice (g/d)	83 (57,109)	98 (63, 132)	18%	6 (-6, 18)	0.29
Brassica vegetables (g/d)	10 (7, 13)	16 (10, 23)	60%	2 (0.5, 4)	0.01
Other vegetables (g/d)	82 (72, 92)	101 (83, 120)	23%	1 (-5, 6)	0.79
Meat & poultry (g/d)	59 (51, 66)	67 (5, 83)	14%	5 (1, 9)	0.02
Processed meats (g/d)	25 (21, 30)	25 (18, 31)	0%	-1 (-3, 1)	0.41
Cheese (g/d)	18 (15, 21)	20 (15, 24)	11%	-0.2 (-2, 1)	0.67

* Change in nutrient/food per % increase in taste

Appendix C: Supplementary Materials for Chapter 5

Appendix C.1. Food subgroups under the six primary taste clusters

Sweet subgroups	**Neutral subgroups**
Beverages	Bread
Cakes and pastries	Cereal, rice, pasta, pizza
Cereals	Potatoes
Vegetables and beans	Vegetables and beans
Milk and cream	Cheese, egg, skimmed milk
Dairy dessert (fruit yogurt, and ice cream)	Seafoods
Fruit	Others (oil and butter)
Others-sauces	**Savoury subgroups**
Snacks (chocolate and candies)	Takeaway "fast-food" ready meals
Salty subgroups	Composited cooked dishes
Cheese	Sauces
Garlic bread and noodles	Savoury pastries
Snacks	Nuts
Processed meats	**Bitter subgroups**
Others (salt)	Beverages (coffee, tea, alcoholic/wine)
Sour subgroups	Vegetables
Plain yogurt	Dark chocolate
Fruit	
Others (vinegar, pickles, coleslaw, tzatziki)	

Appendix C.2. Classification of food items

	Preference group (1)	Intermediate group (0)	Low-nutrient/energy-dense group (-1)
Water	* Tap water only * Bottled water still or carbonated	* Herbal tea (made-up weight) * Tea (made-up weight) * Black coffee * Soft drinks low calorie	* Coffee (made-up weight) * Drinking chocolate * Alcoholic beverages *Soups *Soft drinks not low calorie
Bread and cereal	*Wholemeal bread *Brown, granary and wheatgerm bread *High fibre breakfast cereals	*White bread *Other breads *Other breakfast cereals	*Biscuits *Buns, cakes, pastries, and fruit pies *Other cereal-based puddings (manufactured) *Sponge puddings *Pizza *Other cereal-based puddings (homemade) *Other cereals (Yorkshire pudding)
Potatoes and grains	*Wholemeal grain *Other potatoes (including homemade dishes) (e.g.. boiled potatoes) *Other cereals (cous cous, bran, oats, semolina ...etc)	*All pasta dishes * All rice dishes *Other potatoes (including homemade dishes) (e.g. mashed, baked and homemade potato salads and dishes) *Other potato products and dishes (manufactured)	*Crisps and savoury snacks *Chips, fried and roast potatoes, and potato products
Vegetables	*All salad and other raw vegetables *Green beans not raw *Leafy green vegetables not raw *Carrots not raw *Vegetables (not raw)	*Other vegetables (dishes) *Tomato puree	none

Fruits	*Apples and pears not canned *Citrus fruit not canned *Bananas *Other fruit not canned	*Apples and pears not canned (baked, stewed (with or without sugar), dried, apple sauce) *Banana (baked bananas) *Other fruit not canned (fruit pie fillings, dried fruit, fruit salad) *Canned fruit in juice *Canned fruit in syrup	*Preserves (jam, fruit spreads) *Fruit juice *Smoothies
Milk products	*semi-skimmed milk *1% milk *Skimmed milk * Low fat yogurt	*Whole milk *Yogurt *Cereal-based milk puddings	*Ice cream *Fromage frais and other dairy desserts *Other milk& cream
Cheese	*Cottage cheese	*Cheddar cheese *Other cheese	none
Meat, fish and substitutes	*Other white fish, shellfish, and fish dishes *Oily fish * Chicken and turkey dishes *Baked beans *Peas not raw *Beans and pulses (including ready meal & homemade dishes) *Meat alternatives (including ready meals and homemade dishes) *Nuts and seeds	* Beef, veal and dishes * Pork and dishes * Lamb and dishes * Bacon and ham *Eggs and egg dishes *Liver, products, and dishes *Other meat and meat products	* Coated chicken and turkey manufactured *Burgers and kebabs *Sausages *White fish coated or fried *Meat pies and pastries
Fats and oils	*Polyunsaturated margarine and oils *Other cooking fats and oils not polyunsaturated	*Reduced fat spread *Low fat spread *Block margarine	*Butter *Other cooking fats and oils not polyunsaturated

Appendix C.3. Adolescents' dietary quality scores

	Total sample (n=284)		**Boys (n= 140)**		**Girls (n=144)**		***P* value***
	Mean	95% CI	Mean	95% CI	Mean	95% CI	
DQc%	-2.5	-7.3, 2.2	-4.7	-11.5, 2.0	-0.3	-7.1, 6.4	0.36
DDc%	36.2	34.7, 37.7	38.0	36.0, 40.1	34.4	32.3, 37.0	0.02
DEc%	24.6	23.5, 26.0	25.3	23.7, 27.0	24.0	22.4, 25.2	0.17
DA%	51.2	50.0, 53.0	54.0	51.0, 56.2	48.3	46.2, 50.4	<0.01
DEx%	17.3	16.3, 18.4	19.0	17.5, 20.4	16.0	14.2, 17.3	<0.01
DQI-A%	19.4	17.4, 21.4	19.5	16.6, 22.4	19.3	16.4, 22.1	0.91

DQc = diet quality component
DDc = diversity component
DEc = diet equilibrium component
DA = diet adequacy
DEx = diet excess
* Difference between males and females based on regression test

Appendix C.4. Component loadings for each taste pattern highlighting the factor loading ≥ 0.3 in the table

Taste clusters	Food groups	“Savoury-sour-salty-bitter”	“Neutral”	"Savoury-sweet"	"Sweet"	" Sweet-bitter"
Sweet	Beverages	0.0221	0.1077	**0.4215**	0.0912	-0.0891
	Cakes and pastries	0.0946	0.053	-0.0054	**0.3692**	-0.104
	Cereals	-0.1155	-0.1224	-0.0541	0.2742	0.2481
	Vegetables and beans	0.2543	0.1383	-0.2425	0.1173	0.055
	Milk	-0.0318	-0.0055	0.0102	0.0591	**0.5419**
	Dairy dessert	-0.0192	0.1343	0.1948	**0.3728**	-0.0257
	Fruit	-0.0864	0.0195	-0.1723	**0.4452**	0.0845
	Others-sauces	0.1295	0.2095	0.078	0.0355	**0.3133**
	Snacks (chocolate & candies)	0.0659	-0.1171	0.1024	**0.4183**	-0.0314
Neutral	Bread	-0.1198	**0.4156**	0.1911	0.0058	0.2136
	Cereal, rice, pasta, pizza	-0.0429	-0.0372	-0.1891	0.2588	-0.0138
	Potatoes	-0.0399	0.1517	0.171	-0.1431	0.01
	Vegetables and beans	0.1119	**0.3676**	-0.2537	0.0211	-0.0962
	Cheese, egg, skimmed milk	-0.054	0.2899	-0.1573	0.0058	0.0122
	Seafoods	-0.107	0.2462	-0.0364	0.0927	-0.1079
	Others	-0.0861	**0.4186**	0.0864	0.0069	-0.0848
Savoury	Takeaway meals	0.0589	-0.0338	**0.4289**	-0.1001	0.0468
	Home cooked dishes	0.0964	0.2914	-0.0792	-0.1288	0.1637
	Others	0.0384	0.2318	-0.0493	-0.0121	-0.0447
	Savoury pastries	**0.5131**	-0.0669	0.0604	-0.0431	-0.0268
	Nuts	**0.3912**	-0.13	-0.0905	0.054	0.1761

Salty	Cheese	**0.338**	-0.0672	0.0007	0.01	0.0606
	Garlic bread and noodles	-0.0442	-0.0134	0.248	0.0689	-0.0043
	Snacks	0.1004	0.1011	0.2098	0.2105	-0.0975
	Processed meats	-0.0181	-0.0037	0.0908	0.0768	-0.0589
	Others	0.0936	0.0248	0.2186	0.1177	0.2275
Bitter	Beverages	0.0059	0.0124	-0.0504	-0.1201	**0.4868**
	Vegetables	**0.3364**	0.1658	-0.1621	-0.0623	-0.0497
	Dark chocolate	0.0094	-0.1049	0.0391	0.1019	0.168
Sour	Plain yogurt	0.0011	0.0614	-0.0863	0.0459	0.0302
	Fruit	-0.0512	0.0092	-0.2055	0.1442	-0.1037
	Others	**0.3855**	0.0635	0.1753	0.0298	-0.1772

Appendix C.5. Characteristic of adolescents' energy intake, BMI, and diet quality by quintiles (Q1-Q5) of taste patterns

Outcome variables	Quintiles of taste patterns						
	Savoury-sour-salty-bitter ‘*Salad-bar*’						
	Q1(n=57)	**Q2 (n=57)**	**Q3 (n=57)**	**Q4 (n=57)**	**Q5 (n=56)**	**%Diff Q1&Q5**	***P*-trend**
Energy intake (kcal/d)	1414 (1289, 1540)	1558 (1434, 1683)	1534 (1372, 1696)	1635 (1507, 1764)	1700 (1587, 1813)	20%	<0.01
BMI (Kg/m^2)	20.9 (19.5, 22.4)	20.0 (18.8, 21.3)	20.4 (19.0, 21.9)	21.2 (19.9, 22.4)	23.4 (21.0, 25.0)	12%	0.47
Diet quality (%)	19.6 (15.5, 23.7)	19.1 (12.8, 25.4)	16.4 (11.9, 20.8)	21.0 (17.5, 24.4)	20.8 (17.3, 24.4)	6%	0.33
	Neutral ‘*Hot-food*’						
	Q1(n=57)	**Q2 (n=57)**	**Q3 (n=57)**	**Q4 (n=57)**	**Q5 (n=56)**	**%Diff Q1&Q5**	***P*-trend**
Energy intake (kcal/d)	1454 (1332, 1577)	1582 (1427, 1736)	1600 (1455, 1745)	1524 (1393, 1655)	1705 (1588, 1822)	17%	0.05
BMI (Kg/m^2)	20.7 (19.5, 21.9)	23.0 (20.2, 25.8)	19.9 (18.6, 21/2)	21.9 (20.2, 23.6)	21.2 (19.5, 22.8)	2%	0.70
Diet quality (%)	13.5 (8.7, 18.3)	15.1 (10.9, 19.3)	19.5 (16.0, 23.1)	24.6 (20.5, 28.7)	23.0 (18.9, 27.2)	70%	<0.01
	Savoury-sweet ‘*Takeaway-meal*’						
	Q1(n=57)	**Q2 (n=57)**	**Q3 (n=57)**	**Q4 (n=57)**	**Q5 (n=56)**	**%Diff Q1&Q5**	***P*-trend**
Energy intake (kcal/d)	1383 (1289, 1476)	1344 (1204, 1483)	1588 (1476, 1699)	1691 (1540, 1842)	1888 (1786, 1989)	37%	<0.01
BMI (Kg/m^2)	23.9 (21.3, 26.6)	22.1 (20.6, 23.6)	21.6 (20.1, 23.0)	19.4 (17.9, 20.9)	19.3 (18.4, 20.2)	-3%	<0.01
Diet quality (%)	13.2 (8.7, 17.6)	16.3 (12.0, 20.5)	21.6 (17.6, 25.5)	21.2 (16.3, 26.2)	24.4 (20.8, 28.0)	85%	<0.01
	Sweet ‘*Sweet-snack*’						
	Q1(n=57)	**Q2 (n=57)**	**Q3 (n=57)**	**Q4 (n=57)**	**Q5 (n=56)**	**%Diff Q1&Q5**	***P*-trend**
Energy intake (kcal/d)	1488 (1329, 1647)	1474 (1348, 1600)	1471 (1390, 1552)	1712 (1578, 1845)	1760 (1628, 1892)	18%	<0.01
BMI (Kg/m^2)	20.7 (19.3, 22.1)	21.0 (19.6, 22.5)	20.2 (18.8, 21.5)	22.3 (19.5, 25.1)	22.3 (20.6, 24.0)	8%	0.11
Diet quality (%)	28.8 (25.5, 32.2)	21.2 (16.5, 25.9)	17.1 (13.0, 21.1)	17.9 (14.6, 21.3)	9.9 (5.6, 14.1)	-65%	<0.01
	Sweet-bitter ‘*Beverages*’						
	Q1(n=57)	**Q2 (n=57)**	**Q3 (n=57)**	**Q4 (n=57)**	**Q5 (n=56)**	**%Diff Q1&Q5**	***P*-trend**

Energy intake (kcal/d)	1513 (1349, 1676)	1455 (1340, 1569)	1631 (1503, 1759)	1477 (1379, 1576)	1811 (1702, 1920)	17%	<0.01
BMI (Kg/m^2)	22.7 (20.9, 24.4)	21.6 (20.2, 22.9)	20.8 (18.2, 23.4)	19.9 (18.7, 21.1)	20.9 (19.7, 22.1)	-7%	0.14
Diet quality (%)	16.4 (12.5, 20.2)	20.7 (16.3, 25.1)	18.0 (13.5, 22.5)	22.8 (18.2, 27.4)	20.3 (15.2, 25.4)	24%	0.02

Univariate analysis of association between energy intake, BMI, or diet quality and taste pattern score (per 1 unit adherence)

Appendix D: Supplementary Materials for Chapter 6

Appendix D.1. List of nutrients in the Arabic FDB

Nutrients included in the Arabic FCDB			
Total solids (g)	Thiamin (mg)	cis-Monounsaturated fatty acids/100g Food (g)	Delta-5-avenasterol (mg)
Nitrogen conversion factor	Riboflavin (mg)	Monounsaturated fatty acids per 100g fatty acids (g)	Delta-7-avenasterol (mg)
Glycerol conversion factor	Niacin (mg)	Monounsaturated fatty acids per 100g food (g)	Delta-7-stigmastenol (mg)
Water (g)	Tryptophan/60 (mg)	cis-Polyunsaturated fatty acids /100g FA (g)	Stigmasterol (mg)
Total nitrogen (g)	Niacin equivalent (mg)	cis-Polyunsaturated fatty acids /100g Food (g)	Citric acid (g)
Protein (g)	Vitamin B6 (mg)	Polyunsaturated fatty acids per 100g fatty acids (g)	Malic acid (g)
Fat (g)	Vitamin B12 (µg)	Polyunsaturated fatty acids per 100g food (g)	LEnergy (kcal)
Carbohydrate (g)	Folate (µg)	Saturated fatty acids excluding branch per 100 g fatty acid (g)	LEnergy (kJ)
Energy (kcal)	Pantothenate (mg)	Saturated fatty acids excluding branch per 100 g food (g)	LProtein (g)
Energy (kJ)	Biotin (µg)	Total branched chain per 100g fatty acid (g)	LCarbohydrate (g)
Starch (g)	Vitamin C (mg)	Total branched chain per 100g food (g)	LTotal Sugars (g)
Oligosaccharide (g)	All-trans-retinol (µg)	Total Trans fatty acids per 100g fatty acids (g)	LStarch (g)
Total sugars (g)	13-cis-retinol (µg)	Total Trans fatty acids per 100g food (g)	Sodium (mg)
Glucose (g)	Dehydroretinol (µg)	Tetradecanoic acid C14:0 per 100g fatty acids (g)	Potassium (mg)
Galactose (g)	Retinaldehyde (µg)	Hexadecanoic acid C16:0 per 100g fatty acids (g)	Calcium (mg)
Fructose (g)	Alpha-carotene (µg)	Tetradecanoic acid C14:0 per 100g food (g)	Magnesium (mg)
Sucrose (g)	Beta-carotene (µg)	Hexadecanoic acid C16:0 per 100g food (g)	Phosphorus (mg)

Maltose (g)	Cryptoxanthins (µg)	cis n-6 C20:3 Eicosatrienoic acid per 100g fatty acids (g)	Iron (mg)
Lactose (g)	Lutein (µg)	cis n-6 C20:4 Eicosatetraenoic acid per 100g fatty acids (g)	Copper (mg)
Alcohol (g)	Lycopene (µg)	cis n-3 C20:5 Eicosapentaenoic acid per 100g fatty acids (g)	Zinc (mg)
Non-starch polysaccharide (NSP) (g)	25-hydroxy vitamin D3 (µg)	cis n-3 C22:6 Docosahexaenoic acid (DHA) per 100g FA (g)	Chloride (mg)
AOAC fibre (g)	Cholecalciferol (µg)	cis n-6 C20:3 Eicosatrienoic acid per 100g food (g)	Manganese (mg)
Cholesterol (mg)	5-mehtyl folate (µg)	cis n-3 C20:5 Eicosapentaenoic acid per 100g food (g)	Selenium (µg)
Saturated fatty acids per 100g fatty acids (g)	Alpha-tocopherol (mg)	cis n-3 C22:6 Docosahexaenoic acid (DHA) per 100g food (g)	Iodine (µg)
Saturated fatty acids per 100g food (g)	Beta-tocopherol (mg)	Total Phytosterols (mg)	Retinol (µg)
Total n-6 polyunsaturated fatty acids per 100g fatty acid (g)	Delta-tocopherol (mg)	Other Cholesterol and Phytosterols (mg)	Carotene (µg)
Total n-6 polyunsaturated fatty acids per 100g food (g)	Gamma-tocopherol (mg)	Phytosterol (mg)	Retinol Equivalent (µg)
Total n-3 polyunsaturated fatty acids per 100g fatty acid (g)	Alpha-tocotrienol (mg)	Beta-sitosterol (mg)	Total Vitamin D (µg)
Total n-3 polyunsaturated fatty acids per 100g food (g)	Delta-tocotrienol (mg)	Brassicasterol (mg)	Total Vitamin E (mg)
cis-Monounsaturated fatty acids /100g FA (g)	Gamma-tocotrienol (mg)	Campesterol (mg)	Phylloquinone - Vitamin K1 (µg)

Appendix D.2. Detailed number of food items in the Arabic FDB

Existing Middle Eastern publications (160 items)		UK myfood24 FCDB (1585 items)	
Food category	**Number of foods**	**Food category**	**Number of foods**
Meat-based dishes	37	Meats (beef and lamb)	222
Desserts	32	Vegetables	250
Cereal-based dishes	29	Fruits	159
Vegetable-based	13	Seafood	148
Seafood-based dishes	12	Chicken, turkey, eggs	89
Fruit	12	Spices	81
Chicken-based	10	Biscuits & cakes	77
Bean-based dishes	10	Dairy	61
Dairy products	5	Beans	58
Branded products (271 items)		Savoury snacks & nuts	53
Food category	**Number of foods**	Dressings & sauces	48
Dairy products	100	Bread & flour	38
Cakes & Biscuits	37	Juices & drinks	36
Juices	29	Cereals & porridge	34
Croissants and pies	19	Pasta &noodles	33
Breads	18	Soups	33
Frozen meat products	15	Oils & ghee	22
Cereal, pasta &	9	Chocolate &candies	21
Processed meat	8	Pastries & pies	20
Spreads	7	Coffee & tea	19
Flours	6	Rice & couscous	17
Ready-to-eat products	6	Syrup, honey & jams	16
Seafood product	6	Jelly & puddings	15
Sauces	4	Salads	14
Frozen burgers	4	Soda/Carbonated	7
Oil/Fat	2	Cheesecakes &tarts	7
Frozen vegetables	1	Pizza	7

Appendix E: Supplementary Materials for Chapter 8

Appendix E.1. Validity checking of the taste classification

Food	Our work (Values= respondents answers)						Others work (Values= mean intensity)					Validity outcome
	Sweet	Salty	Sour	Bitter	Savoury	Neutral	Sweet	Salty	Sour	Bitter	Savoury	
Lamb	3	86	0	1	3	14	11	38	5	2	36	Agreed
Processed meat e.g. sausages	3	76	1	1	0	11	5	46	10	1	23	
Burgers, kebab	0	8	0	0	0	1	10	31	11	1	27	
Chicken kebab	0	8	0	0	0	1	4	37	6	1	17	
nuggets	0	8	0	0	0	1	7	35	3	1	21	
Meat/chicken-based dishes e.g. biryani	1	98	0	0	0	10	6	37	2	2	32	
Cheese pie	0	99	0	3	0	7	6	54	10	1	23	
Eggs boiled, poached	5	68	0	6	0	28	5	10	2	1	8	
White fish steamed, grilled, baked, fried	0	6	0	0	0	2	2	13	3	2	12	
Fish curry, prawn curry	1	98	0	0	0	10	6	37	2	2	32	
Oily fish meals e.g. salmon, herring, mackerel, fresh tuna	3	54	3	3	1	18	3	29	10	1	26	
Tinned fish e.g. tuna canned in oil	0	6	1	0	0	1	3	37	19	2	31	
Tinned fish canned in water	0	5	1	1	0	1	4	25	16	2	22	
Whole milk	48	11	1	9	0	35	12	3	4	1	1	

Semi-skimmed milk	47	9	2	10	0	31	12	3	4	1	1
Skimmed milk	34	11	3	7	0	32	14	2	5	1	1
Plain yogurt, sour cream, buttermilk	13	28	50	5	0	12	4	4	54	2	2
Soft full-fat cheese	12	77	5	0	0	10	2	9	7	1	3
Mixed leaf salad, lettuce, rocket	8	20	9	31	0	38	7	1	2	6	1
Spring onions, chives, leeks	5	17	5	32	0	27	5	2	3	11	2
Pasta with tomato or cheese sauces	0	7	0	0	0	2	9	29	11	0	25
Pot noodle	0	99	0	0	0	10	9	45	3	1	37
Rice dishes (e.g. fried rice with chicken or egg)	0	6	0	0	0	3	6	39	2	1	27
Pizza	0	7	0	0	0	2	12	32	11	1	29
Broccoli	3	25	4	14	0	27	6	4	5	4	6
Cauliflower	11	25	3	11	0	28	6	3	4	3	4
Cucumber	22	31	9	7	0	38	6	1	4	4	1
Peas	36	16	3	4	0	20	15	4	2	1	5
Onions	9	27	9	33	0	25	9	3	8	31	3
Mashed potato	13	72	0	4	0	17	7	44	3	1	15
Baked potato	10	75	2	4	1	15	15	44	8	1	18
Potato chips/waffles or roast	2	6	0	0	0	1	9	15	3	0	7
Canned baked beans	11	76	3	0	8	10	18	28	6	1	16
Vegetable soup	9	70	2	2	0	10	19	32	16	1	27

Clear soup (eg. consommé, stock cubes)	0	79	7	0	0	10	10	39	6	3	21
Plain biscuits eg. digestives, shortbread	59	12	0	1	3	23	51	11	0	3	2
Cheese straws, cheese flavoured biscuits	0	9	0	0	0	1	6	41	2	0	8
Prawn crackers, papadums/poppadom	6	62	6	3	0	5	12	29	1	0	26
Coffee drinks with milk, unsweetened (e.g. latte, cappuccino)	3	0	0	5	0	0	8	2	9	44	1
Twiglets, pretzels	4	89	0	2	0	7	6	45	1	0	4
Unsalted nuts	9	37	2	20	0	38	7	8	1	6	9
Honey roasted peanuts	6	2	0	0	0	0	42	11	1	4	2
Pasta-tomato sauce, tomato puree	9	48	10	0	0	10	20	39	24	1	33
Pesto	9	44	7	0	0	7	5	57	12	2	23
Lasagne	1	6	0	0	0	1	12	42	8	1	32
Biscuits with fruits or currants	66	3	5	2	0	6	30	7	5	1	1
Milkshake, hot chocolate, flavoured milk	9	0	0	0	0	0	37	6	2	7	0
Custard, mousse, dairy desserts, rice pudding, jelly	8	0	0	0	0	0	43	4	5	5	1

Ice cream	9	0	0	0	0	0	46	6	2	3	1
Breakfast cereal with chocolate or honey or fruit	7	0	0	0	0	1	41	12	1	5	0
High fibre breakfast cereal with chocolate or honey or fruit	5	1	0	0	0	2	23	9	3	1	1
Black coffee	0	0	0	8	0	0	2	1	9	63	1
Black tea	21	4	4	54	1	9	4	1	5	20	1
Ready to drink fruit juice (carton/can)	9	0	0	0	0	0	50	2	33	7	0
Fizzy drinks (e.g. lemonade)	9	0	0	0	0	0	41	1	23	5	0
Cakes and sweet muffins	9	0	0	0	0	0	47	10	2	4	1
Chocolate biscuits, chocolate chip cookies	9	0	0	0	0	0	59	13	1	4	1
Sweet peppers	27	21	5	19	3	19	11	2	8	11	4
Boiled sweets and gums	9	0	0	0	0	0	46	2	19	2	0
Jam	9	0	0	0	0	0	74	3	19	1	0
Honey	9	0	0	0	0	0	76	4	1	3	0
Fruit pies and crumbles	6	1	1	0	0	0	54	11	14	1	2
Mango	6	0	2	0	0	0	42	0	15	2	0
Papaya	6	0	2	0	0	0	31	1	2	2	2
Apples, pears	87	1	14	1	0	6	27	1	17	1	1
Grapes	66	0	36	2	1	3	30	1	25	2	0

Melon	80	2	4	3	0	6	25	1	1	0	1
Banana	7	0	0	0	0	2	29	1	2	1	1
Carrots	62	7	1	12	0	21	15	2	2	1	7
Cheese spreads	15	74	5	1	0	7	6	55	22	5	18
Feta cheese	7	66	17	2	1	3	9	37	22	2	24
Vegetable samosa, pakora	6	77	4	0	4	10	16	24	1	1	12
Eclairs, doughnuts, cream, or iced bun	9	0	0	0	0	0	44	10	1	1	2
Crisps	0	9	0	0	0	0	9	45	5	2	13
Sweetcorn	9	0	0	0	0	0	15	2	0	0	0
Coleslaw, Tzatziki, raita	11	26	49	3	0	9	15	24	32	1	7
Meats quiche, pastry, and pies	5	86	2	1	0	14	7	45	4	1	17
Salted nuts	0	9	0	0	0	0	12	32	1	4	11
Mustard	6	27	35	15	1	6	6	37	47	10	5
French salad dressing	16	10	36	3	0	8	10	41	56	2	11
Fruit yogurt and fromage frais	6	0	0	1	0	0	34	3	27	1	1
Breakfast cereal without honey, chocolate, fruit (e.g. cornflakes)	74	4	0	1	0	27	14	9	2	1	2
White bread	0	5	0	0	0	4	5	11	2	2	0
Chicken or meat soup	4	86	1	0	2	9	12	33	28	0	28

Marconi with tomato sauce	7	82	6	2	4	8	9	29	11	0	25	
Vegetable curry	17	72	2	1	0	5	11	28	2	1	21	
White boiled rice	0	3	0	0	0	6	3	2	2	2	4	Neutral
Plain pasta	0	3	0	0	0	6	3	3	2	1	1	
Beef	3	86	0	1	3	14	4	27	3	2	35	savoury/salty
Chicken, duck	1	92	0	1	1	14	5	28	2	1	28	
Mushrooms	4	36	4	8	2	23	7	5	3	2	18	
satay sauce	23	25	3	3	1	11	26	24	4	2	32	
Egg fried, omelette, scrambled egg	0	7	0	0	0	2	1	12	0	0	17	
Wholemeal bread	0	1	0	5	0	2	4	11	2	2	0	Disagreed
Spinach	2	33	12	23	0	12	7	4	4	8	3	
Cabbage	6	30	10	14	0	34	3	1	3	6	1	
Olives	4	41	48	2	0	7	4	31	6	4	18	
Tomato ketchup	5	3	0	0	0	1	28	29	42	1	22	
Croissant plain	5	1	0	0	0	3	13	19	2	1	1	
Mayonnaise	14	55	11	8	1	14	10	25	33	1	8	
Tomatoes	31	27	21	5	0	22	10	3	19	3	12	

Appendix E.2. Classification of food items

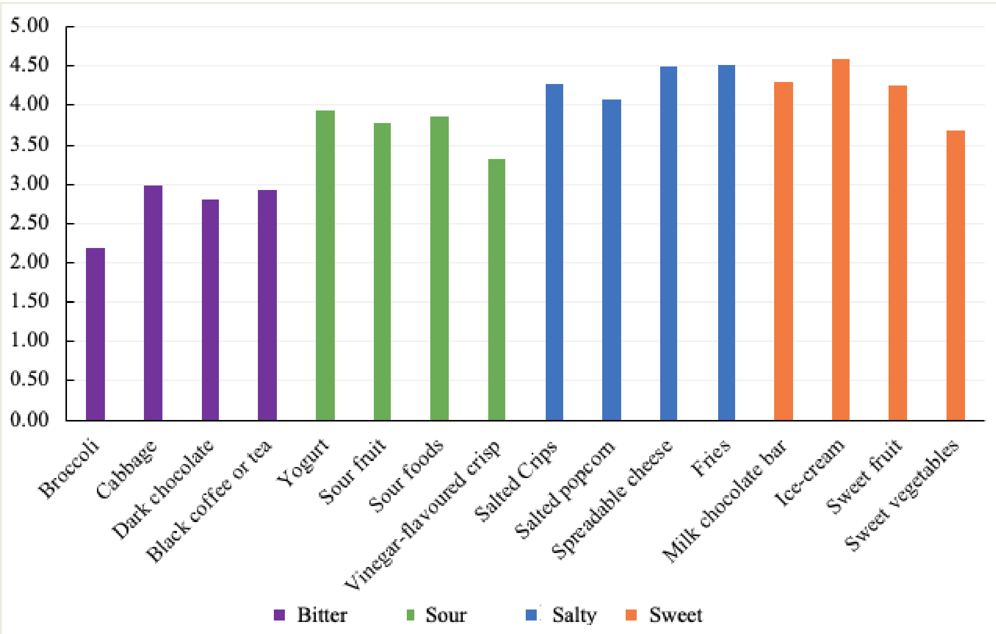
	Preference group (1)	Intermediate group (0)	Low-nutrient/energy-dense group (-1)
Water	* Tap water only * Bottled water still or carbonated	* Tea (made-up weight) * Black coffee * Soft drinks low calorie	* Coffee (made-up weight) * Drinking chocolate *Soups *Soft drinks not low calorie
Bread and cereal	*Wholemeal bread	*White bread *Other breads	*Biscuits *Buns, cakes, pastries, and fruit pies (manufactured) *Pizza
Potatoes and grains	*Other potatoes (including homemade dishes) (e.g. boiled potatoes) *Other cereals (bran, oats, etc)	*All pasta dishes * All rice dishes *Other potatoes (including homemade dishes) (e.g. mashed, baked and homemade potato dishes) *Other potato products and dishes (manufactured)	*Crisps and savoury snacks *Chips
Vegetables	*All salad and raw vegetables *Leafy green vegetables not raw *Carrots not raw *Vegetables (not raw)	*Other vegetables (dishes) *Tomato puree	None
Fruits	*Apples and pears not canned *Citrus fruit not canned *Bananas	*Other fruit not canned (fruit pie fillings, dried fruit, fruit salad) *Canned fruit in juice *Canned fruit in syrup	*Preserves (jam, fruit spreads) *Fruit juice *Smoothies
Milk products	*semi-skimmed milk *Skimmed milk * Low fat yogurt	*Whole milk *Yogurt	*Ice cream *Other milk& cream

Cheese	*White cheese	*Cheddar cheese	None
Meat, fish and substitutes	*Other white fish, shellfish, and fish dishes * Chicken dishes *Peas not raw *Beans (including ready meal & homemade dishes) *Nuts and seeds	* Lamb and dishes *Eggs and egg dishes *Other meat and meat products	* Coated chicken manufactured *Burgers and kebabs *White fish coated or fried *Meat pies and pastries
Fats and oils	*Polyunsaturated margarine and oils	*Fat spread	*Butter *Other cooking fats

Appendix E.3. Cronbach's alpha value and liking score of the combined items/taste presented as mean and standard deviation (SD)

Taste groups	Cronbach's alpha	Mean liking (SD)
Sweet	0.54	16.83 (1.99)
Salty	0.53	17.39 (1.72)
Sour	0.53	14.91 (3.08)
Bitter	0.62	10.91 (3.83)

Appendix E.4. The mean Likert score for each item



Appendix E.5. Participants' responses

	Like it a lot	I like it	Neither nor	Don't like it	Don't like it at all	Never tried
Broccoli	3 (7%)	9 (20%)	9 (20%	5 (11%)	13 (28%)	7 (15%)
Cabbage	3 (7%)	13 (28%)	17 (37%)	6 (13 %)	7 (15%)	0
Dark chocolate	4 (7%)	16 (35%)	6 (13%)	12 (26%)	8 (17%)	1 (2%)
Black coffee or tea	9 (20%)	11 (24%)	8 (17%)	4 (9%)	14 (30%)	0
Yogurt	12 (26%)	24 (52%)	5 (11%)	5 (11%)	0	0
Sour fruit	12 (26%)	20 (43%)	9 (20%)	3 (7%)	1 (2%)	1 (2%)
Sour foods	19 (41%)	14 (30%)	6 (13%)	3 (7%)	3 (7%)	1 (2%)
Vinegar-flavoured crisp	13 (28%)	8 (17%)	12 (26%)	7 (15%)	6 (13%)	0
Salted Crips	16 (35%)	27 (59%)	3 (7%)	0	0	0
Salted popcorn	12 (26%)	27 (59%)	6 (13%)	1 (2%)	0	0
Spreadable cheese	28 (61%)	13 (28%)	5 (11%)	0	0	0
Fries	29 (63%)	12 (26%)	5 (11%)	0	0	0
Milk chocolate bar	21 (46%)	18 (39%)	7 (15%)	0	0	0
Ice-cream	31 (67%)	11 (24%)	4 (9%)	0	0	0
Sweet fruit	20 (43%)	19 (41%)	6 (13%)	1 (2%)	0	0
Sweet vegetables	8 (17%)	20 (43%)	13 (28%)	5 (11%)	0	0

Appendix E.6. Examples of food under each taste

Taste clusters	Foods
Sweet	Breakfast cereal, biscuits, vegetables (e.g. carrot, tomato), fruit (e.g. apple, melon), milk, sauces (e.g. satay sauce)
Salty	Takeaway foods (e.g. burgers, chicken sandwiches, pizza), home-cooked foods, Crackers, eggs, vegetable-based products (e.g. samosa, curry, stew), beans, meat/poultry-based products (e.g. pies, soups, biryani), sauces (e.g. white sauce, cheese sauce)
Sour	Plain yogurt, mustered, sweet-sour sauce, olives, common plant-based items (e.g. Tabula, Fattoush)
Bitter	Black tea, green tea, tea with milk unsweetened
Neutral	Breadsticks, vegetables (e.g. cucumber), unsalted nuts/popcorn, sauces (e.g. tahini, mayonnaise)
Sweet-sour	Pomegranate, cherries, grapes, pineapple, grapefruit, tamarind, apple juice unsweetened

Appendix E.7. Generated taste clusters from the Hieratical cluster analysis