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Modelling optimal diets for quality and cost: examples from Inuit and First Nations communities in Canada

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Abstract

This review summarizes aspects of the 2017 Canadian Nutrition Society symposium, “Modelling diets for quality and cost: examples from Inuit and First Nations in Canada”. Indigenous peoples in Canada experience a high prevalence of nutrition-related chronic disease due to the poor quality and high cost of their food supply. Since European colonisation, they have transitioned from a diet of minimally processed traditional foods (game, fish and plants) procured using pursuits such as hunting, fishing, gathering, and horticulture to a diet comprised mostly of processed market foods. This nutrition transition is the result of factors such as colonial policies and practices; climate change; environmental degradation; contaminants in traditional foods; and limited availability of, or access to, economical and healthful market foods. Presenters Malek Batal and Laurie Chan characterized the contemporary diets of First Nations and Inuit populations and demonstrated novel methods for modelling more optimal diets using two datasets: the First Nations Food, Nutrition and Environment Study and the Inuit Health Survey. It was demonstrated how the NOVA classification characterized the portion of the diet consisting of processed foods. Dietary components were then manipulated to reduce ultra-processed food and drink intake to increase the Healthy Eating Index score. Linear programming was explained as a way to mathematically design theoretical diets that aim to optimize food cost, nutrition quality, and contaminant level of traditional foods. While diet-modelling methodologies have limitations, they provide a basis for engaging Indigenous peoples and governments to develop nutrition goals and policies anchored in contemporary food realities.

Keywords

Nova classification; diet optimization; healthy eating index; diet modelling; nutrition transition; ultra-processed foods; linear programming; Indigenous; First Nations; Inuit

Introduction

Prior to the arrival of Europeans to the Indigenous territories that now comprise Canada, Inuit and First Nations peoples fed themselves by harvesting wild plants, game and fish. Some First Nations cultures practiced horticulture and supplemented their diets with domesticates such as corn, beans, squash and sunflowers. Indigenous diets comprised of these country or traditional foods (Trad-Foods) were highly diverse, with food and nutrient intakes dependent on geography, season and cultural practices. The evidence suggests that these diverse Indigenous diets of whole or minimally processed foods provided sufficient energy and nutrients to support good health. Furthermore, the procuring, processing and storing of Trad-Foods required significant energy expenditure, which maintained good metabolic health (Willows 2005).

Beginning with European colonisation, Indigenous peoples underwent a nutrition transition from Trad-Foods to store-bought market foods with accompanying reductions in the amount of energy spent on subsistence activities (Batal et al. 2018b; Egeland and Harrison 2013; Kuhnlein 2015). Initially, the diet of Trad-Foods was supplemented with staples such as flour, sugar, baking powder, oats, lard and tea available at fur trading posts (Vallianatos and Willows 2016). The transition was accelerated by colonial policies and practices that dispossessed Indigenous peoples from their traditional territories and assimilated Indigenous children into Euro-Canadian culture by placing them in residential schools, effectively severing them from their culture, including their food culture (Adelson 2005). Factors contributing today to reductions in Trad-Foods are climate change resulting in the loss of species biodiversity and changing patterns of game migration (Ford 2012; Ford et al. 2010; Kuhnlein 2015), habitat loss due to development, and pollution of Trad-Foods from industrial activities (Chan et al. 2006; Donaldson et al. 2010; Ford 2012). Factors that contribute to Indigenous consumers purchasing

energy-dense and nutrient-poor market foods, including ultra-processed products (UPP) (i.e., mostly energy-dense and nutrient-poor industrial food and drink formulations made from refined substances) (Moubarac et al. 2017), are the intrinsic qualities of UPP, such as a low cost on a per calorie basis, long shelf-life, high palatability due to the use of flavour enhancers (Darmon and Drewnowski 2008; Monteiro et al. 2017); the limited availability of nutritious and perishable market foods in many rural and remote Indigenous communities; and prevalent food insecurity in Indigenous communities (Expert Panel on the State of Knowledge of Food Security in Northern Canada 2014; Willows 2005; Willows et al. 2009).

Although Trad-Foods are substantially diminished in the contemporary diet of Indigenous peoples from historic proportions, they are still an integral part of Indigenous cultures that connect Indigenous peoples to their traditional territories and foster in them a sense of Indigenous identity (Vallianatos and Willows 2016), promote holistic health (Dussault et al. 1993) and contribute to diet quality by improving intake of important nutrients such as protein, vitamin D, iron and magnesium, among others (Chan et al. 2011, 2016; Chan et al. 2012, 2014; Downs et al. 2009; Egeland et al. 2011; Jamieson et al. 2012; Johnson-Down and Egeland 2010; Johnson-Down and Egeland 2013; Kuhnlein and Receveur 1996, 2007). Unfortunately, despite the many benefits of Trad-Foods, some of them can also be a source of environmental contaminants (Juric et al. 2017; Liberda et al. 2011; Liberda et al. 2014; Marushka et al. 2017). For example, long-range atmospheric transport results in elevated levels of contaminants in Arctic communities; fish and marine mammals, which are an important aspect of the Inuit diet, are most affected (Carrie et al. 2010; Laird et al. 2013a). Indigenous peoples are often asked to weigh the nutritional and cultural benefits of Trad-Foods against the health risks of consuming them, sometimes resulting in unnecessary decreases in the intake of these beneficial foods

(Berkes et al. 1994; Berner et al. 2016; Laird et al. 2013b). The restriction in Trad-Food intake as a result of contamination concerns often does not take into account mitigating effects of the foods themselves. For example, shellfish can contain mercury; however, the selenium in shellfish may mitigate the harms of mercury exposure by increasing the activity of glutathione transferase (Gaxiola-Robles et al. 2014).

Developing Optimal Diets for Indigenous Peoples

As the Nutrition Transition progressed, Indigenous peoples following a predominantly Western-type dietary pattern (Wirfalt et al. 2013) began to suffer from a high burden of nutrition-related chronic diseases (NRCD) such as obesity, insulin resistance, type 2 diabetes and cardiovascular disease (Anderson et al. 2016; Johnson-Down et al. 2015; Kolahdooz et al. 2017; Lavigne-Robichaud et al. 2018; Roberts et al. 2015). The comorbidities of NRCD and other health conditions has resulted in a 4-7 year lower life expectancy among Indigenous individuals compared to non-Indigenous individuals in Canada (McNally and Martin 2017). To prevent obesity and other NRCD there is an urgent need for culturally appropriate nutritional interventions and dietary guidelines for Indigenous populations that take into account the barriers that Indigenous peoples face in accessing Trad-Foods and healthy market foods (Willows et al. 2012). Mathematically modelling diets for Indigenous peoples based on food availability, cultural appropriateness, nutrition and economic feasibility while achieving nutritional goals is one way to propose realistic food intake patterns to Indigenous peoples, with the knowledge that creating diets that are simultaneously optimal for cost, cultural acceptance and nutrition can be difficult (Raymond et al. 2018).

This review summarizes two presentations given at the May 2017 Canadian Nutrition Society symposium called “Modelling diets for quality and cost: examples from Inuit and First

Nations in Canada” that described ways to model diets for Indigenous adults to improve nutritional intake, given their food realities. An objective of the symposium was to determine whether realistic and affordable diets that achieve nutritional goals while minimizing contaminant risk can be formulated for Indigenous peoples by focusing on locally available foods. Dr. Malek Batal summarized research from the First Nations Food, Nutrition and Environment Study (FNFNES) (First Nations Food Nutrition and Environment Study 2018). With respect to First Nations peoples living on-reserve, he described the types of Trad-Foods in the diet; diet quality based on the Healthy Eating Index (Garriguet 2009); how the portion of the diet containing UPP could be determined from the NOVA classification of food (Batal et al. 2018a; Batal et al. 2018b); that diets with a higher fraction of Trad-Foods have a lower fraction of UPP; and, that reducing UPP in the diet results in a higher Healthy Eating Index score. Dr. Laurie Chan presented research from the Inuit Health Survey (Inuit Health Survey 2007-2008 2018) about the relationship between Inuit traditional food consumption and human contaminant levels, and the use of linear programming to formulate nutritionally-optimal and economical dietary patterns within acceptable contaminant thresholds. Tiff-Annie Kenny, a member of Dr. Chan’s research team, completed the mathematical diet modelling research that was presented. The symposium was introduced and chaired by Dr. Noreen Willows, who had also contributed to results reported for the FNFNES.

The First Nations Food and Environment Study (FNFNES)

FNFNES was designed to contribute an improved understanding of the diet and environment of First Nations adults 19 years and older living below the 60th parallel (Chan et al. 2011, 2016; Chan et al. 2012, 2014; First Nations Food Nutrition and Environment Study 2018). The FNFNES has several components including a household questionnaire examining diet, health,

harvesting of Trad-Foods and food security. Dietary data collection took place in the fall, beginning in 2008. Trained community members administered questionnaires. A 3-stage multiple pass method was used to collect 24-hour dietary recall data and a food frequency questionnaire (FFQ) collected Trad-Foods consumption over the past year (Batal et al. 2018a; Batal et al. 2018b; Chan et al. 2011, 2016; Chan et al. 2012, 2014). Informed consent was given by each participant. Ethical approval to collect and/or analyze data was obtained from Health Canada, the University of Northern British Columbia, the University of Alberta, the University of Ottawa and the University of Montreal.

At the symposium, the results of FNFNES dietary data collected from 2008-2013 were reported for 3700 adults living on reserve from the provinces of British Columbia, Alberta, Manitoba and Ontario (Figure 1). Food insecurity (including marginal, moderate and severe food insecurity) was very high and affected between 41.4% of households in Ontario and 53.9% of households in Alberta (Table 1). Almost one-quarter (22.7%) of participants consumed Trad-Foods at least once on the 24-hour food recall. Average daily intakes of Trad-Foods ranged from 81 grams per day in British Columbia to 29 grams per day in Alberta (Table 1). Compared to days when Trad-Foods were not consumed, days when Trad-Foods were consumed had significantly more protein, zinc, iron, and vitamins D, B6, and B12 and less saturated fat and sodium (Chan et al. 2011, 2016; Chan et al. 2012, 2014). The most frequently reported traditional food in all 4 provinces was moose. Other top Trad-Foods included additional ungulates (deer, elk, caribou), birds (grouse, duck), fish (salmon, pike, walleye, whitefish) and plants (raspberries, blueberries, wild mint, maple syrup). In order of importance, barriers to traditional food consumption identified by FNFNES participants were a lack of equipment and transportation; absence of a hunter in the family; lack of time for hunting; climate change;

limited availability of game; lack of knowledge; and, government regulations restricting the harvest of Trad-Foods.

Among FNFNES participants, the intakes of vegetables and fruit, grain products, milk and alternatives were lower than recommended by Canada's Food Guide to Healthy Eating whereas the intake of meat and alternatives was higher than recommended (Chan et al. 2011, 2016; Chan et al. 2012, 2014; Health Canada 2007). Processed meats were the predominant source of fats and saturated fats while canned soups and potato chips were the predominant sources of sodium.

NOVA (a name, not an acronym) is a food classification method that distinguishes foods according to the degree of processing (Moubarac et al. 2017). Using NOVA, foods consumed by FNFNES participants were categorised as UPP, or not (Moubarac et al. 2017). After controlling for energy intake, age and gender, participants ate 300 grams more UPP on days when Trad-Foods were not included in the diet. Participants were then classified into quintiles of UPP consumption. Comparing consumers in the highest quintile of UPP intake to the lowest quintiles of UPP intake, the percentage of energy intake from protein was lower by fifty percent (12.8% of energy intake compared to 24.7% of energy intake) and the percentage of energy from free sugars (i.e., glucose, fructose, sucrose or table sugar added to foods and drinks by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates) was higher by more than fifty percent (19.8% of energy intake compared to 8.32% of energy intake) (Batal et al. 2018b). Other dietary differences were higher sodium intake and sodium/potassium ratio and lower iron and vitamin A intakes in the highest quintile of UPP consumption compared to the lowest quintile of UPP consumption. Only 5.5% of dietary

recalls contained Trad-Foods for the highest consumers of UPP whereas 42.3% of dietary recalls contained Trad-Foods for the lowest consumers of UPP.

The diets of women participating in the FNFNES were classified using the Healthy Eating Index (HEI) (Garriguet 2009). Higher HEI scores implying better diet quality were associated with lower UPP consumption and greater consumption of Trad-Foods (e.g., ~28% of 24-hour recalls mentioned Trad-Foods in the highest HEI quartile versus ~11% in the lowest HEI quartile). HEI scores were grouped into diet quality categories (Garriguet 2009). The mean HEI score for women aged 19-30 years participating in the FNFNES was 47, implying a poor-quality diet, while mean energy intake was 8473 kJ (2025 kilocalories). To explore ways to improve healthy eating, the HEI score and energy intake was estimated when all UPP in the diet was removed; however, this was unrealistic because energy intake was reduced to 2983 kJ (713 kilocalories) considering the ubiquity of UPP in the diet. In a more realistic scenario where the grams of UPP were decreased by 50% and all other foods were increased by 30%, the HEI increased to 64, implying a diet that requires improvement (but is not of poor quality), and energy was 8464 kJ (2023 kilocalories).

Inuit Health Survey

The Canadian Inuit Health Survey (Inuit Health Survey 2007-2008 2018) was a cross-sectional study conducted in the late summer and fall of 2007 and 2008. All 36 Inuit communities (33 coastal and 3 inland) in Nunavut, the Inuvialuit Settlement regions and Nunatsiavut were visited (Figure 2). Data collection included: a household questionnaire; household food security; FFQ and 24-hour diet recalls; clinical examination; nutrition markers; and contaminants. A total of 2097 adults participated and completed a dietary recall survey. Ethics approval was obtained

from McGill University, the Nunavut and Aurora Research Institutes. Written informed consent was obtained from all participants. All methods are described elsewhere (Saudny et al. 2012).

Inuit participants of the IHS consumed a mean of 164 g/day of country food (meat, 116 grams; fat, 46 grams; organs, 2 grams), which contributed 16% of energy intake (Table 2). Commonly consumed Trad-Foods based on responses to the FFQ were ungulates (caribou), fish (Arctic char), pinnipeds (ringed seal) and berries, with over 50% of the population consuming them. Of the 2074 Inuit participants who provided blood samples, 35% were above the Toxicological Reference Values for mercury established by Health Canada (Laird et al. 2013b). One-quarter of IHS participants and 43% of women of child-bearing age in Nunavut had elevated blood mercury levels, with ringed seal liver being the major source of mercury. However, blood mercury concentrations were positively correlated with intakes of selenium, DHA and EPA, which are essential nutrients found in the Trad-Foods of Inuit including fish and marine mammals (Laird et al. 2013b).

Using IHS data, Chan's group used a mathematical technique that allows for the generation of theoretical diets that are nutritionally adequate; toxicologically acceptable; and cost affordable (Figure 3). Models considered many constraints: Trad-Foods availability; safe contaminant intake thresholds in the diet; nutritional adequacy of the diet; normative consumption patterns; total diet energy; and, food budget limitations. Modelling indicated that increasing country food intake to ensure nutrient adequacy would decrease the cost of the diet but would substantially increase mercury and polychlorinated biphenyl (PCB) intake. To achieve nutrient adequacy and a safe contaminant intake, organs obtained from wild animals were eliminated in diet modelling. However, this led to a 45% increase in the cost of the diet as compared to the usual intake.

Discussion

Nutrition research has traditionally focused on single nutrients in relation to health; however, recent appreciation of the complex synergistic interactions among nutrients and other food constituents has led to a growing interest in total dietary patterns (Tucker 2010; Wirfalt et al. 2013). This symposium review provided examples from the First Nations Food, Nutrition and Environment Survey (FNFNES) and Inuit Health Study (Wahlqvist et al. 2009) of novel ways to model contemporary Indigenous diets in Canada to conform to nutrient requirements; minimize contaminant exposure from traditional food sources; promote the use of local, cultural foods; reduce consumption of highly processed food; and, be economically attainable. Linear programming was used with IHS data to generate a nutritionally sound diet that incorporated local, culturally acceptable foods; however, the cost of the diet was higher than the actual diet, which is problematic given high food insecurity among Inuit (Expert Panel on the State of Knowledge of Food Security in Northern Canada 2014). Similarly, a linear programming approach in Tanzania resulted in a diet using locally available foods that minimized key nutrient inadequacies but was not cost-effective for poor families (Raymond et al. 2018). Populations such as the Inuit that experience both poverty and high food insecurity may therefore also require interventions that reduce household food insecurity in order to implement diets based on linear programming (Expert Panel on the State of Knowledge of Food Security in Northern Canada 2014).

The NOVA classification was used with FNFNES data to determine which foods were UPP - ultra-processed foods and beverages containing little or no whole food but a large number of additives such as preservatives, sweeteners, sensory enhancers, vitamins/minerals, colorants, flavours and processing aids (Batal et al. 2018a; Batal et al. 2018b). The diet of FNFNES

participants was scored in terms of the extent to which it met the full set of nutrition recommendations of the Healthy Eating Index. Higher Healthy Eating Index scores indicating better diet quality were associated with greater Trad-Foods intake and lower UPP intake. Scores were recalculated based on simulated scenarios which decreased UPP while increasing other food components to provide ways for individuals to improve their dietary pattern. However, before making recommendations for Indigenous peoples to decrease UPP intake, it is important to establish whether this shift is possible by striving to better understand some of the systemic reasons for UPP consumption, such as their ubiquity in the communities' food retailers, their relative low cost compared to harvested food, long shelf life, and the quality of the fresh fruits and vegetables in remote locations.

Participants of both the FNFNES and IHS harvested and consumed a variety of traditional animal and plant foods from their local food systems. The inclusion of Trad-Foods in the diet of Indigenous peoples is important considering that Trad-Foods are nutritionally-dense and an essential component of food security for many Indigenous peoples, unlike for other Canadians where food security is chiefly determined by financial access to store-bought market foods (Egeland and Harrison 2013; Egeland et al. 2011). There are many reasons why Indigenous peoples cannot or will not increase Trad-Foods consumption, some which still need to be further explored before Trad-Foods consumption can be fully endorsed. For example, environmental threats (i.e., mining, forestry, hydro, urban development) reduce Indigenous peoples' ability to access foods from their traditional food system (Egeland et al. 2011; Kuhnlein and Receveur 1996; Turner et al. 2013). The contaminant burden of some Trad-Foods underscores the need to develop communication strategies that promote the healthfulness of Trad-Foods while informing of the contaminant risks associated with consuming them. Using the IHS, it was determined that

some Trad-Foods which contain contaminants also provide beneficial nutrients. Furthermore, not all Trad-Foods have the same contaminant burden and regional variations in contaminant burden do occur; therefore, Trad-Foods lower in contaminants could substitute for Trad-Foods higher in contaminants (Laird et al. 2013b).

Conclusions

The methods for optimising diets of Indigenous peoples described in this symposium review may help program planners and policy makers respond to the complex challenges facing Indigenous communities to achieving healthy diets, which include maximizing traditional food consumption while minimizing processed food consumption, contaminant intake from traditional food, and cost. The examples of diet modelling can help nutrition researchers explore ways to increase diet quality for Indigenous peoples using actual eating patterns, although realistic improvements may be difficult to achieve given financial constraints, food insecurity, limited access to healthy market foods, reduced access to Trad-Foods in the environment, the contaminant burden of some Trad-Foods, and changing taste preferences. The methodologies we describe provide the basis for engaging Indigenous peoples and program planners to develop realistic nutrition goals and policy anchored in their food reality.

Conflict of Interest

The authors have no conflicts of interest to report

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Table 1. Demographic, anthropometric, health and dietary characteristics of adults 19 years and older from 58 on-reserve First Nations communities in British Columbia, Manitoba, Alberta and Ontario (Canada), 2008-2013.

Province/ Characteristic	British Columbia	Alberta	Manitoba	Ontario
N	1060	573	680	1387
Age ¹ (y)	44.5±14.3	44.8±14.6	42.8±14.4	46.9±15.8
Gender				
Women (%)	62.4	61.3	66.3	61.7
Men (%)	37.6	38.7	33.7	38.3
Food Insecurity ² (%)	46.8	52.9	48.0	41.4
Diabetes ³ (%)	NA	18.5	19.8	27.0
Overweight ⁴				
Women (%)	37.0	32.0	25.0	29.0
Men (%)	37.0	37.0	39.0	42.0
Obese ⁵				
Women (%)	42.0	49.0	59.0	53.0
Men (%)	49.0	37.0	47.0	43.0
Traditional food ⁶ (g/day)	81.0	29.0	45.0	43.0
Ultra-processed products ^{1,7} (%)	49.9	54.1	56.7	55.6
total energy/day)				
Healthy Eating Index ⁸	49.3	49.2	47.0	50.9

NA: not available. ¹Mean±SD. ² Food security established using the income-related Household Food Security Survey Module (HFSSM) adapted from food security module developed in the U.S and adapted for First Nations households (includes severe, moderate and marginal food insecurity). ³Self-reported prevalence. ⁴ 25≤BMI<30. ⁵BMI≥30. ⁶Frequency from food frequency questionnaire multiplied by the average portion size from the 24-hour recall. ⁷Ultra-processed products based on the NOVA classification (Batal et al. 2018b). ⁸Canadian adaptation of the Healthy Eating Index (Garriguet 2009).

Table 2. Average grams per day and percent total daily energy for traditional or country food categories consumed by the Inuit Health Survey participants.

	Average (grams/day)	%Total energy
Country Food - Total	164	15.8
Country Food - Meat	116	10.9
Country Food - Fat	46	4.3
Country Food - Organs	2	0.6

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Figure 1 Map of number of First Nations communities in British Columbia, Alberta, Manitoba and Ontario that participated in the First Nations Food, Nutrition and Environment Study (FNFNES) from 2008-2013

Figure 2. Map of communities recruited in the Inuit Health Survey (all communities) and the Inuit Child Health Survey (outlined communities) (El Hayek Fares and Weiler 2016) (reprinted with Permission)

Figure 3. Linear programming optimization

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TDMI: total departure from the mean food intake, ABS: absolute value, m_i : mean of a variable, X_i : decision variable or constraint