

Helpful or harmful? An examination of the relationship between low- and no-calorie sweetener exposure and dietary intake and health

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Statement of Contributions

This thesis consists in part of four manuscripts that have been prepared for publication.

Exceptions to sole authorship include:

Chapter 4: Andrade L, Lee KM, Sylvetsky AC, and Kirkpatrick SI. Low-calorie sweeteners and human health: a rapid review of systematic reviews.

Chapter 5: Andrade L, Rondeau I, Sylvetsky AC, Hussain S, Singh N, Wallace MP, Dodd KW, and Kirkpatrick SI. Classifying sources of low- and no-calorie sweeteners with the Canadian food composition database.

Chapter 6: Andrade L, Sylvetsky AC, Singh N, Wallace MP, Dodd KW, and Kirkpatrick SI. Exposure to and sources of low- and no-calorie sweeteners among individuals living in Canada: Estimates from the 2015 Canadian Community Health Survey—Nutrition.

Chapter 7: Andrade L, Dodd KW, Sylvetsky AC, Wallace MP, and Kirkpatrick SI. Diet quality in relation to the probability of consuming low- and no-calorie sweeteners among individuals in Canada.

As lead author of these four chapters, I was responsible for conceptualizing the study designs, contributing to the data collection and/or measure selection, conducting the data analysis, and drafting the manuscripts. My co-authors provided guidance during each step of the research and provided feedback on draft manuscripts, with significant editorial contributions from my advisor, Dr. Sharon Kirkpatrick. Under Dr. Sharon Kirkpatrick's supervision, I also prepared the remaining chapters in this thesis, which were not written for publication.

Abstract

Background: Poor dietary patterns are a major contributor to chronic disease morbidity and mortality globally. Many governments and health authorities have implemented public health initiatives to improve dietary patterns, including by reducing added sugars intake. Replacing added sugars with low- and no-calorie sweeteners is becoming increasingly common, both in the food supply and by individuals. Although low- and no-calorie sweeteners approved for use are considered safe from a toxicological perspective, their long-term impacts on health and chronic disease risk are contested.

Objectives: The objectives of this dissertation were to 1) summarize evidence from systematic reviews examining associations between consumption of low- and no-calorie sweeteners and chronic conditions and intermediate risk factors (**Chapter 4**); 2) develop a standardized approach to classify food codes used in nutrition surveillance in Canada as sources of low- and no-calorie sweeteners (**Chapter 5**); 3) estimate the proportion of individuals in Canada reporting the consumption of sources of low- and no-calorie sweeteners or tabletop sweeteners on a given day (**Chapter 6**); 4) characterize the nutrition profiles of sources of low- and no-calorie sweeteners (**Chapter 6**); and 5) assess diet quality in relation to the probability of consuming low- and no-calorie sweeteners among individuals in Canada (**Chapter 7**).

Methods and results: **Chapter 4** presents a rapid review of systematic reviews of randomized and non-randomized clinical trials and observational studies investigating associations between low- and no-calorie sweetener consumption and health outcomes and intermediate risk factors in adults and children. The search strategy returned 409 results, 25 of which met the eligibility criteria and underwent quality appraisal using the AMSTAR-2 assessment tool. Data from nine systematic reviews assessed as high- or moderate-quality were included in the narrative synthesis. Randomized controlled trials tended to report no association or beneficial impacts of consumption, whereas non-randomized trials and other observational studies observed no association or negative impacts on outcomes of interest, such as type 2 diabetes. There was limited evidence examining associations between consumption of sweeteners and diet quality.

Chapters 5, 6, and 7 drew on 24-hour dietary recall data from the 2015 Canadian Community Health Survey—Nutrition Public Use Microdata File (2015 CCHS—Nutrition). In

Chapter 5, a classification system was developed to categorize food codes used to code the 24-hour recalls as sources of sweeteners. First, food code descriptions were reviewed for confirmatory keywords, such as “low-calorie sweetener,” and possible source keywords, such as “diet.” Food codes with descriptions containing confirmatory keywords were categorized as sources, whereas those with descriptions containing possible source keywords progressed to step two. In step two, the descriptions for matching food codes in the U.S. Food and Nutrient Database for Dietary Studies were examined for confirmatory keywords. In step 3, the remaining possible sources were assessed using an online search of grocery store websites. A total of 76 food codes (1.5%) were classified as sources of low- and no-calorie sweeteners and 46 recipe codes used in the 2015 CCHS—Nutrition contained sources as ingredients. Steps 2 and 3 identified 41 food code sources not identified by Step 1 alone.

In **Chapter 6**, the classification system was applied to recall data for individuals aged 1 year and above living in the Canadian provinces. The proportions reporting consumption of at least one source on a given day were estimated overall and by age, sex, household income, and self-reported diabetes status. Commonly reported sources were examined by age group, and the nutritional profiles of sources were examined relative to the 2019 Canada’s Food Guide. About one in 10 children aged 1-13 years (8.4%, 95% CI: 6.6, 10.2) and adolescents aged 14-18 years (10.7%, 95% CI: 7.6, 13.8) and one in five adults (19.8%, 95% CI: 16.2, 23.4) 19 years and above consumed sources of sweeteners on a given day. Among adults with diabetes, four in 10 (42.4%, 95% CI: 36.1, 48.7) consumed a source of low- and no-calorie sweeteners on a given day compared to approximately one in five (18.2%, 95% CI: 14.2, 22.0) who did not report having diabetes. Foods sweetened with low- and no-calorie sweeteners were more frequently consumed than beverages among children and adolescents (children: 5.5% (95% CI: 4.0, 7.0) vs. 3.1% (95% CI: 2.3, 3.9), respectively; adolescents: 6.2% (95% CI: 3.4, 9.1) vs. 4.1% (95% CI: 2.8, 5.4)), whereas adults consumed beverages more frequently than foods (10.9% (95% CI: 7.6, 14.2) vs. 7.7% (95% CI: 7.0, 8.4), respectively). On a given day, 4% of adults consumed tabletop sweeteners; estimates for children and adolescents were not reported due to small sample sizes. Diet sodas were the most frequently consumed beverage source across all three age groups. Yogurts were the most frequently consumed food source among children, whereas meal replacements, including protein powders, were the most frequently consumed food source among

adolescents and adults. No food codes classified as sources of low- and no-calorie sweeteners were considered ‘foundational’ according to the 2019 Canada’s Food Guide Food Classification System.

In **Chapter 7**, diet quality, measured using the 2019 Healthy Eating Food Index (HEFI-2019), was assessed in relation to the probability of consuming sources of low- and no-calorie sweeteners among respondents aged 2 years and older, overall and by sex and diabetes status. Higher HEFI-2019 scores, which represent closer alignment with the 2019 Canada’s Food Guide, were calculated based on simulated distributions of usual intakes estimated using the National Cancer Institute’s multivariate Markov chain Monte Carlo (MCMC) method. Variables (e.g. vegetables and fruit, free sugars) used to arrive at HEFI-2019 scores were modelled jointly with a variable indicating an individual’s probability to consume low- and no-calorie sweeteners on a recall day; probabilities of consumption were expressed as quintiles. There was weak evidence ($P=0.08$) of lower (-6.1 points, 95% CI: -13.1, 0.8) HEFI-2019 total scores among children aged 2 to 13 with the highest probability of consuming low- and no-calorie sweeteners (i.e. quintile 5) compared to children with the lowest probability. Among males 14 years of age and above, there was moderate evidence ($P=0.04$) of higher (4.6 points, 95% CI: 0.1, 9.1) HEFI-2019 total scores among those with the highest probability of consuming low- and no-calorie sweeteners compared to those with the lowest probability. There was little to no evidence of meaningful differences in HEFI-2019 total scores in relation to probability of consuming sources of low- and no-calorie sweeteners among females aged 14 years and above or among adults 19 years and above with and without diabetes.

Conclusion: This dissertation makes several contributions to the evidence to inform policies related to low- and no-calorie sweeteners in Canada. First, the inconsistent associations between the use of sweeteners and health in the literature contribute to differing dietary guidance across health authorities. This lack of clarity on how and by whom low- and no-calorie sweeteners should be consumed emphasizes the importance of ongoing monitoring of population-level consumption patterns. Second, this dissertation presents a standardized approach to identifying sweetener sources in Canada’s national food composition database, enabling consistent classification across studies. Third, for the first time, evidence on population-level exposure to low- and no-calorie sweeteners from foods, beverages, and tabletop sweeteners

in Canada and associations between diet quality and the probability of consuming low- and no-calorie sweeteners can inform healthy eating policies, such as Canada's Healthy Eating Strategy.

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List of Abbreviations

ADI	Acceptable daily intake
AMPM	Automated Multiple Pass Method
BMI	Body mass index
CCHS—Nutrition	Canadian Community Health Survey—Nutrition
DRI	Dietary Reference Intakes
EFSA	European Food Safety Authority
FNDDS	Food and Nutrient Database for Dietary Studies
FDA	Food and Drug Administration
FID	Food ingredient details
FRL	Food recipe level
HEI	Healthy Eating Index
HEFI-2019	Healthy Eating Food Index—2019
JECFA	Joint FAO/WHO Expert Committee on Food Additives
LCS	Low-calorie sweetener
LNCS	Low- and no-calorie sweetener
MCMC	Markov Chain Monte Carlo
NCI	National Cancer Institute
NOAEL	No observable adverse effect level
NRSI	Non-randomized studies or interventions
RA	Reference amounts
RCT	Randomized controlled trial
SE	Standard error
SR	Systematic review or Standard reference
US	United States
USDA	United States Department of Agriculture
WHO	World Health Organization
24HDR	24-hour dietary recall

Chapter 1

Introduction

1.1 Overview and scope

With the global rise of diet-related chronic diseases, healthy eating behaviours are a top public health priority (1). Poor dietary patterns are a major contributor to chronic disease morbidity and mortality (2–5). Many governments and public health authorities have implemented initiatives to improve dietary patterns, including those aimed at reducing free or added sugars intake. As a result, replacing free or added sugars with low- and no-calorie sweeteners is becoming increasingly common, both in the food supply (because of industry reformulation efforts) and by individuals. With little to no energy and nutrients, low- and no-calorie sweeteners are, in theory, potentially useful tools to support public and population health efforts, specifically those related to reducing the intake of sugars. However, evidence supporting the benefits of low- and no-calorie sweeteners consumption from an epidemiological perspective remains inconsistent and unclear.

Low- and no-calorie sweeteners are referred to by many names. For the purposes of this dissertation, the term low- and no-calorie sweeteners refer to artificial sweeteners, nonnutritive sweeteners, high-intensity sweeteners, artificial sweeteners, natural noncaloric sweeteners (e.g., those derived from natural products, such as Stevia or Monk Fruit extract), and sugar alcohols (e.g., xylitol and sorbitol).

To inform public health guidance provided by Health Canada, a rapid review of systematic reviews was undertaken to summarize the state of the evidence examining associations between the consumption of low- and no-calorie sweeteners and chronic diseases of public health concern across the life course. The findings from this review underscored the critical lack of evidence on low- and no-calorie sweetener consumption among individuals living in Canada, a gap that needed to be addressed. This lack of evidence was the driving force for the secondary analyses using data from Canada's most recent national nutrition survey, the 2015 Canadian Community Health Survey—Nutrition, presented in this dissertation.

The objectives of this dissertation were to 1) summarize evidence from systematic reviews examining associations between consumption of low- and no-calorie sweeteners and chronic conditions and intermediate risk factors; 2) develop a standardized approach to classify

food codes used in nutrition surveillance in Canada as sources of low- and no-calorie sweeteners; 3) estimate the proportion of individuals in Canada reporting the consumption of sources of low- and no-calorie sweeteners or tabletop sweeteners on a given day; 4) characterize the nutrition profiles of sources of low- and no-calorie sweeteners; and 5) assess diet quality in relation to the probability of consuming low- and no-calorie sweeteners among individuals in Canada.

This dissertation provides, for the first time, comprehensive estimates of low- and no-calorie sweetener exposure from foods, beverages, and tabletop sweeteners among individuals living in the Canadian provinces. Further, it describes a novel methodological approach undertaken to model diet quality conditional on the probability of consuming low- and no-calorie sweeteners. Findings from these analyses suggest potential differences in diet quality in relation to low- and no-calorie sweetener consumption by age and sex. These findings contribute to the ongoing discussion about the role of low- and no-calorie sweeteners in public health nutrition policy.

1.2 Dissertation organization

This dissertation is comprised of eight chapters. Following this overview chapter, background on low- and no-calorie sweeteners and a summary of pertinent literature that informed the directions of the research within this dissertation are provided in **Chapter 2**. **Chapter 3** summarizes the rationale and details the research objectives for each of the studies described in **Chapters 4-7**.

Chapters 4-7 are comprised of manuscripts that address the research objectives listed in Chapter 3. These chapters include manuscripts that have been published (Chapter 4), are currently under review (Chapter 5), or are prepared for future submissions for publications (Chapters 6 and 7).

Chapter 4 presents the rapid review of systematic reviews published in *Nutrition Reviews* in 2020. **Chapter 5** outlines the classification system developed to identify food codes from Canada's national food composition database as sources of low- and no-calorie sweeteners, which was then applied in the analyses presented in **Chapters 6 and 7**. Chapter 5, in the form presented in this dissertation, is under review in the *Journal of Food Composition and Analysis* (submitted March 24, 2024, revisions requested August 23, 2024).

Finally, **Chapter 8** summarizes the findings from all four chapters and highlights this dissertation's strengths and limitations. It further discusses the implications of these findings from a public health policy perspective and opportunities for future research rooted in these studies' findings.

Chapter 2

Literature Review

2.1 Healthy eating and human health

Diet-related diseases remain a leading cause of morbidity and mortality globally (6), solidifying the importance of promoting diet quality and healthy dietary patterns to promote overall health and well-being and reduce chronic disease (7). Nutritious foods form the basis of healthy dietary patterns. Positive associations between healthy dietary patterns and health outcomes are in part due to the regular consumption of nutrient-dense foods low in saturated fats, sugars, and sodium. In contrast, the regular consumption of foods and beverages high in these nutrients is associated with poorer health outcomes (8).

In Canada, dietary guidance related to sugars is specific to free sugars intake (9), whereas in the U.S., dietary guidelines refer to added sugars (10). Together, free and added sugars contribute to a food's or beverage's total sugars content. Added sugars refer to the mono- and disaccharides added to a food or beverage during the manufacturing, processing, or preparation stages. In contrast, free sugars encompass added sugars plus sugars naturally occurring in honey, syrups, fruit juices, and fruit juice concentrates but exclude naturally occurring sugars found in nutritious foods, including whole fruit and vegetables and unsweetened milk (9,11).

There is mounting evidence demonstrating negative associations between the excessive consumption of free and added sugars and poorer health outcomes, such as type 2 diabetes, weight gain, and obesity (12–15). Much of this evidence is derived from research examining sugar-sweetened beverages specifically, which remain a top source of added and free sugars in the diets of individuals in Canada and the U.S. (16–18). As a result, many governments have implemented policy-level initiatives targeting the reduction of free and added sugars to improve population diet quality and health, with a focus on reducing sugar-sweetened beverage intake (19,20).

Released in 2016, the federal government of Canada announced its commitment to improving the food environment to make it easier for individuals and families to make healthy eating choices (21). Canada's Healthy Eating Strategy is a three-pronged approach that aims to 1) enhance healthy eating information available to the consumer, 2) improve the nutritional quality of foods, and 3) protect vulnerable groups, such as children, from the tactics employed by the food and beverage

industry to influence eating attitudes and decisions (21). Two relevant examples of enhancing healthy eating information available to the consumer are the updated 2019 Canada's Food Guide and updated nutrition labelling regulations, which include front-of-package nutrition 'warning' symbols on foods and beverages high in sodium, sugars, and saturated fats (22).

Canada's dietary guidelines (9) provide explicit guidance for health professionals and policymakers on the use of low- and no-calorie sweeteners. While low- and no-calorie sweeteners are not currently the focus of either the new front-of-package nutrition 'warning' symbols or initiatives to improve the nutritional quality of available foods, the current focus on sugars, specifically free sugars content, could have unintended impacts that result in greater availability of low- and no-calorie sweeteners in the food supply and subsequent consumption among the population (23). Taxes on sugar-sweetened beverages, for example, have been recommended by national and international bodies as appropriate public health actions to curb sugar intake (11,24–26). However, some evidence suggests that this narrow focus could have unintended consequences (23).

Such policies appear to have been successful in encouraging product reformulation by the food industry in other jurisdictions, with global estimates suggesting a decrease in the use of caloric sweeteners over the years (27–29). However, concurrently, a shift to a higher availability of foods and beverages sweetened with low- and no-calorie sweeteners has been observed, a shift not perceived as beneficial by some experts (30–34). Lastly, considering the importance of establishing healthy eating habits early in life (35), Canada's Healthy Eating Strategy has identified the need for and importance of regulations to restrict the advertising of certain foods and beverages to children (21). While the current focus of the proposed regulations is on foods and beverages of poor nutritional value, specifically those high in sugars, saturated fats and sodium, policymakers at Health Canada undertook consultations to determine if the regulation should also include certain foods sweetened with low- and no-calorie sweeteners (36).

Many health organizations have weighed in on the debate regarding the helpfulness or harmfulness of low- and no-calorie sweeteners. Some have highlighted the evidence supporting the consumption of foods and beverages sweetened with low- and no-calorie sweeteners as a means to reduce intake of free and added sugars and calories, particularly among adults with obesity actively engaging in weight loss/management strategies and individuals with diabetes (37–39). For example, the American Heart Association identified the replacement of sugar-sweetened beverages with

beverages sweetened with low- and no-calorie sweeteners as an initial step in the dietary change process, specifically for adults who are habitual consumers, have a strong desire for sweet taste, and who are averse to unsweetened alternatives (40). However, some organizational bodies have highlighted the limited evidence available to support the recommendation to use low- and no-calorie sweeteners more broadly by all individuals in the population, particularly children and adolescents (37,40,41). Experts also note that any potentially beneficial effect from reducing intake of free and added sugars and calories by using low- and no-calorie sweetened products is negated if an individual compensates for these reductions, for example, by consuming more of the low- and no-calorie sweetened product or by consuming additional and less nutritious foods alongside these sugar-free alternatives (42–45).

Table 1 provides a summary of recommendations and positions taken by various health and government organizations in relation to low- and no-calorie sweetener consumption.

Table 1: Summary of guidance on the use of low- and no-calorie sweeteners from health-related organizations globally

Organization	Year	Document title	Position	Population considered
World Health Organization	2023	Use of non-sugar sweeteners: WHO guideline	“WHO suggests that non-sugar sweeteners ¹ not be used as a means of achieving weight control or reducing the risk of noncommunicable diseases (conditional recommendation).” Source: (46), pg.20	Children. Adults, including pregnant individuals.
Health Canada	2019	Canada’s dietary guidelines for health professionals and policymakers	“The sweeteners that have been approved in Canada include sugar alcohols and high-intensity artificial or naturally sourced sweeteners. However, as there are no well-established health benefits associated with the intake of sweeteners, nutritious foods and beverages that are unsweetened should be promoted instead.” Source: (9), pg.26	Children. Adults.

¹ Includes all artificial and naturally occurring sweeteners not classified as sugars. Excludes sugar alcohols.

Organization	Year	Document title	Position	Population considered
			“Sugar substitutes do not need to be consumed to reduce the intake of free sugars.” Source: (9), pg.22	
U.S. Department of Agriculture and U.S. Department of Health and Human Services	2020	Dietary guidelines for Americans 2020-2025: make every bite count with the dietary guidelines	“It should be noted that replacing added sugars with low- and no-calorie sweeteners may reduce calorie intake in the short-term and aid in weight management, yet questions remain about their effectiveness as a long-term weight management strategy.” Source: (10), pg.42 “In addition, low- and no-calorie sweeteners, which can also be called high-intensity sweeteners, are not recommended for children younger than 2.” Source: (10) pg. 61	Infants and toddlers. Children. Adults
American Academy of Pediatrics	2019	The use of nonnutritive sweeteners in children	This policy document is intended to provide pediatric providers with an overview of the available evidence and provides guidance for evidence to discuss with parents or guardians and patients. This guidance includes (1) safety regulations of approved sweeteners; (2) weight loss and/or stabilization results are observed in the short-term, but long-term data are lacking; (3) there is no evidence of an association between sweetener consumption and hyperactivity in children; (4) currently, there is insufficient evidence to suggest an effect between consumption and changes in appetite or taste preference. A position for or against the use of low- and no-calorie sweeteners was not provided in this policy document; the lack of data available on children younger than 2 years of age prevented advice for this population. Source: (41)	Children and adolescents.

Organization	Year	Document title	Position	Population considered
American Heart Association's Science Advisory	2018	Low-calorie sweetened beverages and cardiometabolic health	“There is a dearth of evidence on the potential adverse effects of LCS beverages relative to potential benefits. ... at this time, it is prudent to advise against prolonged consumption of LCS beverages by children. (Although water is the optimal beverage choice, children with diabetes mellitus who consume a balanced diet and closely monitor their blood glucose excursions by substituting LCS beverages for sugar-sweetened beverages (SSB) when needed). For adults who are habitually high consumers of SSB, ... LCS beverages may be a useful replacement strategy to reduce intake of SSBs.” Source: (40) pg. e1	Children. Adults.
American Diabetes Association	2019	Nutrition therapy for adults with diabetes or prediabetes: consensus report	“Replace sugar-sweetened beverages (SSB) with water as often as possible. When sugar substitutes are used to reduce overall calorie and carbohydrate intake, people should be counselled to avoid compensating with intake of additional calories from other food sources.” Source: (47) pg.740	Adults
Diabetes Canada	2018	2018 Clinical Practice Guidelines: Nutrition Therapy	No position was taken. Authors speak to the strength of evidence, stating, “the evidence from systematic reviews and meta-analyses of randomized controlled trials, which give a better protection against bias, have shown a weight loss benefit when non-nutritive sweeteners are used to displace excess calories from added sugars (especially from SSBs) in overweight children and adults without diabetes, a benefit that has been shown to be similar to that seen with other interventions intended to displace	Adults

Organization	Year	Document title	Position	Population considered
			excess calories from added sugars, such as water.” Source: (39) pg. S72-S73.	
Joint statement from the American Heart Association and the American Diabetes Association	2012	Non-nutritive sweeteners: current use and health perspectives	No position was taken. Authors speak to the available evidence, stating, “There are insufficient data to determine conclusively whether the use of NNS to displace calorie sweeteners in beverages and foods reduces added sugars or carbohydrate intakes, or benefits appetite, energy balance, body weight, or cardiometabolic risk factors.” Source: (48) pg. 517.	Children and adults.
American Dietetic Association	2012	Use of nutritive and nonnutritive sweeteners	“It is the position of the Academy of Nutrition and Dietetics that consumers can safely enjoy a range of nutritive and nonnutritive sweeteners when consumed within an eating plan that is guided by current federal nutrition recommendations, such as the Dietary Guidelines for Americans and the Dietary Reference Intakes, as well as individual health goals and personal preference.” Source: (37) pg.1	Children and adults.
Institute of Medicine	2007	Nutrition standards for food in schools	“There is a paucity of evidence on long-term health effects in humans from nonnutritive sweeteners, particularly resulting from exposure initiated in childhood.” Source: (49) pg.46	Children and youth.

2.1.1 Associations between low- and no-calorie sweeteners and human health outcomes of public health concern

A burgeoning body of literature has examined associations between low- and no-calorie sweetener consumption and non-communicable chronic diseases and human health more broadly. According to a 2013 review evaluating associations between low- and no-calorie sweetened beverage

consumption and obesity, type 2 diabetes, and cardiovascular disease, relationships varied depending on study design and the outcome of interest (50). Overall, associations between the consumption of low- and no-calorie sweetened beverages and weight gain and obesity from prospective cohort studies involving adolescents and adults revealed mixed results, including no association, positive associations, and inverse associations (50). While mixed findings from interventional studies, including randomized controlled studies, were also reported, the overall finding from such studies was a beneficial effect for reducing weight gain and risk of obesity when sugar-sweetened beverages were replaced with low- and no-calorie sweetened beverages. However, the magnitude and clinical relevance of these effects were questioned (50). Similar findings were reported in a 2014 review that examined low- and no-calorie sweetened beverage consumption in relation to obesity risk among adolescents and adults (51). Far fewer studies were available for inclusion in the 2013 review in relation to low- and no-calorie sweetened beverage consumption and risk of diabetes, cardiovascular disease, and indicators of metabolic syndrome (e.g., waist circumference, fasting blood glucose, blood lipids, and blood pressure), indicating an area in need of further research. Additionally, methodological considerations, including exposure assessment, residual confounding, and reverse causation, were noted as challenges that limited the reliability and validity of findings from prospective cohort studies (50).

Much of the available research has focused on low- and no-calorie sweetener consumption in relation to anthropometric outcomes, particularly weight gain and obesity (50,51). This is likely because outcomes such as weight gain can be observed in shorter timeframes compared to non-communicable chronic diseases such as type 2 diabetes and cardiovascular disease, making them conducive to examinations using experimental study designs, such as randomized controlled trials and observational study designs. The primary mechanism of action supporting an inverse association (or beneficial effects) between no- and low-calorie sweetener consumption and weight, adiposity, and obesity is the reduction of sugars, supporting a calorie deficit. Assuming a complete substitution or replacement, without compensation with other foods and beverages, this calorie deficit should aid in weight loss and reduced adiposity. In turn, a reduction in the size and amount of adipose tissue should, in theory, result in improved metabolic activity and a reduction in the risk of related non-communicable chronic diseases (52). However, there is a general lack of strong evidence

demonstrating sustained weight loss from short-term randomized controlled trials, which challenges the relevance of this hypothesis among free-living populations (9,10).

Several mechanisms to explain the observed detrimental effects of low- and no-calorie sweeteners have been hypothesized, including activation of sweet-taste receptors, impacts on neuro-hormone secretions, alterations to the gut microbiome and microbiota, and cognitive processes such as developing a preference for sweet foods and beverages (53–55). While many of these mechanisms have been observed in cellular animal-based models, their clinical relevance in humans is debated, primarily due to insufficient evidence (56). Nonetheless, concerns surrounding these uncertainties are heightened when exposure to low- and no-calorie sweeteners is considered in the context of vulnerable populations, such as exposure in utero because of maternal consumption, potential exposure during infancy as a result of transmission through breastmilk (if the breastfeeding individual is consuming sweeteners), and childhood (57,58), leading to advocacy for a precautionary approach in the public health messaging surrounding low- and no-calorie sweetener use (59).

2.1.2 Low- and no-calorie sweeteners consumption and diet quality

There is generally little evidence describing the association between low- and no-calorie sweetener consumption and diet quality, and the evidence available reports different results. Usual intake, or long-term habitual intake, is of particular interest as food-based dietary guidance and nutrient requirements are intended to be achieved over time and not daily (60), and relationships with health and chronic disease are based upon long-term habitual consumption of foods and nutrients and dietary patterns (61). However, existing studies have generally focused on shorter-term intake.

Using the Healthy Eating Index-2005 (HEI-2005) as a measure of alignment of eating patterns with U.S. dietary guidance (with higher scores indicating better diet quality), one cross-sectional study reported higher HEI-2005 scores among low- and no-calorie sweeteners consumers compared to non-consumers (62). The authors attributed the higher scores to closer alignment with guidance on the intake of solid fats, added sugars, and alcohol among consumers of low- and no-calorie sweeteners. However, lower component scores were observed for saturated fats and sodium intake, which is reflective of less alignment with dietary guidance for these nutrients (62). In contrast, a recent year-long randomized controlled trial found no significant differences in changes to mean total HEI-2015 scores among adults with overweight or obesity engaging in weight loss trials

who were assigned to consume either sugar-sweetened beverages, beverages sweetened with low- and no-calorie sweeteners, or unsweetened beverages such as water (63).

Other cross-sectional studies have examined differences between low- and no-calorie sweeteners consumers versus non-consumers in relation to single dietary components. Drawing on data from the U.S. National Health and Nutrition Examination Survey (NHANES) 2007-2012 cycles, one study of adults reported lower carbohydrate and total sugars and higher fibre intake among low- and no-calorie sweeteners consumers compared to non-consumers (64). These findings contrast with those from a cross-sectional analysis of NHANES 2011-2016 data that reported higher intake of carbohydrates and total and added sugars among children and adolescents aged 2-17 years who consumed beverages containing low- and no-calorie sweeteners compared to non-consumers consuming water only (65). Differences in the direction of the effect of sugars are likely in part due to how researchers categorized respondents into the non-consumers group, with Malek et al. (64) including sugar-sweetened beverage consumers and Sylvetsky et al. (65) separating these non-consumers from non-consumers who also did not consume sugar-sweetened beverages.

Because of the synergistic relationships among foods and dietary constituents (66) the nature of associations between sweetener consumption and diet quality may be influenced by the nutritional composition of individual foods and beverages, for example, if low- and no-calorie sweeteners are consumed in foods containing energy and fats versus in beverages with no other energy or source of nutrients (67). Given that diet quality is a multidimensional construct (68), capturing the synergistic relationships among foods and beverages is an important consideration when examining associations between low- and no-calorie sweeteners and diet quality.

2.1.3 Prevalence of consumption of low- and no-calorie sweeteners and common sources

Most studies estimating the proportions of populations that consume low- and no-calorie sweeteners through the food supply come from the U.S. In analyses of dietary recall data collected in NHANES, respondents reporting the consumption of foods and beverages containing low- and no-calorie sweeteners on a given day have been categorized as low- and no-calorie sweetener consumers and non-consumers are typically defined as those respondents reporting no consumption of foods or beverages classified as a source of low- and no-calorie sweeteners on dietary recalls, with some analyses of NHANES considering only one of the two available recalls in the survey and others considering both (64,69–73). Quantifying the amount of low- and no-calorie sweeteners an

individual is exposed to from a food or beverage is difficult when using dietary recall data because current labelling regulations do not require manufacturers to list the amount of sweetener used per serving on labels (74). Food composition databases, therefore, do not specify the low- and no-calorie sweetener content of foods and beverages, and identification of products containing low- and no-calorie sweeteners is typically based on the assessment of food and nutrient database keyword descriptions. While estimates of the proportions of individuals classified as low- and no-calorie sweeteners-consumers vary, likely as a result of differences in the classification approaches, a general trend toward increasing proportions categorized as low- and no-calorie sweeteners-consumers over time has been observed. For example, between 1999/2000 and 2007/08, the proportions estimated to consume low- and no-calorie sweeteners-sweetened products were estimated to have increased from 27% to 32% among U.S. adults and from 9% to 15% among U.S. children (73). Increases in estimates have also been reported when comparing NHANES 2003/04 to 2009/10, from 24% to 29% among U.S. adults and 9% to 21% among U.S. children (69).

Drawing on data from Canada's national nutrition survey, the 2015 Canadian Community Health Survey—Nutrition, the proportion of Canadians 51 years of age and above reporting daily consumption of diet soft drinks (sweetened with low- and no-calorie sweeteners) did not significantly change from 2004 (75). Differences, however, were observed among younger age groups, with significantly fewer children aged 1-13 years and females 14-18 years reporting consumption on a given day (75). However, these consumption estimates are for diet soft drinks alone and did not account for all low- and no-calorie sweetened beverages (e.g., no-added-sugar sports drinks or energy drinks). Low- and no-calorie sweetener exposure from food sources and tabletop additions has not been examined in Canada.

While global estimates of low- and no-calorie sweetened products in the food supply vary, it has been estimated that approximately 4% of Canadian products (assessed in 2013) and U.S. products (assessed in 2015-2017) were sweetened with low- and no-calorie sweeteners (29,76). Beverages, as a category, contained the greatest proportion of products sweetened with low- and no-calorie sweeteners (29,76). Desserts and sweets, milk-based products and dairy alternatives, processed fruit, and other snack foods are also common sources of low- and no-calorie sweeteners (29,76). Drawing on purchasing data from 2005 to 2009, one study estimated that approximately 7% of over 85,000 unique packaged foods and beverages sold in the U.S. were sweetened with low- and

no-calorie sweeteners, either solely (1%) or in combination with caloric sweeteners (~6%) (77). While the extant data suggest the proportion of foods and beverages in the food supply that contain low- and no-calorie sweeteners remains relatively low, shifts toward decreasing purchasing and consumption of caloric sweeteners and concurrent increases in purchasing and consumption of low- and no-calorie sweeteners-sweetened products have been reported (69,77).

Based on national nutrition surveys conducted in the U.S., beverages with low- and no-calorie sweeteners, including carbonated soft drinks, non-carbonated fruit drinks, sports drinks, energy drinks, flavoured waters, flavoured and sweetened milk, and coffees and teas, are the predominant contributors to total low- and no-calorie sweetener intake (78). Commonly consumed food sources sweetened with low- and no-calorie sweeteners include dairy products such as yogurts, condiments such as ketchup and salad dressings, as well as canned fruits and grains and bakery products (78). Similar sources have been reported based on analyses of Australia's national nutrition surveys (79). Currently, there are no comprehensive assessments of low- and no-calorie sweetener exposure from foods, beverages, and tabletop sweeteners among individuals living in Canada.

2.2 Overview of low- and no-calorie sweeteners

Low- and no-calorie sweeteners are regulated as food additives and approved for use by numerous agencies worldwide, including in Canada. This regulatory process involves rigorous investigations of the toxic and carcinogenic effects (80), followed by an evaluation of the evidence by regulatory agencies to ensure the safety of low- and no-calorie sweeteners for human consumption, defined as either low hazard potential (i.e., the potential to cause harm) or low exposure. Because low- and no-calorie sweeteners are intensely sweet, relative to sucrose by weight (**Table 2**), only a small amount is required to impart sweetness comparable to sucrose, providing few to no calories and glycaemic impact (12,81,82).

2.2.1 The safety of low- and no-calorie sweeteners

Low- and no-calorie sweeteners are a heterogeneous group of substances, each with its own unique chemical structure (81,83). Each low- and no-calorie sweetener is assigned its own Acceptable Daily Intake (ADI) value. The ADI is the amount that can be safely consumed every day

over a lifetime without risk of harm (84). This amount is based on the no observable adverse effects level (NOAEL), which is established from animal-based (mostly rodent) studies examining toxicity in relation to reproduction and development, carcinogenicity, and genotoxicity (85). The ADI is set at 1/100 of the NOAEL, ensuring a 100-fold safety factor that accounts for interspecies variation (i.e., differences between animal and human physiology) and differences across the life course and other differences between individuals (86).

The ADI is expressed as milligrams of sweetener per kg body weight per day and is applicable for all ages and life stages, including children and pregnant and breastfeeding individuals (84). However, because of their lower body weights, children are a subpopulation at potential risk for exceeding the ADI, as are individuals with diabetes due to frequent use to control blood glucose levels (87). Conceptually, the ADI is similar to the Tolerable Upper Intake Limit (UL), which is the maximum amount of a nutrient that can be consumed without risk of adverse health effects for most individuals in the population (88). As intake exceeds the UL, it follows that the risk of adverse effects increases as well. However, the UL is based on the total intake of a nutrient from food, water, and supplements, whereas the ADI is established for food additives and GRAS²-designated sweeteners. Apart from erythritol, sugar alcohols are not assigned an ADI because excess consumption will result in gastrointestinal upset; sugar alcohols are, therefore, considered a self-limiting product (89).

2.2.2 Low- and no-calorie sweeteners approved for use in Canada

At the time of writing this dissertation, there were 23 low- and no-calorie sweeteners permitted for use in foods, beverages, or as tabletop sweeteners in Canada (90). **Table 2** lists the nine “high-intensity” sweeteners (excluding sugar alcohols) currently permitted for use, their common (or brand) names, their sweetness relative to sucrose by weight, and their ADI according to regulatory agencies in Canada, the U.S. (i.e., the Food and Drug Administration, FDA), Europe (i.e., the European Food Safety Authority, EFSA), and globally (i.e., the Joint FAO/WHO Expert Committee on Food Additives, JECFA).

² GRAS: Generally Recognized as Safe

Table 2: List of approved sweeteners permitted for use in foods, beverages, and tabletop sweeteners in Canada (excluding sugar alcohols)

Sweetener	Common/ brand name	Sweetness relative to sucrose	Acceptable Daily Intake¹⁻⁴ (ADI) – mg/kg/day	Health Canada⁵ approved uses:
Acesulfame potassium	Sunett Sweet One	200 times	Health Canada: 15 FDA: 15 EFSA: 9 JECFA: 0-15	• Tabletop sweeteners. • Foods including filling mixes, toppings, desserts, yogurts; fruit spreads; salad dressings; confectionery; bakery products; canned fruit; soup base. • Beverages including carbonated beverages, beverage concentrates/mixes, beverages, dairy beverages, and flavoured milk. • Other: breath freshening products; chewing gum.
Aspartame		200 times	Health Canada: 40 FDA: 50 EFSA: 40 JECFA: 0-40	• Tabletop sweeteners. • Foods including breakfast cereals; fillings, desserts, yogurt; fruit spreads, purees, sauces, table syrups; nut/peanut spreads, salad dressings; condiments; confectionery glazes, sweetened seasonings/coating mixes foods; confectionery. • Beverages, including beverage concentrates, beverage mixes, and beverages. • Other: breath freshening products and chewing gum.
Cyclamate	Sucaryl® Sugar Twin® Sweet’N Low® Private label brand	30-50 times	Health Canada: 11 FDA: n/a EFSA: 7 JECFA: 0-11	• Permitted only as a non-food product • Available in packets/ granulated, tablets and liquid form.
Luo han guo	Monk fruit (extract)	100-250 times	Health Canada: n/a FDA: n/a EFSA: n/a	• Tabletop sweeteners. • Foods: not permitted. • Beverages: not permitted.

Sweetener	Common/ brand name	Sweetness relative to sucrose	Acceptable Daily Intake ¹⁻⁴ (ADI) – mg/kg/day JECFA: n/a	Health Canada ⁵ approved uses:
Saccharin	Hermesetas®	200-700 times	Health Canada: 5 FDA: 15 EFSA: 5 JECFA: 0-5	• Tabletop sweeteners. • Foods including canned fruit; frozen desserts; topping mixes; and fruit spreads. • Beverages including alcoholic liqueurs, carbonated non-alcoholic beverages, and preoperative beverages. • Other: breath freshening products; chewing gum.
Steviol glycosides.	Stevia Truvia	200-400 times	Health Canada: 4 FDA: 4 EFSA: 4 JECFA: 0-4	• Tabletop sweeteners. • Foods including breakfast cereals; confectionery glazes; nut/peanut spreads; sweetened seasonings or coating mixes; chocolate confectionery; fruit spreads; purees; salad dressings; sauces; table syrups; fillings; toppings; bakery products; desserts; yogurt; condiments; meal replacement bars; nutritional supplement bars; snack bars; canned fruit. • Beverages, including beverage concentrates and mixes; beverages; beverage flavoured milk. • Other: breath freshening products and chewing gum.
Sucralose	Splenda	650 times	Health Canada: 9 FDA: 5 EFSA: 15 JECFA: 0-15	• Tabletop sweeteners. • Foods including breakfast cereals; fillings; topping mixes; desserts; yogurts; fruit spreads; condiments; salad dressings; confectionery glazes; sweetened seasonings/coating mixes; confectionery; bakery products; processed fruit and vegetable products; puddings; table syrups; canned fruit; pickles,

Sweetener	Common/ brand name	Sweetness relative to sucrose	Acceptable Daily Intake ¹⁻⁴ (ADI) – mg/kg/day	Health Canada ⁵ approved uses:
				relishes; protein isolates; nutritional supplement bars; nutritional supplement dry soup mixes. • Beverages including beverage concentrates; beverage mixes; beverages; dairy beverages; alcoholic beverages; flavoured milk. • Other: breath freshening products and chewing gum.
Advantame	Nil	20,000 times	Health Canada: 0-5 FDA: 32.8 EFSA: 5 JECFA: 0-5	• Tabletop sweeteners. • Foods, including breakfast cereals, nut/peanut spreads, fruit spreads, purees, table syrups; confectionery glazes, sweetened seasoning/coating mixes; fillings, toppings, marinades; salad dressings; condiments and sauces; broth, soups, soup mixes; dietetic confectionery, dietetic confectionery coatings; yogurts. • Beverages, including beverage concentrates, beverage mixes, desserts, and dessert mixes – excludes coffees and teas. • Other: breath freshening products and chewing gum.
Neotame	Newtame NutraSweet	7,000-13,000 times	Health Canada: 2 FDA: 0.3 EFSA: 2 JECFA: 0-2	• Tabletop sweeteners. • Foods including breakfast cereals; fillings, toppings, desserts; yogurt; fruit spreads, table syrups; nut/peanut spreads, salad dressings; condiments; confectionery glazes, sweetened seasonings/coating mixes; confectionery; bakery products. • Beverages, including beverage concentrates, beverage mixes, and beverages. • Other: breath freshening products and chewing gum.

Sweetener	Common/ brand name	Sweetness relative to sucrose	Acceptable Daily Intake¹⁻⁴ (ADI) – mg/kg/day	Health Canada⁵ approved uses:
Thaumatococcus	n/a	2,000 – 3,000 times	Health Canada: 0.9 FDA: n/a EFSA: JECFA: not specified	• Tabletop sweeteners: not permitted. • Foods: not permitted. • Beverages: not permitted. • Other: breath freshening products and chewing gum; salt substitutes; flavourings.

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1. Health Canada: (89,91)
 2. FDA, Food and Drug Administration: (42)
 3. EFSA, European Food Safety Association: (42,92)
 4. JECFA: Joint FAO/WHO Expert Committee on Food Additive (93)
 5. List of permitted sweeteners approved for use in Canada (90)

2.2.3 Metabolism, absorption, and excretion of low- and no-calorie sweeteners

Low- and no-calorie sweeteners have differing biological fates in relation to how they are metabolized and excreted in the human body. The differences in chemical structure are the likely explanation for the observed differences in physiological responses in humans (94,95). **Table 3** summarizes the metabolic fates and routes of excretion (83,96–99) for the nine high-intensity sweeteners currently approved for use in Canada.

Table 3: Summary of low- and no-calorie sweeteners metabolism, absorption, and excretion

Sweetener	Metabolic fate	Route(s) of excretion
Acesulfame-K (potassium)	Not metabolized. Excreted in the same form ingested.	urine
Advantame	Converted to advantame acid.	Faeces and urine
Aspartame	Converted to aspartic acid, phenylalanine and methanol.	n/a
Cyclamate	Partially metabolized in a small proportion of the population (~20%); the remainder excrete it in the form ingested.	Faeces and urine
Monk fruit	Absorbed to some extent	Faeces
Saccharin	Not metabolized. Excreted in the same form ingested.	Urine, faeces
Steviol glycosides	Hydrolysed by gut bacteria to steviol; absorbed and excreted.	Urine
Sucralose	Not metabolized. Excreted in the same form ingested.	Faeces and urine
Thaumatococcus	Normal protein digestion.	n/a

Table adapted from Logue et al. 2016 (96)

Chapter 3

Dissertation rationale and objectives

The concept of this dissertation stemmed from a policy-relevant question posed by Health Canada, specifically, whether foods and beverages sweetened with low- and no-calorie sweeteners should be included in their proposed regulations to restrict advertising of food and beverages to children. There is a strong body of evidence indicating that most food and beverage advertisements targeting children promote items high in saturated fats, sugars, and/or sodium (100). These three nutrients form the basis of the proposed restrictions, given that excess consumption is associated with cardiometabolic markers of non-communicable chronic diseases (8). Because low- and no-calorie sweeteners can replace caloric sweeteners, thereby reducing sugars intake while maintaining the palatability and enjoyment of sweet-tasting foods, they have the potential to serve as a helpful alternative to sugars. However, as described in Chapter 2, the evidence examining associations between low- and no-calorie sweetener consumption and health is mixed. This presents challenges for policymakers who base policy decisions on the best available evidence.

The objective of Study 1 (Chapter 4) was to review the best available evidence examining relationships between low- and no-calorie sweetener consumption and human health outcomes of public health concerns across all age and sex groups. This review revealed the dearth of available evidence in relation to low- and no-calorie sweetener consumption among individuals living in Canada. This finding motivated the remaining studies in this dissertation. The overall objectives of these remaining studies 2-4 were to 1) develop a standardized approach to classify food codes used in nutrition surveillance in Canada as sources of low- and no-calorie sweeteners; 2) to characterize the consumption of low- and no-calorie sweeteners among individuals living in Canada; and 3) to assess the relationship between low- and no-calorie sweeteners consumption and diet quality among individuals living in Canada.

Specifically, we aimed to answer the following research questions:

1. What proportion of individuals living in Canada aged 1 year and older report the consumption of low- and no-calorie sweeteners on a given day?

2. What sources of foods and beverages contribute to low- and no-calorie sweeteners exposure?
3. What is the nutritional profile of the sources of low- and no-calorie sweeteners, and how do they align with Canada's healthy eating recommendations?
4. How does long-term average diet quality vary in relation to the probability of consuming low- and no-calorie sweeteners among individuals aged 2 years and above living in Canada?

Chapter 4

Low-calorie sweeteners and human health: a rapid review of systematic reviews

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Supplementary materials for this chapter can be found in **Appendices A-D**.

4.1 Overview

Low-calorie sweeteners are increasingly prevalent in the food supply, and their consumption has increased in recent decades. Although low-calorie sweeteners approved for use are considered safe from a toxicological perspective, their short- and long-term impacts on chronic disease risk remain uncertain. The aim of this review was to summarize the evidence from systematic reviews on low-calorie sweetener use and chronic conditions and risk factors in children and adults. MEDLINE and the Cochrane Database of Systematic Reviews were searched to identify systematic reviews of randomized and nonrandomized studies that considered low-calorie sweeteners in relation to type 2 diabetes, cardiovascular disease, cancer, anthropometric measures, hypertension, hyperglycemia, hyperlipidemia, insulin resistance, and dental caries. Data were extracted from 9 reviews deemed of moderate or high quality on the basis of AMSTAR-2. Narrative synthesis suggested inconsistent evidence on low-calorie sweetener use in relation to chronic conditions and associated risk factors, with nonrandomized studies suggesting positive associations and randomized studies suggesting negative or no associations. Continued research on the long-term health impacts of low-calorie sweeteners across all life stages is warranted.

Keywords: chronic disease, low-calorie sweeteners, non-nutritive sweeteners, obesity, review of reviews, sugars, type 2 diabetes, weight.

4.2 Introduction

There is a growing body of evidence linking intake of added sugars with suboptimal health outcomes, including weight gain, obesity, increased risk of type 2 diabetes, and other cardiometabolic impairments (13,14,24,101). Consumption of sugar-sweetened beverages is of particular concern given their association with adverse health outcomes (102,103), as well as their ubiquity in the food supply (104). National and international groups have issued recommendations urging limits on intake of added and free sugars (9–11,24), with some jurisdictions implementing or considering policy actions, such as sugar-sweetened beverage taxation (11,24,102,105,106). These actions have raised concerns about a potential corresponding shift from consumption of sugary products to those containing low-calorie sweeteners (LCSs) (30,31,107,108).

In the United States and Canada, LCSs are regulated by the US Food and Drug Administration (109) and the Canadian Food Inspection Agency (110), respectively, and are generally considered safe (85,111–113) at levels below the acceptable daily intake (114). However, uncertainty remains regarding their potential short- and long-term impacts on health and chronic disease-related outcomes, particularly among children (31,40,41,115,116). For example, apprehension due to unknown impact of LCSs on children's health and development was noted by the Institute of Medicine in their 2007 report on nutrition standards for US schools (31) and was echoed in recent statements by the American Academy of Pediatrics (115,116).

The overarching term LCSs encompasses artificial sweeteners, non-nutritive sweeteners, high-intensity sweeteners, polyols or sugar alcohols, and naturally derived noncaloric sweeteners (117). LCSs are considerably sweeter by weight than table sugar (i.e., sucrose) (118), resulting in the use of small quantities of LCSs in place of caloric sweeteners to minimize the caloric and sugar content of foods and beverages (109,118). Studies drawing upon Nielsen Homescan Services (Nielsen Corp.), a commercial data set on packaged food purchases (119), suggest that between 1% and 5% of packaged foods and beverage products in the United States are sweetened with LCSs only, whereas a larger proportion contain both LCSs and caloric sweeteners (28,77). For example, considering 1.2 million packaged food and beverage products, based on data covering 2000, 2006, and 2013, an estimated 7% were sweetened with both caloric sweeteners and LCSs, with an additional 5% sweetened with LCSs only (28). Variations in the proportions of foods and beverages containing LCSs have been reported across countries, with the highest prevalence observed in Mexico (11%), followed by the United States (4%) and Australia and New Zealand (approximately 1% each) (29). Although these estimates were derived from cross-sectional data, the authors hypothesized that the high prevalence of LCSs in foods and beverages in Mexico may be related to product reformulation in response to restrictions on products sold in schools, as well as taxation of sugar-sweetened beverages and so-called junk foods (29).

Data on purchasing patterns are limited to the United States. Drawing on data from Nielson Homescan Services and the Gladson Nutrition database (120), which integrate weekly updates on ingredient lists for national and private-label brands, findings from one study suggest the proportion of households purchasing products with caloric sweeteners decreased from 2000 to 2010 (69). At the same time, based on both chemical and common names for LCSs included in ingredient lists,

purchases of products with LCSs only or with both LCSs and caloric sweeteners increased substantially, particularly among households with children (69). By volume, beverages represented the predominant type of LCS-containing product purchased between 2007 and 2010.

Analyses of dietary intake data from various cycles of the National Health and Nutrition Examination Survey (121) provide insights into levels and sources of LCSs exposure in the United States. Although exact methods and estimates vary across analyses, the results suggest that many adults and children consume foods and beverages containing LCSs. For example, half of adults reported consumption of foods and beverages containing LCSs on at least one of two 24-hour recalls in the 2007-2008 to 2011-2012 cycles of the National Health and Nutrition Examination Survey (64). Analyses of data from the 2009-2010 and 2011-2012 cycles indicate that a quarter of children and 4 in 10 adults in the United States consumed LCSs on at least two days (122), representing an increase of 200% among children and 54% among adults compared with 1999-2000 data (73). However, the degree of change may be inflated by the use of two dietary recalls compared with only one in the earlier analyses. Among pregnant women aged 20-39 years, the prevalence of LCSs-containing food and beverage consumption appeared to increase by approximately 50% between 1999-2004 and 2007-2014 (70).

According to National Health and Nutrition Examination Survey data from 2009-2012, the majority of individuals (80% of children and 56% of adults) consuming LCSs reported intake of LCSs-containing foods or beverages once on a given day (122). Consumption of LCSs-containing products was most frequently reported with meals, compared with snacks or consumption of LCSs-containing products alone, and at home compared with away from home (122). Intake of beverages containing LCSs represented 1% and 5% of total beverage intake by volume among children and adults, respectively (122). Consumption of diet drinks among Americans aged two years or older appears to have increased from 1999-2000 to 2009-2010; among females, consumption of diet drinks on a given day increased from 18% to 21%, and among males, an increase from 14% to 19% was reported (123). Subsequent analyses of National Health and Nutrition Examination Survey data from 2011-2016 suggest approximately 6% of children aged 2-17 years consumed beverages sweetened with LCSs only (≥ 4 oz) on a given day (65).

Given lingering uncertainties regarding the implications of LCSs consumption for long-term human health, the prevalence of LCSs in the food supply, and indications of increased consumption,

a rapid review of systematic reviews was conducted to examine the evidence from randomized, nonrandomized, and observational studies on LCSs use and chronic conditions and risk factors (124,125) among children and adults. The review was undertaken in 2018 to inform Health Canada's healthy eating policies (126) and subsequently updated to capture systematic reviews published to July 2019. Chronic conditions and risk factors identified *a priori* included type 2 diabetes, cardiovascular disease, and cancer, as well as anthropometric measures (e.g. weight, obesity), hypertension, hyperglycemia, hyperlipidemia, and insulin resistance. Potential compensatory mechanisms and mediating factors, such as sweet taste perceptions, energy and sugar intake, and satiety, were also of interest. Given the direct role of sugars in the development of dental caries (127), evidence of the effectiveness (or potential adverse effects) of sugar substitutes (including sugar alcohols such as xylitol) and tooth decay was also considered. Reviews focused on chronic kidney disease were deemed out of scope because it was not identified as a chronic disease or risk condition of public health importance (124,125) and often occurs secondary to obesity, type 2 diabetes, and hypertension (128).

4.3 Methods

Rapid reviews are an emerging approach to synthesize evidence, often for health policy decision-makers (129). The World Health Organization guidelines for rapid reviews (130) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reporting guidelines (131) were followed. Given the abundance of recent systematic reviews evaluating the relationship of LCSs and health-related parameters of interest, evidence from existing research syntheses was prioritized, with the goal of informing public health policy (130). Providing a process for summarizing existing research syntheses, this review was also informed by an umbrella review methodology (132).

4.3.1 Search methods

The search strategy was developed in consultation with an expert in systematic searches of the health literature and informed by a preliminary search to identify appropriate key words. Two research databases, MEDLINE via PubMed and the Cochrane Database of Systematic Reviews, were selected given their well-established relevance to health and biomedicine (133,134) and inclusion of systematic reviews (135). The MEDLINE search was designed to

capture peer-reviewed systematic reviews published in English between January 2013 and July 1, 2019, that examined the association between LCSs consumption and the chronic conditions, risk factors, and compensatory mechanisms of interest in humans. The full MEDLINE search strategy (**Appendix A**) included a comprehensive combination of Medical Subject Headings and keywords for LCSs (e.g. non-nutritive sweetener, aspartame, sugar-free, non-sugar) and relevant health conditions.

Inclusion criteria for systematic reviews determined *a priori* were: (1) the inclusion of randomized control trials (RCTs) and/or nonrandomized studies and/or observational studies conducted with human participants across any life stage, and (2) consideration of associations between LCSs consumption and the chronic conditions and risk factors, as well as the compensatory mechanisms, mediating factors of interest, and dental caries. Reviews evaluating only the safety or toxicity of LCSs and those considering only animal studies were excluded. Reviews that examined studies of LCSs exposure along with other exposures, such as to sugar-sweetened beverages, were included if the authors synthesized and reported findings related to LCSs separately.

The reference management software RefWorks (ProQuest) was used for records management and screening. Records were screened by title and abstract by one author (LA), with a randomly generated list representing 10% of the records independently screened by a second author (SIK) to ensure inclusion and exclusion criteria were appropriately applied. One author (LA) then screened the full texts and searched the reference lists of the included systematic reviews to identify other potentially eligible records.

As recommended by the Cochrane Handbook for Systematic Reviews of Interventions Overview of Reviews (136) methodologies, systematic reviews at low risk of bias (i.e. assessed as of high or moderate quality) were summarized narratively, whereas those assessed as of low or critically low quality were not. Methodological quality was assessed using A Measurement Tool to Assess Systematic Reviews (AMSTAR-2) (137), which provides criteria for evaluating and determining the overall quality of systematic reviews that synthesize evidence from RCTs and nonrandomized studies in healthcare interventions. The 16-item AMSTAR-2 is divided into seven critical domains and nine noncritical domains, enabling the assessment of the overall quality of reviews. High-quality reviews are those without any critical domain violations and no

more than one noncritical domain violation, whereas moderate-quality reviews are affected by two or more noncritical domain violations but no critical domain violations (137). Discretion was used with regard to the criterion that review authors list all excluded studies with justification; this domain was not considered to be violated if the review met the criteria for moderate quality (i.e. no other critical domains were violated) and the number of studies excluded, and justification were provided in a PRISMA flowchart. Quality assessments were conducted by one author (LA) and verified by a second author (KML).

A data extraction spreadsheet was developed, and data extraction was conducted by one author (LA) or a trained research assistant, with independent verification by a second author (LA, KML, or SIK). Characteristics of interest included (1) the review objectives, (2) the nature of studies reviewed (e.g. RCTs or nonrandomized or observational studies), (3) quality appraisal procedures used by the review authors, (4) population characteristics, (5) methods used to synthesize evidence, (6) key findings and conclusions, and (7) funding sources for the review. Findings were narratively synthesized (138) by outcome and age group (i.e. adults vs. children).

4.4 Results

The final search yielded 409 records (**Figure 1**), 23 of which were eligible systematic reviews. Two additional eligible reviews were identified from the reference lists, for a total of 25 reviews that met the inclusion criteria.

4.4.1 Quality appraisal

On the basis of quality assessment (**Appendix B**) performed using AMSTAR-2 (137), four of the 25 reviews were determined to be high quality (139–142), five were of moderate quality (143–147), and 16 were of low or critically low quality (148–163). The low- and critically low-quality reviews were not considered further.

Two high-quality reviews (139,142) did not consider the funding sources of the individual studies reviewed, a noncritical domain violation. For one moderate-quality review (147), a single reviewer completed title and abstract screening (although full-text screening was conducted in duplicate), and a violation of this noncritical domain was thus determined. None of the five moderate-quality reviews provided a complete listing of references for excluded studies (143–147) (a critical domain), but they did indicate the number of excluded studies and provided

a brief justification for exclusion. None of the other domains of the AMSTAR-2 checklist were violated by any of the nine moderate- or high-quality systematic reviews.

Disclosure of conflicts of interest is considered a noncritical domain of AMSTAR-2. However, these factors could influence interpretation when comparing findings across reviews (164). Among reviews assessed as of high or moderate quality, all nine declared no conflict of interests, eight reported no funding or non-industry funding sources, and one did not report a funding source (146).

4.4.2 Review characteristics and findings

Seven of the reviews focused on chronic conditions of interest and/or related risk factors. Two of these addressed compensatory mechanisms, namely energy and sugar intake (139,147). The health-related parameters evaluated in these reviews are summarized in **Table 4**, and key review characteristics and findings are presented in **Table 5**. The characteristics of the remaining two reviews, which focused on dental caries, are summarized separately (**Appendix C**).

4.4.3 LCS use and chronic conditions and risk factors

Of the seven reviews focused on chronic conditions and associated risk factors, four were published in 2017 or later (139,143,146,147), underscoring growing interest in the role of LCSs in human health. Each of these reviews assessed associations between the consumption of various LCSs and anthropometric measures (e.g. body weight, body mass index [BMI], fat mass), cardiometabolic effects, and/or risk of diabetes, and related parameters (139,140,143–147) among males and females. The majority focused on adults only (139,140,143,144,147), one focused solely on children and adolescents (145), and another evaluated evidence pertaining to both adults and children (147). A full list of primary studies evaluated in the reviews addressing chronic conditions and associated risk factors is available in **Appendix D**.

Three of the seven reviews evaluated nonrandomized controlled interventions and/or observational studies and RCTs (143,145,147), one considered RCTs only (139), two considered prospective cohort studies only (140,144), and one examined evidence from cross-sectional studies examining associations between LCSs use and obesity (146). Five reviews conducted meta-analyses when sufficient data were available (139,140,143,146,147). The Cochrane Collaboration Risk-of-Bias tool (165,166) was used in all reviews evaluating RCTs

(139,143,145,147), and three reviews (139,140,147) evaluated the overall quality of evidence using the Grading of Recommendations Assessment, Development and Evaluation system (167). Most RCTs were assessed by the authors of the respective systematic reviews as being at high or unclear risk of bias. The majority of primary observational studies were assessed as moderate to high quality in four reviews (143–146) using the Newcastle-Ottawa Scale (168). Imamura et al. (140) assessed risk of bias using the Cochrane Risk of Bias Assessment Tool: for Nonrandomized Studies of Interventions (ACROBAT-NRSI) (169) guidelines and reported high and unknown risk of bias for all included cohort studies, with no study achieving a low risk-of-bias assessment for the confounding and exposure (i.e. dietary intake) measurement domain. Toews et al. (147) assessed the risk of bias of included observational studies using the Risk of Bias in Nonrandomized Studies of Interventions (ROBINS-I) tool (170) and reported serious risk of bias due to confounding and study misclassification.

4.4.4 LCSs and weight-related anthropometric measures in adults

Four systematic reviews (139,143,146,147) evaluated associations between LCS consumption and body weight and related anthropometric measures among adults, using evidence from RCTs, nonrandomized controlled trials, or observational studies.

Evidence from RCTs. Evidence from RCTs yielded contradictory findings on the impact of LCSs consumption on body weight and related anthropometric measures. Santos et al. (139) found no significant association between aspartame consumption and weight gain or loss among adults, compared with consumption of sucrose (n=2 RCTs) or unsweetened placebo such as water (n=3 RCTs). Azad et al. (143) observed no significant association, compared with unsweetened controls, between LCSs consumption and BMI among individuals with overweight or hypertension (n=3 RCTs), and they found inconsistent effects on waist circumference (n=3 RCTs; significant reductions in waist circumference reported in the 12-month trial, whereas two trials lasting six months reporting no significant changes) and weight change among adults with obesity (n=5 RCTs; significant weight loss was observed in interventions lasting 16-24 months compared with those of a shorter duration [i.e., six months]). Toews et al. (147) reported no significant differences in changes in body weight among LCS consumers compared with control participants consuming sugar or placebo (n=5 RCTs: 4 sugar plus 1 placebo). A subgroup analysis showed differential impacts of LCSs consumption based on initial weight status;

statistically significant decreases in body weight were observed among adults with overweight and obesity (n=3 RCTs lasting four weeks to six months), but no significant differences in body weight were reported among adults in the “normal” BMI range (n=2 RCTs) (147). Toews et al. (147) also reported a small statistically significant decrease in BMI among adults receiving LCSs compared with a control group consuming sucrose (n=2 RCTs).

Evidence from nonrandomized controlled and observational studies. Syntheses of findings from nonrandomized controlled and observational studies on LCSs consumption and body weight and related anthropometric measures among adults are conflicting (143,146,147). Azad et al. (143) reported positive associations between LCSs consumption and BMI (n=3 cohort studies; n=2 measuring continuous intake, and n=1 comparing those in the highest intake quantile with those in the lowest intake quantile) and weight gain (n=4 cohort studies, highest intake quantile compared with lowest intake quantile). On the basis of cross-sectional evidence (n=3 studies), Ruanpeng et al. (146) also reported a positive relationship between LCSs consumption and relative risk of overweight or obesity. Conversely, Toews et al. (147) reported no consistent differences in the relationship between LCSs consumption and weight-related anthropometric measures, based on the results of 7 nonrandomized controlled and observational studies (n=2 nonrandomized controlled studies; n=1 cohort study; n=4 cross-sectional studies).

4.4.5 LCSs and weight-related anthropometric measures in children

Two systematic reviews (145,147) examined associations between LCSs consumption and body weight and related anthropometric measures among children, using evidence from RCTs and observational studies.

Evidence from RCTs. Toews et al. (147) and Reid et al. (145) analyzed data from the same two RCTs differently and arrived at different conclusions. Because of significant differences in the baseline BMI of the study populations, Reid et al. (145) did not pool data from the two RCTs and reported contradictory findings of LCSs consumption on change in BMI z-scores compared with the control group consuming sugar (i.e. a nonsignificant increase in BMI z-score was observed among children considered to be undernourished compared with significant decreases in BMI z-score among healthy children of “normal” weight). In contrast, Toews et al. (147) pooled these data and reported smaller, statistically significant increases in BMI z-score among those

consuming LCSs (sucralose and acesulfame K or sucralose only) versus those consuming sugar (n=2 RCTs).

Evidence from observational studies. Reid et al. (145) also examined evidence from six cohort studies that yielded both null and positive associations between LCSs consumption and anthropometric measures among children. Although heterogeneity in the study populations and outcomes of interest prevented quantitative synthesis of evidence from all six studies, Reid et al. (145) pooled data from two of these studies and reported a significant correlation between LCSs consumption from beverages and increases in BMI (n=2 cohorts). The review conducted by Reid et al. (145) was the only work to explicitly seek to examine the effects of LCSs consumption during the prenatal period and/or exposure during infancy on long-term metabolic health, but no eligible studies were identified.

4.4.6 LCSs and cardiometabolic-related parameters

Santos et al. (139), Toews et al. (147), and Azad et al. (143) examined evidence on the impact of LCSs consumption on cardiovascular disease and/or cardiometabolic related parameters based on findings from RCTs (139,147) and observational studies (143).

Evidence from RCTs. Compared to control participants consuming either an unsweetened placebo (n=3 RCTs) or a sucrose-sweetened comparator (n=2 RCTs), Santos et al. (139) reported no statistically significant differences in total cholesterol and triglycerides levels among participants given aspartame. Small positive associations were reported for high-density lipoprotein levels when LCS consumption was compared with placebo consumption, but negative associations were observed when those consumed LCS were compared with control participants consuming sucrose. The authors questioned the clinical significance of these findings given the small magnitude of effect on high-density lipoprotein levels in both comparisons. In addition, Toews et al. (147) reported significant reductions in systolic blood pressure, but not in diastolic blood pressure, among adults consuming LCSs compared with control adults receiving either sugar or placebo, with greater effects for systolic blood pressures of LCSs consumers were compared with those of participants consuming a caloric comparator such as sugar-sweetened beverages (vs. a noncaloric comparator, such as water) (n=3 RCTs).

Evidence from observational studies. No cardiometabolic-related review outcomes were reported in the RCTs included in the review by Azad et al. (143). However, drawing on

evidence from observational studies, Azad et al. (143) reported an increased risk of hypertension (n=5 cohorts), stroke (n=2 cohorts), and cardiovascular events (n=2 cohorts) among adult consumers in the highest quantile of LCSs consumption compared with those in the lowest quantile, but no significant association was found with coronary heart disease (n=2 cohorts).

4.4.7 LCSs and type 2 diabetes and related parameters

Five reviews (139,140,143,144,147) examined associations between LCSs consumption and type 2 diabetes or related parameters among adults using evidence from RCTs and observational studies.

Evidence from RCTs. Santos et al. (139), Azad et al. (143), and Toews et al. (147) examined evidence from RCTs to evaluate the effect of LCSs consumption on type 2 diabetes and/or diabetes-related risk among adults. Santos et al. (139) reported no significant difference in fasting blood glucose or insulin levels when comparing aspartame with unsweetened placebo (n=5 RCTs) or sucrose-sweetened comparators (n=3 RCTs), though intervention duration varied substantially from one day up to two years. In contrast, Toews et al. (147) reported lower fasting blood glucose levels among adults consuming LCSs compared with those consuming sugar, but they found no significant differences in insulin, insulin resistance, and β -cell function (n=2 RCTs). Azad et al. (143) also reported no significant differences in insulin resistance between groups that consumed LCSs compared with control groups that consumed water or placebo capsules (n=3 RCTs); outcomes for metabolic syndrome and type 2 diabetes were not reported in the RCTs considered.

Evidence from observational studies. Three reviews examined associations between LCSs consumption and type 2 diabetes among adults using evidence from prospective cohort studies (140,143,144), with all three reporting evidence of a positive association between LCSs consumption and type 2 diabetes. Greenwood et al. (144) reported a small positive association between LCSs consumption and type 2 diabetes risk among a generally healthy population of adults from the United States and Europe (n=4 cohorts). However, the authors noted that factors such as dietary practices, physical activity levels, or reverse causality likely confounded this relationship. Similarly, Imamura et al. (140) reported a small positive association between LCSs consumption and the incidence of type 2 diabetes among adults (n=10 cohorts). These authors cited limitations of the evidence due to potential bias and study design heterogeneity (140).

Azad et al. (143) documented a small increased relative risk of type 2 diabetes for each additional serving of LCSs consumed among adults (n=4 cohorts). Azad et al. (143) also reported a higher risk of type 2 diabetes (n=9 cohorts) and metabolic syndrome (n=5 cohorts) among adults whose LCSs consumption was in the highest compared with the lowest quantile of intake. Azad et al. (143) and Imamura et al. (140) identified that publication bias likely contributed to a positive association between LCSs consumption and type 2 diabetes; Greenwood et al. (144) did not evaluate public bias because of the limited number of studies.

4.4.8 LCSs and cancer

Only one review (147) examined the association between LCSs consumption and cancer, drawing on evidence from observational studies. Toews et al. (147) reported on associations between LCSs consumption and cancer in adults and children using evidence from observational studies. Pooling evidence from eight case-control studies, no significant differences in bladder or lower urinary tract cancers were found among adults reporting exposure to LCSs compared with those not exposed (n=8 case-control studies). No significant association was reported between higher doses of aspartame consumption and the incidence of non-Hodgkin lymphoma or nonlymphoid leukemia among adults (n=2 cohort studies). Only one case-control study evaluating LCSs and cancer among children was identified by Towes et al. (147); that study found no significant risk for primary brain tumors when aspartame was consumed, regardless of source, duration, or frequency of consumption.

4.4.9 LCSs and compensatory mechanism/mediating factors

Two reviews (139,147) evaluated diet-related parameters, including energy and sugar intake, from RCTs and nonrandomized controlled studies.

Evidence from RCTs. Evaluating evidence from RCTs, Santos et al. (139) reported no significant differences in energy intake among healthy adults consuming aspartame compared with those consuming either unsweetened placebo or sucrose-sweetened comparators (n=5 and n=4 RCTs, respectively), whereas Toews et al. (147) reported significantly lower mean daily energy intake among adults consuming LCSs compared with control adults consuming sugar (n=4 RCTs). Toews et al. (147) also reported significantly lower daily sugar intakes among

adults with overweight or obesity who consumed LCSs compared with control adults consuming sugar (n=3 RCTs).

Evidence from nonrandomized controlled studies. Toews et al. (147) reported no differences in energy (n=2 nonrandomized controlled trials) or sugar (n=2 nonrandomized controlled trials) intake among adults consuming LCSs compared with adults consuming sugar . Although Toews et al. (147) considered studies that assessed satiety and sweet taste preference, they did not quantitatively synthesize the evidence. No other reviews reported findings on LCSs consumption and satiety or sweet taste preference.

4.4.10 Xylitol and dental caries

Two reviews evaluated the use of a variety of xylitol-containing agents in the prevention of dental caries among children and adolescents (141,142) as well as adults (141). Both considered evidence from RCTs; however, only Riley et al. (2015) were able to synthesize evidence on the effects of xylitol-containing toothpaste on dental caries prevention. From their meta-analysis of two studies, a positive association was reported between xylitol-containing fluoridated toothpaste and the prevention of dental caries in permanent teeth of children, compared with the use of a fluoride-only containing toothpaste (141). The authors of both reviews (141,142) cautioned that small sample sizes and risk of bias limited confidence in their results.

4.5 Discussion

Findings from this rapid review highlight that numerous systematic reviews of the evidence on LCSs consumption and cardiovascular disease, type 2 diabetes, and cancers, and their risk factors have been conducted in recent years. However, a limited number of these reviews are of high or moderate quality, according to the AMSTAR-2 criteria. On the basis of those reviews ascertained to be of high or moderate quality, the evidence related to LCSs consumption and chronic disease risk and associated factors among children and adults is inconsistent, particularly those from nonrandomized controlled interventions and observational study designs. Inconsistencies were also observed among the findings of studies with similar designs, with RCTs demonstrating both beneficial and neutral influences of LCSs on the prevention of weight gain and weight maintenance, and nonrandomized controlled interventions

and observational studies demonstrating neutral and unfavourable (positive) associations with weight-related anthropometric measures, type 2 diabetes, and cardiovascular disease and related risk factors. The evidence related to dental caries is likewise ambiguous. Only one review synthesized evidence on the association between LCSs consumption and cancer and, drawing upon case-control and cohort studies, echoed past findings that an association between LCSs consumption and cancer in humans is not supported by the evidence (171).

Synthesizing this body of evidence is challenging because of heterogeneity in study designs, characterization of LCSs exposure, and analytic methods, potentially contributing to the inconsistency in findings (172). Substantial heterogeneity in the design of individual studies included in the systematic reviews presented challenges in conclusively determining whether LCSs consumption is beneficial or harmful on the health-related parameters of interest (139,140,143–147). In all four reviews evaluating RCTs, individual studies assessed were generally determined to be at high or unclear risk of bias using the Cochrane Collaboration's Risk of Bias Tool (165,166). Furthermore, the utility of generalizing findings from RCTs to healthy policy decision-making has been challenged primarily because of their short duration (143,147), small sample sizes (147,173), and heterogeneity in the baseline health status of participants (145). In addition, RCTs often fail to replicate habitual (i.e. long-term average) consumption of LCSs in the context of typical consumption behaviours in an uncontrolled and complex environment (143,173). Of the six reviews documenting nonrandomized controlled interventions and/or observational studies, the quality of primary studies also varied. Four reviews determined individual studies to be of moderate or high quality using the Newcastle-Ottawa Scale (168), and two noted high, serious, or unclear risk of bias based on the ACROBAT-NRSI (169), and ROBINS-I (170) tools. A key concern when interpreting findings of observational studies is the possibility that associations with LCSs consumption reflect residual confounding and/or reverse causality (48,143). This possibility reinforces the importance of accounting for baseline dietary intake, including exposure to LCSs and weight (or BMI) when evaluating relationships between LCSs and chronic conditions and risk factors from observational studies (48,143). Because consumption of LCSs may be intimately connected to other aspects of dietary patterns and other health-related behaviours, research exploring

associations between LCSs consumption and overall dietary intake would be helpful in understanding the complex role of LCSs in eating patterns and health (48).

Several key areas for continued research are highlighted across reviews. These included understanding the mechanisms by which LCSs affect dietary intake, weight, and cardiometabolic risk factors; accurately characterizing exposure to LCSs; and differentiating effects on the basis of specific types of LCSs. A variety of sweetening agents of differing chemical structures (e.g. sucralose vs. aspartame vs. saccharin) were considered in primary studies evaluated by the included reviews, and many were unable to isolate LCSs exposure; it is plausible that metabolic and health effects may differ by type and dose (53,95) contributing to null or inconsistent effects. Greater specificity in the consideration and reporting of the type, dose, and source of LCSs consumed is recommended for future studies (41,94,143,146,147,174). To support such detailed analyses, enhancements to labelling policies and food composition databases are required to accurately estimate LCSs intake and exposure; this is of particular importance for studies evaluating consumption or exposure during the prenatal, infancy, and early childhood period, given the vulnerability of these stages of life and the potential for long-term impacts.

Despite mixed evidence on the health effects of LCSs, consumption of foods, and particularly beverages, sweetened with LCSs is acknowledged as a helpful option for some individuals in certain contexts. For example, the American Heart Association (40), American Diabetes Association (38), Diabetes Canada (39), and the American Academy of Nutrition and Dietetics (37) identify the benefits of substituting sugar-sweetened products with LCSs-sweetened alternatives for energy and sugar intake, body weight, and blood glucose control among adults actively engaging in weight loss or maintenance and adults with diabetes. The statements by the American Heart Association (40) and American Diabetes Association (38) emphasize that beneficial effects are only achievable if reduced energy intake is not negated by compensatory mechanisms that result in additional energy intake. Meanwhile, the American Academy of Nutrition and Dietetics (Fitch & Keim, 2012), the American Heart Association (40), and the American Academy of Pediatrics (41) acknowledge the lack of evidence supporting the benefits of LCSs consumption among children and youth, with the American Heart Association (40) discouraging LCSs consumption among children. Although explicit statements regarding LCSs use among children and youth were not included in the 2015-2020 Dietary Guidelines for

Americans (175) or the 2019 Canada's Food Guide (9) these guidelines acknowledge the uncertainty of evidence related to LCSs consumption and effectiveness with long-term weight management (175) and health benefits (9). Nonetheless, LCSs-sweetened foods and beverages are noted to be safe for consumption, and the guidelines encourage the consumption of unsweetened alternatives as a method of reducing added sugars intake (9,175).

The findings of this review should be interpreted in light of several considerations. Inclusion of RCTs and nonrandomized controlled and observational studies (primarily prospective cohort studies) provide a comprehensive picture of the evidence available to inform public health policy decisions. However, the primary studies included within the reviews were not examined in depth; therefore, the findings from the present review are subject to the limitations of the reviews in terms of quality appraisals and interpretation of the primary studies. Nonetheless, the reviews included were of high and moderate quality, based on a rigorous assessment of methodological quality using AMSTAR-2. Given the rapid-review methodology, a single researcher conducted screening, although a sample of records was screened by a second researcher to verify the robustness of the screening process. Quality appraisal and data extraction were each validated by a second author or trained research assistant.

The application of AMSTAR-2 (137) resulted in the exclusion of several systematic reviews. The low- and critically low-quality appraisals were assigned due to violations of one or more critical domains within the AMSTAR-2. For example, three reviews (151,153,158) used one research database rather than at least two, as required by AMSTAR-2. As a result of these stringent criteria, these reviews were considered to have not applied a comprehensive search strategy to retrieve relevant evidence, representing a violation of an AMSTAR-2 critical domain. In other cases, reviews lacked evidence of an *a priori* protocol to guide review methods (n=12; 75%). Among the 16 reviews assessed as of low or critically low quality, one review did not include a disclosure of conflict of interest statement (152), one disclosed previous ties to the food industry by some of the review authors (162), seven (149,152,154,157–159,161) did not report their funding source, and two (153,162) received industry funding to complete the review.

Despite the exclusion of these reviews of low- and critically low-quality, coverage of the excluded primary studies evaluating chronic conditions, risk factors, and compensatory mechanisms of interest through the included moderate- and high-quality reviews was good

(**Appendix D**). For randomized studies, approximately 50% of the primary studies considered in the excluded reviews were not assessed by the included systematic reviews that considered chronic conditions, risk factors, and compensatory mechanisms of interest; 75% of these can be attributed to two reviews (157,159) (**Appendix D**). Much of the discrepancy between these two excluded reviews (157,159) and those included in this review can be explained by differences in outcomes of interest, trial duration, and/or mode of LCSs administration. For example, many of the primary RCTs considered in these two reviews (157,159) aimed to evaluate acute outcomes of glucose homeostasis (e.g. blood glucose measured 210 minutes post-ingestion) and/or related factors (e.g. glucagon and gastric-emptying response) when LCSs were taken orally or via intragastric administration. This is in contrast to the focus of the included reviews that aimed to evaluate impacts of LCSs consumption on markers of type 2 diabetes, such as fasting blood glucose (usually measured 8-12 hours postprandially) and insulin resistance when LCSs were consumed in food, beverage, or capsule form for 24 hours or more. When not considering acute outcomes of glucose homeostasis and related factors, approximately 83% of the primary studies considered in the excluded reviews were considered in the included reviews that addressed chronic conditions, risk factors, and compensatory mechanisms.

Included reviews considering nonrandomized controlled interventions and observational studies evaluating longer-term impacts of LCSs consumption and obesity and cardiometabolic outcomes also showed good coverage of primary studies (**Appendix D**). Again, excluding the review that evaluated acute glucose homeostasis from nonrandomized controlled interventions (157), approximately 71% of the primary nonrandomized controlled interventions and observational studies assessed within the reviews excluded were considered by those reviews included.

Among reviews that considered studies evaluating the effects of xylitol-containing agents on the prevention of dental caries, four reviews were excluded (148,150–152) in the present review. Fifty percent of relevant studies (i.e. RCTs) were not included in the two high-quality reviews (141,142) included in the present review; however, 45% of these were considered by the high-quality review authors and excluded for various reasons.

Finally, double counting of primary studies assessed by two or more reviews is a challenge when conducting reviews of systematic reviews (136). Although it is a limitation of

the present study, the overall degree of overlap in primary studies was low. Among randomized studies that addressed chronic conditions, risk factors, and compensatory mechanisms of interest, less than 10% of included primary studies were included in more than one review, and among nonrandomized controlled and observational studies that addressed chronic conditions, risk factors, and compensatory mechanisms of interest, double counting was less than 15%, with the majority of double counting attributed to reviews assessing LCSs consumption and type 2 diabetes. Among the systematic reviews that considered studies evaluating the effect of xylitol-containing agents for the prevention of dental caries outcomes from RCTs, two primary studies (18%) were included in both included reviews.

4.6 Conclusion

Although there is a growing body of literature examining associations between LCSs consumption and chronic disease, the evidence remains inconsistent. The paucity of research evaluating the impact of long-term habitual consumption, particularly during the prenatal, infancy, and early childhood periods, is of concern given the vulnerability of these life stages. Well-designed, long-term RCTs and prospective cohort studies evaluating habitual consumption of individual and combined sources of LCSs are needed to inform policy decisions and recommendations on LCSs use (176,177). Additional research is needed to evaluate long-term consumption of LCSs-containing products in comparison with sugar-sweetened beverages and water, especially given the relevance of this comparison to dietary guidelines, such as Canada's Food Guide and the U.S. Dietary Guidelines for Americans.

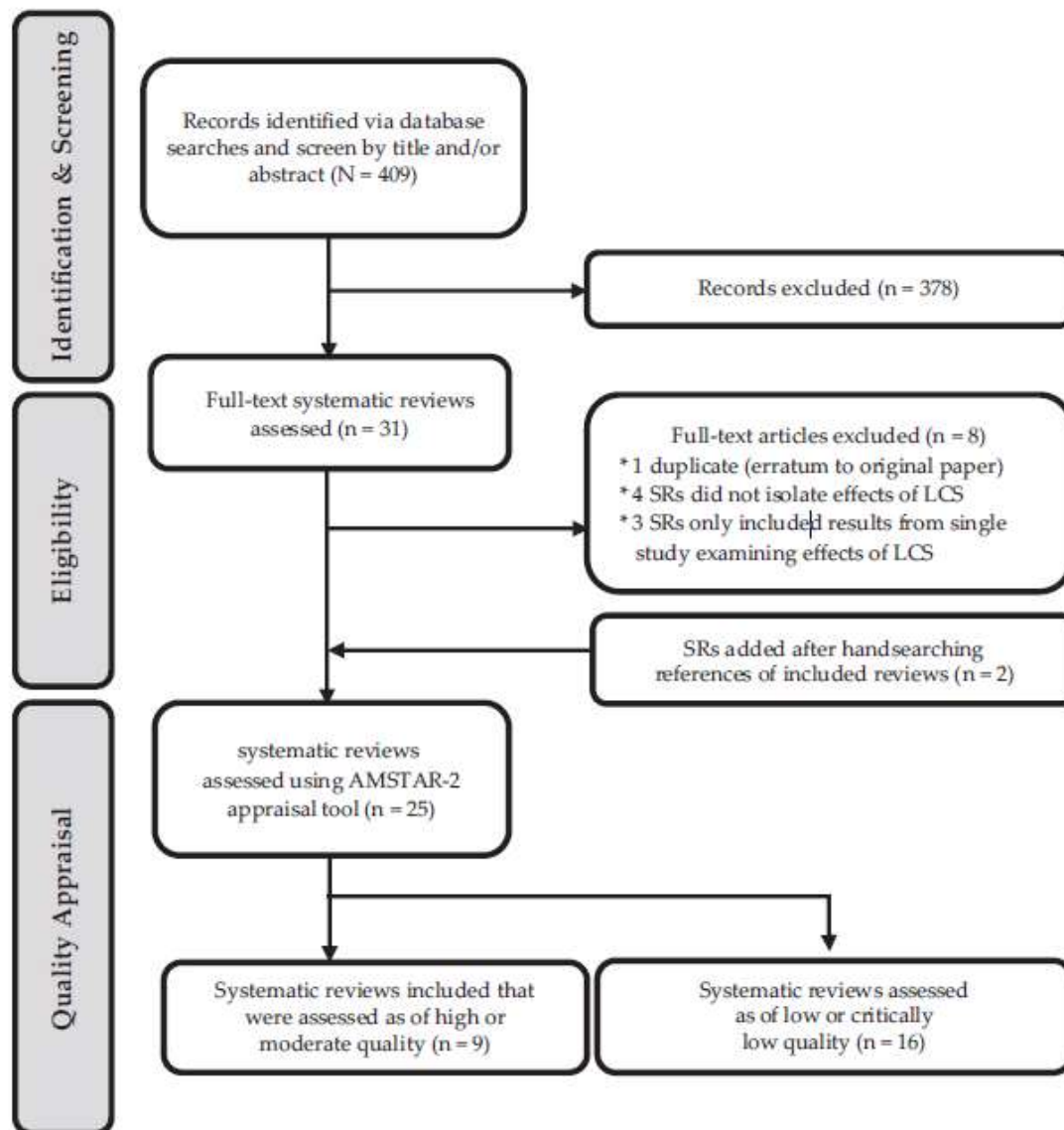


Figure 1: Flow chart illustrating the search and screening process to identify high- or moderate-quality systematic reviews (SRs) examining relationships between consumption of low-calorie sweeteners (LCSs) and chronic conditions, risk factors, potential compensatory mechanisms and mediating factors, and dental caries in humans.

Adapted from Preferred Reporting Items for Systematic Reviews and Meta-Analyses (131).

Table 4: Chronic conditions, risk factors, and compensatory mechanisms of interest synthesized in included systematic reviews^a (N=7)

Reference	Age group	Health-related parameters of interest				
		Anthropometric measures ^b	Type 2 diabetes and related parameters ^c	CVD- and cardiometabolic-related parameters ^d	Compensatory mechanism/mediating factors ^e	Cancer (any)
Azad et al (2017) ^{f,g}	Adult	•	•	•		
Santos et al (2017) ^f	Adult	•	•	•	•	
Toews et al (2019) ^{f,g}	Adult	•	•	•	•	•
	Child	•	• ⁱ	• ^h	• ^{h,i}	• ⁱ
Reid et al (2015) ^{f,g}	Child	•				
Greenwood et al (2014) ^g	Adult		•			
Imamura et al (2015) ^g	Adult		•			
Ruanpeng et al (2017) ^g	Adult	•				

^aExcluding reviews with a focus on dental caries prevention.

^bIncludes weight, body mass index, fat mass, skin fold, and waist circumference.

^cIncludes insulin-related parameters such as homeostatic model assessment of insulin resistance and hemoglobin A1c.

^dIncludes hypertension, stroke, and coronary heart disease as well as risk factors such as total cholesterol, low-density lipoprotein, and high-density lipoprotein levels.

^eIncludes sweet taste perception, energy intake, sugar intake, and satiety.

^fReviewed randomized controlled trials.

^gReviewed nonrandomized trials and/or observational studies.

^hReview authors only reported either single study findings or multiple study findings but not quantitatively synthesize the data; findings from randomized controlled trials.

ⁱReview authors only reported either single study findings or multiple study findings but not quantitatively synthesize the data; findings from nonrandomized trials and/or observational studies.

Table 5: Review characteristics and key findings of high- and moderate-quality systematic reviews^a evaluating LCSs^b consumption and chronic conditions, risk factors, and compensatory mechanisms of interest (N=7)

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
<i>RCTs only</i>								
Santos et al (2017)	Cochrane, LILACS, PubMed, Scopus, Web of Science Grey literature: Open Grey Google Scholar ProQuest Dissertations and Theses Global Timeline: inception until April 13, 2016	Evaluate the impact of aspartame intake on obesity and diabetes-related metabolic parameters in adults; 29 RCTs conducted in high-income countries including Canada, United States, and United Kingdom; Rating: high	Sample sizes varied from 4 to 133 participants, men and women, age range: 18–69 y. Most (n=19) studies were of healthy individuals; remaining 10 studies included individuals with chronic conditions (eg, overweight or obesity, diabetes or insulin resistance).	Primary outcomes: blood glucose control; obesity (BMI, adiposity) Secondary outcomes: glycemic control (and other T2D–related parameters); obesity (energy intake, blood lipids)	Significant variation between studies. LCS exposure included aspartame-sweetened food and beverages, and aspartame capsules. Intervention durations varied between 1 d and 2 y.	Comparators included unsweetened control groups (ie, receiving water or placebo not sweetened with LCS or sugar) and a sucrose control group. Intervention durations varied between 1 d to 2 y.	Aspartame likely not harmful nor beneficial for blood glucose control or insulin response. No differences observed in body weight or energy intake between aspartame consumers and sucrose or control groups. Statistically significant effects of aspartame on serum HDL cholesterol; however, authors challenged the	Most studies had an unclear risk of bias, determined by using the Cochrane Collaboration Risk-of-Bias tool. Evidence from outcomes determined to be of moderate quality using the GRADE system. Methodologies of included studies were similar, contributing to consistent interpretation of findings. Heterogeneity among studies was moderate to

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
							clinical significance of this finding. No other differences observed in lipid parameters.	high.
<i>Combined RCTs and nonrandomized studies of interventions^c</i>								
Azad et al (2017)	Medline, Embase, Cochrane Central Register of Controlled Trials Timeline: inception until January 2016	Examine the association of habitual consumption of LCS and adverse long-term cardiometabolic effects in adults and adolescents. 7 RCTs conducted in United States, China, Brazil, Denmark, and Iran. 30 observational studies with 22 distinct cohorts	RCTS: Female and male adults with overweight, obesity, or hypertension (mean age range: 32–52 y). Nonrandomized trials and/or observational studies: Male and female adolescents and adults. Mean age range, 13–70 y	Primary outcome: BMI (change) Secondary outcomes: Body weight and adiposity (change) T2D and related parameters, overweight or obesity (incidence). Blood pressure and other cardiorenal parameters	RCTS: Various types and sources of LCS consumed (eg, aspartame-sweetened beverages, stevioside capsules). Daily dose varied; adherence to prescribed dose up to participant discretion. Intervention range: 6–24 mo; Median follow-up 6 mo.	RCTS: Comparators included placebo, water, and aspartame avoidance. Interventions ranged from 6 to 24 mo; median follow-up: 6-mo. Nonrandomized trials and/or observational studies: Confounders: Baseline body composition (BMI or other measure)	RCTS: RCTs considered suggest that consumption of LCSs is not consistently associated with weight loss/management (eg, reduced body weight, BMI, or waist circumference). No association reported between LCS consumption and insulin resistance.	RCTS: Most RCTs were at high risk of bias, assessed using the Cochrane Collaboration Risk-of-Bias tool. Differences in trial duration contributed to heterogeneity in study findings. Nonrandomized trials and/or observational studies: Range of methodological qualities assessed using the

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
		conducted in United States, Spain, France, United Kingdom, Australia, Japan, and Denmark. Rating: moderate			Nonrandomized trials and/or observational studies: LCSs included those in artificially sweetened beverages, including sodas, and saccharin. LCS exposure measured by self-report, most often using a FFQ. Observational periods for follow-up: 9.6 mo to 38 years. Median follow-up: 10 y	and diet-sugar intake or total energy, or diet quality score or diet pattern.	No RCTs considered reported metabolic syndrome or T2D outcomes. Nonrandomized trials and/or observational studies: Large prospective cohort studies suggest routine consumption of LCS is associated with increases in body weight, BMI, and waist circumference, and increased risk of obesity, hypertension, metabolic syndrome, T2D, stroke, and cardiovascular disease.	Newcastle-Ottawa Scale (9 point), with majority achieving a moderate quality score.

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
Reid et al (2015)	Medline (OVID), Embase (OVID), Cochrane Database of Controlled Trials (Wiley) Timeline: inception until July 1, 2015	Examine the effect of LCS exposure during gestation, infancy, or early childhood, and long-term adverse metabolic health. 2 RCTs conducted in the Netherlands and South Africa. 6 cohort studies conducted in United States and United Kingdom Rating: moderate.	RCTs: Male and female children (mean age at baseline, 8.2 y). BMI status at baseline differed between studies, with the Dutch trial exploring generally healthy and normal-weight children and South African study exploring undernourished children. Nonrandomized trials and/or observational studies: Male and female children who were generally healthy (mean age: 2–11 y)	Primary outcome: BMI/BMI z-score (change). Secondary outcomes: Weight at birth, Rate of growth, Overweight or obesity (incidence), Total adiposity (change), Central adiposity (change), T2D and related parameters (incidence)	RCTs: Beverages sweetened with LCS. Type and dose differed between studies. Study dose range: 25 mg sucralose alone to 34 mg sucralose plus 12 mg ace-K Interventions range: 8.5–18 mo. Nonrandomized trials and/or observational studies: Type of LCS not specified, but consumption assessed using a variety of methods, including FFQ, food diary, 24-h recall or 3-d food record.	RCTs: Comparator: SSBs (dose range: 21–26 g). Intervention range: 8.5–18 mo Nonrandomized trials and/or observational studies: Confounders included sex, age, baseline BMI, and diet (total energy intake or SSB intake and percent energy from fat). Range of observational periods for follow-up: 6mo to 12 y	RCTs: RCTs evaluated reported contradictory effects on weight gain, with each reporting significant findings. Similarly, contradictory effects on BMI z-scores were reported. Search strategy returned no results for reviews evaluating LCS exposure during gestation or infancy. Nonrandomized trials and/or observational studies: Cohort studies suggest a possible positive association	RCTs: Unclear risk of bias for both included RCTs assessed using the Cochrane Collaboration Risk-of-Bias tool. Significant heterogeneity between baseline BMI between studies. Different reference data sets used to determine BMI z-scores. Nonrandomized trials and/or observational studies: Majority of included studies were judged to be of moderate quality, assessed using the 9-point Newcastle-Ottawa Scale.

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
					Range of observational periods for follow-up: 6mo to 12 y		between LCS intake and weight gain or fat accumulation and BMI. No evidence found evaluating LCS exposure during gestation or infancy.	Inadequate or unclear loss to follow-up a concern for half of included studies, and more than half studied the effects of LCS on nonrepresentative populations.
Toews et al (2019)	Medline, Medline in Process, Medline Daily Update, Embase, Cochrane Central Register of Controlled Trials, WHO International Clinical Trials Registry Platform, ClinicalTrials.gov (searched November 23, 2017). Timeline: Inception until May 25, 2017	Determine the association between consumption of LCS and health (broadly) among child/youth and adult populations 21 RCTs, 35 non-RCTs or observational studies Rating: Moderate	Randomized and nonrandomized trials and observational studies: Generally healthy male and female adults and children with and without overweight and obesity. Specific age ranges not provided. Adults were defined as those aged ≥18 y, children/	Randomized and nonrandomized trials and observational studies: Primary outcomes: Body weight and/or BMI T2D (incidence), eating behaviour, oral health. Secondary outcomes: Development of sweet preference, Cancer (incidence,	RCTs: Various LCS, including aspartame, sucralose, stevia, advantame, and a combination. Type: liquid, mixed, and capsule. Dosage: liquid/mixed aspartame: 278–2400 mg/d or 10–25 mg/kg body weight, with many	RCTs: A variety of comparators were used, including placebo, caloric sugars, no interventions, and aspartame. Frequency and dosage details not provided. Nonrandomized trials and/or observational studies. Non-RCT:	RCTs: Body weight and BMI: among adults, reduced body weight in those with overweight or obesity but not “normal” weight; small, statistically significant decrease in BMI overall. Among children, no significant impact	RCTs: Cochrane Risk-of-Bias tool completed and integrated into overall certainty of evidence assessment. GRADE approach used to assess certainty of evidence. Overall, findings were of low or very low certainty of evidence.

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
			youth were those aged <18 y.	any), cardiovascular disease (incidence)	studies not reporting dosage. sucralose range: 125–500 mg/d, and unknown for 1 study, combinations included 54% aspartame + 23% cyclamate + 22% ace-K + 1% saccharin: 4800–6700 mg, and sucralose + ace-K at 40 mg/kg body weight sucralose + 10 mg/kg body weight ace-K. Aspartame capsule: 15–45 mg/kg body weight and 2700 mg. Stevia capsule: 1000 mg. Advantame capsule: 0.375–0.5	Comparators included: sugar, high-fructose corn syrup, water. Cohort: Confounders controlled for: not stated. Controls included: sugar, aspartame, or no intervention. Case-control: Confounders controlled: not stated. Cross-sectional: Confounders controlled for: not stated.	on body weight (weight gain) but smaller increases in BMI z-scores compared with those consuming sucrose controls. Energy and sugar intake: Among adults, mean daily energy and sugar intake was lower compared with caloric sweetener consumption. T2D and related parameters: lower fasting blood glucose levels observed among adults consuming LCS; no effect observed on insulin levels or resistance measures.	Nonrandomized trials and/or observational studies: Bias was assessed using the ROBINS-I tool and found to have a serious risk of bias. GRADE approach used to assess certainty of evidence from “best available” evidence, which was often RCTs. Limited application of the GRADE approach to NRSIs; when NRSIs were evaluated, authors reported low or very low certainty of evidence.

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
					mg/kg body weight. Duration: liquid or mixed forms: 8 d to 18 mo; Capsules: 7 d to 7 wk. Nonrandomized trials and/or observational studies. Non-RCT (n=8): LCS included combination (ace-k + aspartame), aspartame, stevia, saccharin Type: Mixed, liquid, mouth rinse. Dose was not specified in most studies; 1 study provided 590 mg aspartame, and 1 provided 693–864 mg aspartame or		Nonrandomized trials and/or observational studies Energy intake: Overall, among adults, no difference in energy or sugar intakes were reported among adults consuming sweeteners compared with sugar controls. Cancer (adults): Overall, no differences in cancer risks were observed between adults exposed to sweeteners vs not exposed, or those consuming higher vs lower doses of	

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
					214–256 mg sucralose. Duration: 10–28 d Cohort (n=5): LCS included saccharin or aspartame, in mixed form, as a tabletop sweetener, or liquid form. Dose: 0–5.8 g or more saccharin, 0–28.8 g saccharin; unknown exposure noted in 3 studies (aspartame, saccharin). Exposure range: 1–10 y; unspecified in 2 studies. Case-control (n=16):		sweetener.	

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
					LCS exposure primarily saccharin, aspartame, or cyclamate. Type: Predominantly mixed, but tabletop and liquid forms also used. Dose not specified. Exposure range: _1 y to 15 y; Exposure was unknown for most (n=11). Cross-sectional (n=6): LCS included aspartame, acesulfame, cyclamate, saccharin, sucralose. All in mixed form. Dose and exposure not			

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
					known for most studies (n=5).			
Observational studies only								
Greenwood et al (2014)	The Cochrane Library, MEDLINE, MEDLINE In-Process, EMBASE, CAB Abstracts, ISI Web of Science, BIOSIS Timeline: January 1, 1990, to November 2009. Updated search conducted June 5, 2013	Evaluate association between artificially sweetened beverages and T2D. 4 prospective cohorts (reported in 3 publications) from United States (n=3) and Europe (n=1) Rating: moderate	Males and female adults (age range: 25–75 y), recruited from generally healthy populations	Primary outcome: T2D. Secondary outcomes: none	LCS not specified. Exposure to artificially sweetened soft drinks and diluted syrups self-reported and measured using a FFQ. Observational periods of follow-up: 6–24 y	Age, BMI, sex, dietary intake and quality, smoking status, alcohol consumption, physical activity.	Positive association of LCS consumption and development of T2D	Included studies deemed to be of moderate and high quality, assessed using the 9-point Newcastle-Ottawa Scale. High between-study heterogeneity. Lack of power was noted as a potential limitation to effect estimates.
Imamura et al (2015)	PubMed, Embase, Ovid, Web of Knowledge. Timeline: inception until May 31, 2013. Updated search conducted on February 10, 2014	Evaluate the association of long-term consumption of artificially sweetened beverages and T2D. 10 prospective	Female and male adults (age range: 18–75 y). Six cohorts' mean BMI fell within normal weight classification, remaining 4 cohorts' mean BMI fell within	Primary outcome: T2D (incidence)	Median duration of follow-up: 5.5–21.1 y 8 of the 10 cohorts assessed artificially sweetened beverage consumption via FFQ;	Median duration of follow-up: 5.5–21.1 y Age, sex, race, SES, smoking status, alcohol consumption, physical activity, diet quality, and “clinical	Small positive association of LCS consumption and incidence of T2D. Limited evidence that habitual consumption	Majority of studies were of unknown risk of bias; 2 were at high risk of bias. Overall, quality of evidence was assessed as low

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
		cohorts from United States, European countries, and Japan Rating: high	obese classification.		remaining 2 were assessed via diet history.	factors”	of artificially sweetened beverages contribute to T2D. Findings also suggest that habitual consumption likely also does not reduce the risk.	using the ACROBAT-NRSI guidelines. Publication bias and residual confounding, leading to false positives, likely limitations of included studies.
Ruanpeng et al (2017)	MEDLINE, EMBASE, Cochrane Database. Timeline: Inception through to May 2015.	Evaluate the association between consumption of beverages sweetened with LCS and obesity. 3 cross-sectional studies conducted in United States and Australia with a focus on LCS. Rating: moderate	Male and female adolescents and adults (age range: 16–84 y). Majority of included sample were adults.	Primary outcome: Obesity	Soft drinks sweetened with LCS. Type of LCS not specified and collected via self-report, questionnaire, or telephone interview.	Varied. Common confounders included sex, age, ethnicity, physical activity, smoking status, and body composition.	Increased relative risk for overweight or obesity by participants consuming LCS compared with those who did not consume these beverages.	Included studies were of moderate to high quality, assessed using the 9-point Newcastle-Ottawa Scale. Statistical heterogeneity between included studies was low and may result from variations in type of LCS consumed, differing outcomes,

Reference	Database searched; date ranges of search	Study purpose; design of included studies; AMSTAR-2 rating	Participant characteristics	Outcomes of interest	Interventions of interest	Comparators (or confounders)	Summary of key findings	Additional information
								and differences in covariates considered and adjusted for.
^a Excluding reviews with a focus on dental caries prevention. ^b Includes other commonly used terms such as non-nutritive sweetener or non-sugar substitute. ^c Includes non-RCTs and observational studies. Abbreviations: Ace-K, acesulfame potassium; ACROBAT-NRSI, A Cochrane Risk-of-Bias Assessment tool: for Nonrandomized Studies of Interventions; AMSTAR-2, A Measurement Tool to Assess Systematic Reviews; BMI, body mass index; FFQ, food frequency questionnaire; GRADE, Grading of Recommendations Assessment, Development and Evaluation; HDL, high-density lipoprotein; LCS, low-calorie sweetener; LILACS, Latin American and Caribbean Health Sciences Literature; NRSI, Nonrandomized Studies of Interventions; RCT, randomized controlled trial; ROBINS-I: Risk of Bias in Nonrandomized Studies of Interventions; SES, socioeconomic status; SSB, sugar-sweetened beverage; T2D, type 2 diabetes; WHO, World Health Organization.								

Chapter 5

Classifying sources of low- and no-calorie sweeteners within the Canadian food composition database

Status: Under review at the Journal of Food Composition and Analysis

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5.1 Overview

Low- and no-calorie sweeteners (LNCSs) are sugar substitutes that impart sweetness. Examining exposure to LNCSs is challenging because the amounts of LNCSs in food and beverage products are not standard elements of food composition databases. We identified food codes representing sources of LNCSs in the food composition database used for Canadian surveillance data. First, food code descriptions were searched for keywords (e.g. low-calorie) potentially representing LNCSs. Next, the U.S. Food and Nutrient Database for Dietary Surveys food code descriptions, matched to food codes within the Canadian database, were examined for keywords representing confirmed LNCS sources. Finally, using websites for three Canadian grocers, brand-specific product ingredient lists were examined to determine if they were LNCS sources. Recipe food codes often required an examination of ingredient-level food codes for accurate classification. Of 5,180 food codes, 76 were identified as sources of LNCSs, and an additional 46 recipe food codes were identified as containing a source of LNCSs. The classification system will be applied to national survey data to describe exposure to LNCSs and identify key sources of LNCSs. Standardized identification of food codes as sources of LNCSs can contribute to an evidence base that can be synthesized to inform nutrition policy.

Keywords: Food composition databases, 24-hour dietary recall, low- and no-calorie sweeteners, national nutrition surveys, food codes, recipe codes

5.2 Introduction

Low- and no-calorie sweeteners (LNCSs) are food additives with few, or no calories used to impart sweetness to foods and beverages (178) and are generally considered safe by regulatory organizations worldwide (109,111,112). Many health organizations recognize that the substitution of sugar-sweetened foods and beverages with LNCS-sweetened alternatives can reduce added sugars intake, particularly among certain populations, such as individuals living with diabetes (37,89,179). Guidelines on the use of products sweetened with LNCSs are informed by findings of experimental and observational studies, which rely on data from various dietary assessment methods to estimate exposure to LNCSs (180). Estimating population-level

exposure to LNCSs requires the classification of foods and beverages that contain these additives; however, LNCSs are often not quantified nor consistently identified within food composition databases applied to dietary intake data (181).

Sources of LNCSs have not been comprehensively identified within the Canadian Nutrient File (CNF) (182), the food composition database used to code dietary intake data in Canada. Within the U.S. context, several studies have examined exposure to LNCSs using data from 24-hour dietary recalls (24HDR) collected as part of What We Eat in America (WWEIA), the dietary component of the National Health and Nutrition Examination Survey (NHANES) (183–185). A recent review by Swithers et al. (183) identified four commonly used approaches to classify beverages sweetened with LNCSs using WWEIA data. The first approach involved the examination of food codes according to the organizational structure of the Food and Nutrient Database for Dietary Surveys (FNDDS), which is used to code the WWEIA recall data (184,185). The FNDDS is a relational database comprised of multiple datasets that correspond to the food descriptions, food portions and weights, and nutrient values for WWEIA foods (186). Details for foods and beverages within the FNDDS are derived from the National Nutrient Database for Standard Reference (187). Each FNDDS food and beverage is described by an 8-digit food code. The first digit corresponds to one of nine major food groups, and the second, third, and, in some cases, fourth, digits provide additional detail about the reported food or beverage (186). Studies using the FNDDS have identified beverages sweetened with LNCSs by employing this nomenclature, for example, using food codes beginning with 9255, which corresponds to the subcategory “Fruit juice drinks and fruit flavoured drinks, low calorie” (183).

The second approach to identifying sources of LNCSs identified by Swithers et al. (183) draws upon WWEIA food categories as proxies for LNCS sources based on the category or code descriptions. Starting with the 2015-2016 FNDDS, WWEIA categories were created to characterize foods and beverages. Food codes are grouped into 155 mutually exclusive categories based on how the foods and beverages were commonly consumed. These categories are then grouped into 15 main groups (185). For example, four beverage categories—including 100% juice, diet beverages, sweetened beverages, and coffee/tea—make up the non-alcoholic beverages group (185). Within the diet beverage category, three sub-categories include diet soft drinks, diet sport and energy drinks, and other diet drinks; each sub-category is assigned its own

unique code and description. Researchers can use these categories to facilitate the identification of beverages sweetened with LNCSs. A third approach involved an examination of beverage food codes based on their caloric density, using the U.S. Food and Drug Administration's (FDA) definitions of low- or no-calorie beverages, i.e., less than 40 calories or less than 5 calories per reference amount serving (188). Finally, the fourth approach involved a text-based review of food code descriptions to identify keywords indicative of the presence of LNCSs.

Swithers et al. (183) determined that none of the four approaches accurately and consistently identified all sources containing LNCSs while excluding sources that did not. Approaches 1 and 2 leveraged the existing database organizational structures (i.e., food codes and categories), which streamlines the analytic decision-making process among researchers by identifying entire categories as sources of LNCSs. However, given that the food codes can represent more than one food or beverage (i.e., multiple different products can have the same food code), there is a risk of incorrectly identifying non-LNCS sources as LNCS sources. Relying on caloric density presented similar misclassification challenges, as did the use of text-based approaches (183). Swithers et al. (183) noted that the text-based approach captured substantially more food codes as sources of LNCSs compared to the FNDDS food code and WWEIA category approaches; however, this approach does not fully eliminate the possibility of food code misclassification (183).

There has been limited research examining exposure to LNCSs in Canada. Considering the commonalities between the food supplies (189) and dietary assessment methods used in national surveillance (190) in Canada and the U.S., strategies used in the U.S. can inform the classification of sources of LNCSs within a Canadian food composition database. Our objective was, therefore, to develop a standardized approach to the classification of food codes likely to contain LNCSs in Canada's food composition database. In addition to detailed descriptions of our methods, we provide a list of food codes classified as sources of LNCSs, including the rationale for classification, a noted limitation of past research (183).

5.3 Methods

5.3.1 Data sources

Canada's food composition database consists of data from the Canadian Nutrient File (CNF) and a complementary recipe database maintained by Health Canada (191,192). For the present investigation, food codes from the 2015 CNF and recipe database were considered. The 2015 CNF includes data on up to 152 food components, including energy and macro- and micronutrients, for 5690 unique food codes (192). Estimates reflect values for a generic product, i.e., average value of food and beverage items with similar nutrient profiles available in the Canadian market (182,193). The CNF draws upon data from the U.S. Department of Agriculture (USDA) Nutrient Database for Standard Reference (SR 23-27 for the 2015 CNF), with modifications to reflect products available in the Canadian food supply, as well as differences between the two countries' fortification policies (192). The recipe database, based on FNDDS, provides estimated nutrient values for many mixed dishes (192). Modifications to information in the U.S. recipe database were made to reflect the Canadian food supply, and traditional recipes commonly consumed in Canada, such as poutine, were added (192).

Food codes considered for classification as sources of LNCSs were those that were applied to the 24HDR data collected within the 2015 Canadian Community Health Survey (CCHS)—Nutrition, the most recent nutrition-focused survey at the national level. Limiting the food codes to those applied within the 2015-CCHS—Nutrition ensured that the food codes and recipes considered captured foods and beverages commonly consumed in Canada, as well as facilitating the application of the classification system to the CCHS—Nutrition data. Jointly conducted by Statistics Canada and Health Canada, the 2015 CCHS—Nutrition is a probability-based cross-sectional survey of individuals living in private dwellings in the ten provinces (191,192). The 2015 survey yields representative estimates for individuals aged 1 year and older living in the provinces (192). Individuals who were full-time members of the Canadian Forces, who lived in one of Canada's three Territories, who lived on reserve or other Indigenous settlements, and who lived in some remote areas or institutions, such as prisons or care facilities, were excluded (192).

The 2015 CCHS—Nutrition consisted of a general health survey, which asked health-related and sociodemographic questions, and interviewer-administered 24HDRs (192). The

24HDR was the first component administered using an adapted version of the USDA's Automated Multiple-Pass Method (AMPM) (192,194). The AMPM is an automated five-step interview designed to maximize respondents' recall of foods and beverages consumed in the previous 24 hours (194). All respondents completed the first 24HDR (n=20,487) during an in-person interview, and a subset (n=7,623) completed a second 24HDR, administered via telephone, three to 10 days after their first recall.

Relevant 2015 CCHS—Nutrition Public Use Microdata File (PUMF) datafiles were available from the University of Waterloo library through the Data Liberation Initiative (192) and were downloaded on July 30, 2021. These files included the Food and Ingredient Details data file, the Food Recipe Level data file, and the Food Description Codebook data file (**Table 6**). The Food and Ingredient Details datafile and the Food Recipe Level datafile are the two primary datafiles that contain nutrient values for foods reported consumed in the 2015 CCHS—Nutrition. Individual foods and beverages and recipes reported in the 2015 CCHS—Nutrition are each associated with a unique food code from the CNF or the recipe database. The Food Description Codebook datafile contains the description of the foods (basic or ingredient level) and recipes (191).

We determined that a text-based approach using keywords was the most appropriate method for identifying sources of LNCSs, given the limited transferability of the other three approaches described by Swithers et al. (183) to the Canadian food composition database. Drawing upon text-based methods used in prior research (62,78,122), two categories of keywords were identified *a priori*: confirmatory keywords and possible source keywords (**Figure 2**). Confirmatory keywords included terms such as “low-calorie sweetener” and “artificial sweetener” and specific sweetener names such as “aspartame” and “sucralose.” Possible source keywords included terms such as “sugar-free,” “no added sugar,” “low calorie,” and “light.”

5.3.2 Steps in classifying food codes as sources of LNCSs

Descriptions for food codes applied to data for both recall days within the 2015 CCHS—Nutrition survey, totalling 5,180 food codes, were searched for keywords. This process first required the joining of several individual datafiles since dietary data from the 2015 CCHS—

Nutrition survey are contained in multiple relational food datafiles (191). First, the CCHS Food and Ingredient Details and Food Recipe Level data files were appended to create a dataset that included nutrient values for all basic foods and recipes and their ingredients. This appended data file was subsequently merged with the Food Description Codebook data file by food code, and food code descriptions were manually searched for keywords in Excel to identify food codes as LNCS sources.

Step 1—Review of basic food code descriptions for LNCS keywords

The first step in classifying basic food codes involved a review of the descriptions for all food codes applied to the 2015 CCHS—Nutrition data for keywords indicative of LNCS sources. If a confirmatory keyword was included in the food code description, the food code was classified as containing LNCSs. Food codes with descriptions containing possible source keywords were identified as possible sources of LNCSs and flagged for further investigation through steps 2 and 3. In addition, basic food codes suspected to be sources of LNCSs, based on expert knowledge, were coded as possible sources. The sources of expert knowledge included a data file compiled by Health Canada stakeholders and staff involved in the collection of the 2015 CCHS—Nutrition 24HDR that identified food codes suspected to be sources of LNCSs (personal communication, Isabelle Rondeau, Health Canada). For example, canned fruit in water was flagged as a possible source of LNCSs by Health Canada, even though the corresponding food code descriptions did not contain any of the identified keywords. The research team also identified possible sources based on expert knowledge. For example, protein beverages and powders were flagged as possible sources of LNCSs.

Basic food codes that contained possible source keywords in their descriptions but that were deemed highly unlikely to contain LNCSs, based on expert knowledge, were excluded from further analysis. For example, food codes such as “chicken and vegetable with noodles (diet frozen meal)” were determined not to be a likely source of LNCSs and were excluded from further evaluation.

Step 2—Classification of possible source basic food codes: examination of FNDDS descriptions

To further evaluate possible source basic food codes, FNDDS food code descriptions were examined. FNDDS provided the opportunity for a more nuanced investigation of

ingredients in the relevant foods and beverages because, unlike the Canadian food composition database, FNDDS food descriptions often include brand name product information (185), which could include confirmatory keywords.

For this step, an existing file that matched food codes used in the 2015 CCHS—Nutrition and FNDDS food codes (personal communication, Isabelle Rondeau, Health Canada) was used. This file was created by Health Canada to enable the adaptation of the Automated Self-Administered 24-hour Dietary Assessment Tool (ASA24) to the Canadian context (195,196). The linkage file contained 5,180 food codes, 64% of which were linked to an FNDDS food code by Health Canada. Of these linked food codes, 94% were determined to be an exact match. Exact matches were determined by Health Canada staff based on food code descriptions in the FNDDS and/or the National Nutrient Database for Standard Reference. For example, CNF food code 2926, *Carbonated drinks, cola with aspartame* was determined to be an exact match to FNDDS food code 92400100, *Soft drink, NFS, diet*, based on the linked SR code 14416, *Beverages, carbonated, low calorie, cola or pepper-type, with aspartame, contains caffeine*.

For classifying food codes as possible LNCS sources, only those that had exact matches with FNDDS were considered. The linkage file was first updated to include food codes and corresponding descriptions from the 2015-2016 FNDDS (185) to align with the 2015 CCHS—Nutrition. Then, the FNDDS main food descriptions and additional food descriptions were searched, and if they contained confirmatory keywords, the food code was coded as a source of LNCSs. This was the case even if the food code description in the Canadian database did not contain any possible source keywords. If a food code in the Canadian database identified as a possible source based on Step 1 did not have an exact match to an FNDDS food code, it remained coded as a possible source and underwent further evaluation in Step 3.

Step 3—Classification of possible source basic food codes: online verification

For the remaining codes identified as possible sources in Step 1, an online search of products that matched the food code description was undertaken, using the product information available on Canadian grocer websites that provided online grocery shopping services in 2022. Of seven major Canadian grocers representing over 80% of the grocery market share (197), the websites of the three largest grocers—Sobeys, Metro, and Loblaws (198)—were searched in May and June 2022. In 2021, these grocers accounted for nearly 60% of all grocery sales in

Canada (199). The grocers' websites were manually searched for products matching the descriptions for food codes applied to 2015 CCHS—Nutrition by a trained research assistant (SH); results were reviewed and confirmed by a second researcher (LA). For each product identified, the full name, flavour, and ingredient lists were extracted. In cases in which the ingredient information was not available from any of the three online grocers' websites, a targeted online search of the brand-named products matching the food code description was conducted. Information for each brand of a given product was collected only once as the product name, flavour, and ingredients were assumed to be consistent across the grocers.

Whether a basic food identified as a possible source was classified as a source of LNCSs depended on the proportion of products identified that corresponded with a given food code. If more than 50% of the available products corresponding with a given food code contained LNCSs according to the grocer or manufacturer websites, the basic food code was coded as a source of LNCSs. In cases in which less than or equal to 50% of products identified contained LNCSs, only one product was found online and contained LNCSs, or no product matching a given food code description was found online, the final classification was determined through expert opinion of the authors and evidence from prior research examining sources of LNCSs in the U.S. (78,122).

Table 7 provides an example of the data collected for food code 1551, *Fruit cocktails, canned, water pack, solids and liquids*. Using the search term “fruit cocktail in water,” two products were identified across the three online grocers: the Del Monte® brand was available from two of three grocers, and the No Name® brand was available from one of the three grocers. A review of the nutritional information confirmed the presence of LNCSs as an ingredient in both products, and food code 1551 was classified as a source of LNCSs.

5.3.3 Identification of recipe food codes containing LNCSs: ingredient-level examination

When coding 24HDR within the 2015 CCHS—Nutrition, coders could modify the ingredients used in a recipe by adding, deleting, or substituting ingredient food codes to accurately reflect the consumed food or beverage (191). As a result of this tailoring, the same recipe food code could reflect different ingredients. Therefore, while some recipe food codes could be classified as sources of LNCSs based on confirmatory keywords in their descriptions, this approach did not capture all recipes containing LNCSs. For example, the description for

recipe food code 502439—*Coffee, instant, pre-sweetened, no whitener, powder, water added*—does not contain any confirmatory or possible source keywords. However, in some instances, this recipe included a food code classified as a source of LNCSs as an ingredient (**Table 8**). All recipes were therefore evaluated for inclusion of food codes classified as sources of LNCSs using the steps described previously.

5.4 Results

Based on the three steps described above, 76 of 5,180 (1.5%) food codes were determined to be sources of LNCSs (**Table 9**). Of these, 46% contained one or more confirmatory keywords in their descriptions (n=35). Of the remaining 54% (n=41) that contained a possible source keyword(s) in their descriptions or were suspected to be sources of LNCSs, seven were classified as sources based on confirmatory keywords in the matching FNDDS food code description, 19 were classified as sources based on the online search of grocery sites/branded products, and 15 were classified as sources based on expert opinion, primarily because similar products were confirmed to contain LNCSs. In addition, 46 recipe food codes included one or more of the 76 food codes classified as LNCS sources as ingredients.

Most basic food codes classified as sources of LCNS were beverages (**Table 10**). Other sources included sweet spreads and sauces, low-fat yogurts, tabletop sweeteners, meal replacement powders, canned fruit packed in water, and desserts. **Table 11** lists the frequencies with which recipe codes applied to 2015 CCHS—Nutrition were a source of LNCSs, i.e., contained a food code classified as a source of LNCSs as an ingredient. The most frequently reported sources of LNCSs were protein-powder-based meal replacement beverages, other beverages, and various sweet desserts. Tabletop sweeteners were most commonly used as ingredients in beverages such as coffee and tea (data not shown).

5.5 Discussion

To date, there has been little research to characterize the use of LNCSs in the Canadian food supply or estimate exposure among individuals in Canada based on their reported dietary intake. The classification of food codes used to code dietary intake data in Canada as sources of LNCSs is an important first step in supporting such research, which is critical to informing

policy and practice related to sugars and sweeteners. Overall, 1.5% of food codes applied to the recall data in the 2015 CCHS—Nutrition survey were determined to be sources of LNCSs. This work provides a comprehensive framework that can be adopted and applied by other researchers.

Food composition databases are essential for characterizing a population's dietary intake and identifying food and beverage sources contributing to the intake of nutrients and other dietary components. However, such databases have important limitations (200), including for identifying LNCS sources. The food composition database available in Canada does not include quantitative estimates of LNCSs contained in foods and beverages, nor does it comprehensively identify sources of LNCS. We, therefore, used a text-based approach to identify sources of LNCSs. Food codes with confirmatory keywords in their descriptions could be confidently classified as sources of LNCS. For food code descriptions containing possible source keywords, further examination was required to classify the food code as a source of LNCSs or not. This examination included the use of brand-specific data from the U.S. food composition database or from an online search for products that matched the food code description. Recipe food codes were examined at the ingredient level to determine whether they incorporated food codes identified as LNCS sources. Within the 2015 CCHS—Nutrition data, this process required examining recipe codes applied to the intake data of each respondent, as such codes could be customized at this level to include LNCS sources. It was also necessary to draw upon expert knowledge to make final judgements about the inclusion or exclusion of some food codes as sources. These additional steps beyond the search for confirmatory keywords in food code descriptions were important, as more than half of all food codes identified as sources would have been missed if relying on confirmatory keywords alone.

Despite the use of multiple sources of information, there is the potential for misclassification of food codes initially identified as possible sources and classified as LNCS sources based on further examination. It is unlikely that food codes with descriptions containing the “no added sugar” or “sugar free” keywords were incorrectly classified given that they represent sweet foods and beverages, and the use of LNCSs is the likely approach to add sweetness without added sugars. However, food codes with descriptions containing keywords such as “low calorie,” “calorie reduced,” or “reduced sugars” may represent foods and beverages with low added sugars (and energy) without replacement with LNCSs. This is also a possibility

for food codes with descriptors such as “diabetic,” “diet,” and “dietetic.” Further, the food composition database includes codes for generic or composite foods and beverages, and it is possible that some instances in which a given food code is applied to 24HDR data reflect a food sweetened with LNCSs while other instances do not.

The classification system described can be applied to characterize exposure to LNCSs using dietary intake data coded using the Canadian food composition database, including the 2015 CCHS—Nutrition data, as well as data collected using ASA24-Canada (201) and other systems, such as the R24W, a web-based 24HDR for French-Canadian populations (202). An important consideration is the temporal alignment between the intake data and the food composition data. The food composition data available have not been updated since 2015. The food supply can change rapidly (187) and evidence from elsewhere suggests that the use of LNCSs in the food supply is increasing (203). Drawing on North American country-level sales volume data reported in the Euromonitor Passport database, per capita increases in LNCS-sweetened beverages and packaged foods were observed between 2016 and 2019, with the greatest increases in bottled waters and carbonated drinks (203). Many of the beverage food codes identified as possible sources were classified based on the online verification process. Given that products available online in 2022 may not be representative of products available in 2015, application of the classification system to the 2015 CCHS—Nutrition and other data collected prior to 2022 may result in an overestimation of exposure. However, the use of online verification was limited to food codes flagged as possible LNCS sources based on keywords included in the food code descriptions, suggesting that the risk of overestimation may be minimal, particularly for food codes with the descriptors “no added sugar” or “sugar free,” as noted above. Nonetheless, examining trends in exposure to LNCSs using dietary intake data collected at multiple time points will require updates to the food composition database and to the classification system to reflect changes to the food supply.

Due to restrictions in the Canada Statistics Act (204), it is not possible to include brand-specific product information (182) that could identify specific foods and their ingredients, including LNCS, in food composition databases. However, including more detailed food code descriptions, including confirmatory keywords, in updates to Canada’s food composition database, particularly for foods that are known to be sources, would ease the process of

identifying sources of LNCSs. Improved availability of brand-specific information would also be helpful for verifying the classification of sources within the Canadian food composition database using keywords. For example, ongoing web scraping can be used to track changes in products, including with respect to their use of LNCSs, over time (197). Additionally, strategic partnerships with the food industry can facilitate a regularly updated branded food database, similar to the U.S. Global Branded Food Products Database (205). Such information could make it possible to update the classification system regularly, even without updates to the food composition database, to identify food codes that have been reformulated to include LNCSs.

Nonetheless, updates to the food composition data are necessary to add information for foods and beverages newly introduced to the food supply. Accurate classification of sources could also be supported by additional probing within 24HDRs, particularly for foods and beverages that are common sources of LNCSs and those reported as low in sugars or calories. This additional detail within 24HDR data collected within nutrition surveillance could inform updates to the food codes included in the Canadian food composition database to reflect the food supply and consumption patterns, including the use of specific sweeteners. Monitoring exposure to different types of sweeteners is currently challenging but is important given differences in how they are metabolized (83) and the resulting differential downstream effects on health (95).

5.6 Conclusion

Evidence from other countries suggests that the use of and exposure to LNCSs is increasing (203). The classification system presented here can be applied to characterize exposure to LNCSs among individuals in Canada. The text-based approach to classify LNCS sources was strengthened using multiple approaches to verify possible LNCS sources, including drawing upon brand-specific data from the U.S. food composition database and an online search of Canadian grocer websites. Increasing the level of detail within food composition databases, including the food code descriptions, as well as improving the availability of brand-specific data, can enhance the accurate classification of LNCS sources and enable long-term monitoring of LNCS exposure among individuals in Canada.

Figure 2: Confirmatory and possible source keywords used to classify basic food codes¹ as sources of low- and no-calorie sweeteners (LNCSs)

Confirmatory Keywords: Food codes classified as containing LNCSs
• “low calorie sweetener” or “low-calorie sweetener” or “low-cal sweetener” or “low cal sweetener” • “artificial sweetener” or “artificially sweetened” • “aspartame” or “sucralose” or “saccharin” or “cyclamate” or “advantame” or “acesulfame potassium” or “ace K” or “ace-K” • “stevia” or “steviol glycosides” or “stevia leaf extract” or “rebaudioside A” or “reb A” or “monk fruit extract” or “Luo han guo” • “erythritol” or “neotame” or “sorbitol” or “malitol” or mannitol” or xylitol” • Brand names including Equal, NutraSweet, Sugar Twin, Sunett, Sweet One, Sweet’N Low, Sweet Twin, Necta Sweet, Splenda, Newtame, Truvia
Possible source keywords: Food codes classified as <u>possibly</u> containing LNCSs; further examination required
• “sugar substitute” • “diet” or “dietetic” or “diabetic” • “sugarless” or “sugar less” • “no added sugar” or “no sugar added” • “sugar free” or “sugar-free” • “reduced sugar” or “less sugar” or “low sugar” • “calorie-reduced” or “calorie reduced” • “low calorie” or “low-calorie” • “light” or “lite”

¹Food codes considered included those applied to dietary intake data collected in the 2015 Canadian Community Health Survey—Nutrition.

Table 6: Overview of datafiles used to classify food codes¹ as sources of low- and no-calorie sweeteners

Datafile	Food level	Definition
Food and ingredient details	Basic food	1) Foods that cannot be broken down into other food components (e.g., milk or apple) 2) Recipe foods without nutritional information available for component ingredients and size (e.g., prepared granola bar)
	Ingredient food	3) Components of a recipe reported consumed (either main recipe or sub-recipe level).
Food recipe level	Main recipe	Recipe foods that can be broken down into their component ingredients AND nutritional information and size are available for all ingredients. Some recipes also contain sub-recipes.
Food description codebook	Basic and main recipe	A brief description of a food code used to categorize similar foods. Nutrient values for 1 gram of each food code are also provided.

¹Food codes considered included those applied to dietary intake data collected in the 2015 Canadian Community Health Survey—Nutrition.

Table 7: Sample data extraction fields retrieved from three Canadian grocers' websites to examine available branded products corresponding with a given basic food code description

	Online Grocer		
	1	2	3
Food code, description: 1551, Fruit cocktail, canned, water pack, solids and liquids.			
Search term based on food code description: fruit cocktail in water			
Product name: Del Monte® Fruit Cocktail, packed in water, no sugar added			
Ingredient list: Water, clingstone peaches, pineapple, grapes, cherries (with erythrosine), citric acid, ascorbic acid, sucralose (13 mg per serving)	Yes	No	Yes
Product name: No Name® fruit cocktail in water, no sugar added			
Ingredient list: Ingredient list not provided online but the front of package label states “sweetened with stevia extract” (this would be captured/ documented by the screenshot)			
	Yes	No	No

Table 8: Example of a recipe food code identified as a source of low- and no-calorie sweeteners (LNCSs) because ingredients include one or more food codes classified as sources

ID¹ #	Identifier²	Food code³	Description	Recipe food code⁴	LNCSs Source⁵
A	01	502439	Coffee, instant, pre-sweetened, no whitener, powder, water added	502439	0
A	10	2874	Coffee, instant, regular, powder	502439	0
A	10	2933	Water, municipal	502439	0
A	10	5974	Sweetener, aspartame	502439	1

¹ID: record number of the respondent;

²Identifier: code to identify whether a food code represents a basic food (identifier=00), ingredient (identifier, in this example = 10) or a main recipe food code (identifier=01);

³Food code: CNF or recipe food code assigned to the food or beverage reported in the 24HDR;

⁴Recipe food code: recipe food code to which each individual ingredient food code corresponds;

⁵LNCSs source: low- or no-calorie sweetener source (1=yes; 0=no; determination based on prior Steps 1-3).

Table 9: Food codes¹ classified as sources of low- and no-calorie sweeteners (LNCSS) and rationale for classification

Food code	Food code description	Rationale
1499	Apricot, canned halves with skin, water pack, solids and liquids	No products found online. Expert opinion ²
1527	Cherry, sour, red, canned, water pack, solids and liquids	No products found online. Expert opinion ²
1532	Cherry, sweet, canned, water pack, solids and liquids	No products found online. Expert opinion ²
1551	Fruit cocktail (peach, pear, apricot, pineapple, cherry, grape), canned, water pack, solids and liquids	2/2 products found online contained LNCSS
1567	Grapefruit, canned, water pack, solids and liquids	No products found online. Expert opinion ²
1663	Plum, canned, purple, water pack, solids and liquids	No products found online. Expert opinion ²
1729	Peach, canned halves, water pack, solids and liquids	4/4 products found online contained LNCSS
1732	Pear, canned halves, water pack, solids and liquids	2/2 products found online contained LNCSS
1735	Pineapple, canned, water pack, solids and liquids	No products found online. Expert opinion ²
2912	Tea, instant, unsweetened, lemon flavour, powder	No products found online. Expert opinion ³
2926	Carbonated drinks, cola with aspartame	Confirmatory keyword
2938	Carbonated drinks, non cola with aspartame	Confirmatory keyword
2953	Hot chocolate, with aspartame, mix, powder	Confirmatory keyword
2963	Lemonade with artificial sweetener, powder, water added	Confirmatory keyword
4192	Sweets, syrup, table blend, pancake, calorie-reduced	2/3 products found online contained LNCSS
4232	Dessert, gelatin, dry mix, calorie-reduced, with aspartame, unprepared	Confirmatory keyword
4233	Dessert, gelatin, dry mix, calorie-reduced, with aspartame, prepared with water	Confirmatory keyword
4917	Dessert, frozen, ice cream, light, with aspartame, vanilla	Confirmatory keyword
4979	Carbonated drinks, cola with aspartame, decaffeinated	Confirmatory keyword
5292	Sports drink, fruit flavour, low calorie, ready to drink	8/8 products found online contained LNCSS
5437	Dessert, frozen, ice cream, chocolate, light, no sugar added	Exact match FNDDS food code with confirmatory keyword
5453	Dessert, frozen, ice cream, vanilla, fat-free	Exact match FNDDS food code with confirmatory keyword
5457	Drink, fruit flavour, powder, low calorie, vitamin C, with aspartame	Confirmatory keyword

Food code	Food code description	Rationale
5522	Sweets, syrup, dietetic	Exact match FNDDS food code with confirmatory keyword
5523	Sweets, jams and preserves, dietetic (with saccharin), any flavour	Confirmatory keyword
5558	Instant breakfast, powder, chocolate, sugar-free, with artificial sweetener	Confirmatory keyword
5602	Coffee, instant, powder, with whitener and artificial sweetener	Confirmatory keyword
5603	Juice drink, cranberry-apple, low calorie with vitamin C added	No products found online. Expert opinion ⁴
5625	Dessert, pudding, chocolate dry mix, instant, low calorie, unprepared	2/2 products found online contained LNCSs
5629	Dessert, pudding, chocolate, dry mix, regular, low calorie, unprepared	No products found online. Expert opinion ⁵
5630	Dessert, pudding, all flavours except chocolate, dry mix, regular, low calorie, unprepared	No products found online. Expert opinion ⁵
5631	Dessert, pudding, all flavours except chocolate, dry mix, instant, low calorie, unprepared	3/3 products found online contained LNCS
5710	Coffee, instant, mocha, powder, with whitener and artificial sweetener, decaffeinated	Confirmatory keyword
5740	Dessert, pudding, vanilla, ready-to-eat, fat free	Exact match FNDDS food code with confirmatory keyword
5742	Dessert, pudding, chocolate, ready-to-eat, fat free	Exact match FNDDS food code with confirmatory keyword
5750	Dessert, frozen, ice cream, vanilla, light, no sugar added, chocolate coated	Exact match FNDDS food code with confirmatory keyword
5751	Dessert, frozen yogurt, chocolate, skim milk, with artificial sweetener	Confirmatory keyword
5974	Sweetener, aspartame	Confirmatory keyword
5975	Sweetener, sucralose	Confirmatory keyword
5977	Sweetener, saccharin	Confirmatory keyword
6327	Water, fruit flavour, sweetened with artificial sweetener	Confirmatory keyword
6334	Dessert, frozen, ice cream, vanilla, reduced sugar	Exact match FNDDS food code with confirmatory keyword
6951	Yogurt, fruit flavoured, artificially sweetened, fat-free (0-0.5% M.F.), with added vitamin D	Confirmatory keyword

Food code	Food code description	Rationale
6952	Yogurt, vanilla flavoured with artificial sweetener, fat-free (0-0.5% M.F.) with added vitamin D	Confirmatory keyword
7025	Dessert, frozen yogurt, flavours not chocolate, skim milk, with artificial sweetener	Confirmatory keyword
7038	Dessert, frozen, ice cream, fat-free, no sugar added, flavours other than chocolate	4/4 products found online contained LNCS
7174	Energy drink, shot, sugar-free	No products found online. Expert opinion ⁶
7177	Energy drink, sugar-free, low-calorie	11/11 products found online contained LNCS
7188	Vitamin water, lemon/orange flavours, low-calorie	2/2 products found online contained LNCS
7210	Cherry, sour, canned, water pack, drained	No products found online. Expert opinion ²
7228	Beverage, protein drink, ready-to-drink, light	5/9 products found online contained LNCS
7230	Juice drink, orange, calorie-reduced	2/2 products found online contained LNCS
7231	Beverage, protein powder, whey based, powder	13/14 products found online contained LNCS
7232	Plant-based beverage, protein powder, soy-based powder	18/19 products found online contained LNCS
7233	Beverages, high protein powder	No products found online. Expert opinion ⁷
7238	Vitamin water, flavours not lemon/orange, low-calorie	5/5 products found online contained LNCS
7245	Sweetener, herbal extract powder from Stevia leaf	Confirmatory keyword
7281	Coffee and cocoa (mocha) powder, with whitener and low-calorie sweetener	Confirmatory keyword
7294	Dessert, frozen, fudge bar, no sugar added, with artificial sweetener	Confirmatory keyword
7295	Cookie, shortbread, plain, commercial, no sugar added, with artificial sweetener	Confirmatory keyword
7457	Beverage mix, chocolate flavour, powder, no added sugar	No products found online. Expert opinion ⁸
7477	Beverage mix, chocolate flavour, powder, no added sugar, with 2% M.F. milk	No products found online. Expert opinion ⁸
403792	Meal replacement, powder, diet	3/6 products found online. Expert opinion ⁹
403802	Sweetener, cyclamate	Confirmatory keyword
403953	Cranberry juice cocktail, with vitamin C, with aspartame, bottled	Confirmatory keyword
404210	Meal replacement, ready-to-drink, high protein (all flavours)	5/8 products found online contained LNCS
404214	Meal replacement, ready-to-drink, diabetic (all flavours)	3/3 products found online contained LNCS

Food code	Food code description	Rationale
404269	Meal replacement, bar	5/5 products found online contained LNCS
500029	Hot chocolate, made from dry mix with low-calorie sweetener, water added	Confirmatory keyword
502378	Sugar replacement or substitute, saccharin-based, liquid	Confirmatory keyword
504204	Pudding, chocolate, dry mix, low calorie, containing artificial sweetener, prepared with milk	Confirmatory keyword
504206	Pudding, flavours other than chocolate, dry mix, low calorie, containing artificial sweetener, prepared with milk	Confirmatory keyword
504394	Gelatin, dessert, dietetic, with fruit, sweetened with low-calorie sweetener	Confirmatory keyword
504757	Tea, made from powdered instant, with artificial sweetener (iced tea)	Confirmatory keyword
504765	Tea, NS as to type, presweetened with low-calorie sweetener (ready to drink)	Confirmatory keyword
505185	Coffee and cocoa (mocha), made from instant mix, with whitener and low-calorie sweetener, decaffeinated	Confirmatory keyword

¹Food codes considered included those applied to dietary intake data collected in the 2015 Canadian Community Health Survey—Nutrition.

²Reclassified as a source of LNCSs because the canned fruit packed in water products found online were found to contain LNCSs.

³Food code was a key ingredient used in a recipe food code with a confirmatory keyword in its description.

⁴Online search returned many low-calorie cranberry-fruit mixes that contained LNCSs; therefore, it was assumed the cranberry-apple mix did too.

⁵Given that the instant version was found to contain LNCSs, it was assumed the regular low-calorie counterpart did as well and food code was also a key ingredient in a recipe food code with a confirmatory keyword in its description.

⁶Targeted product search revealed the presence of Sucralose.

⁷As both whey-based and plant-based counterparts contained LNCSs, this food code with a generic description was assumed to be the same.

⁸Food code represents a sweet product, and given the no sugar added claim, it was assumed the sweetness was imparted using LNCSs.

⁹Given knowledge of products containing LNCSs in the United States, it was assumed that foods assigned these food codes were sources of LNCSs.

Table 10: Reported frequencies of basic food codes classified as sources of low- and no-calorie sweeteners based on the first and second recalls, 2015 Canadian Community Health Survey—Nutrition

Food code	Frequency	Food code Description
2926	1458	carbonated drinks, cola with aspartame
6951	619	yogurt, fruit flavoured, artificially sweetened, fat-free (0-0.5% M.F.), with added vitamin D
5975	575	sweetener, sucralose
403802	544	sweetener, cyclamate
2938	417	carbonated drinks, non-cola with aspartame
4979	347	carbonated drinks, cola with aspartame, decaffeinated
5523	316	sweets, jams and preserves, dietetic (with saccharin), any flavour
6327	264	water, fruit flavour, sweetened with artificial sweetener
6952	175	yogurt, vanilla flavoured with artificial sweetener, fat-free (0-0.5% M.F.), with added vitamin D
7245	161	sweetener, herbal extract powder from Stevia leaf
4192	154	sweets, syrup, table blend, pancake, calorie-reduced
5603	112	juice drink, cranberry-apple low calorie, with vitamin C added
404210	87	meal replacement, ready-to-drink, high protein (all flavours)
7230	79	juice drink, orange, calorie-reduced
5292	68	sports drink, fruit flavour, low calorie, ready-to-drink
5977	62	sweetener, saccharin
2963	59	lemonade with artificial sweetener, powder, water added
5974	58	sweetener, aspartame
7177	37	energy drink, sugar-free/low calorie
4233	32	dessert, gelatin, dry mix, calorie-reduced, with aspartame, prepared with water
404269	29	meal replacement, bar
7231	28	beverage, protein powder, whey-based, powder
1551	27	fruit cocktail (peach, pear, apricot, pineapple, cherry, grape), canned, water pack, solids and liquid
7295	26	cookie, shortbread, plain, commercial, no sugar added, with artificial sweetener
7038	22	dessert, frozen, ice cream, fat-free, no sugar added, flavours other than chocolate
404214	22	meal replacement, ready-to-drink, diabetic (all flavours)
5742	20	dessert, pudding, chocolate, ready-to-eat, fat-free
7233	20	beverages, high protein powder
403953	19	cranberry juice cocktail, + vitamin C + aspartame, bottled

7025	16	dessert, frozen yogurt, flavours not chocolate, skim milk, with artificial sweetener
7238	13	vitamin water, flavours not lemon/orange, low-calorie
5522	12	sweets, syrup, dietetic
6334	12	dessert, frozen, ice cream, vanilla, reduced sugar
1729	11	peach, canned halves or slices, water pack, solids and liquid
7228	11	beverage, protein drink, ready-to-drink, light
5453	9	dessert, frozen, ice cream, vanilla, fat-free
7294	9	dessert, frozen, fudge bar, no sugar added, with artificial sweetener
7477	8	beverage mix, chocolate flavour, powder, no added sugar, with 2% M.F. milk
4917	7	dessert, frozen, ice cream, light, with aspartame, vanilla
5740	6	dessert, pudding, vanilla, ready-to-eat, fat-free
5751	5	dessert, frozen yogurt, chocolate, skim milk, with artificial sweetener
7188	5	vitamin water, lemon/orange flavours, low-calorie
5437	4	dessert, frozen, ice cream, chocolate, light, no sugar added
403792	4	meal replacement, powder, diet
1567	3	grapefruit, canned, water pack, solids and liquid
1732	3	pear, canned halves, water pack, solids and liquid
1735	2	pineapple, canned, water pack, solids and liquid
5602	2	coffee, instant, powder, with whitener and artificial sweetener
1499	1	apricot, canned halves with skin, water pack, solids and liquid
1527	1	cherry, sour, red, canned, water pack, solids and liquid
1532	1	cherry, sweet, canned, water pack, solids and liquids
5630	1	dessert, pudding, all flavours except chocolate, dry mix, regular, low calorie, unprepared
5710	1	coffee, instant, mocha, powder, with whitener and artificial sweetener, decaffeinated
5750	1	dessert, frozen, ice cream, vanilla, light, no sugar added, chocolate coated
7174	1	energy drink, shot, sugar-free
7210	1	cherry, sour, canned, water pack, drained
7281	1	coffee and cocoa (mocha) powder, with whitener and low-calorie sweetener

Table 11: Reported frequencies of recipe food codes identified as sources of low- and no-calorie sweeteners based on first and second recalls, 2015 Canadian Community Health Survey—Nutrition

Food code	Frequency	Food code Description
505262	265	Protein powder, water added (whey protein)
505263	205	Protein powder, milk added (whey protein)
504765*	122	Tea, NS as to type, presweetened with low-calorie sweetener (ready-to-drink)
504171	38	Milk fruit drink (Smoothie)
501358	36	Cheesecake with fruit
501478	32	Pie, cherry
502439	30	Coffee, instant, pre-sweetened, no whitener, powder, water added
502504	29	Rum and cola
504145	29	Fruit smoothie drink, made with fruit or fruit juice only (no dairy products)
505191	25	Fruit-flavored drink, made from powdered mix, low-calorie
504206*	20	Pudding, flavours other than chocolate, dry mix, low calorie, containing artificial sweetener, prepared with milk
505264	19	Protein powder, juice added (whey protein)
500029*	19	hot chocolate, made from dry mix with low-calorie sweetener, water added
501213	17	Sandwich, peanut butter and jelly
504394*	14	Gelatin dessert, dietetic, with fruit, sweetened with low-calorie sweetener
504757*	14	Tea, made from powdered instant, with artificial sweetener (iced tea)
504204*	13	Pudding, chocolate, dry mix, low calorie, containing artificial sweetener, prepared with milk
501583	11	Turnover or dumpling, cherry
504126	11	Meal replacement, powder, diet, reconstituted with milk
502378*	9	Sugar replacement or substitute, saccharin-based, liquid
504975	8	Cocoa and sugar mixture, reduced sugar, milk added, NS as to type of milk
502452	7	Tea, NS as to type, presweetened with sugar
502454	7	Tea, NS as type, sweetened, NS as to sweetener, decaffeinated
502457	7	Tea, made from powdered instant, unsweetened
500046	6	Meal replacement, powder, diet, reconstituted with water
500045	4	Instant breakfast, powder, with 2% milk (Ready to drink)
504779	4	Hot chocolate, made from dry mix, milk added

505185*	4	Coffee and cocoa (mocha), made from powdered instant mix, with whitener and low-calorie sweetener, decaffeinated
501480	3	Pie, cherry, individual size or tart
501551	3	Cobbler, cherry
504173	3	Milkshake, homemade or fountain-type, flavours other than chocolate
504700	3	Coffee, instant, 50% less caffeine, powder, water added
500059	2	Ice cream cone, no topping, flavours other than chocolate
501494	2	Pie, plum, 2 crusts
502440	2	Coffee and cocoa (mocha), instant, with whitener, pre-sweetened, powder, water added
502453	2	Tea, NS as to type, sweetened, NS as to sweetener (Lemon-flavoured)
502503	2	Bourbon and soda (Scotch and soda, rum and soda)
502759	2	Chocolate flavour mix beverage, powder, 2% milk added
500022	1	Yogurt, frozen, sandwich
500026	1	Chocolate, flavour mix beverage, powder, 1% milk added
500028	1	Hot chocolate, made from dry mix, water added
500077	1	Light ice cream cone, flavours other than chocolate (formerly ice milk)
501322	1	Muffin, fruit and/or nuts (Blueberry, cranberry nut)
501449	1	Cookie, oatmeal
501479	1	Pie, cherry, one crust
501593	1	Danish pastries, with cheese
501884	1	Cherry pie filling
502398	1	Gelatin dessert with fruit
502481	1	Fruit-flavoured drink, made from powdered mix, low calorie, with vitamin C added
504391	1	Gelatin dessert with fruit and whipped cream
504622	1	Yogurt, frozen, cone, chocolate, low-fat milk
504764	1	Mixed berries, frozen
505189	1	Carbonated non-citrus juice drink
505190	1	Fruit drink, low-calorie

*Food codes for which the description contains a confirmatory keyword.

Chapter 6

Exposure to and sources of low- and no-calorie sweeteners among individuals living in Canada: Estimates from the 2015 Canadian Community Health Survey

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Supplementary material for this chapter can be found in **Appendix E**.

6.1 Overview

Given the current global public health emphasis on the harmful effects of exceeding recommendations of free and added sugars, substituting sugar-sweetened foods and beverages with low- or no-calorie sweetened alternatives offers a straightforward way for individuals to meet dietary guidelines while still enjoying sweet-tasting items. However, according to Canada's 2019 dietary guidelines, low- and no-calorie sweeteners, while safe to consume, are not encouraged as a strategy to reduce free sugar intake. Little is known about the consumption of low- and no-calorie sweeteners from foods, beverages, and tabletop sweeteners among individuals living in Canada. The objectives of this study were to estimate the proportion of individuals living in Canada who consumed low- and no-calorie sweeteners on a given day, identify the most frequently consumed sources, and examine sources of sweeteners in relation to nutrients of public health concern. Data were drawn from the 2015 Canadian Community Health Survey—Nutrition, which included the administration of 24-hour dietary recalls coded using Canada's 2015 national food composition database. Using the first recall, survey-weighted proportions of individuals consuming sources of sweeteners were estimated by age, sex, total household income, and self-reported diabetes status (adults only). The frequency of consumption events involving a source of low- and no-calorie sweeteners was also estimated by age and sex. The nutritional profile of sweetener sources was compared to standards established in the 2019 Canada's Food Guide Food Classification System. On a given day, 8% of children (1-13 years), 11% of adolescents (14-18 years), and 20% of adults (19 years and above) consumed at least one source of sweeteners. A higher proportion of adults who self-reported diabetes consumed sources of sweeteners (42%) compared to those without diabetes (18%). Diet sodas were the most frequently consumed beverage type across all age groups. The most frequently consumed low- and no-calorie sweetened food among children was low-fat yogurt. In contrast, the most frequently consumed low- and no-calorie sweetened foods among adolescents and adults were meal replacements and protein powders. No source of low- and no-calorie sweeteners was considered a 'nutritious' option, according to Canada's Food Guide. Findings from this study can inform public health nutrition policies to support healthy eating, including those related to sugars.

6.2 Introduction

Low- and no-calorie sweeteners are food additives commonly used to replace free and added sugars in foods and beverages. Health Canada currently permits nine low- and no-calorie sweeteners for use in foods, beverages or as a tabletop sweetener, including advantame, acesulfame potassium, aspartame, saccharin, monk fruit extract, neotame, certain steviol glycosides, sucralose, and thaumatin (90), in addition to sugar alcohols. Low- and no-calorie sweeteners are generally accepted as safe to consume within pre-established ranges, often defined by an Acceptable Daily Intake (ADI). However, uncertainty remains about their impact on long-term health outcomes (206), particularly in the context of habitual exposure and when exposure occurs during critical periods of growth, such as during pregnancy, infancy, and childhood (57). While interventional studies suggest a beneficial role of low- and no-calorie sweeteners for weight loss and management (207), evidence from observational studies reports neutral or unfavourable associations between low- and no-calorie sweetener intake and body weight (45). Similarly, conflicting evidence on the influence of low- and no-calorie sweeteners on blood sugar control and type 2 diabetes risk is reported in observational studies (140). Discrepancies are likely due, at least in part, to how and by whom low- and no-calorie sweeteners are being used; for example, by adults actively engaging in a weight loss trial versus the general population incorporating foods and beverages sweetened with low- and no-calorie sweeteners into their usual eating patterns.

Data on trends in sweeteners in the Canadian food supply are lacking. However, one recent analysis estimated that approximately 4% of 15,342 packaged products examined in Canada in 2013 contained a low- or no-calorie sweetener (76). Drawing on Euromonitor sales data from 2007 to 2019, the use of low- and no-calorie sweeteners in beverages sold in North America increased by 119%, whereas a 5% decrease was observed in foods during this same period (203). Correspondingly, population-level dietary intake data from the U.S. suggests that the proportions of individuals consuming foods and beverages containing sweeteners have increased over time (73,208). An early analysis of data from the Nationwide Food Consumption Survey (1965-1991) and the National Health and Nutrition Examination Survey (NHANES, 1991-2004) suggested that the prevalence of exposure to foods and beverages containing

sweeteners among individuals aged two years and older increased from 3% to 15% between 1965 and 2004 (56). Another NHANES analysis suggests that sweetener exposure from foods and beverages changed from 9% to 15% among children and 27% to 32% among adults living in the U.S. between 1999 and 2008 (73). More recent analyses of NHANES data from 2012 estimate that one in four children (25.1%) and almost one in two adults (41.4%) living in the U.S. consumed foods and beverages containing sweeteners on a given day (122).

Exposure to low- and no-calorie sweeteners has been shown to differ in relation to sociodemographic characteristics. Among adults living in the U.S., higher consumption of any source of low- and no-calorie sweeteners has been observed with higher age, among females compared to males, and among those with higher incomes compared to lower incomes (72,122). Further, estimates of exposure to low- and no-calorie sweeteners are higher among individuals diagnosed with diabetes compared to those without a diabetes diagnosis (122). While modelling studies suggest that exposure to low- and no-calorie sweeteners from beverages remains well below the acceptable daily intake (ADI) levels among individuals living in Canada, even among high consumers (209), little is known about the consumption of low- and no-calorie sweetened food and beverages, the sources of exposure, and their nutritional profiles among individuals living in Canada. While the dietary guidelines that accompany the 2019 Canada's Food Guide (CFG) acknowledge the safety of low- and no-calorie sweeteners, they simultaneously guide healthcare professionals to promote "nutritious foods and beverages that are unsweetened" pg.26 (9), citing the lack of strong evidence of low- and no-calorie sweeteners' health benefits. In addition, there are concerns that foods and beverages containing low- and no-calorie sweeteners may contribute to excess consumption of nutrients of public health concern, such as saturated fat, free sugars, and sodium (59).

The objectives of this study were to 1) estimate the proportions of individuals in Canada who consume sources of low- and no-calorie sweeteners from foods, beverages and tabletop sweeteners on a given day by public health-relevant sociodemographic characteristics (i.e., age, sex, income, and diabetes status); 2) identify the most frequently consumed sources of low- and no-calorie sweeteners by age and sex, and 3) to examine the nutritional profile of low- and no-calorie sweetener sources in relation to nutrients of public health concern identified in the 2019 Canada's Food Guide. Given the proximity to the U.S. and similar food supplies between the two

countries, we hypothesized that the proportion of individuals consuming foods and beverages sweetened with low- and no-calorie sweeteners would be comparable to estimates from the U.S. and that beverages would be the primary source of exposure. In addition, we hypothesized that the prevalence of consumption would be higher among females compared to males, higher with higher age, higher among individuals with higher incomes, and higher among individuals with diabetes compared to individuals without diabetes. Finally, we hypothesized that foods and beverages sweetened with low- and no-calorie sweeteners would not be foods and beverages encouraged by the 2019 Canada's Food Guide.

6.3 Materials and Methods

Data were drawn from Canada's most recent national nutrition survey, the 2015 Canadian Community Health Survey—Nutrition (2015 CCHS—Nutrition) (192). Analyses and reporting are in line with guidance from the 2015 CCHS—Nutrition User Guide (191). Ethics clearance was not required for the use of these publicly available data.

6.3.1 Data sources

2015 Canadian Community Health Survey—Nutrition

The 2015 CCHS—Nutrition provides a cross-sectional snapshot of dietary intake and related health conditions of individuals living in the ten Canadian provinces. Data were collected using a general health survey, which asked health-related and sociodemographic questions, and interviewer-administered 24-hour dietary recalls (24HDR) (192). Individuals 1 year of age and older living in private dwellings were included. For children 1 to 5 years of age, a parent or guardian proxy reported all data, whereas for children 6 to 11 years of age, reporting was completed by the child with assistance from a parent or guardian. Individuals 12 years of age and older completed the interview themselves unless a mental or physical disability prevented this, in which case, the parent or guardian proxy reported on the individual's behalf. Individuals excluded from the 2015 CCHS—Nutrition included individuals living on Indigenous reserves or settlements, in certain remote areas, in Canada's three Territories, in institutions such as prisons or care facilities, and those who were full-time Canadian armed forces members. These exclusions represented approximately 10% of the survey's target population (192). Overall, the

2015 CCHS—Nutrition sampling strategy was designed to be representative of the population in terms of age, sex, socioeconomic status, and geographic location (192).

This study drew on data from the 2015 CCHS—Nutrition Public Use Microdata Files (PUMF) made available through the Data Liberation Initiative (192); data files were downloaded on July 30, 2021. A key difference between the 2015 CCHS—Nutrition Master Files and the PUMF is the suppression of confidential information to protect individual anonymity (191).

Dietary intake data

The 24HDR was the first component of the survey and was administered using an adapted version of the U.S. Department of Agriculture (USDA)’s Automated Multiple-Pass Method (AMPM) (192,194). The AMPM is an automated five-step interview designed to maximize respondents’ recall of foods and beverages consumed in the previous 24 hours (194). Health Canada modified the AMPM to reflect the Canadian food supply and commonly used measures (192). Briefly, the five steps of the AMPM include 1) a quick list, which involves respondents reporting all foods and beverages consumed in any order and without interruptions from the interviewer; 2) forgotten foods, whereby the interviewer prompts and probes respondents for commonly forgotten foods; 3) time and occasion for all foods and beverages reported consumed; 4) detailed cycle step, which probes respondents about the details provided in steps 1 through 3; and 5) a final review, whereby the interviewer collects data on any additional foods or beverages consumed that were not reported in the prior steps.

All respondents (n=20,487) completed the first 24HDR during an in-person interview, and a subset (n=7,623) completed a second 24HDR, administered via telephone, three to ten days after their first recall and on a different day of the week than the first interview. For the present analyses, data from the first 24HDR were used because a single 24HDR can be used to reflect the average usual intake at the group level (210).

All foods and beverages reported during the 24HDR were coded using Canada’s national food composition database, which is comprised of data from the 2015 Canadian Nutrient File (CNF) and a complementary recipe data file maintained by Health Canada (192). Each food code within the database represents the generic nutritional profile derived from similar products in the marketplace in 2015 (182). Food codes were assigned at the basic, ingredient, or recipe levels. Nutritional information for all reported foods and beverages is contained in the 2015 CCHS—

Nutrition Food Ingredient Details (FID) and Food Recipe Level (FRL) data files, which were appended together for analysis. To avoid double counting energy and nutrient data, ingredient-level food codes were excluded from the analytic dataset (196,211).

Identifying dietary sources of sweeteners

Data on the amount, and in some cases, the type, of low- and no-calorie sweeteners is unavailable in Canada's food composition database. Food codes that are sources of low- and no-calorie sweeteners were identified using a three-step approach as described in **Chapter 5**. Briefly, a text-based keyword search of all food code descriptions was undertaken. Food codes were searched for keywords determined *a priori*, including confirmatory (e.g., low-calorie sweetener, aspartame) and possible source (e.g., no sugar added) keywords. Food codes containing a confirmatory keyword in the descriptions were classified as sources of low- and no-calorie sweeteners. Food codes containing possible source keywords were further examined and categorized based on a review of corresponding food code descriptions from the U.S. Food and Nutrient Database for Dietary Surveys (FNDDS), which contains brand-specific data and, for some codes, an examination of the nutritional information of products available from three Canadian online grocery retailers. The identification of foods and beverages containing sweeteners considered basic food codes (e.g., diet soda) and ingredients used in recipes (e.g., diet sodas used in the preparation of the Rum and Cola recipe), as well as tabletop sweeteners.

6.3.2 Sociodemographic characteristics of interest

Sociodemographic variables of interest included age, sex, household income, and diabetes status (for adults 19 years and older) based on known differences in low- and no-calorie sweetener intake (72,79,122). Information on racial and ethnic identity was not available in the 2015 CCHS—Nutrition PUMF. Age categories aligned with those used for the Dietary Reference Intakes (DRI) and included children 1 to 13 years, adolescents 14 to 18 years, adults 19 to 30, 31 to 50, 51 to 70, and 71 years of age and older. Survey respondents were asked to report their household income for the past 12 months. To protect their confidentiality, the 2015 CCHS—Nutrition PUMF data files do not include continuous income information (192). For the present analysis, the eight categories available in the PUMF were grouped into four categories to balance cell sizes, and included low (\$0 to \$39,999), low-middle (\$40,000 to \$79,999), middle-

high (\$80,000 to \$139,999), and high (\$140,000 and higher). Self-reported diabetes status (yes/no) was assessed among adults aged 19 years and older.

6.3.3 Statistical analysis

Analyses were conducted using SAS version 9.4 (SAS Institute, Cary, N.C., USA). Survey procedures were used to account for the complex multistage survey design. Survey weights provided by Statistics Canada were applied to improve the representativeness of estimates and account for non-response bias (192).

The proportions of individuals consuming any food codes classified as sources of sweeteners on the intake day were estimated. Specifically, PROC SURVEYFREQ was used to estimate proportions consuming any source of low- and no-calorie sweeteners by age group, age-sex group, household income, and self-reported diabetes status (adults 19 and older only). A DOMAIN analysis, which considers the entire population when generating variation estimates (212), was used to estimate proportions for subgroups. Bootstrap weights provided as part of the PUMF were used to generate variance estimates for the proportion estimates using Balanced Repeated Replication. The Wald chi-square test—the Wald F statistic for 2x2 tables and the adjusted Wald F statistics for tables larger than 2x2—was used to test differences in prevalence by sex across all age subgroups and low- and no-calorie sweetener types. *P* values were interpreted with a level of evidence approach (213). In this approach proposed by Muff et al. (213), results from statistical tests are not interpreted as a binary outcome, i.e., statistically significant or not. Rather, *P* values are interpreted along a gradient of evidence ranging from little to no evidence (*P* value >0.1) to very strong evidence (*P* value <0.001).

The frequencies of consumption events of food codes classified as sources of low- and no-calorie sweeteners were estimated among children, adolescents, and adults. Although it is not possible to quantify the amounts of sweeteners consumed, the weighted mean amounts consumed for each source of sweeteners were estimated using PROC SURVEYMEANS; this analysis was limited to those who consumed at least one source of low- and no-calorie sweeteners on the recall day. Common uses of tabletop sweeteners reported at the basic food code level (i.e., not used as an ingredient in a recipe code) were examined based on a review of 10% of all reported consumption events. Although analyses were conducted at the food code level, food codes were organized into mutually exclusive categories to facilitate reporting and

interpretation. The categories used previously in the analysis of data from the 2015 CCHS—Nutrition (196) include soda, yogurt/kefir, and dairy desserts, for instance. The categories and corresponding food codes were further grouped as foods, beverages, or tabletop sweeteners.

The nutritional profile of food codes classified as low- and no-calorie sweeteners was examined in relation to energy (kcal) and nutrients of public health concern, specifically saturated fat, free sugars, and sodium, described per 100-gram (or 100 mL) serving. Free sugars estimates were obtained from Rana et al. (214). The examination of food code alignment with Canada's Food Guide was completed using a data file provided by Health Canada. This data file contained all applicable 2015 Canadian Nutrient File food codes matched to the 2019 Canada's Food Guide Food Classification System's food categories and assigned to Tiers (215). Nutritious foods that are encouraged are classified as Tier 1 level foods. Foods that undermine healthy eating and contribute to excess consumption of saturated fat, free sugars, or sodium are classified as Tier 3 level foods. Foods not classified as Tiers 1 or 3 are classified as Tier 2 level foods. Tier assignment is dependent upon which food category each food code belongs to (based on typical usage and the food origin), followed by an examination of the total amounts of saturated fat, sugars, and sodium (215). For example, food code 1491, *Apple, dried, sulphured, stewed, no sugar added* and food code 1492, *Apple dried, sulphured, stewed, added sugar*, belong to the Fruit category. Based on their nutritional profile, food code 1491 is assigned to Tier 1 because it does not contain free sugars, sugar substitutes, added fats, or added sodium. However, food code 1492 is assigned to Tier 2 because it does contain free sugars but does not exceed the "high in" sugar criterion set for Tier 3-level fruits, which is based on the reference amount (RA) or typical amount of food consumed in one eating occasion (216). Food codes not assigned to a tier include baby and toddler foods, meal replacements and supplements, alcoholic beverages, miscellaneous foods and ingredients (e.g., spices and unprepared ingredients), and foods and beverages that cannot be classified due to missing data (215).

6.4 Results

The unweighted analytic sample (n=20,483) was comprised of 52% females (**Table 12**). Approximately 22% of the sample were children 1 to 13 years old, 10% were adolescents aged 14 to 18, and the remaining 68% were adults aged 19 years and older. Among adults, 9%

reported having diabetes. Similar proportions (~27%) of the sample reported household incomes in the lowest (\$0 to \$39,999) and middle-high (\$80,000 to \$139,999) range, whereas 30% and 15% reported household incomes in the low-middle (\$40,000 to \$79,999) and high (\$140,000 and higher) ranges, respectively; fewer than 0.1% did not report a household income.

6.4.1 Proportions of respondents reporting consumption of sources of low- and no-calorie sweeteners on a given day

Overall, 8.4%, 10.7%, and 19.8% of children, adolescents, and adults, respectively, reported consuming any source of low- and no-calorie sweeteners on a given day (**Table 13**). By sweetener type, the prevalence of exposure was higher for low- and no-calorie sweetened foods compared to beverages among both children aged 1 to 13 and adolescents aged 14 to 18 (children: 5.5% vs. 3.1%, respectively; adolescents 6.2% vs. 4.1%, respectively). Among adults, the prevalence of exposure was higher from beverage sources than food sources (10.9% vs. 7.8%, respectively). The use of tabletop sweeteners was not prevalent among children and adolescents, whereas one in 25 (4%) adults 19 years of age and older reported exposure to these products on the recall day, most often as additions to coffee and tea (data not shown). Cyclamate and sucralose were the most frequently reported types of tabletop sweeteners.

There was little to no evidence to suggest differences in proportions consuming low- and no-calorie sweeteners between males and females across most age categories; the one exception was among adults aged 51 to 70 years. In this instance, there was strong evidence that the prevalence of consumption of food sources was higher among females compared to males (P value=0.005). There was little to no evidence to support differences in the proportions of individuals reporting consumption of low- and no-calorie sweeteners by income (data not shown).

For most comparisons between adults with and without diabetes, there was very strong evidence of differences in the prevalence of consumption of low- and no-calorie sweeteners based on diabetes diagnosis. Low- and no-calorie sweetener consumption was more prevalent among individuals reporting a diabetes diagnosis (42.4%) compared to those who did not have diabetes (18.2%) (P value<0.0001) (**Table 13**). The proportion consuming beverage sources of low- and no-calorie sweeteners was more than two times higher among individuals with diabetes than those without (26.0% vs. 9.8%, respectively, P value<0.0001), and the proportion

consuming tabletop sweeteners was more than five times higher among those with diabetes (16.4% vs. 3.0%, respectively, P value <0.0001). However, there was weak evidence that a higher proportion of individuals with diabetes reported consumption of foods sweetened with low- and no-calorie sweeteners on the recall day compared to individuals without diabetes (11.3% vs. 7.4%, respectively, P value =0.08).

6.4.2 Frequency of consumption events of low- and no-calorie sweeteners by source on a given day

Among children aged 1 to 13 years, the frequency of consumption of low- and no-calorie sweetened foods was higher than the frequency of consumption of low- and no-calorie sweetened beverages (**Table 14**). Among adolescents aged 14 to 18 years and adults 19 years and older, the frequency of consumption of low- and no-calorie sweetened beverages was higher than the frequency of consumption of low- and no-calorie sweetened foods. Diet sodas were the most frequently reported beverage sub-category consumed across all three age groups. Among children and adolescents, sweetened coffee, tea, hot chocolate, energy drinks, and flavoured waters were common sources of exposure, with flavoured waters being the most frequently reported within this beverage sub-category. Low- and no-calorie sweetened yogurts were a frequent source of food exposure across all three age groups. Protein powders and ready-to-consume meal replacements were common sources of food exposure among adolescents and adults. Consumption events by sex are reported in **Table 15**.

6.4.3 Nutritional profile of food codes classified as sources of low- and no-calorie sweeteners

Table 16 shows the nutritional composition of low- and no-calorie sweetener food codes ($n=76$), as well as the alignment of these food codes with the 2019 Canada's Food Guide using the 2019 Canada Food Guide Food Classification System (215). **Figure 3** illustrates the flow of assigning food codes to one of the Canada Food Guide Classification Tiers. Because the classification system only applied to "as consumed" foods and beverages and not those in their unprepared forms, approximately one-fifth (22.4%, $n=17$) of the low- and no-calorie sweetener food codes were not assigned to a Tier. **Appendix E** provides the nutritional profile per 100 grams for food codes not classified into a Tier in their unprepared forms. An additional 12 food codes (15.8%) were not assigned to a Tier because they were therapeutic meal replacements

(n=4) or miscellaneous foods (n=3) or because the required nutritional information to classify to a Tier was missing (n=5).

None of the remaining food codes (n=47, 62%) classified as sources of low- and no-calorie sweeteners were considered nutritious foods promoted by Canada's Food Guide (Tier 1). About a quarter (26.3%) were classified as foods that should not be consumed regularly (Tier 3). Dairy desserts made up the largest proportion of Tier 3 food codes. Food codes in this Tier also included low- and no-calorie sweetened fruit and sweetened drinks, jams and jelly, syrups, and grain-based desserts. About a third of food codes (35.5%) did not meet the criteria for Tiers 1 or 3 and were assigned to Tier 2. Tier 2 food codes included low- and no-calorie sweetened sodas, fruit and other sweetened drinks, canned fruits, yogurt, and desserts.

6.5 Discussion

This study is the first to our knowledge to examine exposure to low- and no-calorie sweeteners from beverages, foods, and tabletop sweeteners among individuals living in Canada. Results indicate that almost one in 10 children and adolescents and one in five adults consumed low- and no-calorie sweeteners on a given day, with a higher prevalence of exposure occurring with higher age. Overall, there was little to no evidence to suggest that the prevalence of consumption differed by sex, except for within the 51-70-year age group, in which case, there was strong evidence of a higher prevalence of consuming low- and no-calorie sweetened foods among females compared to males. However, considering all other comparisons made, this finding of a difference may be due to chance. There was little to no evidence to suggest that the prevalence of consumption differed by household income. This finding, while not in line with research from the U.S., is in line with estimates from Australia (79). There was very strong evidence of higher prevalence of consumption of low- and no-calorie sweeteners from any source, as well as from beverages and tabletop sweeteners among individuals living with diabetes compared to individuals without diabetes. Sources of exposure to low- and no-calorie sweeteners varied across sociodemographic characteristics, and no sources were classified as nutritious options according to the 2019 Canada's Food Guide Food Classification System.

According to our analyses, and in line with previous research from other jurisdictions (122), low- and no-calorie sweetened beverages remain an important source of exposure across

all age groups. This finding is unsurprising given the public health attention to the harmful health impacts of consuming free and added sugars beyond the recommended limits, particularly from sugar-sweetened beverages. Sugar-sweetened beverages remain a top contributor of free and added sugars in Canada and the U.S. (16,17), and substituting sugary drinks with their low- and no-calorie sweetened counterparts represents a readily achieved substitution. On a given day, the most frequently reported source among children was low- and no-calorie sweetened fat-free yogurt. Of all the food sources of low- and no-calorie sweeteners, sweetened low-fat yogurt may be one of the healthier choices, considering yogurt provides important nutrients such as calcium and vitamin B12 (35). Consistently, it is classified as a Tier 2 food according to the 2019 Canada's Food Guide Food Classification System. In contrast, meal replacements and protein powders were the most frequently reported food sources among adolescents and adults. Assuming individuals are in energy balance, these replacement items may be displacing nutritious foods and beverages that contribute a variety of macro- and micro-nutrients. This is particularly concerning for adolescents who are still growing and establishing eating patterns that will track into adulthood (217).

We hypothesized that the prevalence of exposure to low- and no-calorie sweeteners among individuals living in Canada would be similar to prevalence estimates in the U.S. Compared to recent estimates from the U.S. (122), the proportion of individuals living in Canada reporting consumption of foods and beverages containing low- and no-calorie sweeteners is lower, and more in alignment with prevalence estimates from Australia (79). While there are slight discrepancies between Canada and the U.S. in age category cutoffs used in analyses, the prevalence of exposure in Canada is less than half the prevalence of exposure among individuals living in the U.S. (i.e. children and youth: 9.1% vs. 25.1%; adults: 19.8% vs. 41.4%) (122). Differences are also apparent in the prevalence of exposure by low- and no-calorie sweetener type. Among children and adolescents (1-18 years), on a given day, a higher prevalence of exposure from food sources compared to beverages was observed in Canada (5.7% vs. 3.4%, respectively) compared to the U.S. (7.8% vs. 19.0%). The prevalence of exposure to tabletop sweeteners was lower among adults living in Canada compared to the U.S. (4.0% vs. 14.1%, respectively) (122). While adults' exposure to low- and no-calorie sweetened beverages was

higher than exposure to foods in both countries, the prevalence of exposure to beverages was substantially lower in Canada compared to the U.S. (10.9% vs. 30.8%, respectively) (122).

The present study did not examine whether the prevalence of consumption of low- and no-calorie sweeteners varied by sex among adults self-reporting diabetes. However, rates of diabetes in Canada are somewhat higher among men compared to women (9.4% vs. 8.1%) (218). According to analyses of U.S. data, men with diabetes were more likely to consume any type of low- and no-calorie sweetener compared to women with diabetes (17.1% vs. 11.2%, respectively) (219). Future analyses examining consumption by sex could inform tailored dietary interventions to support individuals living with diabetes. Further, the 2015 CCHS—Nutrition did not include populations living in Canada's Territories, who may experience higher rates of diabetes (220,221). Examination of the use of sweeteners overall and in relation to characteristics such as diabetes diagnoses among individuals in the Territories is a notable gap in the current evidence.

Methodological differences may contribute, in part, to differences in prevalence estimates between the U.S. and Canada. One methodological difference that could explain the observed variations in prevalence estimates is the number of days for which dietary recall data were analysed. Recent prevalence estimates from the U.S. were based on reported consumption of low- and no-calorie sweeteners from two 24HDR recalls per person, whereas our analyses were based on a single 24HDR per person. In the U.S., the NHANES seeks to collect two 24HDRs from all respondents (121), whereas in Canada, only a subset completed a second recall (192). While a second recall is required to estimate distributions of usual intakes (192,210), a single 24HDR is appropriate to estimate the mean usual intake for a population. However, for foods and beverages consumed episodically, including low- and no-calorie sweeteners, it is possible that some individuals living in Canada did not consume any source of sweeteners on their recall day, leading to underestimation in prevalence estimates. There is some evidence to support this assertion from U.S. studies. For example, one study drawing on NHANES data from 1999 to 2008 estimated the prevalence of exposure from any source of low- and no-calorie sweeteners among adults 20 years and older based on a single 24HDR to be approximately 30% (72) compared to 41% based on the use of two 24HDR from the 2009 to 2012 NHANES cycles (122), though the comparison is confounded by differences in the time periods examined.

Higher consumption of low- and no-calorie sweeteners among individuals with higher weights and body mass index (BMI) (71) and among individuals engaging in weight loss efforts (219) has previously been reported. Therefore, observed differences in the prevalence of consumption of sweeteners between Canada and the U.S. may also be, in part, due to the higher rates of overweight and obesity in the U.S. compared to Canada (222). However, examining low- and no-calorie sweeteners, or any dietary recall data, by weight and BMI is challenging given the differential misreporting of energy and dietary components by body weight status (223). The measurement error structure of misreporting by body weight status is multifactorial and not well understood (224) but may lead to the masking of differences in true intake (225).

Perceptions of the safety and healthfulness of low- and no-calorie sweeteners may also influence reporting of their use. Some ‘natural’ sweeteners are afforded a health halo and perceived more favourably than others (226,227). In one study surveying young adults 16 to 30 years of age living in Canada, almost one-third of respondents reported trying to consume fewer ‘artificial’ sweeteners compared to one-quarter trying to consume fewer ‘natural’ low- and no-calorie sweeteners (226). Similarly, the synthetic origin of some low- and no-calorie sweeteners reduced the perceived safety of such sugar substitutes among U.K. adults (228). While perception was not measured directly, a recent study examining low- and no-calorie sweeteners purchases in the U.S. reported a 25% increase in products (predominantly beverages) sweetened with *rebaudioside A* (a steviol glycoside marketed as Stevia®) between 2002 and 2018, which the authors attribute to consumer preference for more ‘natural’ sweeteners (27). Perceiving low- and no-calorie sweeteners as unsafe and unhealthy could potentially bias respondents’ dietary recall in the direction of underreporting when part of a health survey, specifically due to social desirability bias. It is not currently possible to determine whether such biases are consistent across surveys of individuals in Canada and the U.S.

Low- and no-calorie sweeteners are promoted as part of public health interventions to reduce energy and free and added sugars intake among populations. Evidence examining the impact of these policies, including subsequent reformulations of high-sugar products with low- and no-calorie sweeteners by the food industry, is limited but growing. The United Kingdom’s Soft Drinks Industry Levy is one example that resulted in many manufacturers reformulating their sugary beverages with low- and no-calorie sweeteners to comply with the lower sugar

regulations (229). Similar findings were observed in Chile with the implementation of their 2016 Food Labelling and Advertising Law (230). In addition to reduced sugars content, an increase in the replacement of sugars with low- and no-calorie sweeteners in not only beverages but also foods, including yogurts, desserts, and ice creams, has been observed in Chile (230). According to our analyses, most beverages sweetened with low- and no-calorie sweeteners contained little to no free sugars, which indicates a complete replacement of caloric sugars with their low- and no-calorie sweetener counterparts. However, many food sources of sweeteners were found to contain free sugars, representing products containing a blend of low- and no-calorie sweeteners and caloric sugars (203). Evidence describing the magnitude of free and added sugars reductions and subsequent energy (kcal) of foods sweetened with low- and no-calorie sweeteners is limited. In a recent analysis of breakfast cereals and bakery products, reformulation efforts by manufacturers, whereby caloric sugars were substituted with low- and no-calorie sweeteners, resulted in products that contained the same amount of energy (kcal) or a higher energy content compared to their original reference counterparts (231,232). Caution is therefore warranted about the potential benefits of foods sweetened with low- and no-calorie sweeteners.

No food code classified as a source of low- and no-calorie sweeteners is considered ‘nutritious’ according to the 2019 Canada’s Food Guide Food Classification System. Currently, dietary guidance in Canada encourages individuals to reduce their free sugars intake by choosing unsweetened alternatives instead of reaching for low- and no-calorie sweetened versions (9). However, for some individuals, replacing foods and beverages high in free and added sugars with products sweetened with low- and no-calorie sweeteners may be an interim step toward full replacement with unsweetened versions (40). Additional educational support may aid high consumers of low- and no-calorie sweeteners to shift their eating patterns to align with Canada’s Food Guide more closely. For example, other jurisdictions have introduced population-level education initiatives such as warning symbols and statements to draw attention to the fact that a product contains one or more low- and no-calorie sweeteners so consumers can make an informed decision (233). However, care should be taken to provide information about low- and no-calorie sweeteners in ways that do not stigmatize the consumption of these products or consumers themselves. Further, such interventions will likely be more effective if paired with targeted consumer education initiatives that discuss the consumption of these sweeteners in the

context of an overall healthy dietary pattern (234). In addition to education, other factors influence eating patterns and should be considered (235). For example, environmental supports, such as Canada's Food Guide Friendly Initiative (236), a voluntary initiative that encourages publicly funded institutions to create healthier food environments can support adherence to Canada's dietary guidelines by increasing the availability of nutritious foods and beverages. These efforts can be enhanced by advertising and marketing strategies that make the placement, promotion, and price of these nutritious foods more visible, available, and affordable to the consumer.

When interpreting findings from this study, strengths and limitations should be considered. This study's key strength was its use of national nutrition survey data, which provides reasonably representative estimates of intake among individuals living in Canada's provinces. However, some key subgroups, such as Indigenous individuals living on reserve and individuals living in Canada's three Territories, are excluded from the 2015 CCHS—Nutrition and therefore, findings may not be generalizable to these groups. Further, the accuracy of prevalence estimates is dependent on the method of classifying food codes as sources of low- and no-calorie sweeteners. As discussed in **Chapter 5**, while our method was systematic and multi-pronged, limitations in the underlying data to support classification may have led to over- or underestimation of the prevalence of consumption of sources of sweeteners. Over or underestimation may also have come about due to systematic measurement error affecting 24HDR data (225).

6.6 Conclusion

Given the public health focus on the detrimental health effects of consuming excess free and added sugars and concerns that the food and beverage industry would quickly adapt to regulations targeting free and added sugars by reformulating using low- and no-calorie sweeteners, it is important to monitor not only the food supply but the population's consumption of low- and no-calorie sweetened foods and beverages. The current analyses provide important insight into the prevalence of exposure to and sources of low- and no-calorie sweeteners among individuals living in Canada. Findings from this study can inform monitoring and surveillance activities, as well as public health nutrition initiatives to support healthy eating patterns.

Table 12: Socio-demographic and health-related characteristics of interest, 2015 Canadian Community Health Survey—Nutrition, PUMF, analytic sample (n=20,483)

Characteristics	Unweighted frequencies n (%)	Weighted percents (%, 95% CL*)
Sex	9,747 (47.6)	49.3 (47.9, 50.8)
Male	10,736 (52.4)	50.7 (49.2, 52.1)
Female		
Age (years)		
Children 1 to 13	4,573 (22.3)	14.1 (13.3, 14.8)
Adolescents 14 to 18	1,995 (9.7)	5.7 (5.2, 6.1)
Adults 19 and above	13,915 (67.9)	80.3 (79.4, 81.2)
Income¹		
Lowest	5,690 (27.8)	23.6 (22.3, 24.8)
Low-middle	6,211 (30.3)	29.7 (28.4, 31.0)
Middle-high	5,515 (26.9)	29.5 (28.2, 30.9)
Highest	3,044 (14.9)	17.1 (16.0, 18.3)
Has diabetes²		
Yes	1,258 (9.1)	6.9 (6.2, 7.6)
No	12,617 (90.9)	93.1 (92.4, 93.8)

¹ Total household income categories: Low = \$0 to \$39,999; Low-Middle = \$40,000 to \$79,999; Middle-High = \$80,000 to \$139,999; High = \$140,000 and higher. Excludes missing respondents (n=23)

² Self-reported diabetes status among adults 19 years and above. Excludes missing respondents (n=40).

*95% CL: 95% confidence limits for weighted percent

Table 13: Weighted prevalence of exposure to sources of low- or no-calorie sweeteners (LNCS), based on the first dietary recall reported in the 2015 Canada Community Health Survey—Nutrition among children, adolescents, and adults by age, sex, income and diabetes status.

Characteristics	Any LNCSs	LNCS beverages	LNCS foods	LNCSs tabletop sweeteners
	% (95% CI)			
Age-Sex				
Children and Adolescents, 1 to 18 years				
Male (n=3,296)	9.19 (6.71, 11.67)	3.32 (2.31, 4.33)	5.96 (3.84, 8.08)	Suppressed (n<10)
Female (n=3,272)	8.95 (7.06, 10.84)	3.46 (2.53, 4.38)	5.45 (3.81, 7.10)	Suppressed (n<10)
Combined (n=6,568)	9.07 (7.30, 10.84)	3.39 (2.69, 4.08)	5.71 (4.18, 7.23)	0.25 (0.04, 0.47)
Adults, 19 years and older				
Male (n=6,451)	18.99 (14.84, 23.14)	10.69 (6.54, 14.85)	7.12 (5.95, 8.29)	3.37 (2.63, 4.12)
Female (n=7,464)	20.59 (17.18, 24.00)	11.15 (8.50, 13.81)	8.24 (7.02, 9.47)	4.50 (2.87, 6.13)
Combined (n=13,915)	19.80 (16.19, 23.41)	10.93 (7.63, 14.22)	7.69 (6.98, 8.41)	3.95 (3.09, 4.81)
Children, 1-13 years				
Male (n=2,336)	7.89 (5.43, 10.35)	2.90 (1.70, 4.10)	5.15 (3.09, 7.20)	Suppressed (n<10)
Female (n= 2,237)	8.93 (6.84, 11.03)	3.30 (2.23, 4.37)	5.86 (4.03, 7.68)	Suppressed (n<10)
Combined (n= 4,573)	8.41 (6.60, 10.22)	3.10 (2.29, 3.91)	5.50 (3.99, 7.01)	Suppressed (n<10)
Adolescents, 14-18 years				
Male (n=960)	12.33 (8.07, 16.58)	4.34 (2.58, 6.09)	7.92 (3.92, 11.92)	Suppressed (n<10)
Female (n=1,035)	8.99 (5.37, 12.60)	3.85 (2.04, 5.67)	4.42 (1.34, 7.50)	Suppressed (n<10)
Combined (n=1,995)	10.70 (7.63, 13.78)	4.10 (2.85, 5.35)	6.22 (3.39, 9.06)	Suppressed (n<10)
Adults, 19-30 years				

Characteristics	Any LNCSs	LNCS beverages	LNCS foods	LNCSs tabletop sweeteners
	% (95% CI)			
Male (<i>n</i> =882)	13.61 (9.38, 17.84)	5.02 (3.02, 7.02)	9.18 (5.11, 13.24)	0.71 (0.00, 1.51)
Female (<i>n</i> =1,019)	13.47 (9.42, 17.52)	7.51 (4.86, 10.15)	5.09 (1.29, 8.88)	3.10 (0.00, 7.31)
Combined (<i>n</i> =1,901)	13.54 (10.41, 16.68)	6.20 (4.64, 7.77)	7.23 (4.81, 9.65)	1.85 (0.00, 3.90)
Adults, 31-50 years				
Male (<i>n</i> =2,077)	18.97 (13.19, 24.75)	10.96 (5.45, 16.46)	7.08 (5.38, 8.78)	2.83 (1.55, 4.12)
Female (<i>n</i> =2,469)	21.14 (14.76, 27.52)	11.92 (6.15, 17.69)	8.32 (6.49, 10.16)	4.20 (2.64, 5.75)
Combined (<i>n</i> =4,546)	20.08 (14.29, 25.86)	11.45 (5.95, 16.94)	7.71 (6.50, 8.93)	3.53 (2.53, 4.52)
Older Adults, 51-70 years				
Male (<i>n</i> =2,246)	21.13 (13.56, 28.70)	13.57 (5.65, 21.49)	6.08 (4.72, 7.44)	4.10 (2.94, 5.25)
Female (<i>n</i> =2,420)	23.02 (18.92, 27.11)	12.51 (10.09, 14.92)	9.50 (7.59, 11.41) **	4.94 (3.27, 6.60)
Combined (<i>n</i> =4,666)	22.08 (16.61, 27.55)	13.03 (8.37, 17.69)	7.81 (6.64, 8.97)	4.52 (3.39, 5.66)
Older Adults, 71 years and older				
Male (<i>n</i> =1,246)	21.43 (16.17, 26.69)	10.32 (6.13, 14.52)	7.05 (4.91, 9.19)	7.49 (4.28, 10.70)
Female (<i>n</i> =1,556)	21.46 (17.69, 25.24)	9.94 (7.45, 12.42)	8.67 (6.22, 11.12)	5.98 (3.09, 8.88)
Combined (<i>n</i> =2,802)	21.45 (18.97, 23.93)	10.11 (7.79, 12.43)	7.95 (6.36, 9.55)	6.65 (4.90, 8.40)
Income¹				
Children, 1-13 years				
Low (<i>n</i> =820)	7.47 (4.99, 9.94)	3.01 (1.18, 4.83)	4.91 (2.93, 6.90)	Suppressed (<i>n</i> <10)
Low-Middle (<i>n</i> = 1,251)	8.64 (4.68, 12.59)	2.42 (1.21, 3.63)	6.10 (2.34, 9.86)	Suppressed (<i>n</i> <10)
Middle-High (<i>n</i> = 1,574)	9.18 (6.33, 12.04)	3.13 (1.61, 4.66)	6.19 (3.88, 8.51)	Suppressed (<i>n</i> <10)
High (<i>n</i> = 917)	7.64 (5.21, 10.08)	4.00 (2.03, 5.98)	4.08 (2.48, 5.68)	Suppressed (<i>n</i> <10)

Characteristics	Any LNCSs	LNCS beverages	LNCS foods	LNCSs tabletop sweeteners
	% (95% CI)			
Adolescents, 14-18 years				
Low (n=378)	7.69 (1.05, 14.33)	3.02 (0.00, 6.10)	3.60 (0.00, 8.46)	Suppressed (n<10)
Low-Middle (n=545)	11.08 (5.78, 16.38)	2.96 (1.29, 4.63)	6.53 (1.29, 11.77)	Suppressed (n<10)
Middle-High (n=657)	11.57 (7.28, 15.87)	4.39 (2.22, 6.56)	7.55 (3.38, 11.71)	Suppressed (n<10)
High (n=410)	11.17 (5.45, 16.88)	5.78 (2.45, 9.11)	5.74 (1.31, 10.17)	Suppressed (n<10)
Adults, 19 years and older				
Low (n=4,492)	19.17 (14.22, 24.12)	10.78 (6.44, 15.12)	6.53 (5.36, 7.71)	4.39 (2.98, 5.80)
Low-Middle (n=4,415)	19.34 (15.42, 23.27)	10.09 (6.92, 13.26)	7.27 (6.04, 8.49)	5.19 (2.59, 7.79)
Middle-High (n=3,284)	20.16 (15.50, 24.82)	11.61 (7.24, 15.98)	8.55 (6.70, 10.40)	2.91 (1.31, 4.52)
High (n=1,717)	21.03 (18.09, 23.98)	11.53 (9.12, 13.93)	8.80 (6.80, 10.79)	2.71 (1.64, 3.79)
Has diabetes ²				
Has diabetes				
Yes (n=1,258)	42.44 (36.14, 48.74) *	25.99 (20.88, 31.09) *	11.27 (7.88, 14.66)	16.36 (11.89, 20.84) *
No (n=12,617)	18.15 (14.25, 22.05)	9.81 (6.28, 13.33)	7.44 (6.71, 8.18)	3.03 (2.16, 3.91)

¹ Total household income: Low = \$0 to \$39,999; Low-Middle = \$40,000 to \$79,999; Middle-High = \$80,000 to \$139,999; High = \$140,000 and higher. Excludes missing respondents (*n*=23)

² Self-reported diabetes diagnosis

Notes: *P* values are compared within groups by low- and no-calorie sweetener type (i.e. any beverages, foods, and tabletop sweeteners). The following denotes the strength of evidence: * *P* value <0.0001; ***P* value <0.01; all other comparisons had little to no evidence of significant differences (*P* value >0.1<1.0). 95% Confidence Interval (CI) estimated using 500 bootstrap weights.

Table 14: Reported frequencies of low- and no-calorie sweetener food code consumption events and weighted mean amounts of source consumed on a given day among children 1-13 years, adolescents 14-18 years, and adults 19 years and above using the 2015 Canadian Community Health Survey—Nutrition.

			Children, 1-13 years (n=436)		Youth, 14-18 years (n=250)		Adult, 19+ years (n=2,887)	
Food code	Food code description	Reference Amount (g)	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹
<i>Beverages</i>								
<i>Sodas</i>								
2926 ²	Carbonated drinks, cola with aspartame	375.40	40	245.89 ± 59.93	49	412.65 ± 39.77	1010	382.91 ± 12.52
2938 ²	Carbonated drinks, non-cola with aspartame	375.40	23	244.98 ± 24.44	15	274.25 ± 47.19	269	293.74 ± 15.99
4979 ²	Carbonated drinks, cola with aspartame, decaffeinated	375.40	6	217.15 ± 51.06	17	396.77 ± 39.37	241	341.40 ± 13.14
<i>Sweetened coffee, tea, hot chocolate, energy drinks, and flavoured water</i>								
5292 ²	Sports drink, fruit flavour, low calorie, ready-to-drink	380.30	7	416.97 ± 93.75	11	520.72 ± 27.07	37	617.02 ± 141.20
5602 ²	Coffee, instant powder, with whitener and artificial sweetener	2.60	0	—	0	—	2	57.48 ± 14.38
5710 ²	Coffee, instant, mocha, powder, with whitener and artificial sweetener, decaffeinated	2.60	0	—	0	—	1	280.79 —
6327 ²	Water, fruit flavour, sweetened with artificial sweetener	375.60	37	299.85 ± 33.90	24	467.88 ± 111.70	149	442.29 ± 41.69
7174 ²	Energy drink, shot, sugar-free	381.00	0	—	0	—	1	50.80 —
7177 ²	Energy drink, sugar-free/low-calorie	378.00	0	—	7	553.39 ± 203.24	26	405.21 ± 30.84
7188 ²	Vitamin water, lemon/orange flavours, low-calorie	368.60	0	—	0	—	5	498.24 ± 85.04
7238 ²	Vitamin water, flavours not lemon/orange, low-calorie	368.60	2	300.33 ± 17.07	1	581.16 —	10	458.86 ± 3 3.74
7281 ²	Coffee and cocoa (mocha) powder, with whitener and low-calorie sweetener	2.60	0	—	0	—	1	162.30 —
7477 ²	Beverage mix, chocolate flavour, powder, no added sugar, with 2% M.F. milk	297.42	1	172.70 —	0	—	2	364.59 ± 17.95
500029 ²	Hot chocolate, made from dry mix with low-calorie sweetener, water added	264.16	4	243.09 ± 44.90	1	249.99 —	8	269.17 ± 15.96
502439 ³	Coffee, instant, pre-sweetened, no whitener, powder, water added	251.50	0	—	1	191.14 —	16	247.27 ± 38.24
502440 ³	Coffee and cocoa (mocha), instant, with whitener, pre-sweetened, powder, water added	251.50	0	—	0	—	2	191.14 ± 0.00
502452 ³	Tea, NS as to type, presweetened with sugar	250.50	1	185.37 —	0	—	5	517.08 ± 20.03

			Children, 1-13 years (n=436)		Youth, 14-18 years (n=250)		Adult, 19+ years (n=2,887)	
Food code	Food code description	Reference Amount (g)	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹
502453 ³	Tea, NS as to type, sweetened, NS as to sweetener (Lemon-flavoured)	250.50	0	—	0	—	1	305.61 —
502454 ³	Tea, NS as to type, sweetened, NS as to sweetener, decaffeinated	250.50	1	29.64 —	1	290.58 —	3	300.26 ± 3.89
504757 ²	Tea, made from powdered instant with artificial sweetener (iced tea)	375.65	3	189.38 ± 1.22	2	603.51 ± 260.26	7	287.87 ± 7 0.86
504765 ²	Tea, NS as to type, presweetened with low-calorie sweetener (ready-to-drink)	375.38	5	131.50 ± 32.98	9	435.23 ± 145.60	89	247.12 ± 16.95
504779 ³	Hot chocolate, made from dry mix, milk added	264.16	1	200.77 —	0	—	2	238.79 ± 21.00
504975 ³	Cocoa and sugar mixture, reduced sugar, milk added, NS as to type of milk	n/a	1	211.34 —	2	412.11 ± 0.00	5	207.11 ± 112.54
505185 ²	Coffee and cocoa (mocha), made from powdered instant mix, with whitener and low-calorie sweetener, decaf	251.50	0	—	0	—	3	219.06 ± 19.03
Fruit drinks								
2963 ²	Lemonade with artificial sweetener, powder, water added	378.90	7	463.82 ± 56.04	5	190.05 ± 37.31	35	324.89 ± 116.71
5603 ²	Juice drink, cranberry-apple low calorie, with vitamin C added	253.60	22	250.12 ± 32.38	7	231.77 ± 32.40	59	219.84 ± 15.14
7230 ²	Juice drink, orange, calorie-reduced	253.60	16	266.56 ± 29.55	7	201.76 ± 18.03	42	189.92 ± 29.22
403953 ²	Cranberry juice cocktail, plus vitamin C, plus aspartame, bottled	267.33	1	417.30 —	0	—	16	232.62 ± 33.57
502481 ³	Fruit-flavoured drink, made from powdered mix, low calorie, with vitamin C added	380.39	1	270.60 —	0	—	0	—
505189 ³	Carbonated non-citrus juice drink	393.08	0	—	0	—	1	94.34 —
505191 ³	Fruit-flavored drink, made from powdered mix, low-calorie	380.40	8	386.54 ± 54.87	1	791.23 ± —	7	336.02 ± 35.14
Flavoured milk								
500026 ³	Chocolate, flavour mix beverage, powder, 1% milk added	264.16	0	—	0	—	1	306.42 —
502759 ³	Chocolate flavour mix beverage, powder, 2% milk added	279.42	1	340.89 —	0	—	0	—
Coffee and tea								
502457 ³	Tea, made from powdered instant, unsweetened	250.50	1	200.40 —	0	—	6	263.75 ± 52.52
504700 ³	Coffee, instant, 50% less caffeine, powder, water added	279.42	0	—	0	—	3	191.14 ± 0.00
100% fruit juices								
504145 ³	Fruit smoothie drink, made with fruit or fruit juice only (no dairy products)	222.00	1	177.60 —	1	257.52 —	24	562.61 ± 120.22

			Children, 1-13 years (n=436)		Youth, 14-18 years (n=250)		Adult, 19+ years (n=2,887)	
Food code	Food code description	Reference Amount (g)	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹
Alcoholic beverages								
502504 ³	Rum and cola	n/a	0	—	0	—	23	380.78 ± 71.15
Foods								
Meal replacements and meal replacement powders								
7228 ²	Beverage, protein drink, ready-to-drink, light	257.80	0	—	3	443.44 ± 205.75	5	132.51 ± 84.61
7231 ²	Beverage, protein powder, whey-based	23.30	0	—	8	32.51 ± 7.44	14	27.12 ± 4.61
7233 ²	Beverages, high protein powder	23.30	1	61.00 —	2	58.05 ± 10.41	14	35.41 ± 10.52
403792 ²	Meal replacement, powder, diet	35.13	0	—	0	—	4	16.19 ± 12.94
404210 ²	Meal replacement, ready-to-drink, high protein (all flavours)	266.27	3	257.60 ± 9.50	4	324.62 ± 14.74	62	289.67 ± 17.73
404214 ²	Meal replacement, ready-to-drink, diabetic (all flavours)	266.27	0	—	0	—	15	239.89 ± 15.75
404269 ²	Meal replacement, bar	45.00	5	64.17 ± 1.17	0	—	15	77.05 ± 11.85
500045 ³	Instant breakfast, powder, with 2% milk (Ready to drink)	n/a	0	—	0	—	4	451.65 ± 189.95
500046 ³	Meal replacement, powder, diet, reconstituted with water	278.41	0	—	0	—	4	324.12 ± 18.58
504126 ³	Meal replacement, powder, diet, reconstituted with milk	n/a	0	—	1	30.88 —	9	79.42 ± 29.87
505262 ³	Protein powder, water added (whey protein)	n/a	4	65.79 ± 51.16	15	239.26 ± 104.17	181	212.07 ± 30.75
505263 ³	Protein powder, milk added (whey protein)	n/a	9	70.36 ± 38.08	23	335.06 ± 52.11	132	264.17 ± 33.19
505264 ³	Protein powder, juice added (whey protein)	n/a	1	328.84 —	2	284.96 ± 41.78	16	208.30 ± 79.60
Yogurt and kefir								
6951 ²	Yogurt, fruit flavoured, artificially sweetened, fat-free (0-0.5% M.F.), with added Vitamin D	175.00	100	113.38 ± 8.83	32	114.88 ± 18.20	341	113.47 ± 6.57
6952 ²	Yogurt, vanilla flavoured, with artificial sweetener, fat-free (0-0.5% M.F.), with added Vitamin D	175.00	28	111.10 ± 7.03	9	151.02 ± 19.08	93	149.24 ± 14.78
Syrups, toppings, frostings, whipped toppings								
4192 ²	Sweets, syrup, table blend, pancake, calorie-reduced	60.80	28	26.30 ± 6.78	15	15.55 ± 7.30	59	24.28 ± 1.66
5522 ²	Sweets, syrup, dietetic	30.40	2	29.29 ± 1.39	0	—	4	19.07 ± 4.84
Pastries and donuts								
501583 ³	Turnover or dumpling, cherry	n/a	1	102.81 —	0	—	8	354.31 ± 123.55
Non-meat, legume dishes								

			Children, 1-13 years (n=436)		Youth, 14-18 years (n=250)		Adult, 19+ years (n=2,887)	
Food code	Food code description	Reference Amount (g)	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹
501213 ³	Sandwich, peanut butter and jelly	n/a	3	88.83 ± 1.76	1	131.45 —	9	117.53 ± 9.23
<i>Non-grain, non-dairy, non-plant-based desserts</i>								
4233 ²	Dessert, gelatin, dry mix, calorie-reduced, with aspartame, prepared with water	130.00	6	72.95 ± 23.12	0	—	14	157.51 ± 22.40
7294 ²	Dessert, frozen, fudgesicle bar, no sugar added, with artificial sweetener	84.00	2	41.00 ± 0.00	1	41.00 —	4	59.62 ± 11.67
504391 ³	Gelatin dessert with fruit and whipped cream	n/a	0	—	0	—	1	226.98 —
504394 ³	Gelatin dessert, dietetic, with fruit, sweetened with low-calorie sweetener	n/a	5	145.03 ± 42.23	0	—	8	95.15 ± 20.36
<i>Jams and jellies</i>								
5523 ²	Sweets, jams and preserves, dietetic (with saccharin), any flavour	14.20	38	11.94 ± 1.75	7	15.33 ± 2.01	201	14.71 ± 1.23
501884 ³	Cherry pie filling	92.61	0	—	0	—	1	16.50 —
<i>Dairy desserts</i>								
4917 ²	Dessert, frozen ice cream, light, with aspartame, vanilla	103.29	1	137.38 —	1	87.92 —	4	154.98 ± 51.12
5437 ²	Dessert, frozen ice cream, chocolate, light, no sugar added	114.42	2	73.73 ± 33.97	0	—	1	112.59 —
5453 ²	Dessert, frozen ice cream, vanilla, fat-free	108.86	1	92.66 —	0	—	5	27.41 ± 12.78
5630 ²	Dessert, pudding, all flavours except chocolate, dry mix, regular, low calorie, unprepared	n/a	1	100.00 —	0	—	0	—
5740 ²	Dessert, pudding, vanilla, ready-to-eat, fat-free	130.00	2	88.66 ± 32.43	0	—	4	100.28 ± 1.62
5742 ²	Dessert, pudding, chocolate, ready-to-eat, fat-free	130.00	8	83.02 ± 11.75	1	99.00 —	8	116.47 ± 7.58
5750 ²	Dessert, frozen, ice cream, vanilla, light, no sugar added, chocolate coated	188.00	0	—	0	—	1	312.00 —
5751 ²	Dessert, frozen yogurt, chocolate, skim milk, with artificial sweetener	147.79	0	—	0	—	4	218.05 ± 76.32
6334 ²	Dessert, frozen ice cream, vanilla, reduced sugar	52.44	1	73.00 —	1	34.87 —	8	50.13 ± 23.40
7025 ²	Dessert, frozen yogurt, flavours, not chocolate, skim milk, with artificial sweetener	106.91	2	38.27 ± 1.06	0	—	12	110..30 ± 31.78
7038 ²	Dessert, frozen ice cream, fat-free, no sugar added, flavours other than chocolate	108.06	4	67.09 ± 5.29	4	116.88 ± 11.03	9	290.68 ± 97.40
500022 ³	Yogurt, frozen, sandwich	125.00	0	—	0	—	1	65.00 —
500059 ³	Ice cream cone, no topping, flavours other than chocolate	125.00	0	—	0	—	1	125.00 —
500077 ³	Light ice cream cone, flavours other than chocolate (formerly ice milk)	125.00	1	118.00 —	0	—	0	—

			Children, 1-13 years (n=436)		Youth, 14-18 years (n=250)		Adult, 19+ years (n=2,887)	
Food code	Food code description	Reference Amount (g)	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹
501358 ³	Cheesecake with fruit	125.00	5	82.30 ± 29.13	3	51.80 ± 12.19	21	102.11 ± 17.24
504171 ³	Milk fruit drink (Smoothie)	n/a	4	242.00 ± 41.56	0	—	27	392.44 ± 26.75
504173 ³	Milkshake, homemade or fountain-type, flavours other than chocolate	238.80	0	—	0	—	2	511.03 —
504204 ²	Pudding, chocolate, dry mix, low calorie, containing artificial sweetener, prepared with milk	130.00	2	119.40 ± 1.10	1	113.00 —	5	109.96 ± 6.87
504206 ²	Pudding flavours other than chocolate, dry mix, low calorie, containing artificial sweetener, prepared	130.00	7	111.59 ± 7.22	0	—	7	114.08 ± 10.99
504622 ³	Yogurt, frozen, cone, chocolate, low-fat milk	125.00	1	78.00 —	0	—	—	—
Cookies								
7295 ²	Cookie, shortbread, plain, commercial, no sugar added, with artificial sweetener	30.00	3	96.63 ± 68.02	0	—	17	16.54 ± 3.84
501449 ²³	Cookie, oatmeal	30.00	0	—	0	—	1	26.00 —
Canned/jarred fruit								
1499 ²	Apricot, canned halves with skin, water pack, solids and liquid	171.50	0	—	0	—	1	10.13 —
1527 ²	Cherry, sour, red, canned, water pack, solids and liquid	172.22	0	—	0	—	1	15.25 —
1551 ²	Fruit cocktail (peach, pear, apricot, pineapple, cherry, grape), canned, water pack, solids and liquid	167.29	8	96.07 ± 21.12	0	—	9	72.27 ± 11.69
1567 ²	Grapefruit, canned, water pack, solids and liquid	172.22	1	195.94 —	0	—	2	362.66 ± 183.52
1729 ²	Peach, canned halves or slices, water pack, solids and liquid	172.22	5	115.79 ± 38.56	0	—	5	159.86 ± 31.19
1732 ²	Pear, canned halves, water pack, solids and liquid	171.13	0	—	0	—	2	167.40 ± 18.57
1735 ²	Pineapple, canned, water pack, solids and liquid	173.63	0	—	0	—	1	144.00 —
7210 ²	Cherry, sour, canned, water pack, drained	118.58	1	84.00 —	0	—	0	—
Baked desserts								
501478 ³	Pie, cherry	n/a	2	24.48 ± 1.18	0	—	23	67.83 ± 20.35
501480 ³	Pie, cherry, individual size or tart	n/a	1	117.00 —	0	—	2	150.27 ± 22.24
501494 ³	Pie, plum, 2 crusts	n/a	0	—	0	—	2	144.54 ± 50.73
501551 ³	Cobbler, cherry	n/a	0	—	0	—	3	66.24 ± 33.82
Tabletop sweeteners								

			Children, 1-13 years (n=436)		Youth, 14-18 years (n=250)		Adult, 19+ years (n=2,887)	
Food code	Food code description	Reference Amount (g)	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹
5974 ²	Sweetener, aspartame	0.50	0	—	0	—	50	0.83 ± 0.17
5975 ²	Sweetener, sucralose	n/a	1	0.49 —	4	1.71 ± 0.54	403	1.22 ± 0.09
5977 ²	Sweetener, saccharin	n/a	0	—	0	—	45	1.12 ± 0.27
7245 ²	Sweetener, herbal extract powder from Stevia leaf	n/a	3	2.25 ± 0.81	1	6.00 —	118	1.46 ± 0.36
403802 ²	Sweetener, cyclamate	0.80	0	—	0	—	412	1.64 ± 0.14
502378 ²	Sugar replacement or substitute, saccharin-based, liquid	n/a	2	0.93 ± 0.33	0	—	5	9.57 ± 6.35

¹Weighted mean amount reported consumed in grams (equivalent amount in mL for beverages). SE=standard errors.

²Food code confirmed to be a source of low- and no-calorie sweeteners.

³Recipe that contains a confirmed source of low- and no-calorie sweeteners as an ingredient.

Abbreviations: NS=not specified. N/A= not available.

Table 15: Reported frequencies of low- and no-calorie sweetener food code consumption events and weighted mean amounts of source consumed on a given day among children 1-13 years, youth 14-18 years, and adults 19 years and older by sex, using the 2015 Canadian Community Health Survey—Nutrition.

			Children, 1-13 years (n=436)				Youth, 14-18 years (n=250)				Adult, 19 years and above (n=2,887)			
Food code	Food code description	RA (g)	Males (n=216)		Females (n=220)		Males (n=133)		Females (n=117)		Males (n=1,276)		Females (1,611)	
			# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	#events	Mean amount (g ± SE) ¹
Beverages														
Sodas														
2926 ²	Carbonated drinks, cola with aspartame	375.40	26	266.56 ± 83.97	14	196.52 ± 46.16	21	371.72 ± 24.65	28	446.17 ± 69.09	483	389.01 ± 18.88	527	375.09 ± 15.44
2938 ²	Carbonated drinks, non-cola with aspartame	375.40	7	260.58 ± 50.18	16	239.49 ± 28.55	8	355.36 ± 0.00	7	179.50 ± 49.20	113	293.94 ± 22.07	156	293.54 ± 23.25
4979 ²	Carbonated drinks, cola with aspartame, decaffeinated	375.40	4	223.97 ± 104.18	2	211.41 ± 54.65	12	412.63 ± 46.27	5	313.39 ± 33.60	102	349.96 ± 27.82	139	334.61 ± 8.79
Sweetened coffee, tea, hot chocolate, energy drinks, and flavoured waters														
5292 ²	Sports drink, fruit flavour, low calorie, ready-to-drink	380.30	5	444.66 ± 99.42	2	181.82 ± 147.50	8	508.97 ± 42.26	3	544.60 ± 24.39	28	652.04 ± 169.13	9	488.09 ± 56.36
5602 ²	Coffee, instant powder, with whitener and artificial sweetener	2.60	0	—	0	—	0	—	0	—	2	57.48 ± 14.38	0	—
5710 ²	Coffee, instant, mocha, powder, with whitener and artificial sweetener, decaffeinated	2.60	0	—	0	—	0	—	0	—	1	280.79 —	0	—
6327 ²	Water, fruit flavour, sweetened with artificial sweetener	375.60	17	373.39 ± 61.90	20	254.30 ± 27.99	13	403.24 ± 122.01	11	565.20 ± 168.65	50	450.58 ± 74.86	99	433.76 ± 41.55
7174 ²	Energy drink, shot, sugar-free	381.00	0	—	0	—	0	—	0	—	0	—	1	50.80 —
7177 ²	Energy drink, sugar-free/low-calorie	378.00	0	—	0	—	5	560.64 ± 215.26	2	256.53 ± 7.43	13	441.77 ± 45.38	13	357.59 ± 40.01
7188 ²	Vitamin water, lemon/orange flavours, low-calorie	368.60	0	—	0	—	0	—	0	—	2	359.82 ± 271.43	3	537.45 ± 94.64
7238 ²	Vitamin water, flavours not lemon/orange, low-calorie	368.60	2	300.33 ± 17.07	0	—	0	—	1	581.16 —	4	391.86 ± 25.32	6	463.37 ± 33.71

			Children, 1-13 years (n=436)				Youth, 14-18 years (n=250)				Adult, 19 years and above (n=2,887)			
Food code	Food code description	RA (g)	Males (n=216)		Females (n=220)		Males (n=133)		Females (n=117)		Males (n=1,276)		Females (1,611)	
			# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	#events	Mean amount (g ± SE) ¹
7281 ²	Coffee and cocoa (mocha) powder, with whitener and low-calorie sweetener	2.60	0	—	0	—	0	—	0	—	0	—	1	162.30 —
7477 ²	Beverage mix, chocolate flavour, powder, no added sugar, with 2% M.F. milk	297.42	0	—	1	172.70 —	0	—	0	—	1	374.19 —	1	227.39 —
500029 ²	Hot chocolate, made from dry mix with low-calorie sweetener, water added	264.16	2	195.30 ± 10.05	2	314.17 ± 15.58	0	—	1	249.99 —	2	268.57 ± 59.94	6	269.48 ± 17.43
502439 ³	Coffee, instant, pre-sweetened, no whitener, powder, water added	251.50	0	—	0	—	0	—	1	191.14 —	4	278.12 ± 19.87	12	240.63 ± 46.36
502440 ³	Coffee and cocoa (mocha), instant, with whitener, pre-sweetened, powder, water added	251.50	0	—	0	—	0	—	0	—	2	191.14 ± 0.00	0	—
502452 ³	Tea, NS as to type, presweetened with sugar	250.50	0	—	1	185.37 —	0	—	0	—	1	280.56 —	4	530.03 ± 6.90
502453 ³	Tea, NS as to type, sweetened, NS as to sweetener (Lemon-flavoured)	250.50	0	—	0	—	0	—	0	—	0	—	1	305.61 —
502454 ³	Tea, NS as type, sweetened, NS as to sweetener, decaffeinated	250.50	1	29.64 —	0	—	1	290.58 —	0	—	0	—	3	300.26 ± 3.89
504757 ²	Tea, made from powdered instant with artificial sweetener (iced tea)	375.65	2	185.32 ± 0.00	1	190.33 —	1	821.43 —	1	280.49 —	1	305.53 —	6	284.33 ± 86.29
504765 ²	Tea, NS as to type, presweetened with low-calorie sweetener (ready-to-drink)	375.38	0	—	5	131.50 ± 32.98	3	474.86 ± 220.08	6	306.74 ± 37.47	45	214.10 ± 11.93	44	290.50 ± 32.22
504779 ³	Hot chocolate, made from dry mix, milk added	264.16	0	—	1	200.77 —	0	—	0	—	0	—	2	2238.79 ± 21.00

			Children, 1-13 years (n=436)				Youth, 14-18 years (n=250)				Adult, 19 years and above (n=2,887)			
Food code	Food code description	RA (g)	Males (n=216)		Females (n=220)		Males (n=133)		Females (n=117)		Males (n=1,276)		Females (1,611)	
			# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	#events	Mean amount (g ± SE) ¹
504975 ³	Cocoa and sugar mixture, reduced sugar, milk added, NS as to type of milk	n/a	0	—	1	211.34 —	0	—	2	412.11 ± 0.00	1	412.11 —	4	173.64 ± 122.01
505185 ²	Coffee and cocoa (mocha), made from powdered instant mix, with whitener and low-calorie sweetener, decaf	251.50	0	—	0	—	0	—	0	—	1	191.13 —	2	236.32 ± 3.18
Fruit drinks														
2963 ²	Lemonade with artificial sweetener, powder, water added	378.90	2	594.23 ± 103.25	5	377.92 ± 17.29	3	218.12 ± 62.72	2	169.69 ± 44.97	18	749.33 ± 184.31	17	181.93 ± 52.49
5603 ²	Juice drink, cranberry-apple low calorie, with vitamin C added	253.60	10	203.71 ± 14.94	12	262.28 ± 37.94	5	207.23 ± 4.51	2	474.72 ± 108.74	22	257.21 ± 21.30	37	189.23 ± 18.18
7230 ²	Juice drink, orange, calorie-reduced	253.60	7	261.36 ± 14.47	9	271.38 ± 57.20	4	238.15 ± 38.86	3	184.62 ± 22.74	26	236.57 ± 28.88	16	129.78 ± 21.08
403953 ²	Cranberry juice cocktail, plus vitamin C, plus aspartame, bottled	267.33	0	—	1	417.30 —	0	—	0	—	4	276.48 ± 16.67	12	202.34 ± 43.54
502481 ³	Fruit-flavoured drink, made from powdered mix, low calorie, with vitamin C added	380.39	0	—	1	270.60 —	0	—	0	—	0	—	0	—
505189 ³	Carbonated non-citrus juice drink	393.08	0	—	0	—	0	—	0	—	0	—	1	94.34 —
505191 ³	Fruit-flavored drink, made from powdered mix, low-calorie	380.40	3	303.75 ± 77.56	5	400.83 ± 64.66	1	791.23 —	0	—	3	345.05 ± 60.47	4	325.30 ± 33.18
Flavoured milks														
500026 ³	Chocolate, flavour mix beverage, powder, 1% milk added	264.16	0	—	0	—	0	—	0	—	1	306.42 —	0	—
502759 ³	Chocolate flavour mix beverage, powder, 2% milk added	279.42	1	340.89 —	0	—	0	—	0	—	0	—	0	—
Coffee and tea														

			Children, 1-13 years (n=436)				Youth, 14-18 years (n=250)				Adult, 19 years and above (n=2,887)			
Food code	Food code description	RA (g)	Males (n=216)		Females (n=220)		Males (n=133)		Females (n=117)		Males (n=1,276)		Females (1,611)	
			# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	#events	Mean amount (g ± SE) ¹
502457 ³	Tea, made from powdered instant, unsweetened	250.50	0	—	1	200.40 —	0	—	0	—	0	—	6	263.75 ± 52.52
504700 ³	Coffee, instant, 50% less caffeine, powder, water added	279.42	0	—	0	—	0	—	0	—	0	—	3	191.14 ± 0.00
100% fruit juices														
504145 ³	Fruit smoothie drink, made with fruit or fruit juice only (no dairy products)	222.00	0	—	1	177.60 —	1	257.52 —	0	—	9	410.97 ± 61.32	15	634.26 ± 139.35
Alcoholic beverages														
502504 ³	Rum and cola	n/a	0	—	0	—	0	—	0	—	14	392.76 ± 97.15	9	347.08 ± 34.61
Foods														
Meal replacements and meal replacement powders														
7228 ²	Beverage, protein drink, ready-to-drink, light	257.80	0	—	0	—	0	—	3	443.44 ± 205.75	4	189.54 ± 94.76	1	15.25 —
7231 ²	Beverage, protein powder, whey-based	23.30	0	—	0	—	7	32.72 ± 7.61	1	12.00 —	11	29.38 ± 5.83	3	20.96 ± 6.50
7233 ²	Beverages, high protein powder	23.30	0	—	1	61.00 —	1	66.00 —	1	43.00 —	8	40.73 ± 21.76	6	29.72 ± 2.32
403792 ²	Meal replacement, powder, diet	35.13	0	—	0	—	0	—	0	—	3	8.13 ± 7.13	1	47.30 —
404210 ²	Meal replacement, ready-to-drink, high protein (all flavours)	266.27	3	257.60 ± 9.50	0	—	2	327.73 ± 31.52	2	321.00 ± 0.00	27	300.77 ± 26.33	35	276.47 ± 26.18
404214 ²	Meal replacement, ready-to-drink, diabetic (all flavours)	266.27	0	—	0	—	0	—	0	—	8	218.24 ± 32.56	7	256.22 ± 3.84
404269 ²	Meal replacement, bar	45.00	1	32.50 —	4	65.00 ± 0.00	0	—	0	—	7	81.50 ± 14.96	8	59.32 ± 3.69
500045 ³	Instant breakfast, powder, with 2% milk (Ready to drink)	n/a	0	—	0	—	0	—	0	—	0	—	4	451.65 ± 189.95

			Children, 1-13 years (n=436)				Youth, 14-18 years (n=250)				Adult, 19 years and above (n=2,887)			
Food code	Food code description	RA (g)	Males (n=216)		Females (n=220)		Males (n=133)		Females (n=117)		Males (n=1,276)		Females (1,611)	
			# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	#events	Mean amount (g ± SE) ¹
500046 ³	Meal replacement, powder, diet, reconstituted with water	278.41	0	—	0	—	0	—	0	—	2	39.82 ± 27.68	2	337.67 ± 0.00
504126 ³	Meal replacement, powder, diet, reconstituted with milk	n/a	0	—	0	—	1	30.88 —	0	—	4	58.19 ± 17.88	5	230.05 ± 11.42
505262 ³	Protein powder, water added (whey protein)	n/a	2	35.73 ± 37.64	2	143.29 ± 119.00	15	239.26 ± 104.17	0	—	94	198.46 ± 54.32	87	226.96 ± 25.04
505263 ³	Protein powder, milk added (whey protein)	n/a	3	45.51 ± 16.83	6	81.61 ± 57.09	17	344.94 ± 61.54	6	291.01 ± 84.01	71	311.28 ± 41.02	61	174.46 ± 31.18
505264 ³	Protein powder, juice added (whey protein)	n/a	1	328.84 —	0	—	2	284.96 ± 41.78	0	—	9	181.25 ± 98.08	7	303.32 ± 47.04
<i>Yogurt and kefir</i>														
6951 ²	Yogurt, fruit flavoured, artificially sweetened, fat-free (0-0.5% M.F.), with added Vitamin D	175.00	48	96.38 ± 4.98	52	125.32 ± 14.49	8	91.28 ± 15.31	24	123.48 ± 23.37	113	111.83 ± 11.89	228	114.40 ± 7.69
6952 ²	Yogurt, vanilla flavoured, with artificial sweetener, fat-free (0-0.5% M.F.), with added Vitamin D	175.00	15	106.66 ± 5.55	13	131.29 ± 22.91	1	131.61 —	8	157.17 ± 23.56	35	177.33 ± 22.09	58	130.48 ± 16.16
<i>Syrups, toppings, frostings, whipped toppings</i>														
4192 ²	Sweets, syrup, table blend, pancake, calorie-reduced	60.80	12	40.52 ± 10.88	16	15.93 ± 1.97	9	39.04 ± 12.89	6	6.82 ± 1.92	23	25.60 ± 3.14	36	23.56 ± 1.94
5522 ²	Sweets, syrup, dietetic	30.40	1	5.00 —	1	30.01 —	0	—	0	—	0	—	4	19.07 ± 4.84
<i>Pastries and donuts</i>														
501583 ³	Turnover or dumpling, cherry	n/a	1	102.81 —	0	—	0	—	0	—	7	370.40 ± 121.80	1	47.25 —
<i>Non-meat, legume dishes</i>														
501213 ³	Sandwich, peanut butter and jelly	n/a	1	84.04 —	2	88.90 ± 2.07	1	131.45 —	0	—	5	123.80 ± 13.70	4	104.31 ± 13.10
<i>Non-grain, non-dairy, non-plant-based desserts</i>														

			Children, 1-13 years (n=436)				Youth, 14-18 years (n=250)				Adult, 19 years and above (n=2,887)			
Food code	Food code description	RA (g)	Males (n=216)		Females (n=220)		Males (n=133)		Females (n=117)		Males (n=1,276)		Females (1,611)	
			# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	#events	Mean amount (g ± SE) ¹
4233 ²	Dessert, gelatin, dry mix, calorie-reduced, with aspartame, prepared with water	130.00	4	98.23 ± 8.07	2	51.94 ± 47.06	0	—	0	—	2	149.15 ± 66.09	12	157.92 ± 23.45
7294 ²	Dessert, frozen, fudgesicle bar, no sugar added, with artificial sweetener	84.00	2	41.00 ± —	0	—	0	—	1	41.00 —	2	73.00 ± 0.00	2	41.00 ± 0.00
504391 ³	Gelatin dessert with fruit and whipped cream	n/a	0	—	0	—	0	—	0	—	0	—	1	226.98 —
504394 ³	Gelatin dessert, dietetic, with fruit, sweetened with low-calorie sweetener	n/a	3	147.37 ± 52.38	2	99.00 ± 4757	0	—	0	—	1	15.00 —	7	106.36 ± 23.79
Jams and jellies														
5523 ²	Sweets, jams and preserves, dietetic (with saccharin), any flavour	14.20	22	15.01 ± 2.25	16	6.12 ± 1.29	4	16.99 ± 2.23	3	12.06 ± 2.74	89	16.26 ± 2.11	112	13.69 ± 1.50
501884 ³	Cherry pie filling	92.61	0	—	0	—	0	—	0	—	1	16.50 —	0	—
Dairy desserts														
4917 ²	Dessert, frozen ice cream, light, with aspartame, vanilla	103.29	0	—	1	137.38 —	1	87.92 —	0	—	2	240.00 ± 0.00	2	89.88 ± 41.08
5437 ²	Dessert, frozen ice cream, chocolate, light, no sugar added	114.42	1	480.00 —	1	56.00 —	0	—	0	—	0	—	1	112.59 —
5453 ²	Dessert, frozen ice cream, vanilla, fat-free	108.86	1	92.66 —	0	—	0	—	0	—	2	13.55 ± 4.17	3	50.18 ± 21.41
5630 ²	Dessert, pudding, all flavours except chocolate, dry mix, regular, low calorie, unprepared	n/a	0	—	1	100.00 —	0	—	0	—	0	—	0	—
5740 ²	Dessert, pudding, vanilla, ready-to-eat, fat-free	130.00	2	88.66 ± 32.43	0	—	—	—	0	—	2	113.03 ± 0.063	2	99.48 ± 0.92
5742 ²	Dessert, pudding, chocolate, ready-to-eat, fat-free	130.00	4	98.87 ± 1.01	4	72.34 ± 11.11	1	99.00 —	0	—	3	99.81 ± 0.26	5	122.17 ± 6.36

			Children, 1-13 years (n=436)				Youth, 14-18 years (n=250)				Adult, 19 years and above (n=2,887)			
Food code	Food code description	RA (g)	Males (n=216)		Females (n=220)		Males (n=133)		Females (n=117)		Males (n=1,276)		Females (1,611)	
			# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	#events	Mean amount (g ± SE) ¹
5750 ²	Dessert, frozen, ice cream, vanilla, light, no sugar added, chocolate coated	188.00	0	—	0	—	0	—	0	—	0	—	1	312.00 —
5751 ²	Dessert, frozen yogurt, chocolate, skim milk, with artificial sweetener	147.79	0	—	0	—	0	—	0	—	1	85.00 —	3	242.26 ± 87.65
6334 ²	Dessert, frozen ice cream, vanilla, reduced sugar	52.44	1	73.00 —	0	—	1	34.87 —	0	—	3	11.86 ± 8.91	5	92.07 ± 21.37
7025 ²	Dessert, frozen yogurt, flavours, not chocolate, skim milk, with artificial sweetener	106.91	2	38.27 ± 1.06	0	—	0	—	0	—	5	237.49 ± 47.10	7	72.94 ± 5.21
7038 ²	Dessert, frozen ice cream, fat-free, no sugar added, flavours other than chocolate	108.06	2	69.55 ± 4.26	2	57.17 ± 14.36	4	116.88 ± 11.03	0	—	4	129.00 ± 45.79	5	390.20 ± 58.26
500022 ³	Yogurt, frozen, sandwich	125.00	0	—	0	—	0	—	0	—	0	—	1	65.00 —
500059 ³	Ice cream cone, no topping, flavours other than chocolate	125.00	0	—	0	—	0	—	0	—	0	—	1	125.00 —
500077 ³	Light ice cream cone, flavours other than chocolate (formerly ice milk)	125.00	0	—	1	118.00 —	0	—	0	—	0	—	0	—
501358 ³	Cheesecake with fruit	125.00	1	160.77 —	4	69.12 ± 31.47	0	—	3	51.80 ± 12.19	10	123.46 ± 18.42	11	78.17 ± 26.98
504171 ³	Milk fruit drink (Smoothie)	n/a	1	417.94 —	3	225.97 ± 47.85	0	—	0	—	10	458.49 ± 12.61	17	326.04 ± 27.06
504173 ³	Milkshake, homemade or fountain-type, flavours other than chocolate	238.80	0	—	0	—	0	—	0	—	0	—	2	511.03 ± 0.00
504204 ²	Pudding, chocolate, dry mix, low calorie, containing artificial sweetener, prepared with milk	130.00	0	—	2	119.40 ± 1.10	1	113.00 —	0	—	2	103.77 ± 5.35	3	121.00 ± 4.55
504206 ²	Pudding flavours other than chocolate, dry mix, low calorie,	130.00	4	120.70 ± 4.29	3	95.91 ± 12.21	0	—	0	—	3	101.16 ± 2.97	4	121.32 ± 14.59

			Children, 1-13 years (n=436)				Youth, 14-18 years (n=250)				Adult, 19 years and above (n=2,887)			
Food code	Food code description	RA (g)	Males (n=216)		Females (n=220)		Males (n=133)		Females (n=117)		Males (n=1,276)		Females (1,611)	
			# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	#events	Mean amount (g ± SE) ¹
	containing artificial sweetener, prepared													
504622 ³	Yogurt, frozen, cone, chocolate, low-fat milk	125.00	1	78.00 —	0	—	0	—	0	—	0	—	0	—
Cookies														
7295 ²	Cookie, shortbread, plain, commercial, no sugar added, with artificial sweetener	30.00	2	146.26 ± 66.18	1	12.00 —	0	—	0	—	8	22.30 ± 5.25	9	13.39 ± 4.62
501449 ²³	Cookie, oatmeal	30.00	0	—	0	—	0	—	0	—	0	—	1	26.00 —
Canned/jarred fruits														
1499 ²	Apricot, canned halves with skin, water pack, solids and liquid	171.50	0	—	0	—	0	—	0	—	0	—	1	10.13 —
1527 ²	Cherry, sour, red, canned, water pack, solids and liquid	172.22	0	—	0	—	0	—	0	—	0	—	1	15.25 —
1551 ²	Fruit cocktail (peach, pear, apricot, pineapple, cherry, grape), canned, water pack, solids and liquid	167.29	2	113.00 ± 0.00	6	93.85 ± 24.24	0	—	0	—	3	63.14 ± 5.92	6	145.04 ± 24.29
1567 ²	Grapefruit, canned, water pack, solids and liquid	172.22	1	195.94 —	0	—	0	—	0	—	0	—	2	362.66 ± 183.52
1729 ²	Peach, canned halves or slices, water pack, solids and liquid	172.22	4	160.03 ± 26.92	1	61.00 —	0	—	0	—	1	160.00 —	4	159.85 ± 34.08
1732 ²	Pear, canned halves, water pack, solids and liquid	171.13	0	—	0	—	0	—	0	—	—	—	2	167.40 ± 18.57
1735 ²	Pineapple, canned, water pack, solids and liquid	173.63	0	—	0	—	0	—	0	—	0	—	1	144.00 —
7210 ²	Cherry, sour, canned, water pack, drained	118.58	1	84.00 —	0	—	0	—	0	—	0	—	0	—

			Children, 1-13 years (n=436)				Youth, 14-18 years (n=250)				Adult, 19 years and above (n=2,887)			
Food code	Food code description	RA (g)	Males (n=216)		Females (n=220)		Males (n=133)		Females (n=117)		Males (n=1,276)		Females (1,611)	
			# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	# events	Mean amount (g ± SE) ¹	#events	Mean amount (g ± SE) ¹
<i>Baked desserts</i>														
501478 ³	Pie, cherry	n/a	1	21.26 —	1	25.20 —	0	—	0	—	13	65.49 ± 18.21	10	69.33 ± 32.87
501480 ³	Pie, cherry, individual size or tart	n/a	0	—	1	117.00 —	0	—	0	—	1	167.85 —	1	120.00 —
501494 ³	Pie, plum, 2 crusts	n/a	0	—	0	—	0	—	0	—	0	—	2	144.54 ± 50.73
501551 ³	Cobbler, cherry	n/a	0	—	0	—	0	—	0	—	1	68.79—	2	65.64 ± 48.10
<i>Tabletop sweeteners</i>														
5974 ²	Sweetener, aspartame	0.50	0	—	0	—	0	—	0	—	27	0.75 ± 0.22	23	1.00 ± 0.25
5975 ²	Sweetener, sucralose	n/a	1	0.49 —	0	—	3	1.40 ± 0.41	1	4.44 —	186	1.19 ± 0.11	217	1.24 ± 0.14
5977 ²	Sweetener, saccharin	n/a	0	—	0	—	0	—	0	—	29	0.56 ± 0.17	16	1.64 ± 0.42
7245 ²	Sweetener, herbal extract powder from Stevia leaf	n/a	3	2.25 ± 0.81	0	—	0	—	1	6.00 —	47	2.27 ± 0.90	71	0.97 ± 0.09
403802 ²	Sweetener, cyclamate	0.80	0	—	0	—	0	—	0	—	189	1.62 ± 0.11	223	1.64 ± 0.21
502378 ²	Sugar replacement or substitute, saccharin-based, liquid	n/a	0	—	2	0.92 ± 0.32	0	—	0	—	3	12.23 ± 7.75	2	0.74 ± 0.41

¹Weighted mean amount reported consumed in grams (equivalent amount in mL for beverages). SE=standard errors.

²Food code confirmed to be a source of low- and no-calorie sweeteners.

³Recipe that contains a confirmed source of low- and no-calorie sweeteners as an ingredient.

Abbreviations: NS=not specified. N/A= not available.

Table 16: Nutritional profile of food codes classified as sources of low- and no-calorie sweeteners per 100 grams prepared form and alignment with the 2019 Canada’s Food Guide Food Classification System.

Food code	Food code description	Energy (kcal)	Free Sugars (g)	Saturated fat (g)	Sodium (mg)	CFG Food Class ¹
Fruit drinks						
2963	Lemonade with artificial sweetener, powder, water added	3.000	0.000	—	4.000	②
5603	Juice drink, cranberry-apple low calorie, with vitamin C added	19.000	4.600	—	5.000	③
7230	Juice drink, orange, calorie-reduced	21.000	4.170	—	4.000	③
403953	Cranberry juice cocktail with vitamin C, with aspartame, bottled	15.000	2.840	—	2.000	③
Soda						
2926	Carbonated drinks, cola with aspartame	2.000	0.000	—	8.000	②
2938	Carbonated drinks, non-cola with aspartame	—	0.000	—	16.000	②
4979	Carbonated drinks, cola with aspartame, decaffeinated	1.000	0.000	—	4.000	②
Sweetened coffee, tea, hot chocolate, energy drinks, sports drinks, flavoured and vitamin waters						
5292	Sports drink, fruit flavour, low calorie, ready-to-drink	11.000	0.000	—	35.000	②
6327	Water, fruit flavour, sweetened with artificial sweetener	1.000	0.000	—	14.000	②
7174	Energy drink, shot, sugar-free	8.000	0.130	—	29.000	②
7177	Energy drink, sugar-free/low-calorie	6.000	0.360	—	0.700	②
7188	Vitamin water, lemon/orange flavours, low-calorie	2.000	0.000	—	0.100	②
7238	Vitamin water, flavours not lemon/orange, low-calorie	7.000	0.030	—	0.700	②

Food code	Food code description	Energy (kcal)	Free Sugars (g)	Saturated fat (g)	Sodium (mg)	CFG Food Class ¹
7477	Beverage mix, chocolate flavour, powder, no added sugar, with 2% M.F. milk	68.000	1.269	1.435	78.961	③
500029	Hot chocolate, made from dry mix with low-calorie sweetener, water added	30.599	3.056	0.144	73.856	③
504757	Tea, made from powdered instant, with artificial sweetener (iced tea)	2.034	0.027	0.000	3.306	②
504765	Tea, NS as to type, presweetened with low-calorie sweetener, ready-to-drink	2.530	0.339	—	2.987	②
505185	Coffee and cocoa (mocha), powdered instant mix, with whitener and low-calorie sweetener, decaf	32.050	2.548	0.829	39.202	③
Jams and Jelly						
5523	Sweets, jams and preserves, dietetic (with saccharin), any flavour	132.000	37.810	0.016	—	③
Syrups, toppings, frostings, whipped toppings						
4192	Sweets, syrup, table blend, pancake, calorie-reduced	165.000	32.800	—	178.000	③
5522	Sweets, syrup, dietetic	40.000	0.000	—	21.000	🌀
Tabletop sweeteners						
5974	Sweetener, aspartame	365.000	80.700	—	—	🌀
5975	Sweetener, sucralose	336.000	80.330	—	—	🌀
5977	Sweetener, saccharin	360.000	85.190	—	428.000	🌀
7245	Sweetener, herbal extract powder from Stevia leaf	—	0.000	—	—	🌀
403802	Sweetener, cyclamate	—	0.000	—	—	🌀
502378	Sugar replacement or substitute, saccharin-based, liquid	8.288	1.961	—	12.785	🌀
Meal replacements						

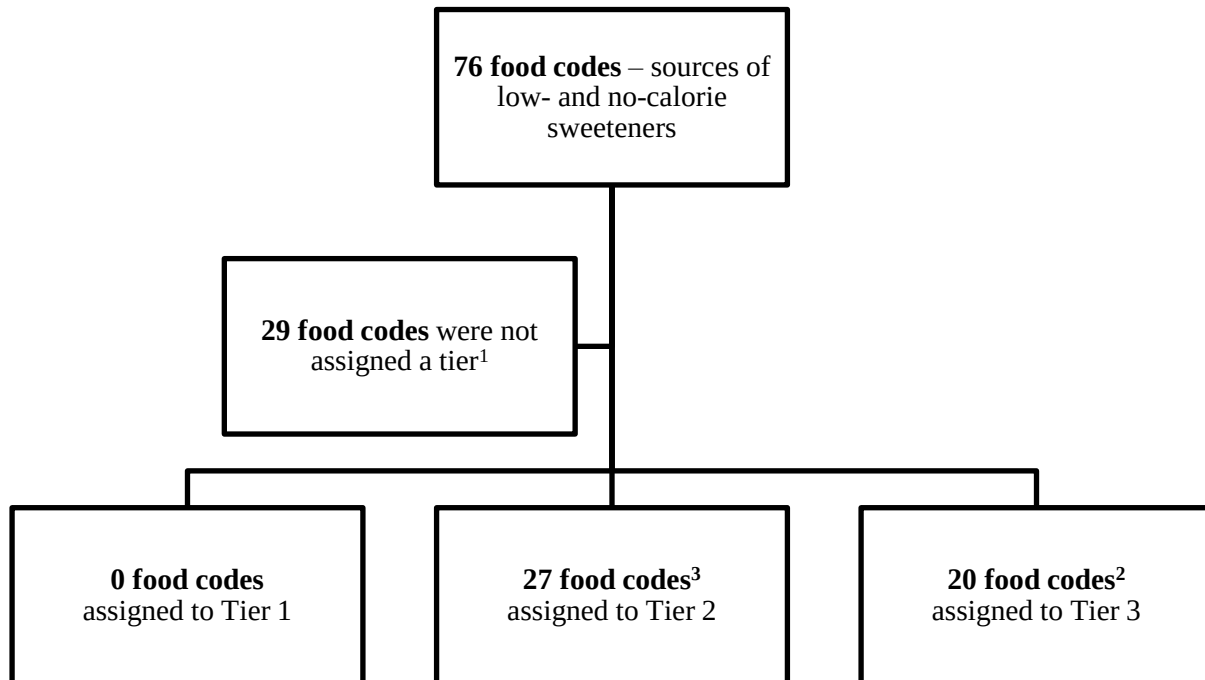
Food code	Food code description	Energy (kcal)	Free Sugars (g)	Saturated fat (g)	Sodium (mg)	CFG Food Class ¹
7228	Beverage, protein drink, ready-to-drink, light	37.000	0.656	0.234	112.000	^x _x ^x
404210	Meal replacement, ready-to-drink, high protein (all flavours)	95.000	—	0.180	90.700	^x _x ^x
404214	Meal replacement, ready-to-drink, diabetic (all flavours)	75.000	1.580	0.395	71.000	^x _x ^x
404269	Meal replacement, bar	399.000	20.205	6.630	413.000	^x _x ^x
Canned or jarred fruits						
1499	Apricot, canned halves with skin, water pack, solids and liquids	27.000	0.000	0.011	3.000	②
1527	Cherry, sour, red, canned, water pack, solids and liquids	36.000	0.000	0.023	7.000	②
1532	Cherry, sweet, canned, water pack, solids and liquids	46.000	0.000	0.028	1.000	②
1551	Fruit cocktail (peach, pear, apricot, pineapple, cherry, grape), canned, water pack, solids and liquids	32.000	0.000	0.006	4.000	②
1567	Grapefruit, canned, water pack, solids and liquids	36.000	0.000	0.014	2.000	②
1663	Plum, canned, purple, water pack, solids and liquids	41.000	0.000	0.001	1.000	②
1729	Peach, canned halves or slices, water pack, solids and liquids	24.000	0.000	0.006	3.000	②
1732	Pear, canned halves, water pack, solids and liquids	29.000	0.000	0.002	1.000	②
1735	Pineapple, canned, water pack, solids and liquids	32.000	0.000	0.006	1.000	②
7210	Cherry, sour, canned, water pack, drained	42.000	0.000	—	4.000	②
Cookies						
7295	Cookie, shortbread, plain, commercial, no sugar added, with artificial sweetener	431.000	0.000	5.700	476.000	③
Non-grain, non-dairy, non-plant-based desserts						

Food code	Food code description	Energy (kcal)	Free Sugars (g)	Saturated fat (g)	Sodium (mg)	CFG Food Class ¹
4233	Dessert, gelatin, dry mix, calorie-reduced, with aspartame, prepared with water	20.000	0.000	—	48.000	②
7294	Dessert, frozen, fudgesicle bar, no sugar added, with artificial sweetener	105.000	0.000	0.591	102.000	②
504394	Gelatin dessert, dietetic, with fruit, sweetened with low-calorie sweetener	43.198	5.442	0.033	29.726	⊞
Yogurt and kefir						
6951	Yogurt, fruit flavoured, artificially sweetened, fat-free (0-0.5% M.F.), with added vitamin D	40.000	0.000	0.017	41.000	②
6952	Yogurt, vanilla flavoured, with artificial sweetener, fat-free (0-0.5% M.F.), added vitamin D	35.000	0.000	0.020	66.000	②
Dairy desserts						
4917	Dessert, frozen, ice cream, light, with aspartame, vanilla	169.000	4.199	4.048	96.000	③
5437	Dessert, frozen, ice cream, chocolate, light, no sugar added	173.000	0.000	3.610	75.000	③
5453	Dessert, frozen, ice cream, vanilla, fat-free	138.000	4.095	—	97.000	③
5740	Dessert, pudding, vanilla, ready-to-eat, fat-free	89.000	11.794	—	191.000	③
5742	Dessert, pudding, chocolate, ready-to-eat, fat-free	93.000	12.285	—	154.000	③
5750	Dessert, frozen, ice cream, vanilla, light, no sugar added, chocolate coated	221.000	0.000	5.528	104.000	③
5751	Dessert, frozen yogurt, chocolate, skim milk, with artificial sweetener	107.000	0.000	0.505	81.000	③
6334	Dessert, frozen, ice cream, vanilla, reduced sugar	216.000	4.128	6.790	48.000	③
7025	Dessert, frozen yogurt, flavours other than chocolate, skim milk, with artificial sweetener	104.000	0.000	0.488	81.000	③
7038	Dessert, frozen, ice cream, fat-free, no sugar added, flavours other than chocolate	129.000	0.000	—	110.000	③
504204	Pudding, chocolate, dry mix, low calorie, containing artificial sweetener, prepared with milk	73.575	0.000	1.255	274.937	③

Food code	Food code description	Energy (kcal)	Free Sugars (g)	Saturated fat (g)	Sodium (mg)	CFG Food Class ¹
504206	Pudding, flavours other than chocolate, dry mix, low calorie, containing artificial sweetener, prepared with milk	67.753	0.000	1.187	214.205	②

¹Health Canada’s Canada Food Guide (CFG) classification system: ②=Tier 2; ③=Tier 3; ☒= Health Canada Class 8200 is automatically assigned to all meal replacements and foods considered supplements; ☒=Health Canada Class 8500 is assigned to miscellaneous foods such as ingredients, sugarless candies, and unprepared mixes; ☒= Health Canada Class 9900 is assigned to foods and beverages that could not be classified due to missing data values required for classification. “—” indicates nutrient value was absent or currently not available.

Figure 3: Classification of low- and no-calorie sweetener food codes to the 2019 Canada Food Guide Food Classification System Tiers (215).



¹17 food codes were unprepared items and, therefore, not assigned to a Tier. Twelve (12) food codes were not assigned to a Tier because they were identified as meal replacements (x=4 food codes), miscellaneous foods (x=3 food codes), or had missing data required to be assigned to a tier (x=5 food codes). Tabletop sweeteners were not assigned to a Tier.

²Of the 20 tier 3 food codes, 6 were beverages, and 14 were foods.

³Of the 27 tier 2 food codes, 12 were beverages, and 15 were foods.

Chapter 7

Diet quality in relation to the probability of consuming low- and no-calorie sweeteners among individuals in Canada

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Supplementary materials for this chapter can be found in **Appendices F-J**.

7.1 Overview

Diet-related diseases remain a leading cause of morbidity and mortality globally (6), solidifying the importance of promoting dietary practices that support overall health and well-being (7). Low- and no-calorie sweeteners have the potential to contribute to improved diet quality by replacing caloric sweeteners in foods and beverages, thus contributing to reduced free and added sugars intake. However, the evidence supporting this assertion among free-living populations is scant. Using data from the 2015 Canadian Community Health Survey—Nutrition, we examined the relationship between low- and no-calorie sweetener consumption and diet quality among individuals aged 2 years and above by DRI age and sex groups and among adults 19 years and older with and without diabetes. Extending the National Cancer Institute’s (NCI) multivariate Markov Chain Monte Carlo (MCMC) method, we examine Healthy Eating Food Index-2019 (HEFI-2019) scores based on estimated distributions of usual intakes conditional on the probability of consuming low- and no-calorie sweeteners. Among children 2-13 years of age and males 14 years and above, there was weak and moderate evidence, respectively, of differences in HEFI-2019 scores between individuals with the highest probability of consuming low- and no-calorie sweeteners compared to those with the lowest probability; however, the direction of the difference in scores was inconsistent. Among females aged 14 years and above and among adults 19 years and above with and without diabetes, there was little to no evidence of meaningful differences in HEFI-2019 total scores in relation to the probability of consuming sources of low- and no-calorie sweeteners. Findings from this study raise questions about the notion that the inclusion of low- and no-calorie sweeteners is associated with higher diet quality. Further research is required to fully understand differential associations between sweetener use and diet quality by age and sex. Ideally, analyses should employ advanced statistical modelling, such as the NCI multivariate MCMC method, which overcomes the limitations of categorizing individuals as consumers and non-consumers based on short-term intake data and accounts for the multidimensionality of diet quality.

7.2 Introduction

In Canada, nine sweeteners (excluding sugar alcohols) are permitted for use in various foods and beverages or as tabletop sweeteners (90), similar to in the U.S. (237). While evidence on trends in the use of these sweeteners in the Canadian food supply is limited, increases in the presence of foods and beverages sweetened with low- and no-calorie sweeteners have been observed in the U.S., Chile, and the United Kingdom (27,229,230). These increases over time may be partly due to public health nutrition policies aimed at reducing added sugars intake, resulting in reformulation by the food industry to substitute low- and no-calorie sweeteners for added sugars (23).

Studies conducted in the U.S. using data from a nationally representative survey demonstrate the increasing prevalence of consuming foods and beverages sweetened with low- and no-calorie sweeteners among children and adults (122). Based on analyses (presented in **Chapter 6**) of 24-hour dietary recall (24HDR) data from the 2015 Canadian Community Health Survey—Nutrition (2015 CCHS—Nutrition), diet sodas were the most frequently reported beverage sweetened with low- and no-calorie sweeteners among children, adolescents, and adults. Yogurts were the most frequently reported food source among children, whereas meal replacements, including protein powders, were the most frequently reported food source among adolescents and adults. An examination of sources of low- and no-calorie sweeteners in relation to the 2019 Canada's Food Guide found that none were considered 'foundational foods' (Chapter 6). Some sources, such as low- and no-calorie sweetened yogurts, contribute important nutrients such as calcium and vitamin D. However, the 2019 Canada Food Guide encourages the consumption of their unsweetened counterparts (9). Research from the U.S. has identified similar foods and beverages as the most frequently consumed dietary sources of low- and no-calorie sweeteners (64,78).

Foods and beverages sweetened with low- and no-calorie sweeteners are classified as ultra-processed according to the NOVA classification system (238). Defined as “formulations of food substances often modified by chemical processes and then assembled into ready-to-consume hyper-palatable food and drink products using flavours, colours, emulsifiers, and a myriad of other cosmetic additives” (238), ultra-processed foods have been reported to

contribute more calories and nutrients of public health concern (i.e. fat, free sugars, and sodium) compared to products not classified as ultra-processed (239). Epidemiologic studies examining the association between the consumption of ultra-processed products and diet quality consistently report poorer diet quality as the proportion of ultra-processed foods increases (240), likely, in part, due to excess consumption of these nutrients of concern.

With the increasing use of sweeteners in a wide range of foods and beverages across the food supply and the lack of alignment of sources of low- and no-calorie sweeteners with dietary guidelines, it is important to consider how consumption of these foods and beverages is associated with overall diet quality. This is especially important because efforts to reduce added sugars intake are often implemented as part of population-level strategies to improve dietary patterns and reduce chronic disease risk (28). In addition to considering the population as a whole, particular population subgroups, such as children, for whom dietary patterns developed at an early age may track into later life (217), and individuals with diabetes, among whom the use of low- and no-calorie sweetened products are suggested as a strategy to control blood sugar levels (179), warrant attention to inform policies and programs to support healthy eating.

Studies investigating associations between low- and no-calorie sweetener consumption and diet quality using data from a single 24HDR yield conflicting results. For example, using dietary intake data collected in the 2011-2016 cycles of the U.S. National Health and Examination Nutrition Survey (NHANES), Sylvetsky et al. (65) observed higher total and added sugars intake among children who consumed low- and no-calorie sweetened beverages on the recall day compared to children consuming only water (65). In contrast, using data from a single 24HDR recall drawn from the 2011-2012 Australian National Nutrition and Physical Activity Survey, Grech et al. (79) reported no difference in free and total sugars intake among children (2-18 years) who consumed low- and no-calorie sweeteners compared to non-consumers (79). However, lower free sugars intake was observed among males and females 19 years of age and higher sodium intake was observed among males aged 19 years and above who were consumers of low- and no-calorie sweeteners compared to non-consumers (79). These diverging findings across studies, particularly for free and added sugars intake, may be in part due to differences in how consumer and non-consumer groups are defined, specifically, whether consumers of sugar-sweetened beverages are included in the comparator group.

Few studies have examined how the use of sweeteners relates to overall dietary patterns. Similar to studies focusing on individual dietary components, research examining diet quality in a holistic and multidimensional manner has tended to rely on data from a single 24HDR and assessed whether individuals consumed sources of sweeteners on the recall day(s) (62,241). For example, an analysis of data from a single 24HDR collected within the 1999-2008 NHANES observed higher Healthy Eating Index-2005 (HEI-2005) scores among adults who consumed sources of low- and no-calorie sweeteners on the recall day compared to non-consumers (62). Similarly, drawing on data from a single 24HDR collected as part of a randomized control trial, Hedrick et al. (241) reported higher Healthy Eating Index-2010 (HEI-2010) scores among adult consumers compared to non-consumers living in rural communities and in lower socioeconomic conditions (241). Both sets of authors report that important drivers of higher HEI total scores were higher scores for the solid fats, added sugars, alcohol (and empty calories) components (62,241). However, the dichotomization of respondents as either consumers or non-consumers based on a single or even two recalls is problematic given the episodic nature of low- and no-calorie sweetener consumption, i.e., a short-term assessment may not capture all consumers of sweeteners if the recall was completed on a non-consumption day, or conversely, it may capture infrequent consumers who happened to consume a sweetened item on their recall day. In both instances, individuals may be misclassified into a category that is not reflective of their usual intakes, potentially biasing estimates of associations with diet quality (241). Such analyses also do not account for the potential correlations among dietary components, whereby higher consumption of one component may be related with higher or lower intakes of others (242).

The objective of this study was to examine long-term average diet quality conditional on the probability of consuming low- and no-calorie sweeteners among individuals aged 2 years and above in Canada by age group, sex, and diabetes status among adults aged 19 years and older. The analyses focused on probability of consuming sweeteners because the amounts of low- and no-calorie sweeteners in foods and beverages are not included in national food composition databases (other than for tabletop additions), and the amounts consumed of foods or beverages that contain the sweetener are not appropriate proxies for the amounts of sweetener consumed. Although evidence to inform hypotheses is lacking, based on research related to ultra-processed

foods and diet quality (240), we hypothesized lower diet quality among individuals with a higher probability of consuming foods and beverages.

7.3 Materials and Methods

7.3.1 Data and analytic sample

Data were drawn from the 2015 CCHS—Nutrition Public Use Microdata File. The 2015 CCHS—Nutrition is Canada's most recent national-level survey (excluding the three territories) comprehensively examining dietary intake (192). Other individuals not represented by the data include individuals living on reserve and in some remote regions, institutionalized individuals, and full-time members of the Canadian Armed Forces (192). Ethics approval was not required for use of a publicly available dataset.

Dietary intake data were collected via interviewer-administered 24HDR, implemented using the Automated Multiple-Pass Method (AMPM) developed by the U.S. Department of Agriculture and adapted for use in Canada (192). All participants completed the first 24HDR, and a representative subset (37%) completed a second telephone-administered 24HDR 3 to 10 days after their first. Parents or guardians reported dietary intakes for children 5 years or younger. For children 6 to 11 years of age, a parent or guardian was present for the 24HDR and aided if needed. Respondents 12 years of age and older reported dietary intake directly unless a physical or mental disability required the presence and assistance of a parent or guardian.

The 2015 CCHS—Nutrition dataset included 20,487 respondents. Because Canada's Food Guide is tailored to individuals 2 years of age and older, infants younger than 2 years were excluded. Individuals with no caloric intake on their first dietary recall were also excluded. The final analytic sample included 20,103 respondents, 7,426 of whom completed two 24HDRs. Energy and nutrient values for reported foods and beverages were estimated by applying Canada's national food composition database, a standard reference for foods commonly consumed in Canada (182). This database consists of food codes from the 2015 Canadian Nutrient File and a complementary recipe data file.

7.3.2 Sources of low- and no-calorie sweeteners

Food codes were classified as sources of low- and no-calorie sweeteners using the methods described in Chapter 5. Briefly, a text-based search strategy was used to examine food

code descriptions for confirmatory and possible source food codes. Possible source food codes underwent further examination, which included a review of corresponding U.S. Food and Nutrient Database for Dietary Studies (FNDDS) food code descriptions and an online verification of the nutritional information for foods and beverages identified as possible sources.

Usual intake, or long-term average intake, is defined as the probability of consuming a food, beverage, or nutrient multiplied by the average amount consumed on a consumption day (242). As noted, because Canada's national food composition database does not contain information on the amounts of low- and no-calorie sweeteners contained within foods and beverages, the analyses focused on probability of sweetener consumption based on consumption events in the 24HDRs.

7.3.3 Diet quality

The Healthy Eating Food Index-2019 (HEFI-2019) (243,244), which indicates alignment of dietary intake with the healthy food choices recommendations in the 2019 Canada's Food Guide (9), was applied to the 24HDR data to express diet quality. The maximum HEFI-2019 total score is 80, achieved by summing the scores for 10 component scores. Five components are food-based, including vegetables and fruits (20 points), whole-grain foods (5 points), grain foods (5 points), protein foods (5 points), and plant-based protein foods (5 points). One component is based on beverage intake (10 points). Four components are nutrient-based, including fatty acids (5 points), saturated fats (5 points), free sugars (10 points), and sodium (10 points) (**Table 17**). The four nutrient-based components are reverse-scored, so higher consumption proportionally results in lower component scores. Total scores indicate overall diet quality, and component scores aid in the interpretation of total scores by indicating variation in alignment with different recommendations (243,244).

Each of the HEFI-2019 component scores is expressed as a ratio (**Table 17**). For example, the beverage component is derived by summing all unsweetened beverages (i.e., unsweetened coffee and tea, unsweetened milk, and unsweetened plant-based beverages) in the numerator and dividing by the sum of all beverages, including artificially sweetened beverages and sugary drinks. The 2019 Canada's Food Guide encourages a dietary pattern that consists of approximately 50% vegetables and fruits, 25% whole grains, and 25% protein foods (243). To reflect this proportionality, the numerators and denominators for the five food-based components

of the HEFI-2019 are expressed using reference amounts (243,244) (RAs), defined as the amount of food generally eaten during one eating occasion (216). The reference amounts for each food code applied within 2015 CCHS—Nutrition was obtained from Health Canada.

Estimated values of free sugars for food codes within the 2015 CCHS—Nutrition were obtained from Rana et al. (214). The remaining variables to calculate the numerators and denominators for HEFI-2019 components were available within the 2015 CCHS—Nutrition nutrition-related files.

7.3.4 Sociodemographic variables of interest

Sociodemographic data were collected during the general health survey. Age and sex were considered based on observed differences in diet quality reported previously (243,244). Self-reported diabetes was also of interest, given the relevance of sugars to maintaining blood glucose control (89). Self-reported diagnosis of diabetes was queried only of individuals 19 years of age and older.

7.3.5 Statistical methods

Statistical analyses were conducted using SAS Studio, version 9.4 (SAS Institute, Cary, NC, 2013). Analyses were run for four strata, including (1) children aged 2 to 13 years, (2) males 14 years and older, (3) females 14 years and older, and (4) adults 19 years and older with and without diabetes, with covariates included to allow examination of more granular subgroups, as detailed subsequently.

Estimating the usual intake of foods and beverages, particularly episodically consumed foods and beverages (including low- and no-calorie sweeteners), using dietary data collected from short-term assessment tools, such as 24HDRs, requires special considerations, assumptions, and statistical techniques (225). The multivariate Markov Chain Monte Carlo (MCMC) extension to the National Cancer Institute (NCI) method was used to jointly model dietary constituents considered in the numerators and denominators of the HEFI-2019 components. A binary indicator of the event of consuming any source of low- and no-calorie sweeteners was included in the model to enable examination of HEFI-2019 scores based on simulated distributions of usual intakes conditional on the probability of consuming sweeteners. Second 24HDRs, available for a subsample, were used to adjust for within-person variation in intake to

enable estimation of usual intake distributions. A similar approach, using the bivariate extension to the NCI method, has been used to examine the prevalence of excessive nutrient intakes conditional on the probability of consuming voluntarily fortified foods (245).

Overview of the NCI multivariate MCMC method

The NCI method is a statistical technique that estimates distributions of usual, or long-term average, intakes using data from 24HDRs (246). The MCMC extension is a nonlinear mixed model that allows for the joint modelling of multiple correlated dietary constituents, taking into account episodically consumed constituents when estimating usual intake distributions (242,247). It can be thought of as a two-step process: Step 1 fits a two-part (i.e., a probability to consume part and an amount part) measurement error model to describe usual intakes, and Step 2 estimates the distributions of usual intake for all dietary constituents modelled.

Before applying the NCI multivariate MCMC method, it is necessary to determine which dietary constituents of interest are episodically consumed (requiring a two-part model) and which are consumed daily (requiring only a one-part model). Dietary constituents can be classified as non-episodic (or daily) if less than 5% of the sample reports zero intake. If 10% or more of the sample reports zero intakes, the dietary constituent should be considered episodic and modelled using both the probability and amount parts of the model (further described in the following section). If between 5% and 10% of recalls have zero intakes, it is suggested that both the amount part only and the two-part model be examined to determine the best model fit (225). For the present study, because all respondents completed the first 24HDR, this recall was used to assess the episodicity of each dietary constituent. Six dietary constituents used in the construction of HEFI-2019 components were episodically consumed among children, whereas seven dietary constituents were considered episodic among males and females 14 years and above (**Appendix F**). Because a substantial number of 24HDRs included no consumption of any source of low- and no-calorie sweeteners, low- and no-calorie sweeteners were treated as an episodically consumed dietary constituent.

The NCI method Step 1: Fitting a two-part measurement error model to describe usual intakes

In Step 1, a two-part model that describes relationships between usual intake and covariates of interest, as well as estimating the within- and between-person variability in intake, is fitted (242). In the probability part of the model, a consumption-day indicator (i.e., probability of consumption that is reflective of a person's tendency to consume a given food or beverage) for each episodic dietary constituent is created, informed by person-level covariates (e.g., age, sex) in the model (242). In the amount part of the model, the within-person variability, including day-to-day variation in intake and other random errors associated with short-term dietary assessment methods (e.g., nuisance effects due to weekend versus weekday consumption day and whether data are from the first or second dietary recall), is estimated using the sample of respondents with two dietary recalls. The within-person variability is assumed to be the same across all individuals in a given stratum.

For each dietary constituent considered, two sets of latent variables are created: one for the probability of consumption and one for the amount (247). However, for dietary constituents consumed nearly every day by most individuals, only one set of latent variables is created for the amount part because the probability part is assumed to be one (247). These latent variables represent the between-person random effect and an individual-level within-person deviation (247). In addition to the unobserved latent variables, Step 1 estimates parameters for the covariate pattern based on covariates included in the model. The probability and amount parts of the model are linked in two ways: 1) by allowing common covariates in each part, and 2) by allowing the unobserved latent variables for the between-person random effect in the probability and usual consumption-day amounts part to be correlated (242).

The NCI method Step 2: Estimating the distribution of usual intake

In Step 2, the parameters estimated in Step 1 are used to simulate usual intake distributions for each dietary constituent for a pseudo-population that maintains a similar covariate pattern distribution as observed in the original sample (242). To improve the precision of the estimated distributions, the model generates distributions for 100 pseudo-persons for every respondent in the sample; distributions maintain the same covariate patterns as the respondent but simulate different person-specific effects of intake (242). The within-person variability

estimated in Step 1 is not included in the simulated population's usual intake distributions, and nuisance effects (e.g., day of the week and dietary recall sequence) are accounted for. By accounting for these random errors, the estimated usual intake distributions better reflect between-person differences in usual intakes. At the end of Step 2, usual intake distributions for each dietary constituent modelled jointly with the probability of consuming low- and no-calorie sweeteners for all respondents in a stratum are constructed.

Additional considerations and steps taken to model usual intake distributions

The multivariate MCMC method makes several assumptions and requires data to meet certain requirements. First, the method assumes multivariate normal data. Because dietary data are known to be highly skewed (248), the amounts of each dietary constituent were transformed using a Box-Cox transformation specific to their distributions, so data residuals approximated normality. Second, for non-episodically consumed constituents, it is assumed that all participants have a consumption amount greater than zero. Therefore, zero intakes for dietary constituents determined to be non-episodic were replaced with a value equal to half the minimum amount reported. For low- and no-calorie sweeteners³, because information on amounts consumed of low- and no-calorie sweeteners was not available, a small amount (i.e., 0.0001) was imputed to satisfy the modelling requirements, but the amount portion was not interpreted.

Third, the method requires at least 50 independent replicate observations (or recalls) with consumption events to estimate within-person variation (249); this requirement was confirmed for all dietary constituents across four strata. Previous analyses using NHANES data estimated distributions of usual intakes among strata including children 2 to 8 years, males 9 years and above, and females 9 years and above (60,250). However, for the present analyses, fewer than 50 children 2 to 8 years of age had a second dietary recall, including the consumption of at least one source of low- and no-calorie sweeteners, preventing the estimation of within-person variation.

³ Because the amounts of low- and no-calorie sweeteners (LNCS) in foods and beverages were not available, an LNCS variable was simulated by multiplying a consumption day indicator (based on observed consumption of LNCS-sweetened products) multiplied by a latent amount that was randomly generated. The distribution of this LNCS variable was transformed to resemble a normal distribution with a mean of zero and a standard deviation of two, as required for the NCI method.

When children 9 to 13 years were added to the children's stratum, the minimum number of replicate recalls for low- and no-calorie sweeteners was achieved.

Stratifying allows the usual intake distributions to vary by stratum, while covariates allow for estimating the distributions of usual intake for particular groups of interest (225,248). For children in the 2 to 13-year stratum, sex and age (categorized according to the Dietary Reference Intakes (DRI) age groups (251)) were included as covariates. For females 14 years and older and males 14 years and older strata, only the DRI-age group was included as a covariate. For the 19-year-old and older stratum, sex, DRI-age group, and self-reported diabetes diagnosis were included as covariates. Covariates to account for nuisance effects, including an indicator of recall sequence (i.e., first vs. second dietary recall) and day of the week (i.e., weekday vs. weekend day), were included in models for all strata to account for the variation that they may contribute (225).

Finally, an examination of outliers in each dietary constituent's distribution was undertaken on dietary data on the original, untransformed scale. Outliers were defined as values less than the 25th quartile minus three times the interquartile range (i.e. $<Q_{25} - 3 \cdot IQR$) or values greater than the 75th quartile plus three times the interquartile range (i.e. $>Q_{75} + 3 \cdot IQR$). When identified, these values were Winsorized (rather than excluded) so they would not exert undue influence.

Applying the HEFI-2019 scoring algorithm

After completing Steps 1 and 2 to simulate usual intake distributions for each dietary constituent of interest, the HEFI-2019 scoring algorithm was applied. Each HEFI-2019 component score was derived by summing the appropriate dietary constituents⁴ that make up each component's numerator and denominator. Next, ratios for each HEFI-2019 component were constructed. Finally, the HEFI-2019 component ratios were scored according to the HEFI-2019 scoring standards, and the HEFI-2019 total score was estimated by summing each of the 10 component scores (243,252).

⁴ Because only one individual in the entire 2015 CCHS—Nutrition survey reported consuming plant-based beverages, the unsweetened plant-based beverage dietary constituent was set to zero in the HEFI-2019 scoring algorithm macro (252)

Interpreting results

For interpretability, HEFI-2019 total and component scores are expressed relative to quintiles of the probability of consuming any sources of low- and no-calorie sweeteners. Specifically, the distributions for each dietary constituent involved in the construction of each HEFI-2019 component ratios were jointly modelled with the distribution of the probability of consuming low- and no-calorie sweeteners. This approach of categorizing respondents based on the distributional quintiles recognizes the variability in the probability of consuming low- and no-calorie sweeteners within a population and accounts for the within-person variation in intakes of foods and beverages sweetened with low- and no-calorie sweeteners (245). It also overcomes the limitations of dichotomizing respondents as consumers or non-consumers based on a single or even two dietary recalls, an approach used in previous research to date.

HEFI-2019 scores were interpreted in terms of meaningful differences between quintiles of the probability of consuming any sources of low- and no-calorie sweeteners. This approach was based on previous research using the Healthy Eating Index-2015 (HEI-2015), whereby the developers suggest that a difference of 5- to 6-points in total scores between independent groups, based on observed standard deviations and a moderate effect size of 0.5, may be meaningful (253). Drawing on estimated standard deviations of HEFI-2019 total scores (personal communications, Didier Brassard), differences in HEFI-2019 scores across quintiles were considered meaningful if a 4-point or 4.6-point difference was observed for children 2 to 18 years and adults 19 years and above, respectively. To examine if a dose-response relationship potentially existed between the probability of consuming low- and no-calorie sweeteners and HEFI-2019 total scores, we decided, *a priori*, to examine differences between the HEFI-2019 total scores for the highest probability to consume (i.e. quintile 5) to the lowest probability to consume (i.e. quintile 1); differences were tested using *t* tests. *P* values are reported and interpreted in terms of the strength of the evidence (213). For example, a *P* value between 0.01 and 0.05 is interpreted as ‘moderate’ evidence, whereas a *P* value between 0.05 and 0.1 is interpreted as providing ‘weak’ evidence. *P* values between 0.1 and 1.0 are interpreted as contributing little to no evidence (213). This approach of evaluating findings from a ‘strength of evidence’ approach versus an arbitrarily chosen threshold to determine ‘significance’ (or non-significance) recognizes that public health decisions should be based on the totality of evidence

and not findings from one single study (254). Instead, the magnitude of effects is reported along with a measure of the effect estimates variability. Differences in HEFI-2019 component scores were qualitatively examined to assess whether differences in total scores were attributable to particular HEFI-2019 components. Specifically, differences between HEFI-2019 component scores in quintile 5 and quintile 1 were calculated and expressed as a percentage of their total component score, standardizing each component as they are weighted differently.

Survey weights provided by Statistics Canada were included in all analyses to generate estimates representative of all individuals living in Canada's provinces. Given the complex survey sampling design, bootstrap weights provided by Statistics Canada were applied to estimate 95% confidence intervals and standard errors.

7.4 Results

Overall, 52% of the unweighted analytic sample were female, approximately 31% were children and adolescents aged 2 to 18, and among adults 19 years and above, 9.1% reported having diabetes (**Table 18**).

Mean HEFI-2019 component scores for all four strata are visualized using radar plots in **Figures 4-19**; exact mean scores plus standard errors are included in **Appendices G-J**.

There was weak evidence ($P=0.08$) of a lower (-6.1 points, 95% CI: -13.1, 0.8) HEFI-2019 total score among children aged 2 to 13 years with the highest probability of consuming low- and no-calorie sweeteners compared to children with the lowest probability of consuming low- and no-calorie sweeteners (**Table 19**). Similar findings were observed for males and females in this age group. Lower HEFI-2019 component scores were observed with higher probability of consuming low- and no-calorie sweeteners, with the exception of the protein foods component, in which case, scores were the same across all five quintiles (**Appendix G**). For the free sugars component score, the difference in scores between quintile 5 and quintile 1 was -13% and for the plant-based protein foods component score, the difference in scores between these two quintiles was -16%. However, because there was only weak evidence of lower HEFI-2019 total scores, we did not conduct statistical tests of differences at the component score level.

Among males 14 years of age and above, there was moderate evidence ($P=0.04$) of a higher (4.6 points, 95% CI: 0.1, 9.1) HEFI-2019 total score among those with the highest

probability versus those with the lowest probability to consume low- and no-calorie sweeteners (**Table 19**). A similar magnitude of difference was observed among the subgroup of males aged 14 to 18 years (4.2 points, 95% CI: -0.4, 8.7), but the evidence to support this difference as meaningful was weak ($P=0.07$). Mean HEFI-2019 total scores were not meaningfully different in relation to probability of consumption of sources of low- and no-calorie sweeteners across the remaining DRI age subgroups among males 19 years of age and above. Higher HEFI-2019 component scores were observed with higher probability of consuming low- and no-calorie sweeteners, with the exception of the vegetables and fruit and protein foods component scores, for which little to no difference in scores was observed (**Appendix H**). For the free sugars component score, the difference in scores between quintile 5 and quintile 1 was 18%; for the plant-based protein foods component score, the difference in scores between these two quintiles was 16%.

There was little to no evidence of meaningful differences in HEFI-2019 total scores in relation to probability of consuming sources of low- and no-calorie sweeteners among females aged 14 years and above or among adults 19 years and above with and without diabetes (**Table 19**). HEFI-2019 component scores for females 14 years and above and adults 19 years and above with and without diabetes are included in **Appendices I** and **J**, respectively.

7.5 Discussion

This study is the first to examine diet quality conditional on the probability of consuming low- and no-calorie sweeteners. While there appeared to be meaningful differences in HEFI-2019 total scores between individuals with the highest probability to consume low- and no-calorie sweeteners and individuals with the lowest probability to consume sweeteners among some DRI age-sex subgroups, particularly children and males 14 years and above, the evidence to support this interpretation was generally weak.

The association between diet quality and probability of consuming sweeteners diverged by age group and sex (among individuals 14 years and above). HEFI-2019 total scores among children 2 to 13 years were generally poor and meaningfully lower among children with the highest probability of consuming low- and no-calorie sweeteners. A similar pattern was observed for HEFI-2019 free sugars scores, which is surprising given that low- and no-calorie sweeteners

are intended as substitutes for free sugars. Poorer alignment with Canada's free sugars guidance with higher probabilities of consuming sweeteners warrants further examination as this finding could signal greater intakes of foods and beverages with free sugars at the expense of more nutritious alternatives. Our finding of lower HEFI-2019 free sugars scores for children 2 to 13 years among those with higher probabilities of consuming low- and no-calorie sweeteners is in line with results from Sylvetsky et al. (65) when non-sugar-sweetened beverage consumers were used as the comparator. However, the finding is not consistent with other research that compared low- and no-calorie sweetener consumers against non-consumers that included sugar-sweetened beverage consumers (65). These diverging findings reinforce the importance of clearly specifying the comparator when analyzing observational data. In the present analyses, a comparator was not specified, partly because low- and no-calorie sweetener exposure could come from multiple sources, i.e., beverages, foods, and tabletop sweeteners.

Findings of higher HEFI-2019 total scores among males aged 14 years and above with the highest probability of consuming low- and no-calorie sweeteners compared to males with the lowest probability are in line with results reported by Drewnowski & Rehm (62) and Hedrick et al. (241); however, neither study examined these associations by sex or gender. In the present study, minimal, if any, differences were observed in HEFI-2019 total scores among females 14 years and above. Similar patterns were observed for HEFI-2019 free sugars scores among both males and females. These observed differences by sex suggest potentially important differences in how males and females are incorporating low- and no-calorie sweetened foods and beverages into overall dietary intakes, with males making the intended substitutions and females potentially compensating with less nutritious foods and beverages.

Compensation for foods and beverages containing added or free sugars (and energy) is a concern when low- and no-calorie sweetened products are included in the diets of free-living individuals (162), including for use as part of nutrition therapy among adults with diabetes and prediabetes (47). Although low- and no-calorie sweeteners may be helpful for individuals with diabetes to control their blood sugar levels, overall diet quality is important for preventing and managing type 2 diabetes (255). In our analyses, there was little to no evidence to support a difference in HEFI-2019 total scores between adults with the highest probability to consume low- and no-calorie sweeteners and adults with the lowest probability. However, both males and

females who self-reported a diabetes diagnosis appear to have had higher HEFI-2019 free sugars scores compared to those who did not self-report having diabetes, although we did not test the statistical significance of these differences. Higher HEFI-2019 free sugar scores among individuals with diabetes would be consistent with previous findings of higher prevalence of consumption of low- and no-calorie sweetened beverages and tabletop sweeteners among individuals who self-reported a diabetes diagnosis (**Chapter 6**).

From a population-level perspective, Canada's current dietary guidelines acknowledge the safety of low- and no-calorie sweeteners but do not recommend their use as an approach to reducing free sugar intake (9). This is likely a prudent public health recommendation, given the conflicting evidence and findings from the current study. The generally low HEFI-2019 total scores and low scores for free sugars and sodium, nutrients of public health concern (9) in relation to low- and no-calorie sweetener consumption, observed among children 2 to 13 years of age are of particular concern, considering the importance of dietary patterns to overall growth and development. Health Canada is currently examining the inclusion of low- and no-calorie sweetened foods and beverages in their proposed advertising restrictions regulation (36), which would limit the advertising of certain foods and beverages high in saturated fats, free sugars, and sodium to children 12 years and under. Considering the findings of this study, this approach may be warranted. To further inform this policy approach, future research could examine whether intended substitutions are co-occurring with higher probabilities of consuming low- and no-calorie sweeteners among free-living populations. For example, extending the methodological approach used in this study to include a binary variable indicating consumption of sugar-sweetened beverages in the modelling would allow the comparison of diet quality scores between children who consume sugar-sweetened beverages and those who do not in relation to the probability of consuming low- and no-calorie sweetened beverages.

The methods used in this study overcame an important limitation of existing research examining the relationship between low- and no-calorie sweeteners and diet quality, specifically, the potential to misclassify individuals as low- and no-calorie sweetener consumers (or non-consumers) based on a single or even two dietary recalls. The modelling applied accounted for episodically consumed dietary components, including sweeteners, as well as correlations among dietary components. Further, the data were drawn from the most recent source of nationally

representative detailed dietary intake data, with weighting applied to represent the population of Canada's provinces. Several caveats should also be considered when interpreting our results. First, the current analyses could not identify true never consumers and assumed that all respondents had at least some chance, albeit small, of consuming sources of low- and no-calorie sweeteners. Although mitigation strategies to overcome this limitation have been suggested (225,256), we did not have access to data, such as from a frequency questionnaire that would allow us to identify individuals who are likely to be true non-consumers, e.g., based on a response of 'never' to a question about low- and no-calorie sweetener consumption, or biomarkers of low- and no-calorie sweetener consumption (257). Instead, distributions of low- and no-calorie sweetener intake were simulated using a miniscule amount not materially different from zero (i.e., 0.0001 grams). Therefore, the impact of not capturing true never consumers is likely not a concern (256). Second, self-reported dietary intake data are subject to measurement error (225). Although 24HDRs measure dietary intake with less bias than other dietary assessment methods, they are not free from bias (225). Previous research has demonstrated that less healthy foods are underreported more often, whereas healthier foods are overreported more often (253). As a result, HEFI-2019 scores likely overestimate true diet quality (253). However, as described in **Chapter 6**, the error structure of intake data on foods and beverages sweetened with low- and no-calorie sweeteners is unknown and may differ in relation to the perceived 'naturalness' (and, by extension, healthfulness) of the sweetener. Despite the errors associated with self-reported dietary data, until such time that a perfect, error-free dietary assessment tool becomes available, we must rely on self-reported intake data to inform public health nutrition policy to support population-level dietary practices (225). The thresholds established to define meaningful differences between HEFI-2019 total scores are likely conservative, given that the original developers of the HEFI-2019 index identified a 3-point difference between males and females as both meaningfully different and statistically significant (HEFI-2019 total score difference, 3.1, 95% CI: 2.0, 4.1) (244).

7.6 Conclusion

Findings from the present study contribute to our understanding of diet quality, as measured by the HEFI-2019, conditional on the probability of consuming low- and no-calorie

sweeteners. While low- and no-calorie sweetened foods and beverages are thought to support individuals in reducing free and added sugars intake and, therefore, improve diet quality, findings from the present study suggest this might not be the case across all subgroups. As a population-level intervention to reduce free and added sugars intake, consuming low- and no-calorie sweetened foods and beverages may not necessarily have the intended outcomes. To evaluate the relative benefit or harm of low- and no-calorie sweetener consumption on overall diet quality at the population level, future research should examine how low- and no-calorie sweeteners are being incorporated into overall dietary patterns. Continued monitoring of population-level intakes in relation to diet quality and chronic diseases of public health concern is also warranted, particularly in light of public health interventions aiming to reduce free and added sugars intake that may lead to higher use and consumption of low- and no-calorie sweeteners.

Table 17: Healthy Eating Food Index-2019 (HEFI-2019) components, measures, and scoring standards

#	Component name	Measurement (ratio)	Max pts	Unit	Standard, min score	Standard, max score
1	Vegetables and fruit	Total vegetables and fruit ^a / total foods ^b	20	RA/RA	No vegetables and no fruits	≥0.50
2	Whole-grain foods	Total whole-grain foods ^c / total foods ^b	5	RA/RA	No whole-grain foods	≥0.25
3	Grain foods ratio	Total whole-grain foods ^c / total grain foods ^d	5	RA/RA	No whole-grain foods	1.0
4	Protein foods	Total protein foods ^e / total foods ^b	5	RA/RA	No protein foods	≥0.25
5	Plant-based protein foods	Plant-based protein foods ^f / total protein foods ^e	5	RA/RA	No plant-based foods	>0.50
6	Beverages	(Plain water including carbonated + unsweetened beverages) ^g / total beverages ^b	10	g/g	No water, no unsweetened beverages	1.0
7	Fatty acids ratio	(Mono- + polyunsaturated fats) / total saturated fat	5	g/g	≤1.1 ⁱ	≥2.6 ^j
8	Saturated fats	Total saturated fat/energy	5	%E (kcal/kcal)	≥15%E ^k	<10%E
9	Free sugars	Total free sugars/energy	10	%E (kcal/kcal)	≥20%E ^k	<10%E
10	Sodium	Total sodium/energy	10	mg/kcal	≥2.0 ^k	<0.9 ^l

^a All vegetables and fruits regardless of fat, sodium or free sugar content; excludes fruit juice (i.e., considered as sugary drinks in CFG-2019).

^b Includes all foods consumed and beverages considered in protein foods (i.e., unsweetened milk and unsweetened plant-based beverages that contain protein); excludes all other beverages as well as solid fats, oils and spreads, and culinary ingredients (e.g. spices and baking soda).

^c Foods where the first ingredient is either whole grains or whole wheat, regardless of saturated fat, sodium or free sugar content.

^d Foods where the first ingredient is a grain (whole or not) regardless of saturated fat, sodium or free sugar content.

^e All protein foods, regardless of fat, sodium or sugar content, excluding processed meats (i.e. not considered protein foods in CFG-2019) and sweetened milks (which are considered sugary drinks in CFG-2019).

^f All plant-based protein foods, regardless of saturated fat, sodium or free sugar content.

^g Unsweetened beverages include unsweetened coffee and tea, unsweetened milk and unsweetened plant-based beverages.

^h Total beverages include water (plain or carbonated), coffee, tea, milk and plant-based beverages, fruit and vegetable juices, alcoholic drinks, artificially sweetened beverages and sugary drinks.

ⁱ Approximately the 15th percentile of intake based on data (single 24-hour recall) in Canadians from the 2015 CCHS—Nutrition.

^j Corresponds to the 1st percentile of unsaturated to saturated fats ratios among simulated diets developed to be fully consistent with all recommendations in CFG-2019.

^k Approximately the 85th percentile of intake based on data (single 24-hour recall) in Canadians from the 2015 CCHS—Nutrition.

^l Standard for maximum points based on the CDRR for 14 y and older (i.e., 2300 mg) over the 90th percentile of usual energy intakes in respondents aged 2 y and older from the 2015 CCHS—Nutrition (i.e. approximately 2600 kcal).

Table source: Brassard, Munene, et al., 2022 (243).

Table 18: Demographic and health-related characteristics of the overall analytic sample drawn from the 2015 Canadian Community Health Survey—Nutrition used to examine the joint distribution of Healthy Eating Food Index-2019 (HEFI-2019) scores conditional on the probability of consuming low- and no-calorie sweeteners (n=20,103)

Characteristics	Unweighted frequencies n (%)	Weighted percents (%, standard error)
Sex		
Male	9,554 (47.5)	49.3 (0.76)
Female	10,549 (52.5)	50.7 (0.76)
Age (years)		
2 to 3	951 (4.7)	2.4 (0.16)
4 to 8	1,233 (6.1)	5.6 (0.26)
9 to 13	2,016 (10.0)	5.3 (0.21)
14 to 18	1,995 (9.9)	5.7 (0.23)
19 to 30	1,901 (9.5)	13.6 (0.65)
31 to 50	4,545 (22.6)	31.1 (0.76)
51 to 70	4,660 (23.2)	26.6 (0.67)
71 and above	2,802 (13.9)	9.7 (0.32)
Has diabetes¹		
Yes	1,257 (9.1)	6.9 (0.37)
No	12,611 (90.9)	93.1 (0.37)

¹Among adults 19 years and above.

Table 19: Mean Healthy Eating Food Index-2019 (HEIF-2019) total scores (95% Confidence Intervals (CI)) by quintile of the probability to consume low- and no-calorie sweeteners, by age and sex group, and adults (19 and above) with and without diabetes

	Quintile 1 (95% CI)	Quintile 2 (95% CI)	Quintile 3 (95% CI)	Quintile 4 (95% CI)	Quintile 5 (95% CI)	Difference ¹ (95% CI)	p-value ²
<i>Children, 2 to 13 years</i>							
Both males and females 2 to 13 years	42.6 (37.8, 47.4)	40.7 (38.4, 43.0)	39.5 (37.9, 41.2)	38.3 (35.9, 40.8)	36.5 (31.7, 41.2)	-6.1 (-13.1, 0.8)	0.08
2 to 3 years, males and females	45.3 (40.0, 50.5)	43.3 (40.7, 46.0)	42.3 (40.2, 44.4)	41.2 (38.6, 43.8)	39.5 (34.9, 44.0)	-5.8 (-12.6, 1.1)	0.10
4 to 8 years, males and females	42.2 (37.9, 46.5)	40.5 (38.3, 42.7)	39.4 (37.1, 41.6)	38.2 (34.9, 41.6)	36.6 (31.2, 42.1)	-5.6 (-12.7, 1.5)	0.12
9 to 13 years, males and females	41.3 (35.9, 46.7)	39.5 (36.7, 42.6)	38.5 (36.8, 40.2)	37.4 (35.5, 39.2)	35.6 (31.5, 39.7)	-5.7 (-12.8, 1.4)	0.11
Males, 2 to 13 years	42.2 (37.5, 47.0)	40.2 (37.9, 42.4)	38.9 (37.0, 40.8)	37.8 (35.1, 40.5)	36.0 (31.1, 40.9)	-6.2 (-13.1, 0.7)	0.08
Females, 2 to 13 years	43.1 (38.1, 48.0)	41.3 (38.7, 43.8)	40.2 (38.5, 41.8)	38.8 (36.6, 41.1)	36.9 (32.2, 41.6)	-6.2 (-13.2, 0.9)	0.09
<i>Males 14 years and above</i>							
Males 14 years and above	41.1 (33.3, 48.9)	42.8 (37.3, 48.3)	43.6 (38.5, 48.7)	44.5 (38.9, 50.0)	45.7 (38.4, 53.0)	4.6 (0.1, 9.1)	0.04
14 to 18 years	36.9 (31.4, 42.4)	38.4 (33.9, 42.8)	39.2 (33.9, 44.5)	39.8 (33.4, 46.3)	41.1 (31.9, 50.3)	4.2 (-0.4, 8.7)	0.07
19 to 30 years	38.3 (31.2, 45.3)	39.9 (34.4, 45.4)	40.5 (35.6, 45.3)	41.4 (35.8, 47.1)	42.2 (34.8, 49.6)	3.9 (-0.6, 8.4)	0.08
31 to 50 years	42.3 (35.6, 49.1)	43.7 (38.4, 49.0)	44.5 (39.0, 49.9)	45.1 (38.8, 51.3)	46.2 (37.7, 54.7)	3.9 (-0.6, 8.4)	0.09
51 to 70 years	43.2 (33.7, 52.7)	44.3 (37.2, 51.4)	45.0 (39.0, 51.0)	45.8 (40.1, 51.4)	46.7 (40.5, 53.0)	3.5 (-1.1, 8.2)	0.14
71 years and above	42.4 (33.5, 51.3)	43.7 (37.2, 50.2)	44.5 (38.7, 50.2)	45.1 (39.4, 50.8)	46.3 (39.2, 53.3)	3.8 (-1.1, 8.8)	0.13

Females 14 years and above							
Females 14 years and above	46.8 (41.6, 51.9)	46.6 (42.1, 51.1)	46.3 (42.0, 50.5)	46.1 (42.0, 50.2)	45.7 (41.2, 50.3)	-1.0 (-5.9, 3.8)	0.68
14 to 18 years	41.6 (36.8, 46.3)	41.0 (37.0, 45.0)	40.3 (36.6, 44.1)	39.7 (35.9, 43.5)	39.5 (34.7, 44.2)	-2.1 (-7.4, 3.2)	0.44
19 to 30 years	43.9 (39.1, 48.8)	43.5 (39.3, 47.7)	43.0 (38.9, 47.0)	42.6 (38.4, 46.8)	41.9 (37.0, 46.8)	-2.0 (-7.2, 3.2)	0.44
31 to 50 years	48.1 (42.7, 53.4)	47.3 (42.7, 51.9)	46.9 (42.6, 51.1)	46.5 (42.3, 50.6)	45.8 (41.2, 50.4)	-2.2 (-6.9, 2.5)	0.39
51 to 70 years	49.5 (43.4, 55.5)	49.0 (43.8, 54.2)	48.3 (43.5, 53.2)	48.0 (43.6, 52.5)	47.5 (42.7, 52.2)	-2.0 (-7.1, 3.1)	0.44
71 years and above	47.2 (40.9, 53.5)	46.7 (41.4, 52.1)	46.1 (41.1, 51.1)	45.5 (40.7, 50.3)	44.9 (39.9, 49.9)	-2.3 (-7.6, 3.1)	0.41
Adults 19 years and older, with and without diabetes							
Adults 19 years and above with diabetes	46.5 (39.1, 53.9)	46.3 (39.6, 53.1)	46.1 (39.7, 52.4)	46.0 (40.0, 51.9)	45.8 (40.1, 51.5)	-0.7 (-3.6, 2.2)	0.63
Adults 19 years and above without diabetes	45.3 (39.6, 51.1)	45.2 (39.7, 50.7)	45.1 (39.7, 50.6)	45.1 (39.5, 50.7)	44.9 (38.9, 51.0)	-0.4 (-3.2, 2.5)	0.79
Males with diabetes	45.4 (37.9, 52.8)	45.3 (38.8, 51.8)	45.1 (38.9, 51.2)	45.0 (39.3, 50.6)	44.7 (39.4, 49.9)	-0.7 (-3.5, 2.2)	0.64
Males without diabetes	44.2 (38.8, 49.6)	44.0 (38.9, 49.1)	43.9 (38.9, 48.9)	43.9 (38.8, 49.1)	43.7 (38.2, 49.2)	-0.5 (-3.3, 2.3)	0.73
Females with diabetes	48.0 (40.5, 55.4)	47.6 (40.6, 54.6)	47.3 (40.7, 53.9)	47.2 (40.8, 53.5)	47.0 (40.9, 53.2)	-1.0 (-4.1, 2.2)	0.56
Females without diabetes	46.5 (40.4, 52.7)	46.4 (40.4, 52.4)	46.2 (40.3, 52.1)	46.2 (40.2, 52.3)	46.0 (39.4, 52.6)	-0.5 (-3.5, 2.5)	0.74

¹Difference in mean HEFI-2019 total scores between individuals with the highest probability of consuming low- and no-calorie sweeteners (i.e. quintile 5, Q5) and individuals with the lowest probability of consuming low- and no-calorie sweeteners (i.e. quintile 1, Q1).

²P value of the difference in mean HEFI-2019 total score between Q5 and Q1.

Note: Confidence intervals were estimated using 200 bootstrap weight replicates.

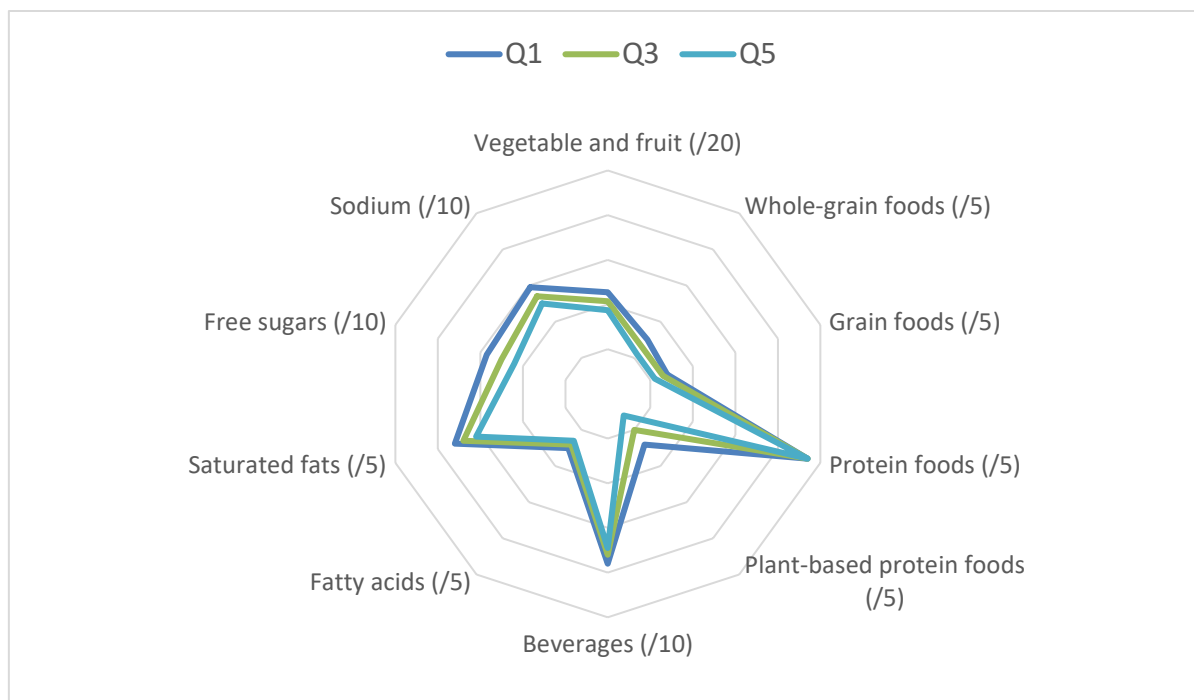


Figure 4: Radar plot for mean HEFI-2019 component scores for males, 2-13 years, using the 2015 CCHS-Nutrition Public Use Microdata File.

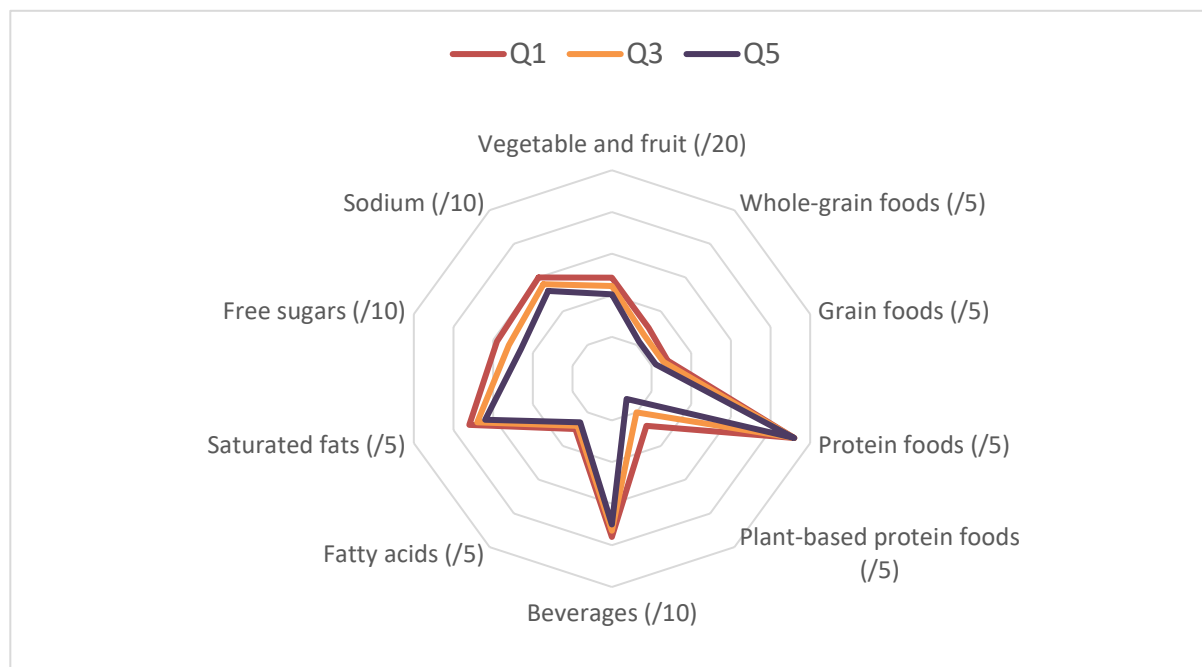


Figure 5: Radar plot for mean HEFI-2019 component scores for females, 2-13 years, using the 2015 CCHS-Nutrition Public Use Microdata File.

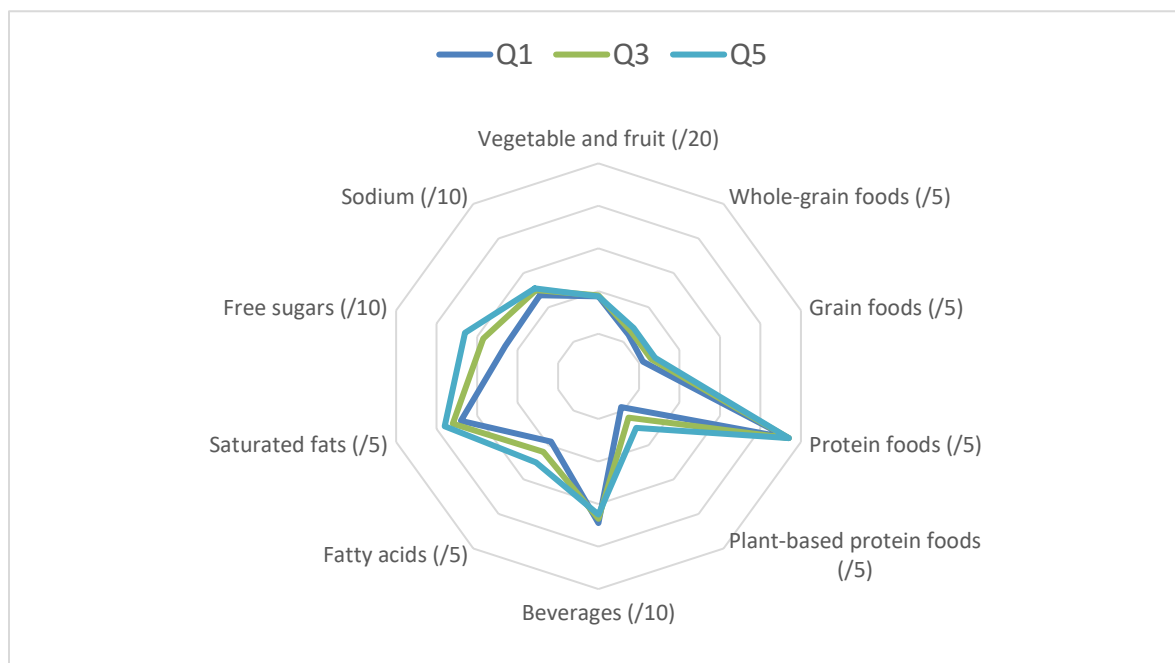


Figure 6: Radar plot for mean HEFI-2019 component scores for males, 14-18 years, using the 2015 CCHS-Nutrition Public Use Microdata File.

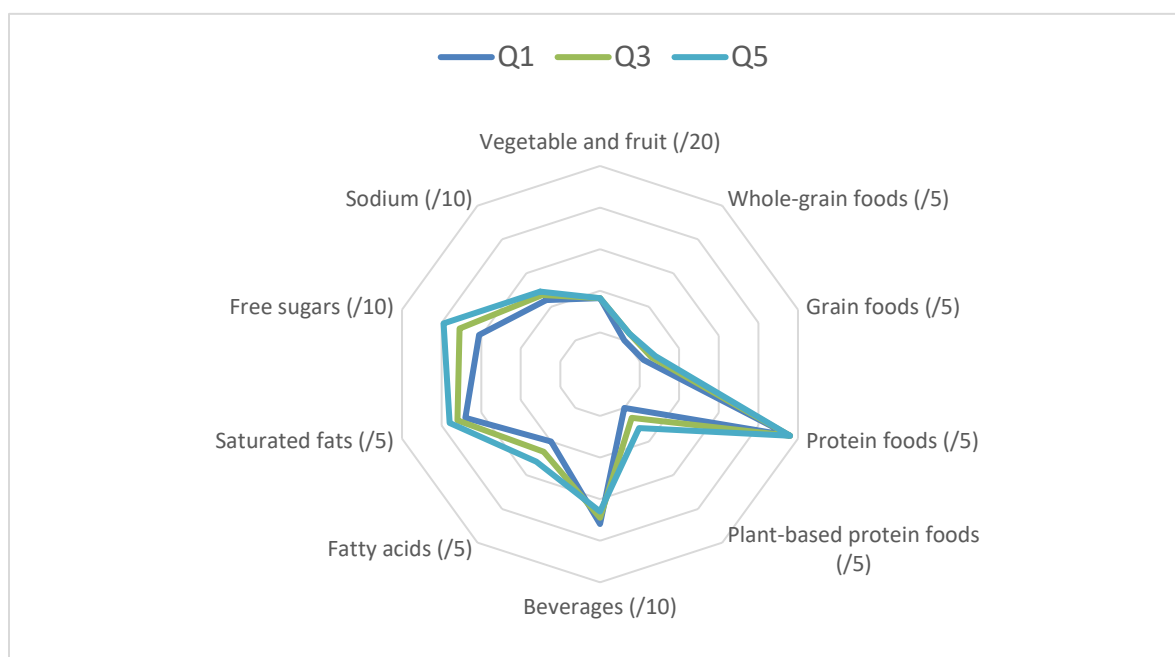


Figure 7: Radar plot for mean HEFI-2019 component scores for males, 19-30 years, using the 2015 CCHS-Nutrition Public Use Microdata File.

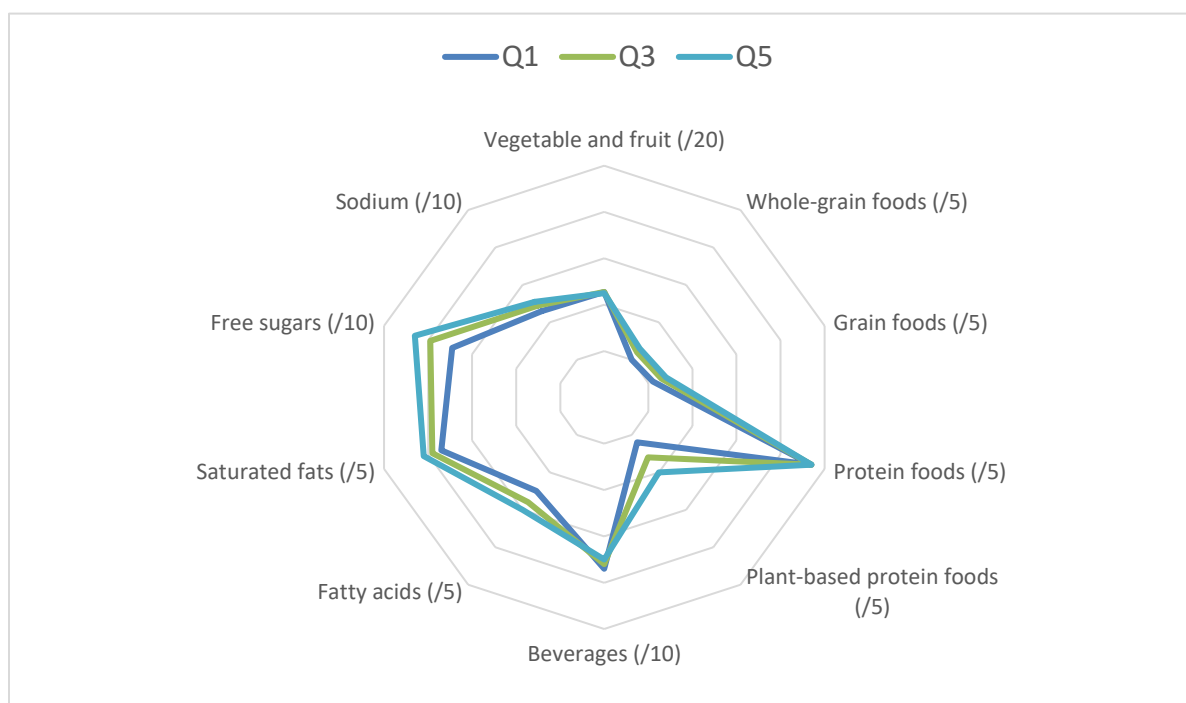


Figure 8: Radar plot for mean HEFI-2019 component scores for males, 31-50 years, using the 2015 CCHS-Nutrition Public Use Microdata File.

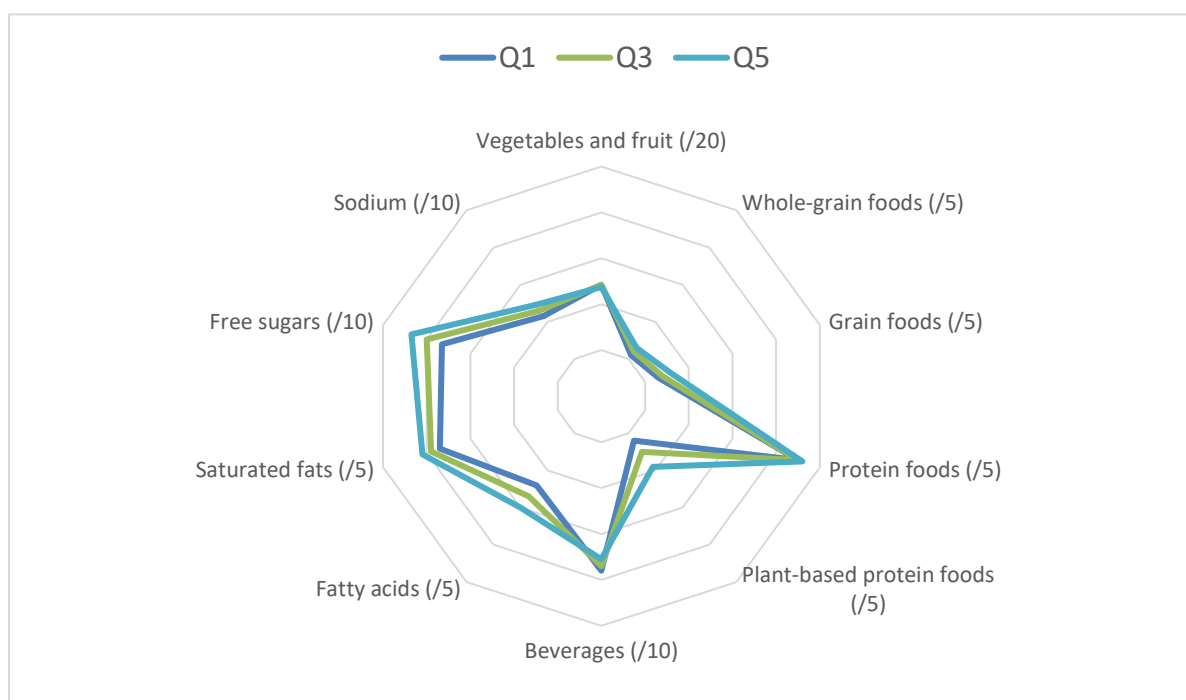


Figure 9: Radar plot for mean HEFI-2019 component scores for males, 51-70 years, using the 2015 CCHS-Nutrition Public Use Microdata File.

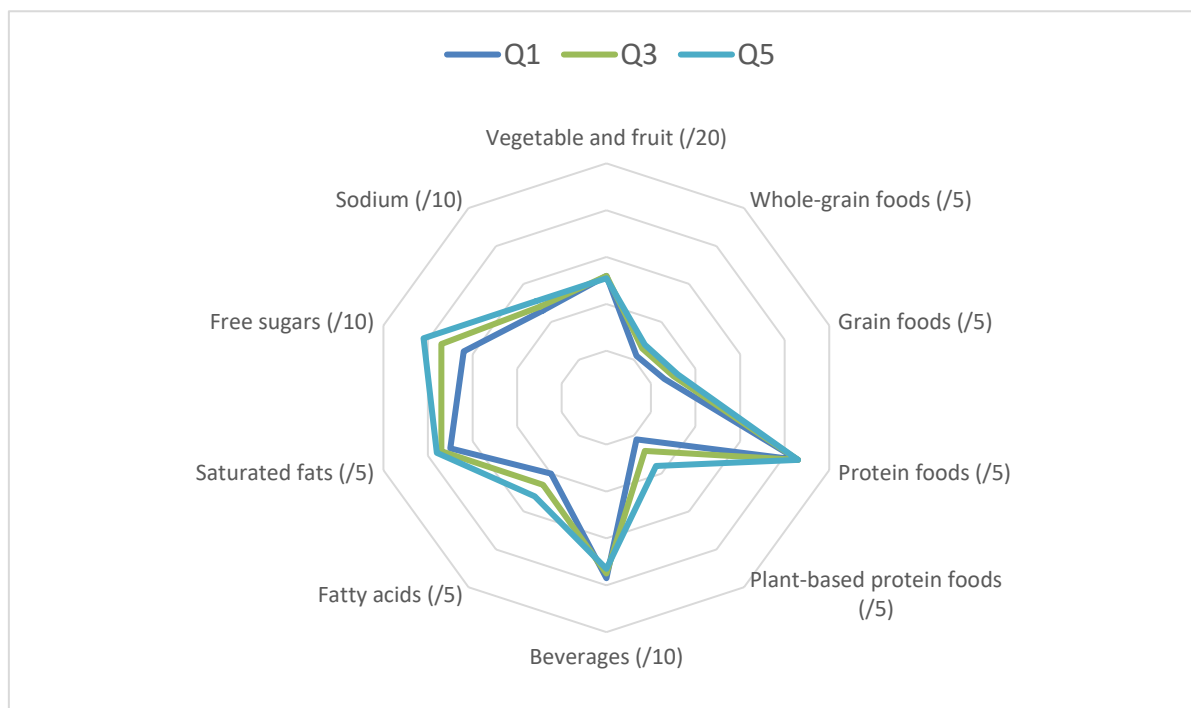


Figure 10: Radar plot for mean HEFI-2019 component scores for males, 71 years and above, using the 2015 CCHS-Nutrition Public Use Microdata File.

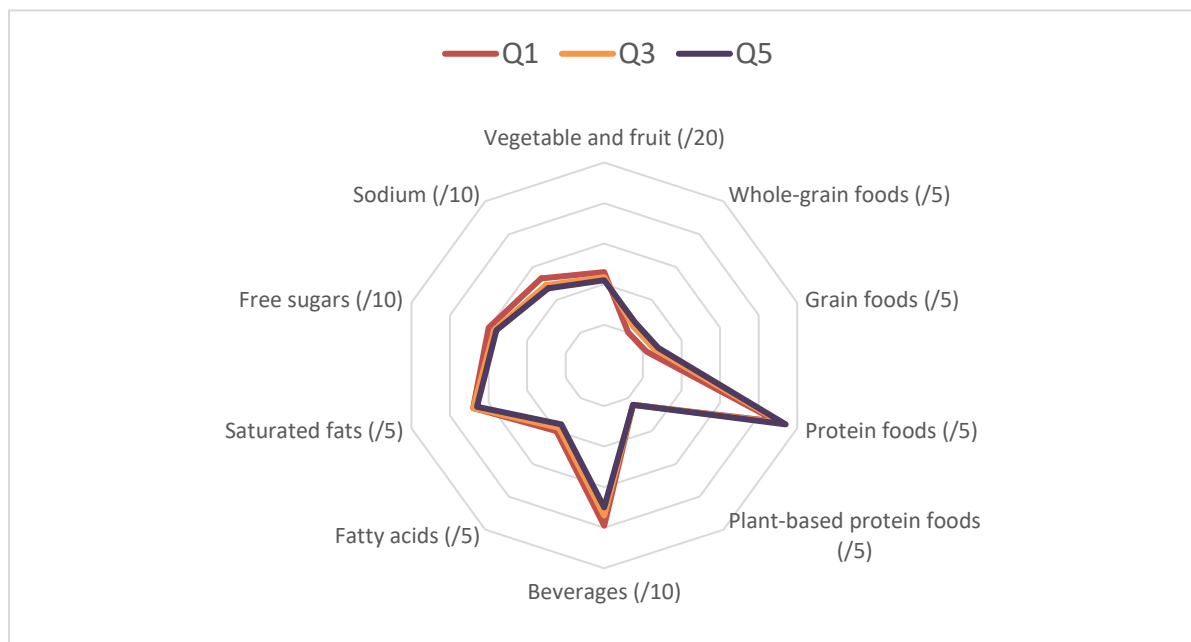


Figure 11: Radar plot for mean HEFI-2019 component scores for females, 14-18 years, using the 2015 CCHS-Nutrition Public Use Microdata File.

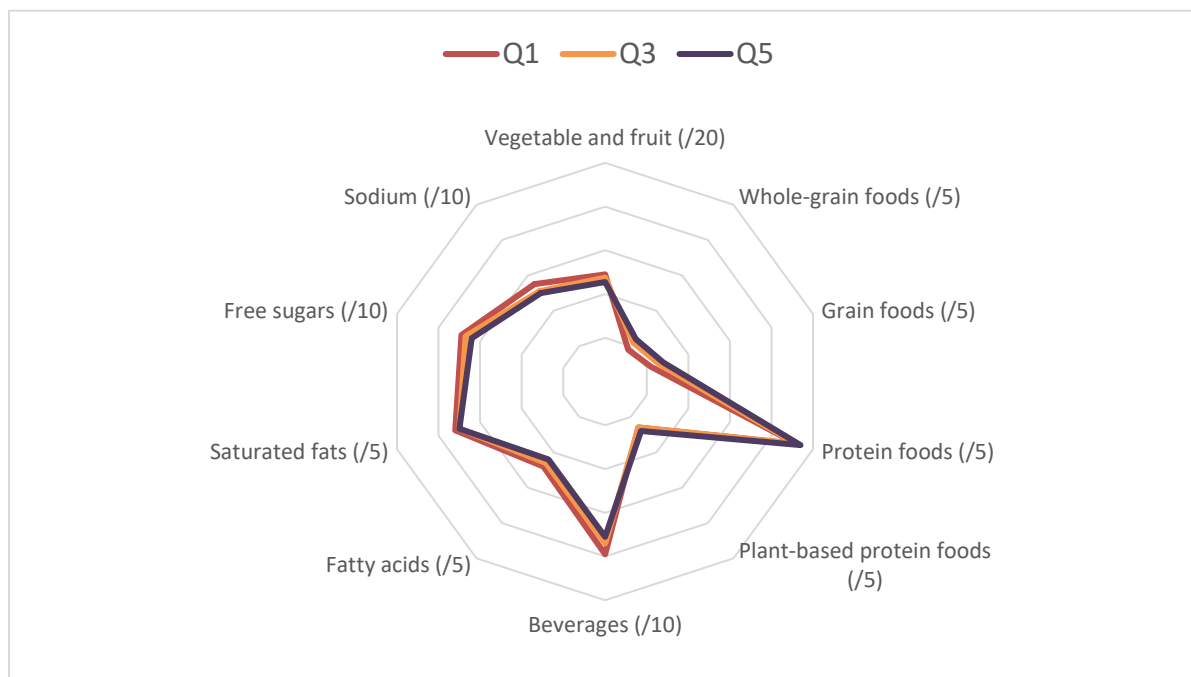


Figure 12: Radar plot for mean HEFI-2019 component scores for females, 19-30 years, using the 2015 CCHS-Nutrition Public Use Microdata File.

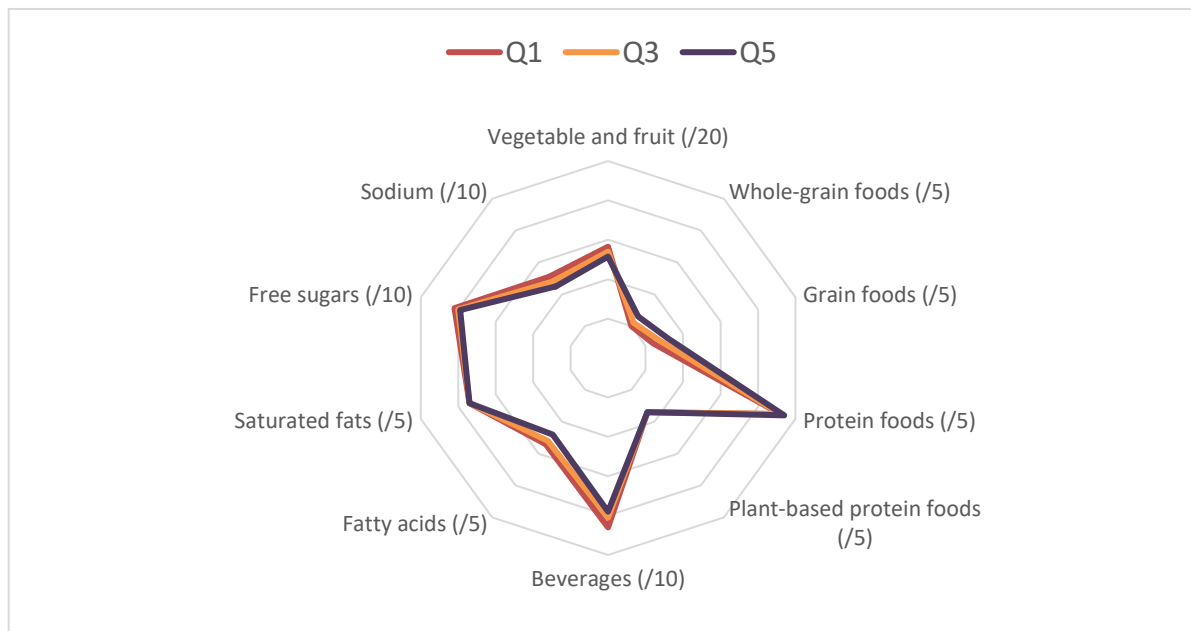


Figure 13: Radar plot for mean HEFI-2019 component scores for females, 31-50 years, using the 2015 CCHS-Nutrition Public Use Microdata File.

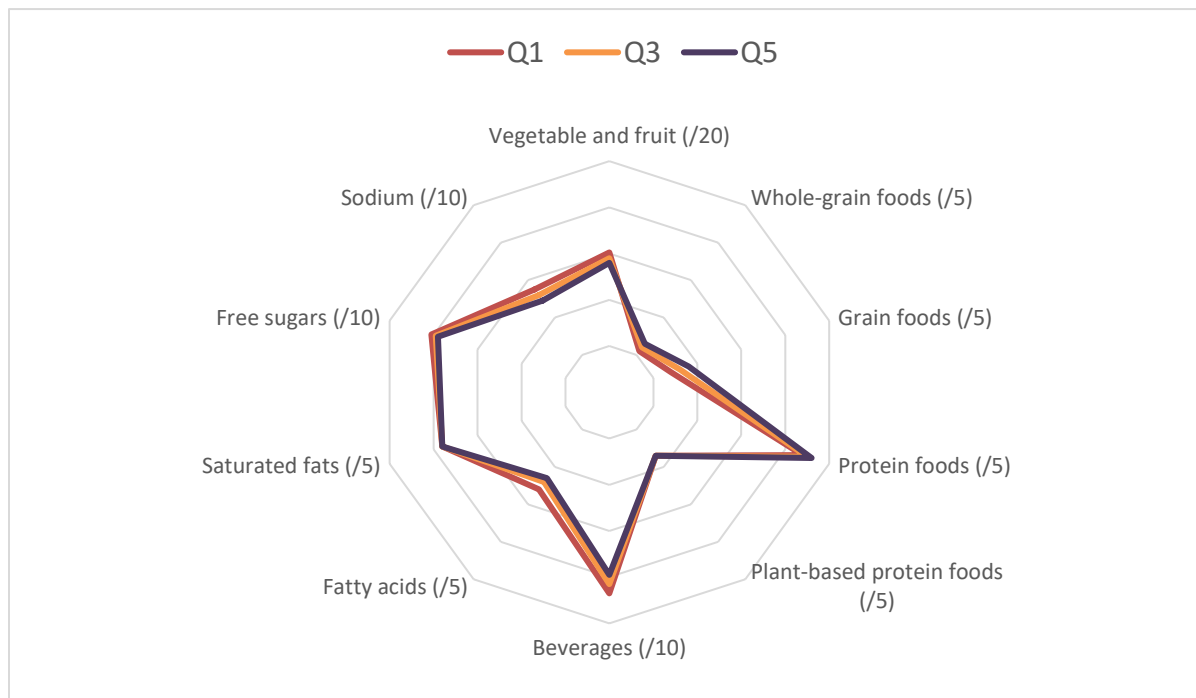


Figure 14: Radar plot for mean HEFI-2019 component scores for females, 51-70 years, using the 2015 CCHS-Nutrition Public Use Microdata File.

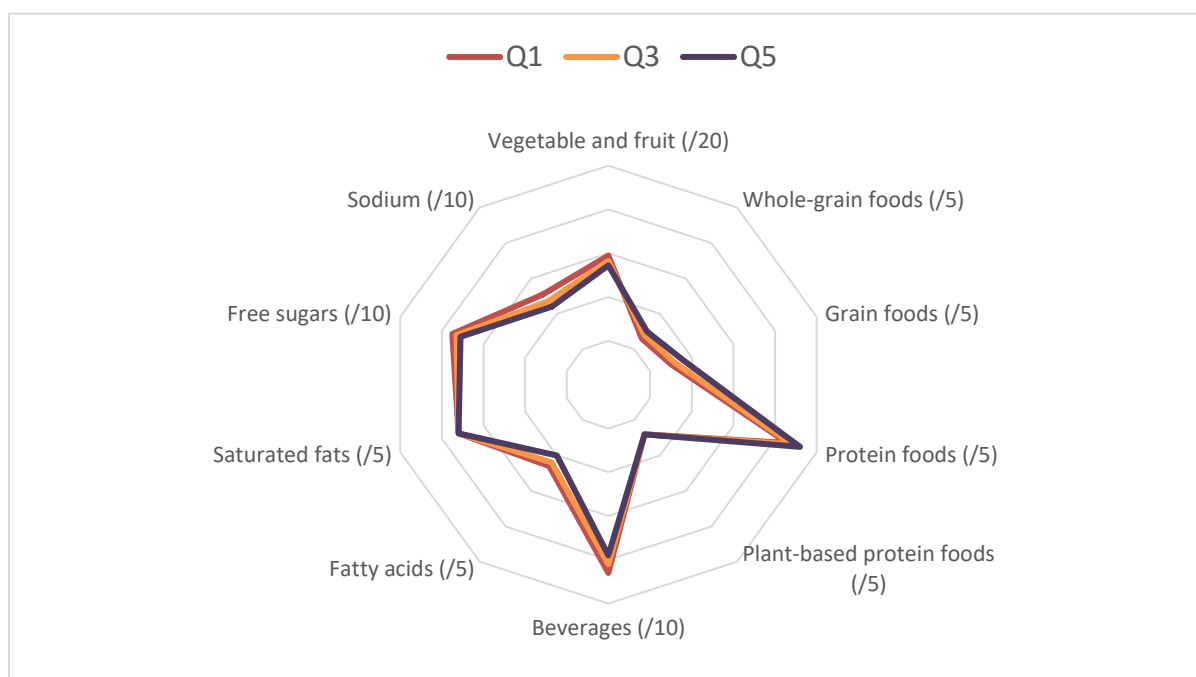


Figure 15: Radar plot for mean HEFI-2019 component scores for females, 71 years and above, using the 2015 CCHS-Nutrition Public Use Microdata File.

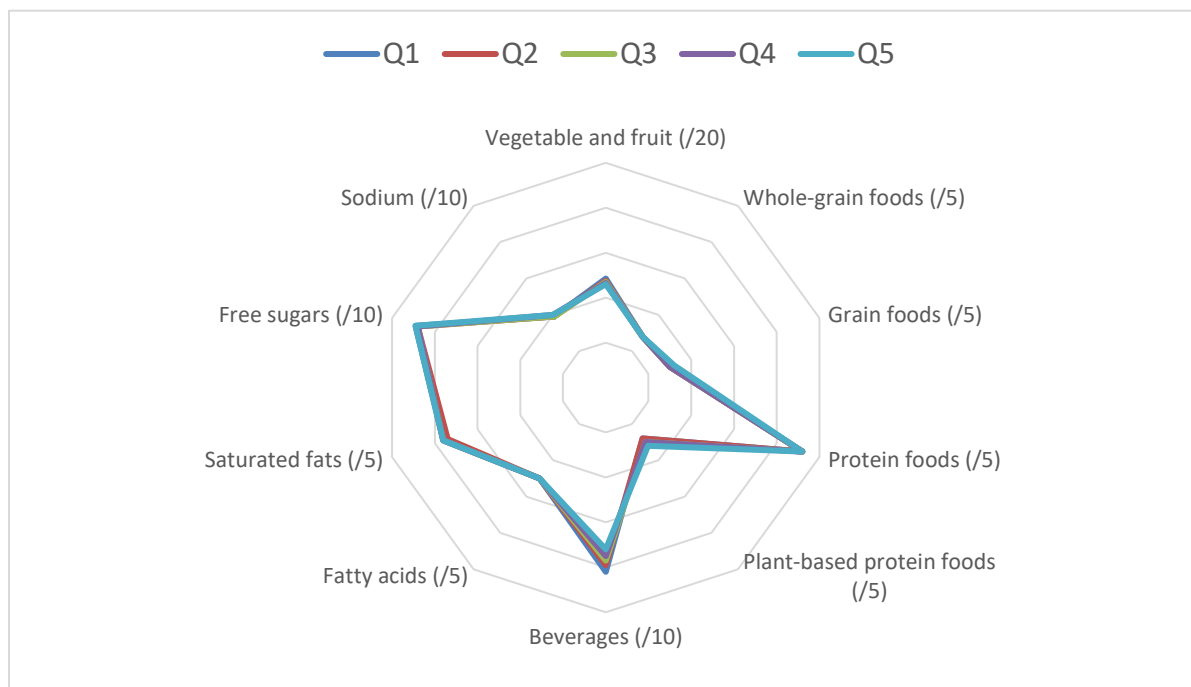


Figure 16: Radar plot for mean HEFI-2019 component scores for males, 19 years and above, with diabetes, using the 2015 CCHS-Nutrition Public Use Microdata File.

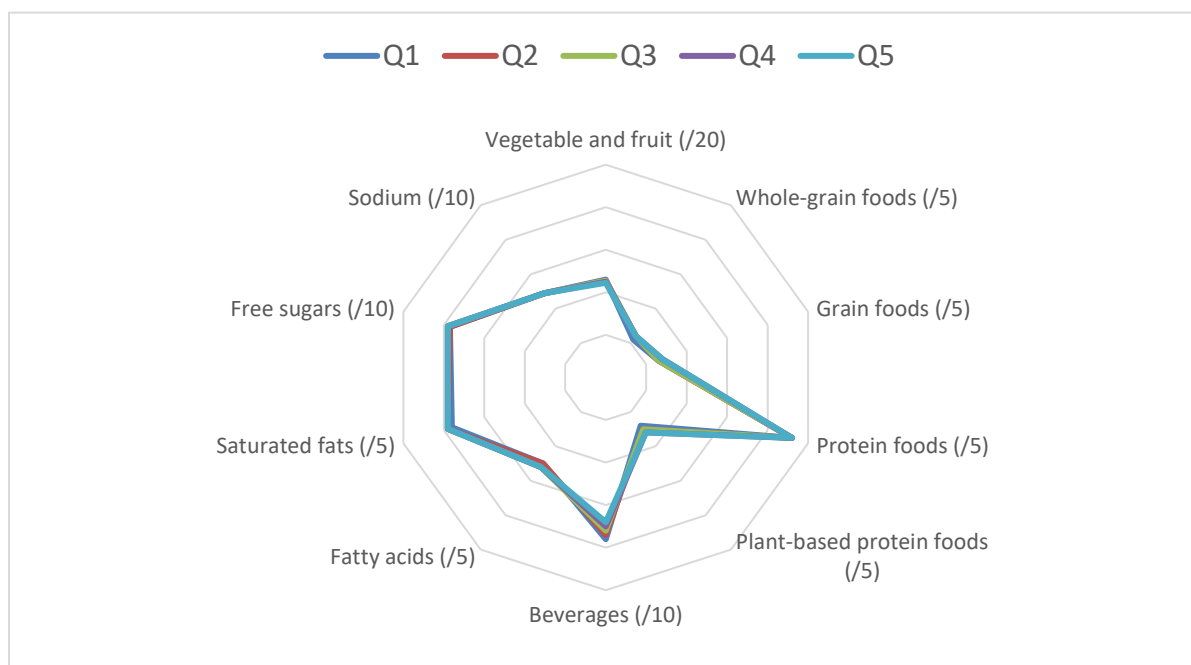


Figure 17: Radar plot for mean HEFI-2019 component scores for males, 19 years and above, without diabetes, using the 2015 CCHS-Nutrition Public Use Microdata File.

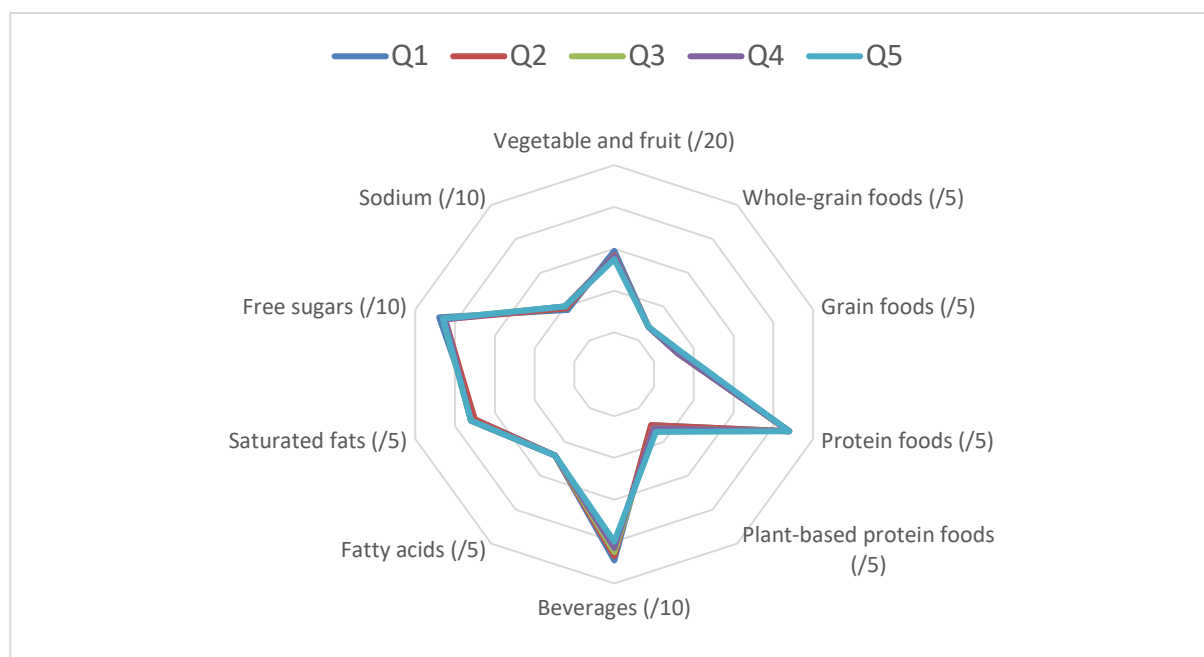


Figure 18: Radar plot for mean HEFI-2019 component scores for females, 19 years and above, with diabetes, using the 2015 CCHS-Nutrition Public Use Microdata File.

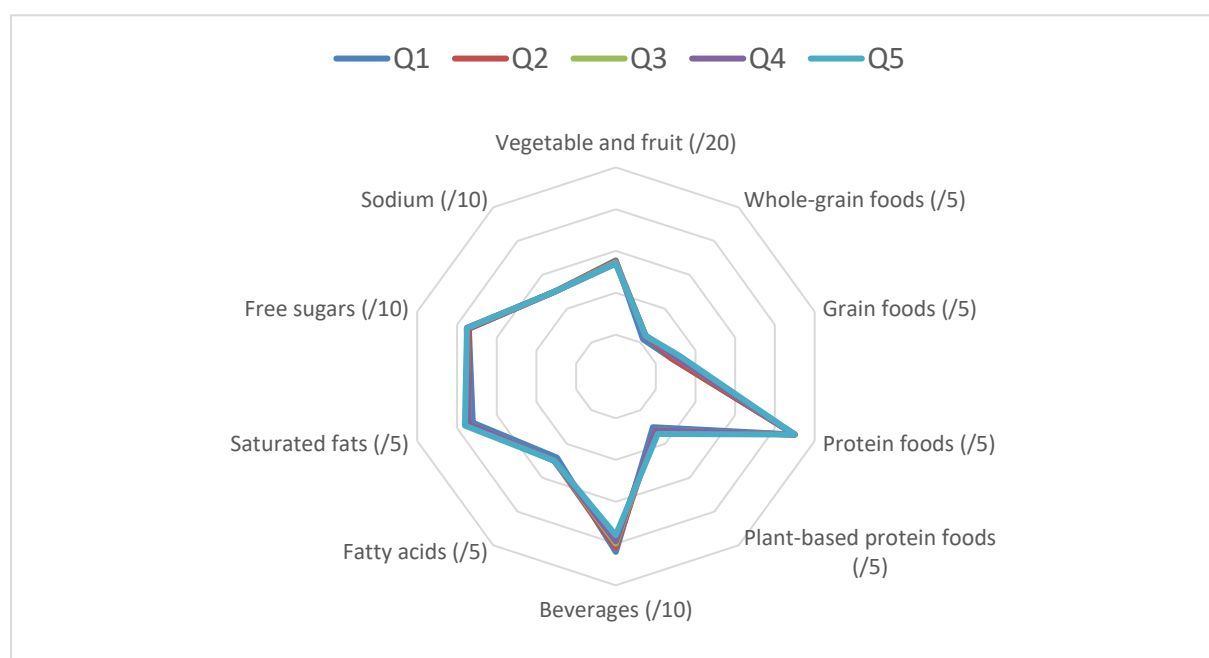


Figure 19: Radar plot for mean HEFI-2019 component scores for females, 19 years and above, without diabetes, using the 2015 CCHS-Nutrition Public Use Microdata File.

Chapter 8

General Discussion

8.1 Overview

Poor dietary patterns are a major contributor to chronic disease morbidity and mortality globally (6). Replacing added sugars with low- and no-calorie sweeteners is becoming increasingly common both in the food supply and among individuals. Although low- and no-calorie sweeteners approved for use are considered safe from a toxicological perspective, their long-term impacts on health and chronic disease risk are a subject of ongoing debate. Given the crucial role diet plays in health and well-being, many governments and health authorities have implemented public health initiatives to improve dietary patterns, including reducing free and added sugars intake. However, there is mounting evidence indicating subsequent increases in low- and no-calorie sweeteners as an unintended consequence (23,229,230), and questions remain as to whether these free and added sugars-initiatives should also target low- and no-calorie sweeteners.

This dissertation addressed important considerations to support decision-makers in providing population-level recommendations in relation to low- and no-calorie sweeteners. The main objectives were to 1) summarize evidence from high-quality systematic reviews examining associations between consumption of low- and no-calorie sweeteners and chronic conditions and intermediate risk factors; 2) develop a standardized approach to classify food codes used in nutrition surveillance in Canada as sources of low- and no-calorie sweeteners; 3) estimate the proportion of individuals in Canada reporting the consumption of sources of low- and no-calorie sweeteners or tabletop sweeteners on a given day; 4) characterize the nutrition profiles of sources of low- and no-calorie sweeteners; and 5) assess diet quality in relation to the probability of consuming low- and no-calorie sweeteners among individuals in Canada.

8.2 Summary of key findings

8.2.1 Chapter 4

Chapter 4 presents a rapid review of systematic reviews of randomized and non-randomized clinical trials and observational studies investigating associations between low- and no-calorie sweetener consumption and health outcomes of public health importance and their

intermediate risk factors in adults and children. This research was undertaken for stakeholders at Health Canada to inform proposed regulations to restrict the advertising of certain foods and beverages to children (258). Given that decision-makers require evidence to inform policy, and these decisions often occur in short timeframes (130), it was determined that a rapid review of already synthesized evidence was the most appropriate and useful review. A preliminary search of the available evidence returned numerous systematic reviews. Therefore, it was further decided that a focus on the best available relevant systematic reviews and meta-analyses completed in the last 5-years (of the review period) would provide the most up-to-date evidence. Of the systematic reviews and meta-analyses included in the rapid review, most were conducted in the latter part of the review period, indicating a growing interest in synthesizing the evidence on the health effects of low- and no-calorie sweetener consumption.

A key finding from the rapid review was the seemingly divergent associations reported in randomized controlled trials, and non-randomized trials and observational studies, with findings from randomized controlled trials indicating beneficial or neutral associations, particularly with anthropometric-related outcomes such as weight gain/loss and obesity. In contrast, findings derived from non-randomized studies, many of which were prospective cohort studies, indicated detrimental or neutral associations for outcomes of interest, including weight and obesity and type 2 diabetes. Since the publication of the rapid review, several systematic reviews and meta-analyses of both randomized controlled trials and prospective cohort studies have been published. Similar to the findings of the rapid review, systematic reviews and meta-analyses of randomized controlled trials report beneficial (or positive linear) associations between low- and no-calorie sweetener consumption and lower weight and risk of obesity among both children and adults (259,260) and glycaemic and insulinemic effects among adults (261), while systematic reviews and meta-analyses of prospective cohort studies continue to suggest an increased risk of poorer cardiometabolic health, including cardiovascular disease and type 2 diabetes, and consumption of low- and no-calorie sweeteners (262–266).

Methodological differences between included primary studies and between systematic reviews were identified and contributed to different conclusions and interpretations. Many of these differences stemmed from different research questions within the primary studies, which subsequently informed methodological approaches, including study design, how low- and no-

calorie sweetener exposure was characterized and measured (i.e., dietary assessment methods), and the selected comparators or contrasts to the exposure (i.e., sugar-sweetened alternatives versus an unsweetened placebo control). These heterogeneities likely contributed to inconsistent findings observed in both randomized controlled trials and non-randomized studies, challenging clear policy directions on the use of low- and no-calorie sweeteners, including within dietary recommendations for health and well-being. Considering the consistently strong evidence suggesting detrimental impacts of excess consumption of free and added sugars, particularly from sugar-sweetened beverages (267,268), continued research examining low- and no-calorie sweetener consumption and human health outcomes, such as cardiometabolic disease, is warranted, with particular attention to minimizing methodological approaches that could introduce potential biases.

A key consideration consistently noted as a limitation of the findings from the included systematic reviews of prospective cohort studies was reverse causality, specifically in relation to body mass index (BMI). Defined as “the situation in which the outcome affects the exposure, rather than the other way around” (254), the adverse associations observed between consumption of low- and no-calorie sweeteners and cardiometabolic outcomes may be artifacts of reverse causation (67,176). Furthermore, the manner in which the exposure (i.e., low- and no-calorie sweeteners) is assessed is an important methodological consideration. If the assessment of low- and no-calorie sweeteners was only conducted at baseline, then observed associations are in relation to a diet that is static and does not change over the course of the study period, a strong and likely unrealistic assumption (254). Instead, researchers should consider conducting a change (in exposure) analysis or substitution analysis (67). Change analyses, in which exposure to low- and no-calorie sweeteners intake is assessed multiple times over the course of the study period (67), likely provide a better reflection (than baseline assessments) of the true exposure-outcome relationships. Substitution analyses are helpful in assessing the intended impact of replacing foods and beverages sweetened with added sugars with alternatives sweetened with low- and no-calorie sweeteners (67). While not commonly used, results from prospective cohort studies employing these methods suggest beneficial effects in relation to cardiometabolic outcomes (269,270).

In addition to the incongruent findings due to study design, the rapid review of systematic reviews highlighted the limited research examining associations between consumption and overall diet quality. Analyses described in chapters 6 and 7 were conducted to address this evidence gap using data from Canada's national nutrition survey. However, before examining the prevalence of exposure to and sources of low- and no-calorie sweetened foods and beverages (Chapter 7) and diet quality (Chapter 8), a process of classifying foods and beverages as sources of low- and no-calorie sweeteners (reported in the 24-hour dietary recalls) was required.

8.2.2 Chapter 5

Chapter 5 describes the three-step, text-based search strategy that was applied to dietary recall data from the 2015 Canadian Community Health Survey—Nutrition Public Use Microdata File (2015 CCHS—Nutrition). A text-based search strategy was required as the amount of low- and no-calorie sweeteners is not currently a component captured in Canada's national food composition database.⁵ A total of 76 (1.5%) food codes from Canada's 2015 food composition database were classified as sources of low- and no-calorie sweeteners. Of these, fewer than half (n=35; 46%) contained a confirmatory keyword in their food code description. Of the 41 (54%) food codes with possible source keywords in their description, most were classified as sources of low- and no-calorie sweeteners based on the online verification process (i.e. step three of the three-step approach) and expert opinion.

An additional 46 recipe codes in the 2015 CCHS—Nutrition were identified as containing a source of sweetener as an ingredient for one or more respondents. Identifying these recipes as sources of low- and no-calorie sweeteners required an examination of the ingredient-level food codes for classified sources of sweeteners, as the recipe code descriptions did not contain either a confirmatory or possible source keyword. In these cases, the recipe code was modified by the coder during the 24-hour dietary recall in the 2015 CCHS—Nutrition. Because the modification was specific to a respondent, the recipe code could not automatically be classified as a source of low- and no-calorie sweeteners. For future analyses that seek to examine

⁵ Canada's food composition database is comprised of the Canadian Nutrient File and a complimentary recipe data file. It is updated for each CCHS—Nutrition survey to accurately reflect foods and beverages reported in the 24-hour dietary recalls.

the prevalence of consumption of foods and beverages containing low- and no-calorie sweeteners, it will be important to examine the ingredient-level food code descriptions of a recipe for possible sources of low- and no-calorie sweeteners and not rely solely on the recipe food code description, particularly in circumstances in which the ingredient-level food code data are removed to prevent double-counting. Otherwise, analyses may underestimate exposure.

8.2.3 Chapter 6

The classification of food codes as sources of low- and no-calorie sweeteners was used to estimate exposure from foods, beverages and tabletop sweeteners among individuals in Canada. This study is the first, to our knowledge, to characterize such exposures. Results indicated that exposure was prevalent among children, adolescents, and adults, with 8.4% (of 4,573 children), 10.7% (of 1,995 adolescents), and 19.8% (of 13,915 adults), respectively, reporting consumption of low- and no-calorie sweeteners from foods, beverages, or tabletop sweeteners. Similar to findings from the U.S. (64,72,122) and Australia (79), the prevalence was higher among older individuals. Also, in line with prior research (79), adults with diabetes had a higher prevalence of exposure from any source of low- and no-calorie sweeteners compared to those without diabetes (40% vs. 18%). There was little to no evidence to suggest the prevalence of exposure differed by sex, a finding not in line with prior research that has indicated consistently higher prevalence among women compared to men (64,72,79,122). Further, there was also little to no evidence indicating higher-income groups had a higher prevalence of exposure compared to lower-income groups, as has been suggested in research conducted in the U.S. (64,72,122) However, this may be due in part to the income categories created based on the household income ranges available in the public-use data file used for the analyses. It was not possible to use a measure of household income that accounts for household composition, such as the Low-Income Measure (LIM) (271). This measure is a preferred representation of low income because measures are adjusted for household expenditures, such as rent/mortgages and utilities, which account for a greater proportion of income for individuals and families living with low incomes (271).

When examining low- and no-calorie sweetener exposure by source type, diet sodas were the beverage type most frequently consumed by children, adolescents, and adults. Low- and no-calorie sweetened yogurts were the most frequently reported food type among children, whereas meal replacements (many of which were protein powders reconstituted with water, milk, or

juice) were the most frequently reported food type among adolescents and adults. According to the 2019 Canada Food Guide Food Classification System (215), no source of low- and no-calorie sweeteners was considered ‘foundational’, i.e., consistent with foods recommended in Canada’s Food Guide, as indicated by an assignment to Tier 1. While most foods were assigned to Tier 3 (i.e., foods that contribute to excess intake of saturated fats, sugars, and/or sodium), some foods, such as yogurts and diet sodas, were assigned to Tier 2 (i.e., foods that are not considered nutritious in Canada’s healthy eating recommendations but do not contribute to high intakes of saturated fats, sugars, or sodium).

8.2.4 Chapter 7

Chapter 7 extends our understanding of the relationship between low- and no-calorie sweetener consumption and healthy eating by jointly modelling diet quality conditional on the probability of consuming low- and no-calorie sweeteners. This research is a novel contribution to the evidence base, both in terms of the methodological approach and in our understanding of how diet quality, estimated based on long-term average intakes, relates to probability of consuming low- and no-calorie sweeteners from foods, beverages, and tabletop sweeteners. This approach is different from previous research that has examined diet quality using surveillance data collected using 24-hour dietary recalls in that respondents were not categorized as either consumers or non-consumers based on a single or even two recalls. Instead, a multivariate approach was used to estimate diet quality scores, using the Healthy Eating Food Index-2019 (HEFI-2019), based on simulated distributions of usual intake conditional on the probability of consuming low- and no-calorie sweeteners.

We hypothesized that diet quality would be lower with higher probabilities of consuming low- and no-calorie sweeteners. This was partially supported when considering children 2 to 13 years of age but not when considering other age and sex groups. Among children 2 to 13 years, both males and females, there was weak evidence ($P=0.08$) of lower HEFI-2019 total scores (-6.1 points, 95% CI: -13.1, 0.8) with the highest probability of consuming low- and no-calorie sweeteners compared to children with the lowest probability of consuming low- and no-calorie sweeteners. Among males 14 years and above, we observed moderate evidence ($P=0.04$) of higher HEFI-2019 total scores (4.6 points, 95% CI: 0.1, 9.1) among those with the highest probability of consuming low- and no-calorie sweeteners compared to those with the lowest

probability to consume. Among females 14 years and above and adults 19 years and above with and without diabetes, there was no evidence of meaningful differences in HEFI-2019 total scores.

Low- and no-calorie sweeteners are marketed as a strategy to help individuals reduce added sugars intake. However, the findings from this study using data from free-living individuals were not consistently in support of this notion. In particular, HEFI-2019 free sugar scores appeared to be lower among children aged 2 to 13 years with a higher probability of consuming sweeteners, although the mean score was generally low regardless of probability to consume sweeteners, indicating poor adherence to Canada's free sugar guidance.

8.3 Overall strengths and limitations of this dissertation

This dissertation makes several important contributions to the low- and no-calorie sweetener evidence base. However, results from each study should be interpreted in relation to their methodological strengths and limitations. An overall strength of this dissertation was the involvement of stakeholders at Health Canada in key aspects of research design and analysis. Beginning with the rapid review, which was conducted to inform Health Canada's proposed regulations to restrict the advertising of certain foods and beverages to children, analytic decisions for Chapters 5, 6, and 7 were made so results would be as policy relevant as possible. Key stakeholders at Health Canada were consulted on multiple occasions and, in the case of Chapter 5, a representative was a co-author on the manuscript.

In Chapter 4, a rapid review was identified as the most appropriate study design given the intended audience, policymakers at Health Canada, and the timeframe for completion. A key strength of the rapid review was the quality appraisal of systematic reviews and the inclusion of only high- and moderate-quality reviews in the synthesis of findings. The purpose of the rapid review was to translate the available evidence for decision-makers to inform public health nutrition policy. By excluding systematic reviews that were assessed as either low- or critically low from a methodological perspective, findings presented in the rapid review constitute the best available evidence upon which policy decisions can be made. Given the abundance of systematic reviews and meta-analyses available (at the time of the rapid review and since its publication) and the inconsistent public health messaging and dietary guidance about the safety and

usefulness of low- and no-calorie sweetened foods and beverages, a concerted effort to examine methodological differences among systematic reviews and meta-analyses may be warranted. Ideally, this would take the form of umbrella reviews because they focus on multiple systematic reviews and meta-analyses (272) and include at least two reviewers completing each relevant step. Careful attention should be paid to the consistency of evidence from studies with similar methodological and design approaches (67).

While our rapid review was systematic as an approach, steps in a systematic review that often require two independent reviewers were streamlined to include one reviewer. This is a generally accepted ‘time saver’ noted in rapid review guidance documents (130) that aids completion in a timely manner. In the present rapid review, a single reviewer was used for the title and abstract review, full-text screening, quality appraisal, and data extraction of full-text steps. Having only a single reviewer could potentially increase the risk of error of not identifying and selecting relevant reviews. However, measures were put in place to minimize these errors. For example, 10% of the original records returned were screened by a second reviewer to ensure appropriate application of the inclusion and exclusion criteria. Further, all quality appraisals and data extraction entries from the included systematic reviews and meta-analyses were verified by a second individual.

A key strength of Chapters 5, 6, and 7 is the use of the 2015 CCHS—Nutrition, which provides representative estimates of the prevalence of low- and no-calorie sweetener consumption on a given day. A strength of Chapter 5 was the systematic and multi-pronged approach to classifying food codes as sources of low- and no-calorie sweeteners in Canada’s national food composition database. The use of the HEFI-2019, which reflects current dietary guidance, in Chapter 7 was also a strength of this dissertation. Further, the application of the NCI multivariate MCMC method accounted for the multidimensional and correlated aspects of dietary components and estimated long-term average daily intakes (247).

An important limitation specific to these chapters, stems from the inherent limitations of food composition databases, both generally and specifically to classifying low- and no-calorie sweetened foods and beverages. Ideally, food codes within composition databases would contain data on the presence and amounts of low- and no-calorie sweeteners. However, this is not the case. To overcome this challenge, a three-step classification method was developed to identify

sources of low- and no-calorie sweeteners. While expanding the available information to make decisions about food codes, the online verification (i.e., Step 3 of 3) of possible source food codes occurred in 2022, seven years after the 2015 CCHS—Nutrition was conducted. Considering how quickly product availability changes due to consumer demand and product reformulation tending toward a greater availability of products sweetened with low- and no-calorie sweeteners, there was the possibility of misclassifying a food code as a source of low- and no-calorie sweeteners based on products available in 2022. However, for some possible source keywords, this was less of a concern. For example, for some sweet foods and beverages, the food code contains keywords such as “no added sugar” or “sugar-free.” In these instances, the sweetness of these foods likely comes from low- and no-calorie sweeteners, as there was no other plausible sugar source to impart sweetness. Nonetheless, the classification of food codes as sources of low- and no-calorie sweeteners was used in both Chapters 6 and 7 and may have resulted in underestimating or overestimating sources, although the resulting direction and magnitude of misclassification is unknown. Potential errors would also be reflected in estimates generated in prevalence estimates (Chapter 6) and diet quality (Chapter 7). Lastly, an important limitation relevant to Chapters 6 and 7 was the lack of consideration of race and ethnicity; however, this variable was not included in the 2015 CCHS—Nutrition Public Use Microdata File. Because race and ethnicity have previously been reported as important correlates of consumption (208), examination of diet quality in relation to the probability of consuming low- and no-calorie sweeteners stratified by race and ethnicity using the 2015 CCHS—Nutrition master file, in which race and ethnicity are available, is warranted.

8.4 Implications for policy and future research

8.4.1 Implications for public health nutrition policy

The findings from this dissertation have several implications for public health nutrition policy and future research. First, in Chapter 5, we developed a method of classifying food codes in Canada’s national food composition database. By publishing details of this approach, other researchers examining low- and no-calorie sweeteners using the 2015 CCHS—Nutrition or other sources of dietary intake data coded using Canada’s national food composition database can

classify food codes in a similar manner, which will facilitate comparisons across research studies.

Although the use of low- and no-calorie sweeteners may be viewed as a method of reducing free and added sugars, the HEFI-2019 free sugars score among children 2 to 13 years was poorer among those with higher probabilities of consuming low- and no-calorie sweeteners. This difference, however, was not consistently observed across all subgroups. A higher free sugars score (indicating better alignment with the guidance on free sugars intake) was observed among males 14 years and above but not among females 14 and above or among all adults aged 19 years and above, either with or without diabetes. These diverging findings raise questions about how low- and no-calorie sweetened products are consumed by different subgroups, and how factors, such as perceptions and motivations, influence decisions to consume low- and no-calorie sweetened products.

Understanding how and by whom low- and no-calorie sweeteners are consumed provides important contextual data to inform policies and interventions (273). For example, the motivations for adolescents' use of meal replacements and protein powders containing sweeteners, which may displace other nutritious foods required for healthy growth and development, warrant attention. Because the use of these supplements may signal the development of disordered eating behaviours to modify weight and/or body shape (274), understanding the motivations of adolescents can inform early interventions targeting both healthy eating and healthy weight. According to a recent analysis by Ganson et al. (275), the consumption of meal replacements, including protein powders, may be an indication of weight gain efforts to enhance muscularity. While observed among both men and women, one study among young adults in Canada estimated the prevalence of this muscularity-oriented eating pattern to be almost four times higher among young adult men than women (276). Given the health implications of disordered eating behaviours (277), a better understanding of the motivations driving the consumption of these products can inform nutrition and public health interventions to improve overall diet quality and general health and well-being.

With Health Canada focusing on reducing free sugars intake to improve diet quality and overall health, it will be important to monitor and evaluate policy interventions that target free sugars intake across life stage and by sex. For example, Health Canada has expanded its suite of

labelling requirements to include front-of-package warning symbols to target foods and beverages high in saturated fat, sugar and sodium (278). Whether these interventions will encourage industry reformulation in Canada, resulting in increased availability of products sweetened with low- and no-calorie sweeteners as observed in Chile (230), with subsequent effects on population-level dietary intakes, is not yet known. Some jurisdictions, such as Mexico, have included warning labels cautioning against the consumption of low- and no-calorie sweeteners by children and adolescents as part of their suite of nutrition labelling policies (233). To date, only one known study has investigated the impact of these warning labels (279). Using a randomized experimental design conducted one month after the labelling regulations were fully implemented, Arellano-Gómez et al. (279) report reduced perceptions of the healthfulness of fruit drinks containing the warning label among Mexican adolescents and adults (14 years and above) randomized to the warning label groups compared to adolescents and adults in the non-warning label group. This study did not, however, examine the impact of these warning labels on actual purchasing or consumption behaviours (279), reinforcing the importance of routine monitoring and evaluation of such public health nutrition policies.

While a comprehensive examination by sweetener type was not possible in this dissertation, given the lack of specificity in Canada's national food composition database, monitoring of low- and no-calorie sweetener availability and consumption to ensure intake beyond the acceptable daily intake (ADI) is not exceeded is warranted, particularly given global estimates indicating an increase in the availability of low- and no-calorie sweeteners in the food supply (203). An important caveat is that monitoring efforts within Canada cannot be at the level of specific low- and no-calorie sweeteners, given recent regulatory amendments to phase out the requirement to list the quantity of sweetener on nutrition ingredient lists (280,281). While this regulatory change prevents an examination of population-level intakes in relation to ADI levels, monitoring efforts can occur at the food and beverage level. In Chapter 6, the most frequently consumed sources of low- and no-calorie sweeteners among individuals living in Canada in 2015 were identified, serving as benchmarks for public health nutrition monitoring and policy evaluation efforts.

Findings presented in Chapters 6 and 7 provide new evidence to inform Canada's Healthy Eating Strategy (21). Currently, dietary guidance targeting health professionals and

policymakers states that “there are no well-established health benefits associated with the intake of sweeteners, and nutritious foods and beverages that are unsweetened should be promoted instead” (9). The equivocal findings reported in the rapid review (Chapter 4) support this recommendation for the population at large at this time. In addition, findings from Chapters 6 and 7 provide evidence for policymakers to consider as they move forward with proposed restrictions on the advertising of foods and beverages to children, a second commitment of the Healthy Eating Strategy. Specifically, lower HEFI-2019 total scores were observed among children with a higher probability of consuming low- and no-calorie sweeteners; a similar pattern was observed for HEFI-2019 free sugars scores. Lower HEFI-2019 total scores may signal the displacement of nutritious foods and beverages recommended by Canada’s Food Guide. The displacement of nutritious foods is a concern that others have raised (122). Further, lower HEFI-2019 free sugars scores may indicate that children with a higher probability of consuming low- and no-calorie sweeteners are also more likely to consume foods and beverages sweetened with free sugars. Given that free sugars are a nutrient of concern targeted in the proposed restrictions on advertising to children, findings from Chapter 7 provide evidence supporting restrictions on advertising of foods and beverages sweetened with low- and no-calorie sweeteners.

8.4.2 Future research

Given strong evidence of links between long-term diet quality and health, well-being and the prevention of chronic diseases (61), continued research is needed to confirm associations between the consumption of low- and no-calorie sweeteners and dietary patterns (282,283). While we were the first to model diet quality conditional on the probability of consuming low- and no-calorie sweeteners, the evidence base will be strengthened by additional research that replicates our approach using more current data for Canada, as well as those for other countries. Such work could extend on the novel methods used in Chapter 7. For example, modelling of diet quality conditional on the probability of consuming low- and no-calorie sweeteners could include covariates such as whether sugar-sweetened beverages were consumed. Canada’s Food Guide recommends that individuals reduce their free sugars intake by choosing unsweetened alternatives (9). Modelling diet quality scores in the presence of a covariate indicating sugar-sweetened beverage consumption would enhance understanding of whether diet quality scores

differ in relation to low- and no-calorie sweetener consumption between individuals who consume sugar-sweetened beverages compared to those who do not.

Fundamental to analyses using dietary intake data from national surveillance are the food composition databases, which convert reported consumption of foods and beverages into energy and nutrient values used to assess diet quality. Routine updates to Canada's national food composition database are needed to maintain a more accurate and current representation of the foods and beverages available in the food supply. Updates to these databases are often tied to foods reported consumed in national nutrition surveys, which reflect actual consumption and not simply food availability. In the absence of routine administration of Canada's national nutrition survey, smaller research and surveillance-related activities that monitor the intake of low- and no-calorie sweeteners are worth exploring. Likely costing less to administer (compared to the costs of administering a national survey), smaller-scale surveys may provide more frequent and timely dietary intake data. However, care should be taken to ensure data are representative of the population of interest, including subgroups that have been underrepresented in nutrition surveillance in Canada to date.

Lastly, future research should examine the prevalence of exposure and consumption patterns of low- and no-calorie sweeteners by additional equity-related sociodemographic characteristics. For the present analyses, it was not possible to examine prevalence and consumption by race and ethnicity nor by a more sensitive measure of income. Considering the potential for product reformulation in response to the current policy initiatives targeting free sugars, having baseline estimates of the prevalence of exposure and consumption patterns before Canada's new labelling regulations, such as the "high in" warning symbols, come into full effect could help in understanding if these policy initiatives have inequitable impacts across the population.

8.5 Conclusion

This dissertation contributes to our understanding of the relationship between low- and no-calorie sweetener consumption, diet quality, and human health. With continued public health efforts to reduce free and added sugars consumption, the availability and consumption of low- and no-calorie sweetened foods and beverages are likely to increase. Dietary intake data drawn from national nutrition surveys are helpful in characterizing current consumption patterns of low-

and no-calorie sweetened foods, beverages, and tabletop sweeteners and are an important source of data to identify discrepancies between dietary intakes and dietary guidance. Taken together, this evidence can be used to inform public health nutrition policies and support healthy eating behaviours.

Further, this dissertation sought to provide insights into whether low- and no-calorie sweeteners are helpful or harmful for dietary quality and chronic diseases of public health concern. Based on the findings from the rapid review, the consumption of low- and no-calorie sweeteners may be helpful for some motivated individuals in their efforts to lose weight or maintain weight loss; however, the evidence is unclear on how helpful or harmful these products are as it relates to the development of non-communicable chronic diseases. Chapter 6 provided insight into the food and beverage sources of low- and no-calorie sweeteners, none of which are considered nutritious foods according to Canada's Food Guide. Based on the findings from the diet quality study, it is unclear how helpful or harmful the consumption of low- and no-calorie sweetened foods and beverages is among individuals 14 years and above. However, there does appear to be a potential for harm in relation to diet quality among children 2 to 13 years old, which warrants further research and ongoing monitoring.

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Appendix A

Chapter 4: MEDLINE search strategy

“non sugar”[tw] OR “nonsugar”[tw] OR Non nutritive sweeteners[mesh] OR Aspartame[mesh] OR aspartame[tiab] OR Saccharin[mesh] OR saccharin[tw] OR Cyclamates OR cyclamate*[tw] OR Xylitol[mesh] OR xylitol[tw] OR Stevia[mesh] OR stevia[tw] OR carbonated beverages[mesh:noexp] OR (non nutritive[tw] AND sweeten*[tw]) OR (nonnutritive[tw] AND sweeten*[tw]) OR (intense[tw] AND sweeten*[tw]) OR (artificial[tw] AND sweeten*[tw]) OR (Low calorie[tw] AND sweeten*[tw]) OR low calorie beverage*[tw] OR (non caloric[tw] AND sweeten*[tw]) OR artificial sugar*[tw] OR "sugar free"[tw] OR sugarfree[tw] OR "reduced sugar"[tw] OR sugar substitute*[tw] OR diabetic food*[tw] OR diabetic beverage* OR diet beverage*[tw] OR diet drink*[tw] OR "diet soda"[tw] OR diet soft drink*[tw] OR sucralose[tw]) NOT (animals[mesh] NOT human[mesh]) AND english[la] AND (review[ptyp] OR review[tw] OR meta analysis[ptyp]).

In MEDLINE, [mesh] searches subject headings; [tw] searches title, abstract, mesh headings and subheadings, and author-supplied keywords; [tiab] searches the title and abstract; and [pytp] restricted publication types to reviews and meta-analyses.

Appendix B
Chapter 4 Supplemental Table 1: Quality appraisal of systematic reviews using AMSTAR-2 criteria

	PICO elements described (Y/N)	Review methods established a priori and deviations justified (Y/N/Partial Y)	Study inclusion criteria described (Y/N)	Comprehensive literature search strategy employed (Y/N/Partial Y)	Study selection performed in duplicate (Y/N)	Data extraction performed in duplicate (Y/N)	List of excluded studies and justifications noted (Y/N/Partial Y)	Included studies described in adequate detail (Y/N/Partial Y)	Satisfactory methods for assessing RoB in RCTs and/or NRSI used (Y/N/Partial Y/NA)	Source of funding for individual studies reported (Y/N)	If meta-analysis conducted, appropriate methods for study design used (Y/N/NA)	If meta-analysis conducted, RoB impact of individual studies assessed (Y/N/NA)	RoB of individual studies accounted for when interpreting results (Y/N)	Satisfactory explanation and discussion of heterogeneity observed (Y/N)	If quantitative synthesis performed, PB investigated and possible impact discussed (Y/N/NA)	Conflict of interest including review funding source described (Y/N)
High-quality systematic reviews																
Imamura et al. (2015)	Yes	Partial	Yes	Yes	Yes	Yes	Yes	Partial	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Riley et al. (2015)	Yes	Partial	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
Santos et al. (2018)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Partial	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Wang et al. (2017)	Yes	Partial	Yes	Yes	Yes	Yes	Yes	Partial	Yes	No	NA	NA	Yes	Yes	NA	Yes
Moderate-quality systematic reviews																
Azad et al. (2017)	Yes	Yes	Yes	Yes	Yes	Yes	*No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Greenwood et al. (2014)	Yes	Partial	Yes	Yes	Yes	Yes	*No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reid et al. (2016)	Yes	Yes	Yes	Yes	Yes	Yes	*No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes
Ruanpeng et al. (2017)	Yes	Partial	Yes	Yes	Yes	Yes	*No	Partial	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Toews et al. (2019)	Yes	Yes	Yes	Yes	No	Yes	*No	Partial	Yes	Yes	Yes	Yes	Yes	Yes	NA	Yes

Low- and critically low-quality systematic reviews

Bruyere et al. (2015)	Yes	No	Yes	Partial	No	No	No	Partial	No	Yes	NA	NA	No	No	NA	Yes
Cheungpasitporn et al. (2015)	Yes	No	Yes	Yes	Yes	Yes	*No	Partial	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Chou et al. (2013)	Yes	Partial	Yes	No	Yes	No	*No	Yes	±	Yes	NA	NA	No	No	NA	Yes
Janakiram et al. (2017)	Yes	No	Yes	No	Yes	No	No	No	Yes	No	No	No	No	No	No	Yes
Karalexi et al. (2018)	Yes	Partial	Yes	No	Yes	Yes	*No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lin et al. (2016)	Yes	No	Yes	Yes	No	Yes	*No	Partial	Yes	No	Yes	No	Yes	Yes	NA	Yes
Marghalani et al. (2017)	Yes	Partial	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	NA	No
Miller & Perez (2014)	Yes	No	Yes	No	No	Yes	*No	Partial	No	No	Yes	No	No	Yes	Yes	Yes
Mishra et al. (2015)	Yes	No	Yes	No	No	No	*No	Partial	No	No	NA	NA	No	Yes	NA	Yes
Narain et al. (2017)	Yes	No	Yes	No	Yes	Yes	*No	Partial	Yes	No	No	Yes	Yes	Yes	NA	Yes
Narain et al. (2016)	Yes	No	Yes	Partial	Yes	Yes	*No	Yes	Yes	No	Yes	Yes	Yes	Yes	NA	Yes

Nichol et al. (2018)	Yes	No	Yes	No	Yes	No	No	Partial	No	No	Yes	No	No	Yes	Yes	Yes
Onakpoya et al. (2015)	Yes	No	Yes	Partial	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Rogers et al. (2016)	Yes	No	Yes	Partial	No	Yes	*No	Yes	±	No	Yes	Yes	Yes	Yes	Yes	Yes
Romo-Romo et al. (2016)	Yes	No	Yes	Yes	No	No	*No	Yes	No	No	NA	NA	No	Yes	NA	Yes
Tucker & Tan (2017)	Yes	Partial	Yes	No	Yes	No	No	Partial	No	No	NA	NA	No	No	NA	Yes

RoB = Risk of Bias;
 PB = Publication bias;
 ± = Received a Yes rating for RCT, but No for NRSI;
 Shaded columns refer to critical domains of the AMSTAR-2;
 Unclear or unknown criteria resulted in rating domain as No;
 *No = reviews provided a detailed PRISMA flowchart (i.e., number, and specific reason for exclusions), but did not provide a complete reference list for excluded studies.

Appendix C

Chapter 4 Supplemental Table 2: Review characteristics and key findings of high-quality systematic reviews evaluating low-calorie sweeteners (LCSs) consumption and dental caries prevention outcomes.

Basic information about systematic review (title, authors, year of publication; # of studies)	Search strategies (# and names of databases searched; date ranges of databases search)	Participant characteristics (e.g., age, sex, ethnicity, stage of disease, comorbidities)	Primary and secondary outcomes of interest listed in Methods section	Interventions of interest (e.g., type of intervention; dose; intensity; frequency; duration)	Comparators (or confounders) (e.g., type of comparator; dose, intensity; frequency; duration)	Summary of key findings	Additional information (Rapid review author's comments; systematic review's limitation; methodological quality)
Randomized Control Trials (only)							
Xylitol-containing products for preventing dental caries in children and adults. Riley P, Moore D, Ahmed F, Sharif MO, Worthington HV. 2015. Purpose: Examine the effects of xylitol-containing products in preventing dental caries in children and adults. Included studies: Ten randomized controlled trials.	Databases searched: 1. Cochrane Oral Health Group's Trials Register (to 14 August 2014) 2. Cochrane Central Register of Controlled Trials (CENTRAL) (The Cochrane Library, 2014, Issue 7) 3. MEDLINE via OVID (1946 to 14 August 2014) 4. EMBASE via OVID (1980 to 14 August 2014) 5. CINAHL via EBSCOhost	Children (aged 1 to 2 months; 6 to 35 months; 9 to 15 months; 2 years; 7 to 12 years; 8 to 10 years; 12 to 13 years; first and second grade; fourth grade) and adults (aged 21 to 80 years), generally healthy individuals not undergoing orthodontic treatments. Settings included: clinical centres of university dental schools in US; schools and dental units in Estonia;	Primary: - Change in dental caries increment Secondary: - Quality of life - Satisfaction (patient) - Cost - Adverse outcomes	Xylitol-containing products (any dose); dosage ranged from 200-600 mg – 8 mg per day for orally consumed xylitol or 3-10% xylitol in toothpaste; duration lasting minimum of 1 year.	No intervention (including routine dental care), placebo, and other xylitol-containing products; duration lasting a minimum of 1 year.	Habitual use of a xylitol-containing fluoridated toothpaste may reduce dental caries in permanent teeth of children compared to a fluoride-only containing toothpaste. Evidence was limited and of low quality to suggest positive effects of other xylitol-containing products.	The majority of participants were included in the two meta-analyzed toothpaste studies. Remaining evidence from single studies Majority of studies were assessed at high risk of bias; n=2 at unclear risk of bias and n=1 at low risk of bias. Author's overall ratings for included studies was low to very low quality. Evaluation conducted according to guidelines from the Cochrane Handbook

Basic information about systematic review (title, authors, year of publication; # of studies)	Search strategies (# and names of databases searched; date ranges of databases search)	Participant characteristics (e.g., age, sex, ethnicity, stage of disease, comorbidities)	Primary and secondary outcomes of interest listed in Methods section	Interventions of interest (e.g., type of intervention; dose; intensity; frequency; duration)	Comparators (or confounders) (e.g., type of comparator; dose, intensity; frequency; duration)	Summary of key findings	Additional information (Rapid review author's comments; systematic review's limitation; methodological quality)
AMSTAR-2 rating ⁶ : High.	(1980 to 14 August 2014) 6. Web of Science Conference Proceedings (1990 to 14 August 2014) 7. ProQuest Dissertations and Theses (1861 to 14 August 2014)	schools and dental clinics in Finland; communities in Republic of the Marshall Islands; dental clinics in Sweden (x2); schools in Costa Rica (x2); healthcare centres in Finland; pediatric dental clinic in US.					for Systematic Reviews and Interventions.
Effects of non-fluoride agents on the prevention of dental caries in primary dentition: A systematic review. Wang Y, Li J, Sun W, Li H, Cannon RD, Mei L. 2017. Purpose: Evaluate the effect of non-	Databases searched: 1. MEDLINE 2. Embase 3. Central (Cochrane Library) 4. CBM (Chinese Biological Medical) database 5. CNKI (Chinese National	Young children (both male and female) aged 6 months to 6 years.	Primary: - Change in dental caries increment or new caries, on primary teeth Secondary outcomes: - Adverse outcomes - Quality of life - Satisfaction (patient)	Xylitol tablet (1-2 per day, depending on age); wipes (6 wipes per day); gummy bear (3 times per day). Intervention durations ranged from 3 to 30 months in duration.	No tablet, placebo wipe and placebo gummy bears used. Intervention durations ranged from 3 to 30 months in duration.	Oral agents did not provide any additional benefit to preventing dental caries in children's primary teeth. Xylitol wipes were found to be beneficial, however study limitations warrant caution when interpreting findings.	No meta-analyses conducted; therefore, evidence from single studies is limiting. Two studies assessed were at high risk of bias and one as low risk of bias. Evaluation conducted according to guidelines from the Cochrane Handbook

⁶ AMSTAR-2: A Measurement Tool to Assess Systematic Reviews (Shea et al. 2017)

Basic information about systematic review (title, authors, year of publication; # of studies)	Search strategies (# and names of databases searched; date ranges of databases search)	Participant characteristics (e.g., age, sex, ethnicity, stage of disease, comorbidities)	Primary and secondary outcomes of interest listed in Methods section	Interventions of interest (e.g., type of intervention; dose; intensity; frequency; duration)	Comparators (or confounders) (e.g., type of comparator; dose, intensity; frequency; duration)	Summary of key findings	Additional information (Rapid review author's comments; systematic review's limitation; methodological quality)
fluoride products in preventing dental caries in children's primary teeth. <u>Included studies:</u> Three of the included studies focused on xylitol. AMSTAR-2 rating: High.	Knowledge Infrastructure) database Timeline: inception to December 2015 (First search) and December 2016 (second search)						for Systematic Reviews and Interventions.(288) Findings from low risk of bias study still warrant caution given the small sample size.

Appendix D
Chapter 4 Supplemental Table 3: Mapping of primary studies
assessed by included and excluded systematic reviews evaluating
chronic conditions (excluding dental caries), risk factors, and
compensatory mechanisms of interest

Primary studies of randomized controlled trials

	<i>High and moderate quality</i>				<i>Low and critically low quality</i>					
	<i>Azad et al (2017)</i>	<i>Santos et al (2018)</i>	<i>Toews et al (2019)</i>	<i>Reid et al (2016)</i>	<i>Miller & Perez (2014)</i>	<i>Rogers et al (2016)</i>	<i>Romo-Romo et al (2016)</i>	<i>Nichol et al (2018)</i>	<i>Onakpoya et al (2015)</i>	<i>Tucker & Tan (2017)</i>
Ambrus et al. 1975										✓
Azari et al. 2017										✓
Baird et al. 2000			✓							
Ballantyne et al. 2011			✓							
Barriocanal et al. 2008							✓		✓	
Berlin et al. 2005								✓		
Black et al. 1991		✓								
Black et al. 1993		✓								
Blackburn et al. 1997	✓	✓	✓		✓	✓				
Brandt et al. 2006								✓		
Brandt et al. 2013								✓		
Brown et al. 2011							✓	✓		✓
Brown et al. 2012							✓			✓
Bruce et al. 1987		✓								✓
Bryant et al. 2014		✓					✓			✓
Burns et al. 1991								✓		
Chan et al. 2000									✓	
Colagiuri et al. 1989		✓					✓			
Cooper et al. 1988							✓			✓
Coppola et al. 2004		✓						✓		
de Ruyter & Seidell et al. 2012			✓							
de Ruyter & Kuijper et al. 2012			✓	✓	✓					
Ebbeling et al. 2006					✓					
Ebbeling et al. 2012					✓					
Ferri et al. 2006	✓								✓	
Flint et al. 2003								✓		
Flood et al. 2006		✓								
Ford et al. 2011							✓			✓
Foster et al. 1998								✓		
Frey et al. 1976			✓							
Gallagher et al. 2016										✓
Gatenby et al. 1997					✓					
Geuns et al. 2007								✓		

	<i>High and moderate quality</i>					<i>Low and critically low quality</i>				
	<i>Azad et al (2017)</i>	<i>Santos et al (2018)</i>	<i>Toews et al (2019)</i>	<i>Reid et al (2016)</i>	<i>Miller & Perez (2014)</i>	<i>Rogers et al (2016)</i>	<i>Romo-Romo et al (2016)</i>	<i>Nichol et al (2018)</i>	<i>Onakpoya et al (2015)</i>	<i>Tucker & Tan (2017)</i>
Ginieis et al. 2018								√		
Gonder-frederick et al. 1987								√		
Gostner et al. 2005					√					
Green et al. 2001								√		
Gregersen et al. 2004							√		√	√
Grotz et al. 2003							√			
Hazali et al. 2014								√		√
Horwitz et al. 1988		√					√	√		√
Hsieh et al. 2003	√								√	
Just et al. 2008								√		√
Kanders et al. 1988		√	√		√					
Kim et al. 2011			√							
Knopp et al. 1976			√		√					
Kuzma et al. 2005		√								
Kuzma et al. 2015			√							
Lapierre et al. 1990		√								
Lavin et al. 1997		√								
Lee et al. 2012			√							
Leon et al. 1989		√								
Lindseth et al. 2014			√							
Little et al. 2009										√
Ma et al. 2009							√			√
Ma et al. 2010							√			√
Madjid et al. 2015	√									
Maersk, Belza, Holst et al. 2012		√					√			
Maersk, Belza, Stodkilde-Jorgensen et al. 2012	√	√	√		√					
Maki et al. 2008			√				√		√	
Maki et al. 2009									√	
Maki, Curry, Reeves et al. 2008									√	
Manning et al. 1992								√		
Manning et al. 1998								√		
Melanson et al. 1999		√					√			√
Messier et al. 1997								√		
Messier et al. 1999								√		
Moller et al. 1991		√								
Naismith et al. 1995 ⁷						√				

⁷ Naismith et al. (1995) was a double-blind non-randomized controlled trial. While categorized as a RCT by Rogers et al. (2016), it is not included in the total number of primary studies of randomized controlled trials but is included in Table SI3-2 (below).

	<i>High and moderate quality</i>				<i>Low and critically low quality</i>					
	<i>Azad et al (2017)</i>	<i>Santos et al (2018)</i>	<i>Toews et al (2019)</i>	<i>Reid et al (2016)</i>	<i>Miller & Perez (2014)</i>	<i>Rogers et al (2016)</i>	<i>Romo-Romo et al (2016)</i>	<i>Nichol et al (2018)</i>	<i>Onakpoya et al (2015)</i>	<i>Tucker & Tan (2017)</i>
Nehrling et al. 1985		√					√			
Newcomer et al. 1999								√		
Nguyen et al. 1998								√		
Njike et al. 2011					√	√				
Okuno et al. 1986							√	√		√
Olalde-Mendoza et al. 2013							√			
Parent et al. 2011								√		
Pepino et al. 2013							√			√
Peters et al. 2016	√									
Prat-Larquemin et al. 2000										√
Raben et al. 2001 ⁸			√		√	√				
Reid et al. 2007		√			√	√				
Reid et al. 2010			√		√	√				
Reid et al. 2014			√							
Rodin et al. 1990		√					√			√
Ryan-Harshman et al. 1987		√								
Sathyapalan et al. 2015		√								
Shigeta et al. 1985								√		
Siegler et al. 2012		√								
Silver et al. 2006									√	
Singleton et al. 1999		√								
Smeets et al. 2005		√						√		√
Spiers et al. 1998			√							
Steinert et al. 2011		√					√			√
Stern et al. 1976		√								
Sylvetsky et al. 2016										√
Taljaard et al. 2013			√	√						
Tate et al. 2012	√				√	√				
Temizkan et al. 2015		√					√			√
Tey et al. 2017								√		√
Tordoff and Alleva. 1990					√	√				
van den Eeden et al. 1991			√							
Walk et al. 2017								√		
Warrington et al. 2011			√							

⁸ Toews et al. (2019) cite the following: Raben A, Moller AC, Vasilaras TH, et al. A randomized 10 week trial of sucrose vs artificial sweeteners on body weight and blood pressure after 10 weeks[abstr]. *Obes Res* 2001;9:86s. We assume this is the same paper cited by Miller & Perez and Rogers et al., which cite Raben A, Vasilaras TH, Müller AC, Astrup A. Sucrose compared with artificial sweeteners: different effects on ad libitum food intake and body weight after 10 wk of supplementation in overweight subjects. *Am J Clin Nutr* 2002; 76:721–729.

	<i>High and moderate quality</i>				<i>Low and critically low quality</i>					
	<i>Azad et al (2017)</i>	<i>Santos et al (2018)</i>	<i>Toews et al (2019)</i>	<i>Reid et al (2016)</i>	<i>Miller & Perez (2014)</i>	<i>Rogers et al (2016)</i>	<i>Romo-Romo et al (2016)</i>	<i>Nichol et al (2018)</i>	<i>Onakpoya et al (2015)</i>	<i>Tucker & Tan (2017)</i>
Wolraich et al. 1994 ⁹						✓				
Wu et al. 2012							✓	✓		✓
Wu, Bound, Zhao et al. 2013								✓		✓
Wu, Bound, Standfield et al. 2013										✓

⁹ Wolraich et al. (1994) was a double-blind non-randomized controlled trial. While categorized as a RCT by Rogers et al. (2016) it is not included in the total number of primary studies of randomized controlled trials, rather is included in the Table below.

Primary studies of non-randomized controlled interventions and observational studies

	High and moderate quality						Low and critically low quality								
	Azad et al (2017)	Greenwood et al (2014)	Imamura et al (2015)	Toews et al (2019)	Reid et al (2016)	Ruanpeng et al (2017)	Miller & Perez (2014)	Karalexi et al (2018)	Mishra et al (2015)	Narain et al (2017)	Narain et al (2016)	Romo-Romo et al (2016)	Rogers et al (2016)	Cheungpasitporn et al (2015)	Tucker & Tan (2017)
Abdallah et al. 1997															✓
Althausen et al. 1937															✓
Andreatta et al. 2008									✓						
Anton et al. 2010												✓			✓
Barrio-Lopez et al. 2013	✓														
Bazzano et al. 2008			✓												
Berkey et al. 2004					✓		✓	✓					✓		
Bernstein et al. 2012	✓										✓				
Bes-Rastrollo et al. 2006	✓														
Bhupathiraju et al. 2013	✓	✓	✓									✓			
Blum et al. 2005					✓			✓							
Bomback et al. 2010	✓														
Bosetti et al. 2009				✓					✓						
Brown et al. 2009															✓
Cabaniols et al. 2011				✓											
Cartwright et al. 1981				✓											
Chan et al. 2014										✓					
Chen et al. 2009	✓												✓		
Chung et al. 2015										✓					
Cohen et al. 2012	✓													✓	
Colditz et al. 1990				✓			✓								
Crichton et al. 2015										✓					
de Koning et al. 2011			✓									✓			
de Koning et al. 2012	✓										✓				
Denova-Gutierrez et al. 2010										✓					
Dhingra et al. 2007	✓		✓							✓		✓		✓	
Duffey et al. 2010			✓											✓	
Duffey et al. 2012	✓		✓									✓	✓		
Duran Aguero et al. 2014				✓											
Duran Aguero et al. 2015				✓											
Duskova et al. 2013															✓
Ejtahed et al. 2015										✓					
Eshak et al. 2012											✓				
Fagherazzi et al. 2013	✓		✓									✓			

	<i>High and moderate quality</i>						<i>Low and critically low quality</i>								
	Azad et al (2017)	Greenwood et al (2014)	Imamura et al (2015)	Toews et al (2019)	Reid et al (2016)	Ruanpeng et al (2017)	Miller & Perez (2014)	Karalexi et al (2018)	Mishra et al (2015)	Narain et al (2017)	Narain et al (2016)	Romo-Romo et al (2016)	Rogers et al (2016)	Cheungpasitporn et al (2015)	Tucker & Tan (2017)
Fernandes et al. 2013				√											
Field et al. 2014	√														
Forshee et a. 2003								√							
Fowler et al. 2008	√					√	√					√	√		
Fowler et al. 2015	√														
French et al. 2013						√									
Fung et al. 2009	√										√				
Gallus et al. 2007				√					√						
Gardener et al. 2012	√										√				
Gearon et al. 2014	√														
Giammattei et al. 2003								√							
Goldfine et al. 1969															√
Goodman et al. 1986				√											
Guo et al. 2014				√											
Gurney et al. 1997				√											
Haines et al. 2007	√														
Hall et al. 2003												√			√
Hartel et al. 1993												√			√
Hasnain et al. 2014					√										
Howe et al. 1977				√											
Iscovich et al. 1987				√											
Johnson et al. 2007					√		√	√							
Kessler et al. 1978				√											
Khosoravi-Boroujeni et al. 2012										√					
Kim et al. 2012														√	
Kirstal et al. 2015														√	
Kral et al. 2008															
Kuk et al. 2016				√											
Kun et al. 1947															√
Lamb et al. 2015								√							
Lana et al. 2015	√														
Larrson et al. 2014											√				
Laska et al. 2012							√	√					√		
Laverty et al. 2015								√							
Lim et al. 2006				√					√						
Ludwig et al. 2001					√			√					√		
Lutsey et al. 2008	√									√		√			
Malik et al. 2014											√				
McCullough et al. 2014				√											
Mezitis et al. 1996												√			√
Mirmiran et al. 2015										√					

	<i>High and moderate quality</i>						<i>Low and critically low quality</i>								
	Azad et al (2017)	Greenwood et al (2014)	Imamura et al (2015)	Toews et al (2019)	Reid et al (2016)	Ruanpeng et al (2017)	Miller & Perez (2014)	Karalexi et al (2018)	Mishra et al (2015)	Narain et al (2017)	Narain et al (2016)	Romo-Romo et al (2016)	Rogers et al (2016)	Cheungpasitporn et al (2015)	Tucker & Tan (2017)
Moller-Jensen et al. 1983				√											
Momas et al. 1994				√											
Mommsen et al. 1983				√											
Moreira et al. 2013										√					
Muraki et al. 2013			√												
Naismith et al. 1995 ¹⁰				√											
Naismith et al. 1995				√											
Najem et al. 1982				√											
Nettleton et al. 2009	√		√			√	√			√		√	√		
Newby et al. 2004					√		√	√							
Nomura et al. 1991				√											
O'Connor et al. 2015	√											√			
O'Connor et al. 2006								√							
Odegaard et al. 2015											√				
Paganini-Hill et al. 2007											√				
Palmer et al. 2008	√		√									√			
Pan et al. 2012	√		√												
Pan et al. 2013													√		
Parker et al. 1997	√			√			√								
Porikos et al. 1982				√											
Renault et al. 2015	√														
Ruiz et al. 2009										√					
Sakurai et al. 2013	√														
Sakurai et al. 2014			√									√			
Sayon-Orea et al. 2014														√	
Schernhammer et al. 2012									√						
Schulze et al. 2004		√	√				√					√			
Serra-Majem et al. 1996				√											
Simon et al. 1975				√											
Skokan et al. 2007															√
Smith et al. 2015	√														
Stanhope et al. 2013				√											
Stanhope et al. 2015				√											
Stinson et al. 2013	√														

¹⁰ Full reference details not provided.

	High and moderate quality						Low and critically low quality								
	Azad et al (2017)	Greenwood et al (2014)	Imamura et al (2015)	Toews et al (2019)	Reid et al (2016)	Ruanpeng et al (2017)	Miller & Perez (2014)	Karalexi et al (2018)	Mishra et al (2015)	Narain et al (2017)	Narain et al (2016)	Romo-Romo et al (2016)	Rogers et al (2016)	Cheungpasitporn et al (2015)	Tucker & Tan (2017)
Striegel-Moore et al. 2006								✓					✓		
Suez et al. 2014												✓			
Tayel et al. 2013														✓	
Teff et al. 1995															✓
The InterAct Consortium, 2013		✓	✓									✓			
Tordoff et al. 1990				✓											
Vanselow et al. 2009													✓		
Vyas et al. 2015	✓														
Winkelmayer et al. 2005														✓	
Wolraich et al. 1994				✓											
Wulaningsih et al. 2017				✓											
Yu et al. 1997				✓											
Zanela et al. 2002				✓											

Appendix E

Chapter 6 Supplemental Table 1: Nutritional profile of food codes classified as sources of low- and no-calorie sweeteners per 100 grams unprepared form and alignment with the 2019 Canada's Food Guide Food Classification System

Food code	Food code description	Energy (kcal)	Free Sugars (g)	Saturated fat (g)	Sodium (mg)	CFG Food Classification ¹	Recipe code ²
Fruit drinks							
5457	Drink, fruit flavour, powder, low calorie, vitamin C, with aspartame	218.000	0.000	—	17.000	☼	505191 502481 505190
Sweetened coffee, tea, hot chocolate, energy drinks, sports drinks, flavoured and vitamin waters							
2912	Tea, instant, unsweetened, lemon flavour, powder	346.000	0.000	0.047	55.000	☼	502457 504757 500029
2953	Hot chocolate with artificial sweetener, mix, powder	377.000	37.65	1.777	876.000	☼	504779 502759 500028 504700 502440
5602*	Coffee, instant, powder, with whitener and artificial sweetener	510.000	59.000	25.128	—	☼	502440
5710*	Coffee, instant, mocha, powder, with whitener and artificial sweetener, decaffeinated	440.000	34.980	11.376	500.000	☼	505185
7281*	Coffee and cocoa (mocha) powder, with whitener and low-calorie sweetener	506.000	34.980	26.260	500.000	☼	— 504975
7457	Beverage mix, chocolate flavour, powder, no added sugar	373.000	0.000	4.545	636.000	☼	502759 500026
Meal replacements							
5558	Instant breakfast, powder, chocolate, sugar-free, with artificial sweetener	358.000	39.000	2.162	717.000	xxx xxx xxx	500045 505262 505263
7231	Beverage, protein powder, whey based, powder	352.000	0.000	0.781	156.000	xxx xxx xxx	504171 504145 505264

Food code	Food code description	Energy (kcal)	Free Sugars (g)	Saturated fat (g)	Sodium (mg)	CFG Food Classification ¹	Recipe code ²
							504126
							500046
							504779
							504173
							505262
7232	Plant-based beverage, protein powder, soy-based powder	388.000	22.220	1.111	733.000	xxx x xxx	505263
							504145
							505262
7233*	Beverage, shake, high protein, powder, unprepared	392.000	2.499	—	1214.000	xxx x xxx	505263
							504171
							505264
							505262
403792*	Meal replacement, powder, diet	394.000	—	1.520	424.200	xxx x xxx	505263
							500046
							500045
Non-grain, non-dairy, non-plat desserts							
4232	Dessert, gelatin, dry mix, calorie-reduced, with aspartame, unprepared	198.00	0.000	—	862.000	☼	504394
							504391
5625	Dessert, pudding, chocolate, dry mix, instant, low calorie, unprepared	356.000	0.546	0.984	2838.000	☼	504204
5629	Dessert, pudding, chocolate, dry mix, regular, low calorie, unprepared	365.000	0.700	1.578	3326.000	☼	504204
5630*	Dessert, pudding, all flavours except chocolate, dry mix, regular, low calorie, unprepared	352.000	2.900	0.018	1765.000	☼	504206
5631	Dessert, pudding, all flavours except chocolate, dry mix, instant, low calorie, unprepared	350.000	0.900	0.099	3750.000	☼	504206

Appendix F

Chapter 7 Supplemental Table 1: Proportion (%) of respondents in each stratum reporting zero intakes of each dietary constituent required for the construction of Healthy Eating Food Index-2019 (HEFI-2019) components, drawn from the first dietary recall, 2015 Canadian Community Health Survey—Nutrition, Public Use Microdata File

Healthy Eating Food Index-2019 (HEFI-2019) dietary constituent	Stratum 1: Children 2 to 13 years	Stratum 2: Males, 14 years and above	Stratum 3: Females, 14 years and above	Stratum 4: Adults 19 years and above
Low- and no-calorie sweeteners	Episodic, 91.4%	Episodic, 81.5%	Episodic, 80.1%	Episodic, 80.2%
Whole grains	Episodic, 39.8%	Episodic, 47.4%	Episodic, 43.6%	Episodic, 45.5%
Protein foods, plant-based	Episodic, 73.7%	Episodic, 64.0%	Episodic, 60.2%	Episodic, 61.1%
Other beverages	Episodic, 26.9%	Episodic, 23.9%	Episodic, 34.3%	Episodic, 29.4%
Milk	Episodic, 22.9%	Episodic, 39.1%	Episodic, 35.6%	Episodic, 37.2%
Vegetables and fruit	Daily, 3.9%	Daily, 4.3%	Daily, 3.8%	Daily, 4.0%
Refined grains	Daily, 3.3%	Episodic, 9.8%	Episodic, 12.9%	Episodic, 11.8%
Protein foods, animal-based	Daily, 4.1%	Daily, 4.3%	Daily, 5.8% ²	Daily, 5.0%
Other foods	Daily, 4.9%	Episodic, 6.6%	Episodic, 7.8%	Episodic, 7.2%
Water	Episodic, 7.4%	Daily, 2.7%	Daily, 1.9%	Daily, 2.0%
Saturated fats	Daily, 0%	Daily, 0%	Daily, 0%	Daily, 0%
Mono-unsaturated fats	Daily, 0%	Daily, 0%	Daily, 0%	Daily, 0%
Polyunsaturated fats	Daily, 0%	Daily, 0%	Daily, 0%	Daily, 0%
Free sugars	Daily, 0%	Daily, 0.9%	Daily, 0.7%	Daily, 0.8%
Sodium	Daily, 0%	Daily, 0%	Daily, 0%	Daily, 0%
Energy	Daily, 0%	Daily, 0%	Daily, 0%	Daily, 0%
Plant-based beverages ¹	Episodic, 100%	Episodic, 100%	Episodic, 100%	Episodic, 100%

¹Excluded from the modelling of HEFI-2019 dietary components because the NCI multivariate MCMC method requires an amount to run.

²While greater than 5%, this dietary constituent was modelled as a daily component given the computation effort required to model seven dietary constituents as episodic.

Appendix G

Chapter 7 Supplemental Table 2: Mean HEFI-2019 total and component scores by the probability of consuming low- and no-calorie sweeteners among children 2 to 13 years, by sex, using data drawn from the 2015 Canada Community Health Survey—Nutrition, Public Use Microdata File

Probability of consuming*	Total score	Vegetables and fruits	Whole-grain foods	Grain foods	Protein foods	Plant-based protein foods	Beverages	Fatty acids	Saturated fats	Free sugars	Sodium
Mean HEFI score (standard error of the mean)											
<i>All children, combed male and females, 2 to 13 years, by quintile</i>											
Quintile 1	42.6 (2.4)	9.3 (1.3)	1.5 (0.3)	1.4 (0.3)	4.6 (0.2)	1.4 (0.6)	7.6 (0.5)	1.5 (0.2)	3.6 (0.3)	5.8 (1.1)	5.9 (0.4)
Quintile 2	40.7 (1.1)	8.9 (1.2)	1.4 (0.4)	1.3 (0.4)	4.6 (0.1)	1.1 (0.5)	7.4 (0.3)	1.4 (0.1)	3.5 (0.2)	5.3 (0.5)	5.7 (0.2)
Quintile 3	39.5 (0.8)	8.6 (1.1)	1.3 (0.4)	1.3 (0.4)	4.6 (0.1)	1.0 (0.5)	7.3 (0.3)	1.4 (0.1)	3.4 (0.2)	5.1 (0.3)	5.5 (0.1)
Quintile 4	38.3 (1.2)	8.3 (1.1)	1.2 (0.4)	1.2 (0.4)	4.7 (0.1)	0.8 (0.6)	7.2 (0.3)	1.4 (0.1)	3.3 (0.2)	4.9 (0.5)	5.4 (0.2)
Quintile 5	36.5 (2.4)	7.8 (1.6)	1.1 (0.4)	1.1 (0.4)	4.7 (0.1)	0.6 (0.8)	7.0 (0.5)	1.3 (0.2)	3.2 (0.3)	4.5 (1.1)	5.4 (0.2)
<i>Males, 2 to 13, by quintile</i>											
Quintile 1	42.2 (2.4)	9.0 (1.3)	1.5 (0.3)	1.4 (0.3)	4.7 (0.2)	1.4 (0.6)	7.6 (0.5)	1.5 (0.2)	3.6 (0.3)	5.7 (1.0)	5.9 (0.4)
Quintile 2	40.2 (1.1)	8.6 (1.1)	1.4 (0.4)	1.3 (0.4)	4.7 (0.1)	1.1 (0.5)	7.4 (0.3)	1.4 (0.1)	3.4 (0.2)	5.3 (0.5)	5.6 (0.2)
Quintile 3	38.9 (0.9)	8.3 (1.0)	1.3 (0.4)	1.3 (0.4)	4.7 (0.1)	1.0 (0.5)	7.2 (0.3)	1.4 (0.1)	3.4 (0.2)	5.0 (0.4)	5.4 (0.2)
Quintile 4	37.8 (1.4)	8.0 (1.1)	1.2 (0.4)	1.2 (0.4)	4.7 (0.1)	0.8 (0.6)	7.1 (0.3)	1.4 (0.1)	3.3 (0.2)	4.8 (0.6)	5.3 (0.2)
Quintile 5	36.0 (2.4)	7.6 (1.4)	1.1 (0.4)	1.1 (0.4)	4.7 (0.1)	0.6 (0.6)	6.9 (0.5)	1.4 (0.2)	3.2 (0.3)	4.5 (1.1)	5.0 (0.4)
<i>Females, 2 to 13, by quintile</i>											
Quintile 1	43.1 (2.5)	9.7 (1.4)	1.5 (0.3)	1.4 (0.3)	4.6 (0.2)	1.4 (0.6)	7.6 (0.5)	1.5 (0.2)	3.6 (0.3)	5.8 (1.2)	6.0 (0.4)
Quintile 2	41.3 (1.3)	9.3 (1.2)	1.4 (0.3)	1.3 (0.4)	4.6 (0.1)	1.1 (0.5)	7.4 (0.3)	1.4 (0.1)	3.5 (0.2)	5.4 (0.6)	5.8 (0.2)
Quintile 3	40.2 (0.8)	9.0 (1.1)	1.3 (0.3)	1.3 (0.4)	4.6 (0.1)	1.0 (0.5)	7.4 (0.3)	1.4 (0.1)	3.4 (0.2)	5.3 (0.4)	5.6 (0.2)
Quintile 4	38.8 (1.1)	8.7 (1.1)	1.2 (0.4)	1.2 (0.3)	4.6 (0.1)	0.8 (0.6)	7.2 (0.3)	1.4 (0.1)	3.4 (0.2)	4.9 (0.5)	5.5 (0.2)
Quintile 5	36.9 (2.3)	8.1 (1.2)	1.1 (0.4)	1.1 (0.4)	4.6 (1.1)	0.6 (0.6)	7.0 (0.4)	1.3 (0.2)	3.2 (0.3)	4.6 (1.0)	5.2 (0.4)
*Quintile1: the lowest probability of consuming low- and no-calorie sweeteners; Quintile5: the highest probability of consuming low- and no-calorie sweeteners. HEFI2019 total score out of 80. Standard errors were estimated using 200 bootstrap replicate weights.											

Appendix H

Chapter 7 Supplemental Table 3: Mean HEFI-2019 total and component scores by the probability of consuming low- and no-calorie sweeteners among males, 14 years and above, using data drawn from the 2015 Canada Community Health Survey—Nutrition, Public Use Microdata File

Probability of consumption*	Total score	Vegetables and fruits	Whole-grain foods	Grain foods	Protein foods	Plant-based protein foods	Beverages	Fatty acids	Saturated fats	Free sugars	Sodium
Mean HEFI score (standard error of the mean)											
<i>All males 14 years and above, by quintile</i>											
Quintile 1	41.1 (3.9)	8.8 (1.9)	1.1 (0.3)	1.2 (0.3)	4.6 (0.1)	1.1 (0.7)	7.4 (0.7)	2.3 (0.4)	3.6 (0.3)	6.6 (1.0)	4.5 (0.5)
Quintile 2	42.8 (2.7)	9.0 (1.8)	1.1 (0.3)	1.3 (0.3)	4.6 (0.1)	1.3 (0.3)	7.3 (0.7)	2.5 (0.3)	3.8 (0.2)	7.3 (0.6)	4.7 (0.3)
Quintile 3	43.6 (2.5)	9.0 (1.8)	1.2 (0.3)	1.3 (0.3)	4.6 (0.1)	1.5 (0.6)	7.2 (0.6)	2.6 (0.3)	3.8 (0.2)	7.6 (0.6)	4.8 (0.1)
Quintile 4	44.5 (2.7)	9.1 (1.8)	1.2 (0.4)	1.4 (0.3)	4.6 (0.1)	1.6 (0.6)	7.1 (0.6)	2.7 (0.3)	3.9 (0.2)	8.0 (0.7)	4.8 (0.2)
Quintile 5	45.7 (3.6)	9.1 (1.8)	1.3 (0.4)	1.5 (0.4)	4.6 (0.1)	1.9 (0.7)	7.0 (0.6)	2.9 (0.4)	4.0 (0.3)	8.4 (1.0)	5.0 (0.4)
<i>Males, 14 to 18 years, by quintile</i>											
Quintile 1	36.9 (2.7)	7.5 (1.6)	1.2 (0.3)	1.1 (0.2)	4.7 (0.1)	0.9 (0.6)	6.9 (0.6)	1.9 (0.4)	3.4 (0.3)	4.6 (1.0)	4.7 (0.4)
Quintile 2	38.4 (2.2)	7.6 (1.5)	1.2 (0.4)	1.2 (0.3)	4.7 (0.1)	1.1 (0.5)	6.8 (0.5)	2.1 (0.4)	3.6 (0.3)	5.3 (0.6)	4.8 (0.2)
Quintile 3	39.2 (2.6)	7.6 (1.6)	1.3 (0.4)	1.3 (0.3)	4.7 (0.1)	1.2 (0.5)	6.7 (0.5)	2.2 (0.43)	3.6 (0.3)	5.7 (0.7)	5.0 (0.3)
Quintile 4	39.8 (3.2)	7.5 (1.6)	1.3 (0.4)	1.3 (0.4)	4.7 (0.1)	1.3 (0.5)	6.7 (0.6)	2.3 (0.4)	3.7 (0.3)	6.1 (1.0)	5.0 (0.3)
Quintile 5	41.1 (4.6)	7.5 (1.7)	1.4 (0.5)	1.4 (0.4)	4.7 (0.1)	1.5 (0.6)	6.5 (0.6)	2.5 (0.4)	3.8 (0.5)	6.6 (1.5)	5.1 (0.6)
<i>Males, 19 to 30 years, by quintile</i>											
Quintile 1	38.3 (3.5)	7.3 (1.7)	1.0 (0.3)	1.1 (0.3)	4.8 (0.1)	1.0 (0.6)	7.2 (0.6)	2.0 (0.5)	3.4 (0.4)	6.1 (0.8)	4.4 (0.6)
Quintile 2	39.9 (2.8)	7.4 (1.6)	1.1 (0.4)	1.2 (0.3)	4.8 (0.1)	1.2 (0.6)	7.0 (0.7)	2.2 (0.4)	3.5 (0.4)	6.9 (0.8)	4.5 (0.5)
Quintile 3	40.5 (2.4)	7.3 (1.6)	1.2 (0.4)	1.3 (0.3)	4.8 (0.1)	1.3 (0.5)	6.9 (0.6)	2.3 (0.54)	3.6 (0.3)	7.1 (0.7)	4.7 (0.3)
Quintile 4	41.4 (2.8)	7.4 (1.5)	1.2 (0.4)	1.3 (0.4)	4.8 (0.1)	1.4 (0.7)	6.8 (0.7)	2.4 (0.4)	3.7 (0.3)	7.5 (1.0)	4.7 (0.3)
Quintile 5	42.2 (3.7)	7.3 (1.6)	1.2 (0.4)	1.4 (0.4)	4.8 (0.1)	1.6 (0.7)	6.6 (0.6)	2.6 (0.4)	3.8 (0.4)	7.9 (1.4)	4.9 (0.5)
<i>Males, 31-50 years, by quintile</i>											
Quintile 1	42.3 (3.4)	9.1 (1.9)	1.0 (0.3)	1.1 (0.3)	4.7 (0.2)	1.2 (0.7)	7.4 (0.7)	2.5 (0.4)	3.7 (0.3)	6.9 (0.9)	4.6 (0.4)
Quintile 2	43.7 (2.6)	9.1 (1.8)	1.1 (0.3)	1.2 (0.3)	4.7 (0.1)	1.5 (0.6)	7.3 (0.7)	2.6 (0.3)	3.8 (0.2)	7.5 (0.6)	4.8 (0.2)
Quintile 3	44.5 (2.7)	9.1 (1.8)	1.2 (0.4)	1.3 (0.3)	4.7 (0.1)	1.6 (0.6)	7.2 (0.7)	2.8 (0.3)	3.9 (0.2)	7.9 (0.6)	4.9 (0.2)
Quintile 4	45.1 (3.1)	9.1 (1.8)	1.2 (0.4)	1.3 (0.3)	4.7 (0.1)	1.8 (0.6)	7.1 (0.7)	2.9 (0.4)	4.0 (0.3)	8.1 (0.7)	4.9 (0.3)
Quintile 5	46.2 (4.2)	9.0 (1.9)	1.3 (0.4)	1.4 (0.4)	4.7 (0.1)	2.0 (0.7)	7.0 (0.7)	3.0 (0.4)	4.1 (0.4)	8.6 (1.0)	5.1 (0.5)

Probability of consumption*	Total score	Vegetables and fruits	Whole-grain foods	Grain foods	Protein foods	Plant-based protein foods	Beverages	Fatty acids	Saturated fats	Free sugars	Sodium
	Mean HEFI score (standard error of the mean)										
Males, 51 to 70 years, by quintile											
Quintile 1	43.2 (4.7)	9.7 (2.2)	1.1 (0.4)	1.3 (0.3)	4.5 (0.2)	1.2 (0.8)	7.6 (0.8)	2.4 (0.4)	3.7 (0.4)	7.3 (0.9)	4.3 (0.8)
Quintile 2	44.3 (3.5)	9.7 (2.1)	1.1 (0.4)	1.4 (0.3)	4.5 (0.1)	1.4 (0.6)	7.4 (0.7)	2.6 (0.3)	3.9 (0.3)	7.8 (0.6)	4.5 (0.5)
Quintile 3	45.0 (3.0)	9.7 (2.0)	1.2 (0.4)	1.4 (0.3)	4.5 (0.1)	1.5 (0.6)	7.4 (0.7)	2.7 (0.3)	3.9 (0.2)	8.0 (0.5)	4.6 (0.3)
Quintile 4	45.8 (2.8)	9.7 (2.0)	1.2 (0.4)	1.5 (0.3)	4.5 (0.1)	1.7 (0.6)	7.3 (0.6)	2.8 (0.3)	4.0 (0.2)	8.4 (0.6)	4.7 (0.3)
Quintile 5	46.7 (3.1)	9.5 (2.0)	1.3 (0.4)	1.6 (0.4)	4.6 (0.2)	1.9 (0.6)	7.1 (0.7)	3.0 (0.4)	4.1 (0.2)	8.7 (0.9)	4.9 (0.3)
Males, 71 and older, by quintile											
Quintile 1	42.4 (4.4)	10.4 (2.2)	1.1 (0.4)	1.3 (0.3)	4.3 (0.2)	1.1 (0.8)	7.7 (0.7)	2.0 (0.5)	3.5 (0.4)	6.4 (1.2)	4.6 (0.5)
Quintile 2	43.7 (3.2)	10.3 (2.1)	1.2 (0.3)	1.4 (0.3)	4.3 (0.2)	1.3 (0.7)	7.6 (0.6)	2.2 (0.4)	3.6 (0.3)	7.0 (0.8)	4.7 (0.3)
Quintile 3	44.5 (2.8)	10.4 (2.1)	1.3 (0.3)	1.5 (0.3)	4.3 (0.2)	1.4 (0.6)	7.5 (0.6)	2.3 (0.4)	3.7 (0.2)	7.4 (0.6)	4.8 (0.2)
Quintile 4	45.1 (2.8)	10.3 (2.1)	1.3 (0.3)	1.5 (0.3)	4.3 (0.2)	1.6 (0.6)	7.4 (0.6)	2.4 (0.3)	3.7 (0.3)	7.7 (0.7)	4.9 (0.2)
Quintile 5	46.3 (3.5)	10.2 (2.1)	1.4 (0.4)	1.6 (0.4)	4.3 (0.2)	1.8 (0.6)	7.3 (0.6)	2.6 (0.4)	3.8 (0.3)	8.2 (1.0)	5.1 (0.5)
* Quintile1: the lowest probability of consuming low- and no-calorie sweeteners; Quintile5: the highest probability of consuming low- and no-calorie sweeteners. HEFI2019 total score out of 80. Standard errors were estimated using 200 bootstrap replicate weights.											

Appendix I

Chapter 7 Supplemental Table 4: Mean HEFI-2019 total and component scores by the probability of consuming low- and no-calorie sweeteners among females, 14 years and above, using data drawn from the 2015 Canada Community Health Survey—Nutrition, Public Use Microdata File

Probability of consumption*	Total score	Vegetables and fruits	Whole-grain foods	Grain foods	Protein foods	Plant-based protein foods	Beverages	Fatty acids	Saturated fats	Free sugars	Sodium
Mean HEFI score (standard error of the mean)											
<i>All females, 14 years and above, by quintile</i>											
Quintile 1	46.8 (2.6)	11.0 (1.7)	1.0 (0.3)	1.2 (0.2)	4.5 (0.1)	1.5 (0.3)	8.4 (0.3)	2.5 (0.3)	3.7 (0.3)	7.6 (0.5)	5.3 (0.5)
Quintile 2	46.6 (2.2)	10.9 (1.6)	1.1 (0.2)	1.4 (0.2)	4.6 (0.1)	1.6 (0.3)	8.2 (0.2)	2.4 (0.2)	3.7 (0.2)	7.6 (0.4)	5.1 (0.3)
Quintile 3	46.3 (2.1)	10.8 (1.5)	1.2 (0.2)	1.5 (0.2)	4.6 (0.1)	1.6 (0.2)	8.0 (0.2)	2.4 (0.2)	3.7 (0.2)	7.6 (0.3)	4.9 (0.2)
Quintile 4	46.1 (2.0)	10.7 (1.5)	1.2 (0.2)	1.5 (0.1)	4.6 (0.1)	1.6 (0.1)	7.9 (0.1)	2.4 (0.1)	3.7 (0.1)	7.6 (0.2)	4.8 (0.1)
Quintile 5	45.7 (2.3)	10.6 (1.6)	1.3 (0.3)	1.7 (0.3)	4.7 (0.1)	1.6 (0.3)	7.7 (0.3)	2.3 (0.2)	3.7 (0.3)	7.5 (0.5)	4.7 (0.3)
<i>Females, 14 to 18 years, by quintile</i>											
Quintile 1	41.6 (2.4)	9.2 (1.4)	1.0 (0.3)	1.1 (0.2)	4.5 (0.1)	1.2 (0.3)	7.9 (0.3)	2.0 (0.3)	3.4 (0.3)	6.0 (0.6)	5.3 (0.5)
Quintile 2	41.0 (2.0)	8.9 (1.3)	1.2 (0.2)	1.2 (0.2)	4.6 (0.1)	1.2 (0.2)	7.6 (0.3)	1.9 (0.2)	3.4 (0.3)	5.9 (0.5)	5.1 (0.3)
Quintile 3	40.3 (1.9)	8.7 (1.3)	1.2 (0.2)	1.3 (0.2)	4.6 (0.1)	1.2 (0.2)	7.4 (0.3)	1.9 (0.2)	3.4 (0.3)	5.7 (0.5)	4.9 (0.3)
Quintile 4	39.7 (1.9)	8.5 (1.3)	1.2 (0.2)	1.3 (0.2)	4.6 (0.1)	1.2 (0.3)	7.2 (0.3)	1.8 (0.2)	3.3 (0.3)	5.5 (0.5)	4.9 (0.3)
Quintile 5	39.5 (2.4)	8.4 (1.3)	1.3 (0.3)	1.4 (0.3)	4.7 (0.2)	1.2 (0.4)	7.0 (0.4)	1.8 (0.3)	3.3 (0.4)	5.6 (0.8)	4.7 (0.4)
<i>Females, 19 to 30 years, by quintile</i>											
Quintile 1	43.9 (2.4)	9.8 (1.5)	0.9 (0.3)	1.1 (0.2)	4.6 (0.1)	1.3 (0.4)	7.9 (0.5)	2.4 (0.3)	3.6 (0.3)	6.9 (0.6)	5.5 (0.5)
Quintile 2	43.5 (2.1)	9.6 (1.4)	1.0 (0.2)	1.2 (0.2)	4.6 (0.1)	1.3 (0.3)	7.6 (0.4)	2.4 (0.3)	3.5 (0.3)	6.8 (0.5)	5.3 (0.4)
Quintile 3	43.0 (2.0)	9.5 (1.4)	1.1 (0.2)	1.3 (0.2)	4.6 (0.1)	1.3 (0.3)	7.4 (0.4)	2.3 (0.2)	3.5 (0.3)	6.7 (0.5)	5.1 (0.3)
Quintile 4	42.6 (2.1)	9.3 (1.4)	1.1 (0.2)	1.3 (0.2)	4.7 (0.1)	1.3 (0.3)	7.3 (0.3)	2.3 (0.2)	3.6 (0.3)	6.6 (0.5)	5.1 (0.3)
Quintile 5	41.9 (2.4)	9.1 (1.4)	1.2 (0.3)	1.4 (0.3)	4.7 (0.1)	1.4 (0.3)	7.1 (0.4)	2.2 (0.2)	3.5 (0.4)	6.4 (0.7)	5.0 (0.4)
<i>Females, 31 to 50 years, by quintile</i>											
Quintile 1	48.1 (2.7)	11.3 (1.7)	1.0 (0.3)	1.2 (0.3)	4.6 (0.1)	1.7 (0.4)	8.6 (0.2)	2.7 (0.3)	3.7 (0.3)	8.2 (0.5)	5.1 (0.5)
Quintile 2	47.3 (2.3)	11.0 (1.6)	1.1 (0.2)	1.3 (0.2)	4.6 (0.1)	1.7 (0.3)	8.3 (0.2)	2.6 (0.2)	3.7 (0.2)	8.1 (0.4)	4.8 (0.4)
Quintile 3	46.9 (2.1)	10.8 (1.5)	1.1 (0.2)	1.4 (0.2)	4.6 (0.1)	1.7 (0.3)	8.1 (0.2)	2.6 (0.2)	3.7 (0.2)	8.0 (0.3)	4.8 (0.3)

Probability of consumption*	Total score	Vegetables and fruits	Whole-grain foods	Grain foods	Protein foods	Plant-based protein foods	Beverages	Fatty acids	Saturated fats	Free sugars	Sodium
	Mean HEFI score (standard error of the mean)										
Quintile 4	46.5 (2.1)	10.6 (1.5)	1.2 (0.2)	1.5 (0.2)	4.7 (0.1)	1.7 (0.3)	8.0 (0.2)	2.5 (0.2)	3.7 (0.2)	7.9 (0.4)	4.6 (0.2)
Quintile 5	45.8 (2.3)	10.3 (1.5)	1.3 (0.3)	1.6 (0.3)	4.7 (0.2)	1.7 (0.3)	7.8 (0.3)	2.4 (0.2)	3.7 (0.3)	7.9 (0.5)	4.5 (0.3)
<i>Females, 51 to 70 years, by quintile</i>											
Quintile 1	49.5 (3.0)	12.1 (1.9)	1.1 (0.3)	1.4 (0.3)	4.4 (0.2)	1.7 (0.4)	8.7 (0.2)	2.6 (0.3)	3.8 (0.3)	8.1 (0.6)	5.5 (0.5)
Quintile 2	49.0 (2.6)	11.9 (1.8)	1.2 (0.3)	1.6 (0.2)	4.5 (0.1)	1.7 (0.3)	8.5 (0.2)	2.5 (0.2)	3.8 (0.2)	8.1 (0.5)	5.3 (0.3)
Quintile 3	48.3 (2.4)	11.6 (1.7)	1.2 (0.2)	1.6 (0.2)	4.5 (0.1)	1.7 (0.3)	8.3 (0.2)	2.4 (0.2)	3.8 (0.2)	7.9 (0.5)	5.2 (0.2)
Quintile 4	48.0 (2.2)	11.5 (1.7)	1.2 (0.2)	1.7 (0.2)	4.6 (0.1)	1.7 (0.3)	8.1 (0.2)	2.4 (0.2)	3.8 (0.2)	7.9 (0.4)	5.1 (0.2)
Quintile 5	47.5 (2.4)	11.2 (1.7)	1.3 (0.3)	1.8 (0.3)	4.6 (0.1)	1.7 (0.3)	7.9 (0.2)	2.3 (0.3)	3.8 (0.3)	7.8 (0.5)	4.9 (0.4)
<i>Females, 71 years and above, by quintile</i>											
Quintile 1	47.2 (3.2)	11.8 (1.9)	1.3 (0.4)	1.5 (0.3)	4.3 (0.2)	1.4 (0.3)	8.6 (0.3)	2.3 (0.3)	3.6 (0.3)	7.5 (0.7)	5.1 (0.5)
Quintile 2	46.7 (2.7)	11.6 (1.7)	1.4 (0.3)	1.6 (0.2)	4.4 (0.2)	1.4 (0.3)	8.3 (0.2)	2.2 (0.2)	3.6 (0.3)	7.4 (0.5)	4.9 (0.3)
Quintile 3	46.1 (2.5)	11.3 (1.7)	1.4 (0.2)	1.6 (0.2)	4.4 (0.1)	1.4 (0.2)	8.2 (0.2)	2.2 (0.2)	3.6 (0.3)	7.3 (0.5)	4.7 (0.2)
Quintile 4	45.5 (2.4)	11.1 (1.6)	1.5 (0.2)	1.7 (0.2)	4.4 (0.1)	1.4 (0.3)	8.0 (0.2)	2.1 (0.3)	3.6 (0.3)	7.1 (0.5)	4.6 (0.2)
Quintile 5	44.9 (2.5)	10.9 (1.7)	1.5 (0.3)	1.8 (0.3)	4.6 (0.1)	1.4 (0.4)	7.8 (0.3)	2.0 (0.3)	3.6 (0.4)	7.1 (0.6)	4.4 (0.4)
*Quintile1: the lowest probability of consuming low- and no-calorie sweeteners; Quintile5: the highest probability of consuming low- and no-calorie sweeteners. HEFI2019 total score out of 80. Standard errors were estimated using 200 bootstrap replicate weights.											

Appendix J

Chapter 7 Supplemental Table 5: Mean HEFI-2019 total and component scores by the probability of consuming low- and no-calorie sweeteners among adults, 19 years and above, by sex and self-reported diabetes status, using data drawn from the 2015 Canada Community Health Survey—Nutrition, Public Use Microdata File

Probability of consumption*	Total score	Vegetables and fruits	Whole-grain foods	Grain foods	Protein foods	Plant-based protein foods	Beverages	Fatty acids	Saturated fats	Free sugars	Sodium
	Mean HEFI score (standard error of the mean)										
	<i>Males, 19 years and above, with diabetes, by quintile</i>										
Quintile 1	45.4 (3.7)	9.7 (2.4)	1.4 (0.5)	1.4 (0.4)	4.6 (0.2)	1.4 (0.5)	8.1 (0.4)	2.5 (0.4)	3.7 (0.4)	8.7 (0.4)	3.9 (0.5)
Quintile 2	45.3 (3.2)	9.6 (2.3)	1.4 (0.4)	1.5 (0.3)	4.6 (0.1)	1.4 (0.5)	7.9 (0.3)	2.5 (0.3)	3.8 (0.3)	8.8 (0.3)	3.9 (0.4)
Quintile 3	45.1 (3.0)	9.5 (2.2)	1.4 (0.4)	1.5 (0.3)	4.6 (0.1)	1.5 (0.5)	7.8 (0.3)	2.5 (0.3)	3.7 (0.3)	8.8 (0.3)	3.8 (0.3)
Quintile 4	45.0 (2.8)	9.3 (2.1)	1.4 (0.3)	1.5 (0.3)	4.6 (0.1)	1.5 (0.5)	7.5 (0.3)	2.5 (0.3)	3.8 (0.2)	8.8 (0.3)	3.9 (0.2)
Quintile 5	44.7 (2.6)	9.2 (2.0)	1.4 (0.3)	1.6 (0.3)	4.6 (0.1)	1.6 (0.5)	7.2 (0.3)	2.5 (0.3)	3.8 (0.2)	8.8 (0.3)	4.0 (0.3)
	<i>Males 19 years and above, without diabetes, by quintile</i>										
Quintile 1	44.2 (2.7)	9.2 (2.0)	1.1 (0.3)	1.3 (0.3)	4.6 (0.1)	1.4 (0.5)	7.6 (0.3)	2.5 (0.3)	3.8 (0.2)	7.7 (0.4)	4.8 (0.4)
Quintile 2	44.0 (2.5)	9.0 (1.9)	1.2 (0.2)	1.3 (0.2)	4.6 (0.1)	1.5 (0.4)	7.4 (0.3)	2.5 (0.3)	3.8 (0.2)	7.8 (0.4)	4.8 (0.2)
Quintile 3	43.9 (2.5)	9.1 (1.9)	1.2 (0.2)	1.3 (0.2)	4.6 (0.1)	1.5 (0.4)	7.2 (0.3)	2.6 (0.3)	3.9 (0.2)	7.8 (0.4)	4.9 (0.2)
Quintile 4	43.9 (2.5)	9.0 (1.9)	1.2 (0.2)	1.4 (0.3)	4.6 (0.1)	1.6 (0.4)	7.0 (0.3)	2.6 (0.3)	3.9 (0.2)	7.8 (0.4)	4.9 (0.2)
Quintile 5	43.7 (2.7)	8.9 (1.9)	1.2 (0.2)	1.4 (0.3)	4.6 (0.1)	1.6 (0.4)	6.8 (0.3)	2.6 (0.3)	3.9 (0.2)	7.8 (0.5)	4.9 (0.3)
	<i>Females, 19 years and above, with diabetes, by quintile</i>										
Quintile 1	48.0 (3.7)	11.8 (2.7)	1.4 (0.5)	1.6 (0.4)	4.4 (0.2)	1.5 (0.6)	8.9 (0.3)	2.5 (0.4)	3.5 (0.4)	8.6 (0.5)	3.8 (0.7)
Quintile 2	47.6 (3.5)	11.4 (2.6)	1.4 (0.4)	1.6 (0.4)	4.4 (0.1)	1.5 (0.6)	8.7 (0.3)	2.4 (0.4)	3.6 (0.3)	8.6 (0.4)	4.0 (0.4)
Quintile 3	47.3 (3.3)	11.3 (2.5)	1.4 (0.4)	1.6 (0.4)	4.4 (0.1)	1.6 (0.5)	8.5 (0.3)	2.4 (0.4)	3.5 (0.3)	8.6 (0.4)	3.9 (0.3)
Quintile 4	47.2 (3.2)	11.1 (2.4)	1.5 (0.4)	1.7 (0.4)	4.4 (0.1)	1.6 (0.5)	8.4 (0.3)	2.4 (0.3)	3.6 (0.2)	8.6 (0.4)	4.0 (0.3)
Quintile 5	47.0 (3.1)	11.1 (2.3)	1.4 (0.3)	1.7 (0.4)	4.4 (0.1)	1.7 (0.5)	8.0 (0.3)	2.4 (0.4)	3.7 (0.2)	8.6 (0.5)	4.0 (0.3)
	<i>Females 19 years and above, without diabetes, by quintile</i>										
Quintile 1	46.5 (3.1)	11.1 (2.4)	1.2 (0.3)	1.4 (0.3)	4.5 (0.1)	1.5 (0.5)	8.4 (0.3)	2.4 (0.3)	3.6 (0.3)	7.4 (0.5)	5.0 (0.4)
Quintile 2	46.4 (3.0)	11.0 (2.2)	1.2 (0.2)	1.4 (0.3)	4.5 (0.1)	1.6 (0.4)	8.2 (0.4)	2.5 (0.3)	3.7 (0.2)	7.4 (0.5)	5.0 (0.2)

Probability of consumption*	Total score	Vegetables and fruits	Whole-grain foods	Grain foods	Protein foods	Plant-based protein foods	Beverages	Fatty acids	Saturated fats	Free sugars	Sodium
	Mean HEFI score (standard error of the mean)										
Quintile 3	46.2 (2.9)	10.9 (2.3)	1.2 (0.2)	1.5 (0.3)	4.5 (0.1)	1.6 (0.4)	8.0 (0.3)	2.5 (0.3)	3.7 (0.2)	7.4 (0.5)	5.0 (0.2)
Quintile 4	46.2 (3.0)	10.8 (2.3)	1.2 (0.2)	1.5 (0.3)	4.5 (0.1)	1.6 (0.4)	7.9 (0.4)	2.5 (0.3)	3.7 (0.2)	7.5 (0.5)	5.0 (0.2)
Quintile 5	46.0 (3.3)	10.7 (2.3)	1.2 (0.2)	1.5 (0.3)	4.5 (0.1)	1.7 (0.4)	7.6 (0.4)	2.5 (0.3)	3.8 (0.2)	7.5 (0.6)	5.0 (0.3)
*Quintile1: the lowest probability of consuming low- and no-calorie sweeteners; Quintile5: the highest probability of consuming low- and no-calorie sweeteners HEFI2019 total score out of 80. Standard errors were estimated using 200 bootstrap replicate weights.											

