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Nutritional and Environmental Sustainability of Lentil Reformulated Beef Burger

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Abstract: Numerous studies have shown that replacing a portion of beef with plant-based foods in daily diets of high-income nations can improve health, nutrition, and environmental consequences globally. Pulses are one of the major plant-based protein foods shown to have both environmental and nutritional benefits. For consumers to adopt more plant-based foods in their diets, more options are needed that meet consumer demands for taste, convenience, nutrition, and sustainability along with dietary preferences. Beef-based burger patties can be made more sustainably, nutritiously, and cost-effectively while maintaining palatability by reformulating with a portion of pulses such as whole cooked lentils. The aim of this study was to quantify the nutritional and environmental benefits of such lentil-reformulated beef burgers. Here we compared the nutrient balance score (considering 27 essential macro and micronutrients) and environmental footprints (carbon, bluewater, water scarcity, land use, and biodiversity) of an all-beef burger with a beef burger reformulated with a portion of cooked lentil puree. The geographic resolution of the analysis was Saskatchewan, Canada. Results showed that partial replacement of a lean beef burger with cooked lentil puree increased the nutrient density by ~20%, decreased the life cycle environmental footprint by ~33%, and reduced the cost by 26%. In particular, the lentil reformulated burger had 60 times higher dietary fiber, three times higher total folate, five times higher manganese, and 1.6 times higher selenium than the all-beef burger. We highlight the importance of using high-spatial resolution inventory of agricultural inputs and characterization factors (impacts per unit agricultural inputs) to obtain more accurate environmental results. The results underscore the potential of food innovation to contribute towards multiple global sustainable development goals.

Keywords: lentils; pulses; nutrition; nutrient density; agriculture; carbon footprint; greenhouse gas; beef; burgers; water scarcity; biodiversity

1. Introduction

Governments and the general public are becoming increasingly aware of the importance of dietary sustainability for the achievement of the UN 2030 global sustainable development goals (SDGs) [1]. The three dimensions of sustainability are: social (e.g., nutrition), environmental, and economic. Many studies including the recent EAT-Lancet commission's report on sustainable food systems showed that in order to feed healthy and nutritious diets to a projected 9 billion people by 2050 and at the same time not transgressing the environmental planetary boundaries, meat consumption needs to be reduced especially in high-income nations and replaced with plant-based foods [1–7]. In particular, the high carbon footprint of beef products has received a lot of scientific and media attention over the past decade, as a major contributor to dietary carbon footprints, and to agricultural greenhouse gas emissions as a whole [8,9]. Beef has also been highlighted as a food with a high-water footprint [10,11], and with a large land footprint [12] leading to negative consequences on biodiversity through habitat loss and degradation [13,14]. In some cases though, the production of beef and other ruminants for meat can be relatively beneficial, as grazing land and perennial forage production can provide higher ecological benefits and ecosystems services such as carbon storage and wildlife habitat compared with intensive crop production [15,16].

Plant-based sources of protein typically have much lower carbon, water, and land footprints than animal-based sources of protein [1,9]. Pulses are one of the major plant-based protein foods shown to have both environmental and nutritional benefits [7,17,18]. At the farm level, most pulses do not require irrigation and are well suited for semi-arid, water-scarce regions [19]. Pulse crops can fix atmospheric nitrogen and thus reduce nitrogen fertilizer requirements leading to reduced risk of nitrogen emissions to water and lower greenhouse gas emissions [8]. In addition, incorporating pulses such as peas or lentils in the crop-mix can improve soil health, yield, and protein content of the next crop [18,20]. Per serving, pulses contain high amounts of essential vitamins, minerals, protein, and dietary fiber, and contain no cholesterol and little fat. The consumption of beef and animal meats also has nutritional benefits, as meat contains high amounts of balanced protein, B vitamins, and minerals like iron and zinc per unit serving. At the dietary level, replacing a portion of meat with pulse-based food into daily diets can simultaneously reduce environmental impacts and improve nutritional outcomes worldwide [7,21,22] and this needs to be assessed at a country and individual level. Canada is one of the largest producer of pulses worldwide and recent life cycle assessment (LCA) studies have shown that partial replacement of refined wheat flour with Canadian yellow pea flour in traditional cereal (wheat) based foods such as pan bread, breakfast cereals, or pasta can both improve the nutritional density and decrease the life cycle carbon footprint by up to 10% [7]. In addition, this work also demonstrated that utilizing wheat sourced from improved cropping systems (in this case, from a diverse crop rotation vs. a monoculture rotation), also improved the carbon footprint of the final food product. Apart from yellow peas, lentils are another category of pulses whose increased consumption can improve the sustainability of food systems and diets [23].

Considering the environmental and nutritional benefits of pulses, they are increasingly being included as ingredients in a range of food applications including meat alternatives. For example, pea protein is used in Beyond Burger® products that imitate beef-based foods in texture and appearance but are 100% plant-based [24]. Note that many plant-based meat substitute products to date are based on soy protein isolates and not whole legumes. Many are also not fortified with iron or vitamin B12 and thus cannot be considered equivalent to meat. Regardless, consumers of beef burgers may be reluctant to abandon them altogether in favor of purely plant-based burgers because cultural and personal factors are key to individual food habits [25,26]. Another opportunity exists to improve the sustainability, nutrition, and cost of beef-based burger patties by reformulating them with pulses such as whole cooked lentils. Blended burger and blended meat applications are becoming more popular in foodservice and retail in North America. There is an opportunity to market the sustainability and nutritional advantages of these blended burgers with appropriate quantitative research. However, the exact nutritional and environmental benefits of such lentil-reformulated beef burgers have not yet been quantified. Another research gap is that most studies focus only on greenhouse gas emissions (GHG) as the sole indicator of environmental sustainability or do not take into account production practices while calculating the environmental impacts of foods. It is possible for a product to have low GHG footprint but high land, water or biodiversity footprint depending upon where or how it is grown [9]. Similarly, regarding nutritional sustainability of food items and diets, many studies just focus on caloric or protein requirements while ignoring the micronutrients whose deficiency affect over 2 billion people worldwide [27]. In addition to greenhouse gas emissions, metrics for water use, land use efficiency, and biodiversity impacts have been identified as key indicators of interest by the food industry. Recently, under the ambit of UNEP-SETAC Life Cycle Initiative [28], there have been advancements in methodologies for water use and biodiversity impact assessment by incorporating factors such as regional/local water scarcity [29] as well as endemicity and threat level of species occurring in the region whose natural habitat is being encroached for food production purposes [30].

The objective of this paper is to present the nutritional and environmental (GHG, bluewater, water scarcity, land use, biodiversity) consequences of reformulating beef burger patties with whole cooked Canadian lentils. Rather than using the country-average values, the calculated impacts will take into consideration the exact location of the crop or beef (sub-national level) production and irrigation water source. This will ensure that the environmental impact results are spatially explicit and account for the spatial variability in yield, soil carbon, water scarcity, and biodiversity across Canada. The nutritional quality of the traditional all-beef (without cooked lentils) and reformulated (with cooked lentils) burgers is compared using the relative amounts of 27 essential nutrients and five nutrients of health concern [7].

2. Materials and Methods

2.1. Ingredient Composition of Food Products

Recipes for traditional all-beef and lentil reformulated beef burger patty were obtained from popular websites [31]. The serving size of typical beef burger patty in Canada is 4 oz (i.e., 115 g) containing around 113.77 g of raw ground beef (~98.93% of total mass), one g of salt (0.87%) and 0.23 g of black pepper (0.2%).

On the other hand, the lentil reformulated beef burger patty contains 75.84 g of raw ground beef (66%), and 30.41 g of whole cooked lentils (26.5%), 7.51 g of water while the amounts of salt and pepper remains the same as in the traditional burger patty. The formulation for this product was provided by Lentils.org, an organization tasked with promoting the consumption of lentils in North America and around the world. This organization is promoting this blended burger concept and has tested the recipe. This recipe consists of 67% beef and 33% lentil puree, of which 26.5% is whole cooked lentils and 6.5% is water. (33% lentil puree = 26.5% whole cooked lentils + 6.5% water.)

Since the nutrient composition of regular and lean beef differs considerably, we considered them separately. We thus carried out the nutritional analysis for four different burger patties—regular beef, lean beef, regular beef reformulated with lentil puree, and lean beef reformulated with lentil puree. Lentil puree is simply 80% cooked lentils mixed with 20% water by mass. A list of ingredients used in each of the four patty is listed in Table 1.

Table 1. Mass of raw ingredients (g) required for the production of one serving (4 oz, 115g) of traditional and lentil reformulated beef burger patty.

Ingredients	Salt	Water	Whole Cooked Lentils	Black Pepper	Raw Ground Beef, Regular	Raw Ground Beef, Lean
Regular beef burger with lentil puree	1	7.5	30.4	0.2	75.8	0
Lean beef burger with lentil puree	1	7.5	30.4	0.2	0	75.8
Regular beef burger	1	0	0.00	0.2	113.8	0
Lean beef burger	1	0	0.00	0.2	0	113.8

2.2. Nutrient Composition of Ingredients

The nutrient composition (per 100-g) of raw ingredients used in making beef patties is presented in Table 2. The nutrient composition data for whole cooked green lentils was provided by independent nutrient analysis (Silliker Canada Co., Markham, Ontario, MB, Canada) while for the other ingredients, the values were taken from the Canadian Nutrient File [32].

Table 2. Nutrient composition of burger ingredients are presented, i.e., amounts of energy, 27 essential nutrients and five nutrients of health concern per 100 g of ingredients.

Nutrient Content Per 100 g	Salt	Whole Cooked Lentils	Black Pepper	Raw Ground Beef, Regular	Raw Ground Beef, Lean
Source:	CNF#: 214	Independent analysis	CNF#: 198	CNF#: 2786	CNF#: 2683
Energy (kcal)	0	156	251	293	207
Water (g)	0	61.05	12.46	58.12	66.48
Protein (g)	0	12.82	10.39	16.55	19.58
Dietary fiber (g)	0	9.7	25.3	0	0
α-Linolenic Acid (mg)	0	0.05 *	0.152	0.103	0.055
Linoleic Acid (mg)	0	0.19 *	0.694	0.327	0.248
Vitamins					
Total Folate (μg)	0	42.8	17	7	8
Niacin (mg)	0	2.41 *	2.11	7.775	9.442
Pantothenic acid (mg)	0	0.638 *	1.399	0.562	0.708
Riboflavin (mg)	0	0.073 *	0.180	0.185	0.228
Thiamin (mg)	0	0.169 *	0.108	0.1	0.108
Vitamin A as RAE (μg)	0	20	27	0	4
Vitamin B_6 (mg)	0	0.178 *	0.291	0.212	0.238
Vitamin B_{12} (μg)	0	0	0	2.35	2.35
Vitamin C (mg)	0	1	0	0	0
Vitamin D (μg)	0	0 *	0	0.1	0.1
Vitamin E (mg)	0	0.11 *	1.04	0.17	0.17
Vitamin K (μg)	0	1.7 *	163.7	0.5	1.8
Choline (mg)	0	32.7 *	11.3	56.4	56.4
Minerals					
Calcium (mg)	24	27.6	443	11	10
Copper (mg)	0.03	0.251 *	1.33	0.1	0.082
Iron (mg)	0.33	2.6	9.71	1.8	1.8
Magnesium (mg)	1	40.8	171	17	19
Manganese (mg)	0.1	0.494 *	12.75	0.017	0.01
Phosphorous (mg)	0	132	158	136	161
Potassium (mg)	8	274	1329	231	271
Selenium (μg)	0.1	30 *	4.9	12.7	15
Zinc (mg)	0.1	1.15	1.19	4.18	4.58
Nutrients of concern					
Total Fat (g)	0	0.55	3.26	24.7	13.68
Trans Fat (g)	0	0.01 *	0	0.61	0.462
Saturated Fat (g)	0	0.15	1.392	10.168	5.462
Cholesterol (mg)	0	0	0	66	60
Sugar (g)	0	0.38	0.64	0	0
Sodium (mg)	38758	6	20	60	63

* Data corresponding to these nutrients were not provided by the independent analysis and was imputed from the data for boiled lentils from the Canadian Nutrient File (File #3393).

2.3. Calculation of the Nutritional Quality of Burger Patties

By multiplying the ingredient amounts (from Table 1) with their respective nutrient composition values per g (from Table 2), the amounts of different nutrients in each of the four burger patties were obtained. The nutritional quality of traditional and reformulated patties was determined using the Nutrient Balance Concept (NBC) proposed by Fern et al. [33] and applied by Chaudhary et al. [7] for their yellow pea reformulation study. The NBC provides an aggregated measure of nutrient density of the foods by averaging the ratio of amount of qualifying (essential) or disqualifying (of health concern) nutrients in 2000 kcal of a given food with their daily recommended intake values (DVs). The NBC consists of three metrics: the Qualifying index (QI), the Disqualifying Index (DI), and the Nutrient Balance Score (NBS).

The QI is defined as the mean of the ratio of qualifying nutrients contained in 2000 kcal of a given food relative to their Daily Values (DV) across qualifying nutrients Equation (1).

$$QI_k = \frac{\frac{2000\ kcal}{E_k} \times \sum_{j=1}^{Nq} \frac{a_{k,j}}{DV_j}}{N_q} \tag{1}$$

where QI_k is the QI of an individual food k, 2000 kcal represents the total daily energy intake to which nutrition labelling is based in Canada [34], and E_k is the amount of calories per serving of food k (115 g for patties here). The amount of each qualifying nutrient a relative to DV is represented by $a_{k,j}/DV_j$. N_q is the number of qualifying nutrients (q) considered (N_q = 27) and $a_{k,j}$ is amount of nutrient j in the food k. When the QI value is >1, the food is considered nutrient dense but if the QI value is <1, the food is termed as energy dense [33].

The daily recommended intake values (DVs for qualifying nutrients are summarized in Table 3. DVs are based on Dietary Reference Amounts established by National Academy of Sciences and are based on the population coverage approach [35]. DV for water, protein, α-linolenic acid, and linoleic acid have not been adopted in Canada [36]. Therefore, for these nutrients, Dietary Reference Intakes (DRIs) from the National Academy of Sciences were used and established as the average DVs for men and women ≥19 years of age [37].

Table 3. Summary of Daily Values (DV) for qualifying (essential) nutrients and Mean Reference Values (MRV) for disqualifying nutrients (of health concern) for Canadian Adults used to calculate the Qualifying Index, Disqualifying Index, and Nutrient Balance Score for reformulated and traditional foods.

Qualifying Nutrient	Daily Value
Macronutrients	
Water	3.2 L †
Protein	50 g †
Dietary Fiber	28 g *
α-Linolenic Acid	1.4 g †
Linoleic Acid	14 g †
Vitamins	
Total folate/folic acid	400 µg *
Niacin	16 mg *
Pantothenic acid	5 mg *
Riboflavin	1.3 mg *
Thiamin	1.2 mg *
Vitamin A	900 µg *
Vitamin B_6	1.7 mg *
Vitamin B_{12}	2.4 µg *
Vitamin C	90 mg *
Vitamin D	20 µg *
Vitamin E	15 mg *
Vitamin K	120 µg *
Choline	550 mg *
Minerals	
Calcium	1300 mg *
Copper	0.9 mg *
Iron	18 mg *
Magnesium	420 mg *
Manganese	2.3 mg *
Phosphorous	1250 mg *
Potassium	4700 mg *
Selenium	55 µg *
Zinc	11 mg *

Table 3. *Cont.*

Qualifying Nutrient	Daily Value
Disqualifying Nutrients	**Mean Reference Value per day**
Sugar	100 g *
Sodium	2300 mg *
Total Fat	75 g *
Saturated Fat	20 g *
Cholesterol	300 mg *

* Government of Canada [36]. † Daily Reference Intakes (DRIs) established by The National Academy of Sciences were used as Daily Values for water, protein, α-Linolenic Acid, and linoleic acid [37].

The disqualifying index (DI) represents the levels of 5 nutrients of health concern d (sugar, sodium, total fat, saturated fat, and cholesterol) in a food relative to their daily Maximal Reference Values (MRV):

$$DI_k = \frac{\frac{2000\ kcal}{E_k} \times \sum_{j=1}^{Nd} \frac{a_{k,j}}{MRV_j}}{N_d} \tag{2}$$

DI_k is the disqualifying index for food k. Again, 2000 kcal represents the total daily energy intake, and E_k is the energy content of a serving of patty (115 g). N_d is the number of disqualifying nutrients (q) considered (N_d = 5) and $a_{k,j}$ is amount of disqualifying nutrient j in the food k. MRVs for the five disqualifying nutrients are summarized in Table 3. Trans fatty acids were not included as a disqualifying nutrient in this study as levels were not available for lentils in the Canadian Nutrient File, and the Government of Canada has banned the use of partially hydrogenated oils in Canada [38]. When the DI value is >1, the food is termed as "compromised" because it contains one or more nutrients of health concern in quantities higher than their maximum recommended amounts [33].

The third metric, the nutrient balance score (NBS) is simply the average of qualifying index values of all 27 essential nutrients (N_q = 27) considered here:

$$NBS_k = 100 \cdot \left(\frac{\sum_{q=1}^{Nq} QI_{q,k}}{N_q} \right) \tag{3}$$

NBS_k is the nutrient balance for food k. $QI_{q,k}$ is the qualifying index for each essential nutrient q in food k which is basically equal to the numerator term $a_{k,j}/DV_j$ in Equation (1). Note that when calculating the NBS, any $QI_{q,k} > 1$ is truncated to 1 assuming that if the daily requirement for a specific qualifying nutrient is already met through a food, any increase in its amount will not improve the overall nutrient density of the food. This takes care of those scenarios where a food has very high amount of any one particular nutrient but negligible amounts of all other nutrients. A nutrient balance score (NBS) of 100% implies that the food contains the 100% of the daily requirement of every 27 essential nutrient in a 2000 kcal diet [33].

2.4. Environmental Footprints of Boneless Beef

The life cycle greenhouse gas emissions, bluewater use, and land use footprint of 1 kg of Western Canadian bone free beef at packers' gate were obtained from the recently published report of the Canadian Roundtable for Sustainable Beef (CRSB) [16]. They found that the carbon footprint of bone free beef at packers' gate is 24.5 kg of CO_2eq. At the first life cycle stage "farming or animal production," 11.4 kg of CO_2 equivalents are emitted to produce one kg of live cattle weight at the farm gate. Methane, nitrous oxide, and carbon dioxide are responsible for 57%, 30%, and 13% of the total emissions. The major GHG sources are enteric fermentation methane emissions due to cattle digestion (51.5%), manure production, and management (27.7%) and feed production (19.3%). On-farm energy use and animal transport contribute 1.3% and 0.3% to the total production stage carbon footprint respectively [16].

After the "farming" stage, the next life cycle stage considered was "transportation between farm and packers" that considers fuel consumption during transportation, dressing rate, and loss of animal weight (shrinkage) during transportation. The results after this stage were 18.7 kg CO2eq. per kg of carcass weight. As of this stage, the animal production accounted for >94% of the GHG emissions and environmental impact, with fossil fuel consumed during transportation to packers representing about 5.5% [16].

The third life cycle stage considered was "packing" that constitutes environmental impacts due to the packing of the meat including impacts due to the energy, water, materials such as corrugated cardboard, polyethylene (PE) film, wood, etc., and chemicals used for cleaning and disinfection and emitted effluents. As of this stage, the farming stage contributed to 92–95% of total GHG, water, and land use impacts, while the transportation and packing stage contributed 3–5% and 1–2% of the total footprint respectively [16]. The retail and consumption (food waste by consumers) stages of beef life cycle were not considered as these are assumed to be same for both traditional and lentil reformulated beef burgers.

Regarding water depletion, the Canadian Roundtable for Sustainable Beef (CRSB) report found that on average 235 L of blue water (surface water and groundwater bodies) is required per kg of live weight at the farm gate for Canadian beef production [16]. Water used for irrigation of feed crops (mainly hay, barley, and maize) represents 81% of the total footprint (indirect footprint), while animal water consumption (direct footprint) represents 19%. Groundwater, flowing surface water, and lake water contribute equally about 32% of the animal water consumption.

The land footprint was found to be 93 m^2 of agricultural land per kg of live weight at the farm gate with pasture-dedicated areas contributing 79% and feed ration (hay and barley) dedicated areas contribute 21% of the total land footprint. Note that the land footprint varied widely (21 m^2 to 415 m^2 per kg of live weight) among the farms depending upon the grazing surfaces used [16].

The environmental footprints after the first three life cycle stages were 24.5 kg CO2eq., 508.3 L of water depletion, and 196.4 m^2 of agricultural land occupation per kg of western Canadian bone-free beef meat at packers' end gate. These values were used for our regular and lean beef burger patty environmental analysis.

2.5. Environmental Footprints of Cooked Lentils

Greenhouse gas emissions from the cultivation stage of lentils in western Canada was obtained from recent reports prepared by $(S\&T)^2$ Consultants Inc. for Canadian Roundtable on Sustainable Crops (CRSC; [39]). They found that the carbon footprint of 1 kg of dry lentils produced in Saskatchewan province is −0.1156 kg CO_2eq. after accounting for the positive effect of Western Canadian cropping practices (reduced tillage and reduced summer fallow) on soil organic carbon (SOC). Without accounting for SOC, the carbon footprint of 1 kg lentils is 0.2152 kg CO_2eq.

There were four major sources of production related GHG emissions. Almost 50% of the farming stage carbon footprint of lentils can be attributed to direct/in-direct nitrous oxide (N_2O) emissions from the field, 26% to direct on-farm energy use for cultivation, 18% to fertilizer manufacturing, and 6% to seeds and pesticide manufacturing. The carbon sequestration associated with SOC due to lentil cultivation was found to be −0.331 kg CO_2eq. per kg of lentil produced.

Since the burger patties contain the cooked lentils, the GHG emissions associated with the cooking stage of lentils was also included. It was assumed that 6.67 MJ of energy from Canadian natural gas is required to obtain 1 kg of cooked lentils as mentioned in a recent report [40]. The cooking conversion factor utilized was 2.326 meaning that 1 kg of dry lentils when cooked will yield 2.326 kg of cooked lentils. The GHG emission factor for Canadian natural gas was taken as 0.04988 kg CO_2eq. per MJ [41]. Summing up the cultivation and cooking stage, the total carbon footprint of 1 kg of cooked lentils sourced from Saskatchewan province was 0.283 kg CO_2eq.

The total water requirement of one 1 kg dry lentils grown in Saskatchewan is 1650 L according to a recent study by Ding et al. [42]. In most of the divisions (census divisions) within Saskatchewan, the lentils are rain-fed and the bluewater footprint of lentils is zero. However, some farms in division 7 and 11 of Saskatchewan are irrigated through freshwater from Lake Diefenbaker. In the irrigated areas, around 76% of total water demand of lentils is fulfilled naturally through precipitation and the rest (24%) through irrigation. The bluewater footprint of irrigated lentils is calculated as 398 L/kg (= 0.24 × 1650). The lentil area in division 7 and 11 that are irrigated was derived from a survey of irrigated producers in Saskatchewan [43]. Finally, we calculated the production-weighted bluewater and land footprint for dry lentils produced in Saskatchewan province of western Canada (detailed calculations shown in Table 4). On average, 0.67 L of bluewater and 6.67 m^2 of cropland is used to produce 1 kg of lentils in Saskatchewan. It was assumed that 0.77 L of water is required to obtain 1 kg of cooked lentils [40].

Table 4. Summary of lentil production, land footprint (yield), and bluewater footprint in each census division of Saskatchewan for the year 2017.

Saskatchewan Census Division	Lentil Production (Tonnes)	Lentil Acres (Harvested)	Yield (Tonnes/Acre)	Irrigated/ Rain-Fed	Bluewater Footprint (L/Kg)	Production × Bluewater Footprint
2	164,200	383,800	0.43	Rain fed	0	0
3	233,400	475,500	0.49	Rain fed	0	0
4	140,800	326,200	0.43	Rain fed	0	0
6	222,500	369,800	0.60	Rain fed	0	0
7	352,485	600,814	0.59	Rain fed	0	0
7	2515	4286	0.59	Irrigated	398	1,000,790
8	505,800	813,800	0.62	Rain fed	0	0
11	169,590	246,938	0.69	Rain fed	0	0
11	1210	1762	0.69	Irrigated	398	481,507
12	220,300	285,700	0.77	Rain fed	0	0
13	198,900	273,700	0.73	Rain fed	0	0
	∑ = 2,211,700					∑ = 1,482,297
Weighted average Bluewater footprint for dry Saskatchewan lentils (L/kg)						1,482,297–2,211,700 = 0.67

Data taken from crop production statistics of Saskatchewan government [44].

The environmental footprints from transportation, packaging, retail, and post-consumer recycling stage of lentil life cycle were not taken into account as the impact of these stages is highly site-dependent and within the LCA, these stages often contribute very little to the total footprint of the plant-based foods relative to the production stage [45].

2.6. Water Scarcity Assessment

For assessing the impact of beef and lentil production on regional water scarcity, the Available Water Remaining (AWARE) method recently proposed by Boulay et al. [29] was applied. This method is an outcome of a two-year consensus building process by the Water Use in Life Cycle Assessment (WULCA), a working group of the UNEP-SETAC Life Cycle Initiative [28]. The recommended method, AWARE, is based on the quantification of the relative available water remaining per area once the demand of humans and aquatic ecosystems has been met, answering the question: What is the potential to deprive another user (human or ecosystem) when consuming water in this area? The resulting characterization factor (CF) ranges between 0.1 and 100 and can be used to calculate water scarcity footprints of agricultural products.

The total bluewater footprint of a food product is multiplied with the AWARE agricultural characterization factor for the region where the product was produced to calculate the water scarcity footprint:

$$Water\ Scarcity\ Footprint = Water\ consumption \times CF_{AWARE} \tag{4}$$

The unit of water scarcity footprint is m^3 world eq./m^3 consumed. The characterization factor is limited to a range from 0.1 to 100, with a value of 1 corresponding to a region with the same amount of remaining water per area within a certain period of time as the world average, values <1 for regions with less problems of scarcity than the world average and a value of 10, for example, representing a region where there is 10 times less water remaining per area within a certain period of time as the world average, or that it takes 10 times more surface time to generate an amount of unused water in this region than the world average, assuming a given level of water demand [29].

The AWARE characterization factors are available at the sub-watershed level and monthly time step, globally. The characterization factors values can be aggregated to country or county level and/or annual time step for use with other data at the respective resolutions. Rather than using country or province average values, we therefore derived the AWARE characterization factors at the Saskatchewan census division level to be consistent with the crop production data that is also available at this geographic resolution (Table 4). Since some divisions are drier and water scarce than others, using spatially explicit characterization factors will result in more accurate results.

To this end, the Saskatchewan census divisions' boundary shape files were overlaid with the AWARE characterization factor shape files that provide one characterization factor for each sub-watershed globally. The AWARE characterization factor for a particular division was then calculated by taking the area-weighted average of characterization factors for all sub-watershed occurring in that division. All calculations were performed in Google Earth online.

Table 5 shows the calculated AWARE characterization factors per census division of Saskatchewan along with the production-weighted average water scarcity (AWARE) footprint for Saskatchewan beef, which came out to be 21.34 m^3 world eq./m^3.

Table 5. Summary of cattle production and water scarcity footprint of beef in each census division of Saskatchewan.

Saskatchewan Census Division	Total Cattle Production (in Numbers of Cow)	AWARE CF	Production × CF
1	72,500	3.12	226,200
2	81,900	13.4245	1,099,466
3	92,500	75.705	7,002,712
4	115,000	41.0785	4,724,027
5	75,000	3.12	234,000
6	81,900	3.12	255,528
7	85,000	41.736	3,547,560
8	70,000	35.9015	2,513,105
9	42,500	3.12	132,600
10	30,000	3.265	97,950
11	60,000	4.028	241,680
12	42,500	33.767	1,435,097
13	47,500	20.26	962,350
14	32,500	7.033	228,572
15	37,500	6.02	225,750
16	60,000	6.974	418,440
17	97,500	6.5447	638,108
18	0	5.559	0
	∑ = 1,123,800		∑ = 23,983,148
Weighted average water scarcity (AWARE) footprint for Saskatchewan beef (m^3 world eq./m^3)			23,983,148–1,123,800 = 21.34

Cow production data taken from Statistics Canada [46].

Using a similar approach and the census division-specific production statistics of lentils from Table 4, the average water scarcity (AWARE) footprint for Saskatchewan lentils was calculated as 0.01 m^3 world eq./m^3. However, since the water used in irrigation of lentils comes from Lake Diefenbaker which falls under the watershed with AWARE characterization factor as 6.02 m^3 world eq./m^3, this characterization factor was used to multiply the bluewater footprints of lentils to get their water scarcity footprints.

2.7. Biodiversity Impact Assessment

To translate the land footprint into impacts on biodiversity, the ecoregion-specific characterization factor values provided by Chaudhary & Brooks [30] were used. These characterization factors give the potential species extinctions (mammals, birds, amphibians, reptiles, and plants combined) due to per m^2 of cropland and other land uses in each of the 804 terrestrial ecoregions of the world and were calculated through the countryside species-area relationship model (cSAR) [30].

The characterization factors take into account the number of species within a region per unit area (higher species density means higher projected impact due to human land use), the affinity of all species present in the region to different land use types (higher affinity means species can survive in human land uses and thus lower species loss) and the current extent of human encroachment of the natural habitat of all species within the region (higher encroachment means higher projected loss) [30].

Similar to the AWARE model for assessing water scarcity footprint of products and processes, the above characterization factors have been recommended as "best practice" for assessing the biodiversity footprint of products and processes within life cycle assessment (LCA) studies by the land use working group of the UNEP-SETAC Life Cycle Initiative [28]. The methodology to calculate the biodiversity characterization factors is described below.

The characterization factors are derived using the cSAR model for each ecoregion j and for five different human land uses (cropland, pasture, urban, plantations, and managed forests) (Equation (2)). The characterization factors are provided separately for three levels of management intensity (light, medium, and intense) for each land use type as more intense use implies higher impact on biodiversity of the region. See the supplementary Table S1 of Chaudhary & Brooks [30] for definitions of light, medium, and intense use cropland.

In the first step, the total number of species of taxon g (mammals, birds, amphibians, reptiles, and plants) projected to go extinct ($S_{loss,g,\ j}$) due to human land use in each ecoregion j are calculated using the cSAR model [30]:

$$S^{regional}_{loss,g,j} = S_{org,\ g,j} \cdot \left(1 - \left(\frac{A_{new,j} + \sum_{i=1}^{16} h_{g,i,j} \cdot A_{i,j}}{A_{org,j}} \right)^{z_j} \right) \tag{5}$$

where $S_{org,g,j}$ is the total number of species occurring in each ecoregion's area ($A_{org,j}$) before any human intervention, $A_{new,j}$ is the remaining natural habitat area in the ecoregion currently (in m^2), $A_{i,j}$ is the current area of land use type i (i =1:16) in m^2, z_j is the SAR exponent for the ecoregion, and $h_{g,i,j}$ is the affinity of the taxon g to the land use type i in ecoregion j. See Chaudhary & Brooks [30] for full details on the model.

The model above provides projected extinctions from a particular ecoregion only, but it might be that species occur elsewhere. In order to translate it into global extinctions, in step 2, the projected regional extinctions from Equation (5) are multiplied with a vulnerability score ($0 < VS_{g,j} < 1$) that takes into account the proportion of all species' global habitat range occurring within that ecoregion and the current International Union for Conservation of Nature (IUCN) threat status of all species in that ecoregion. In other words, the VS accounts for the endemicity and threat status of species hosted by a region. A VS equal to one implies that all species in the region are endemic to it and are threatened with extinction according to IUCN Red List [47].

$$S^{global}_{loss,g,j} = S^{regional}_{loss,g,j} \times VS_{g,j} \tag{6}$$

In the third and final step, the total projected species loss in each ecoregion calculated through Equation (6) ($S^{global}_{loss,g,j}$) is allocated to each individual land use type based on their area share and the taxon affinity to them through an allocation factor $a_{i,\ j}$ such that $0 < \ a_{i,\ j} < \ 1$ and $\sum\limits_{i=1}^{16} a_{i,j} = 1$.

$$S^{global}_{loss,g,i,j} = S^{global}_{loss,g,j} * a_{i,\ j} \tag{7}$$

$$a_{i,\ j} = \frac{A_{i,\ j}(1 - h_{g,\ i,\ j})}{\sum_{i=1}^{16} A_{i,j}(1 - h_{g,\ i,\ j})} \tag{8}$$

When the allocated species loss for a particular taxon g Equation (6) is divided by the area of that land use type ($A_{i,\ j}$), it provides the characterization factors reflecting projected species loss due to 1 m^2 of land use in ecoregion j.

The updated characterization factors of Chaudhary & Brooks [30] were used to compare the biodiversity impact of traditional and reformulated beef burger patties' life cycle. Canada has over 50 terrestrial ecoregions differing largely in terms of species richness per unit area, amount of remaining natural habitat, and the intensity of human land uses. Therefore, using a country-average characterization factor might under or overestimate the impact of crop production on biodiversity.

Similar to water scarcity characterization factors, the census division-specific characterization factors were derived by taking the area-weighted average of characterization factors for all ecoregions occurring in that division. These characterization factors were divided by the yield of lentils in each division to get the characterization factors in the unit–potential species loss per kg of dry lentils grown in the division. The calculated biodiversity characterization factors for lentils per census division for five taxa-mammals, birds, amphibians, plants, and taxa-aggregated characterization factors are shown in Table 6. Similar to lentil (crop land use), the biodiversity characterization factors for pasture land use in each of the census division of Saskatchewan were calculated (see Table 7).

Table 6. Characterization factors (in potential species loss per kg × 10^{-12}) for assessing the biodiversity footprint of lentils grown in different census divisions of Saskatchewan, Canada. The characterization factors are zero for census divisions 5, 14, and 18 because the lentil production in these divisions is zero. The aggregated characterization factors are in the unit–potentially disappeared fraction (PDF) per kg × 10^{-12}. See Chaudhary & Brooks [30] for details.

Census Division	Mammals (PSL/Kg)	Birds (PSL/Kg)	Amphibians (PSL/Kg)	Reptiles (PSL/Kg)	Plant (PSL/Kg)	Aggregated (PDF/Kg)
1	4.25	11.6	0.857	0.375	39.6	0.127
2	10.7	23.4	1.82	1.12	64.3	0.268
3	12	20.9	1.58	1.18	30.3	0.25
4	12.4	23.6	1.81	1.25	47	0.277
5	0	0	0	0	0	0
6	4.87	13.2	0.992	0.454	46	0.145
7	8.88	17.3	1.33	0.902	36.8	0.202
8	9.28	16.5	1.25	0.922	25.6	0.197
9	4.75	12.7	0.845	0.215	29.7	0.137
10	3.48	9.46	0.644	0.233	28.1	0.103
11	5.00	13.8	1.09	0.546	52.5	0.151
12	4.59	11.9	0.931	0.482	42.1	0.132
13	5.33	12.3	0.93	0.524	35	0.138
14	0	0	0	0	0	0
15	2.99	8.02	0.545	0.166	21	0.0867
16	2.61	6.92	0.465	0.102	14.6	0.0744
17	3.10	8.17	0.551	0.109	16.1	0.0877
18	0	0	0	0	0	0

Table 7. Characterization factors (in potential species loss per kg × 10^{-12}) for assessing the biodiversity footprint of beef grown in different census divisions of Saskatchewan province of Canada. The aggregated characterization factors are in the unit–potentially disappeared fraction (PDF) per kg × 10^{-12}.

Census Division	Mammals (PSL/Kg)	Birds (PSL/Kg)	Amphibians (PSL/Kg)	Reptiles (PSL/Kg)	Plant (PSL/Kg)	Aggregated (PDF/Kg)
1	0.69	1.88	0.14	0.06	5.85	0.02
2	1.14	2.48	0.19	0.11	6.24	0.03
3	1.46	2.56	0.19	0.13	3.37	0.03
4	1.33	2.53	0.19	0.12	4.59	0.03
5	0.54	1.45	0.09	0.03	3.68	0.02
6	0.73	1.98	0.15	0.06	6.27	0.02
7	1.30	2.52	0.19	0.12	4.89	0.03
8	1.44	2.55	0.19	0.13	3.61	0.03
9	0.55	1.49	0.10	0.02	3.13	0.02
10	0.57	1.56	0.11	0.04	4.24	0.02
11	0.86	2.35	0.18	0.09	8.18	0.03
12	0.88	2.29	0.18	0.08	7.36	0.03
13	0.97	2.21	0.17	0.09	5.78	0.02
14	0.56	1.52	0.10	0.02	2.58	0.02
15	0.57	1.55	0.10	0.03	3.66	0.02
16	0.55	1.51	0.10	0.02	2.83	0.02
17	0.56	1.52	0.10	0.02	2.64	0.02
18	0.46	1.44	0.08	0.0004	0.79	0.01

Out of a total of 7.55649 million hectares of land devoted to cattle production in Saskatchewan, 88% is for grazing (pasture) and 12% is for growing cattle feed crops (see Figure 3.5 on page 109 of report by CRSB [16]). For calculating the characterization factors per kg beef, the area-weighted average of crop and pasture characterization factors for each census division were taken. Finally, the production-weighted characterization factors for Saskatchewan province were calculated for each taxa for use in biodiversity assessment of a typical beef burger patty (see Table 8).

Table 8. Production-weighted average characterization factors (CFs in potential species loss per kg × 10^{-12}) for assessing the biodiversity footprint of beef and lentils in Saskatchewan province of Canada. The taxa aggregated characterization factors are in the unit—potentially disappeared fraction (PDF) per kg × 10^{-12}. These characterization factors were multiplied by amounts of lentil, wheat, and beef in the products to calculate the biodiversity footprint of traditional and reformulated foods.

Taxon	Biodiversity CFs Lentils (PLS/Kg)	Biodiversity CFs Beef (PLS/Kg)
Mammals	8.05	182.71
Birds	16.44	407.39
Amphibians	1.26	29.90
Reptiles	0.81	14.86
Plants	38.33	912.21
Taxa aggregated	0.19	4.59

3. Results

3.1. Nutritional Quality Comparison of Traditional and Reformulated Beef Burgers

It is clear from Table 2 that the amounts of essential nutrients such as dietary fiber, folate, thiamin, vitamins A, C, and minerals such as calcium, iron, magnesium, manganese, and selenium are much higher in lentils compared with beef. On the other hand, the amounts of calories, protein, niacin, riboflavin, Vitamin B6, B12, D, E, and choline are higher in the beef than lentils. Importantly, the amounts of nutrients of health concern such as sodium, fat, and cholesterol are several times higher in beef than lentils. Also, the amounts of essential nutrients in lean beef are in general higher than regular beef.

Table 9 shows that replacing a portion of beef with lentils improves the nutrient density (measured through nutrient balance score, NBS [33], Equation (3)) by >20% compared with traditional beef burger. Highest NBS of 64 is for lean beef burger reformulated with cooked lentil puree while the lowest NBS of 46 is for regular beef burger.

Table 9. Nutrient balance score (NBS [33], Equation (3)) for traditional and lentil reformulated beef burgers.

Type of Burger (One Serving = 115 g)	Nutrient Balance Score
Regular beef burger	45.62
Regular beef burger with lentil puree	56.18
Lean beef burger	54.77
Lean beef burger with lentil puree	63.86

In terms of individual nutrients, replacing regular beef with cooked lentils increased the amount of 21 out of 27 essential nutrients considered while the amount of six essential nutrients were similar in both traditional and reformulated burgers. In particular, the reformulated burger has 60 × higher dietary fiber, three times higher total folate, five times higher manganese, and 1.6 times higher selenium than a regular beef burger.

The amounts of disqualifying nutrients (fat, trans fat, saturated fat, and cholesterol) in lentil reformulated burger were ~17% less than the regular beef burger while the amounts of sugar and sodium in regular and reformulated burgers were almost at the same level. The results therefore show that beef burgers reformulated with cooked lentils are much more nutrient dense than regular beef burgers.

3.2. *Environmental Characterization Factors for Ingredients of Beef Burgers*

Table 10 presents the carbon, bluewater, water scarcity, land use, and biodiversity characterization factors (CFs per kg) of dry lentils, cooked lentils, and boneless beef produced in Saskatchewan province of western Canada. It can be seen that the biodiversity footprint of 1 kg boneless beef is 32 × higher than that of 1 kg of cooked lentils. The land used to produce 1 kg of boneless beef is ~40 × higher than land used to produce 1 kg of cooked lentils.

Table 10. Environmental characterization factors (CFs) of ingredients (per kg) used to make the traditional and reformulated beef burgers. Biodiversity footprint is in taxa-aggregated potentially disappeared fraction (PDF).

Product	Greenhouse Gas (kg CO_2eq.)	Bluewater (L)	Water Scarcity (m^3 World eq.)	Land (m^2)	Biodiversity (PDF)
Dry lentils at farm, 1 kg	−0.1156	0.67	4.033	6.6736	1.90×10^{-13}
Lentils, cooked, 1 kg	0.283	0.29	1.734	2.8691	1.43×10^{-13}
Boneless beef at packers end gate, 1 kg	24.5	508.30	10847	196.4	4.59×10^{-12}

For the beef production, the farming or animal production stage contributed to 92–95% of total GHG, water, and land use impacts, while the transportation and packing stage contributed 3–5% and 1–2% of the total footprint respectively (see CRSB report [16] for full LCA). In contrast, the cooking stage contributed almost 100% to the total carbon footprint of cooked lentils while the lentil cultivation stage contributed almost no GHG emissions (see report hosted by Canadian roundtable for sustainable crops [39]. Also, in contrast with beef, the blue water footprint of the cultivation stage of lentil production is almost zero because the majority of lentils are rain-fed in Saskatchewan.

These characterization factors from Table 10 were multiplied with amounts of each ingredients in each product (see Table 1) to get the final environmental footprint of burgers presented in Table 11. The footprints of other burger ingredients such as black pepper and salt are negligible due to very small amounts used and thus were not considered here.

Table 11. Environmental footprints one serving (115g) of traditional and lentil reformulated beef burgers. Biodiversity footprint is in taxa-aggregated potentially disappeared fraction (PDF).

Type of Burger (One Serving = 115 g)	Greenhouse Gas (Kg CO_2eq.)	Bluewater (L)	Water Scarcity (m^3 World eq.)	Land (m^2)	Biodiversity (PDF)
Regular beef burger with lentil puree	1.87	38.59	823	14.98	3.53×10^{-13}
Regular beef burger	2.79	57.83	1234	22.34	5.22×10^{-13}
% reduction	33.03	33.31	33.33	32.95	32.50

3.3. Environmental Footprint Comparison of Traditional and Reformulated Beef Burgers

Table 11 presents the per serving environmental footprint comparison of traditional and lentil reformulated beef burgers. It can be seen that the environmental footprints reduce by ~33% when the beef burgers are reformulated with cooked lentils.

4. Discussion

Results from this study demonstrate that 33% replacement of ground beef with cooked lentil puree can decrease the environmental footprint by ~33% and concurrently increase the nutritional density (nutrient balance score) of beef burgers by ~20%. These results contribute to the growing body of scientific evidence on the potential for pulses to improve the nutritional and environmental profile of individual foods, diets, and national food systems [1,4,7].

Although the calorie and protein content per unit weight is higher for beef (Table 2), the overall nutrient density is higher for lentil reformulated burger than regular beef burger (Table 9). The increase in nutrient density is primarily due to much higher levels of dietary fiber, manganese, and selenium in lentils than in beef. Thus, our analysis shows the importance of considering all essential nutrients when comparing the nutritional implications of dietary change or food substitutions. Focusing solely on calories or protein can provide misleading results with negative consequences on nutritional security of the region.

The major strength of this environmental footprint analysis is that rather than using site-generic or globally/country averaged emission factors from different databases, we used Saskatchewan-specific datasets for lentil and beef production. For example, as shown in Table 5, the country-average AWARE characterization factor for water scarcity in Canada is 6.578 m^3 world eq./m^3 [29], which is almost three times less than the average characterization factor for Saskatchewan beef (21.34 m^3 world eq./m^3). This is because Saskatchewan is drier than the majority of other regions in Canada. Even within the province of Saskatchewan, the water scarcity characterization factors varied over 20 times from 3.12 m^3 world eq./m^3 in divisions 1, 5, 6, and 9 to 75.7 m^3 world eq./m^3 in division 3. The bluewater footprint of Saskatchewan lentils is almost zero (Table 4) because they are produced through rain-fed agriculture. This is in striking contrast with the global average bluewater footprint of lentils which is 489 L/kg according to Mekonnen & Hoekstra [10].

Similarly, the biodiversity characterization factors also vary considerably across Canada, and using a country-average value is not appropriate. Even within the Saskatchewan province, the biodiversity characterization factors vary by a factor of two across the 18 census divisions (Table 7). Regarding our carbon footprint analysis, we relied on a report that takes into account the positive effect of Western Canadian cropping practices (reduced tillage and reduced summer fallow) on soil organic carbon (SOC) which is often absent in other parts of the world. This shows the importance of including all stages when carrying out LCA of food products. Even without accounting for SOC effects, the carbon footprint of 1 kg lentils in Saskatchewan is 0.2152 kg CO_2eq. which is about five times lower than the world average value provided in other studies [8]. Compared to beef produced in the USA, the environmental footprints of Canadian beef are much lower. For example, Rotz et al. [48] found that the carbon and water depletion footprint of US beef to be 29.1 kg CO_2eq. and 2221 litres per kg of bone-free beef meat at packers' end gate. The corresponding values for Canadian beef are 24.5 kg CO_2eq. and 508 L per kg. This demonstrates the importance of working with high geographic resolution and site-specific values when conducting the environmental footprint analysis of food products. Using country or global average values from existing meta-analysis or literature can lead to misleading results in the case of food products' environmental footprints [9].

Nutritional and environmental benefits of lentil reformulated burger might not be sufficient for its widespread adoption because cost is perceived as a major factor for many consumers [6,49]. However, the price of lean ground beef and raw lentils in Canada is 5.79 US$ per kg and 3.41 US$ per kg respectively, meaning that the cost per serving (115 g) of regular and reformulated beef burgers is 0.65$ and 0.48$ respectively. Therefore, the lentil reformulated burger is 26% cheaper than regular beef burger. Partial replacement of beef with lentils in a burger demonstrates a win-win scenario for all three dimensions (nutrition, environment, and economics) of sustainability.

One of the limitations of our biodiversity analysis is that our characterization factors reflect the negative impact of conversion of native forests or grasslands to agriculture and pasture land use on plants and terrestrial vertebrates (mammals, birds, amphibians, and reptiles) only and do not take into account the impact on other species groups such as invertebrates, soil bacteria, fungi, etc. This is because the underlying data to calculate the characterization factor for invertebrates, soil bacteria, and fungi are not available yet through the International Union for Conservation of Nature (IUCN) [47]. In addition, a method adapted to Canadian agro-ecosystems and considering multiple species groups may better reflect the differences in biodiversity impact between pasture and cultivated crops [16]. Impact on other indicators of biodiversity such as evolutionary history loss should also be studied [50]. Regardless, since the objective was to calculate the relative impact of regular and lentil-reformulated burger, the selected biodiversity characterization factors are able to achieve this.

Since the environmental impacts calculated or compiled here for Saskatchewan were so different than national or world average values, future studies should carry out similar comparisons of regular and reformulated beef burgers based on data from other major beef and lentil producing regions and production systems. Using beef and lentil production data from other regions might change the relative difference in environmental impacts of the two burgers as calculated here using Saskatchewan-specific values. In this study, five indicators of environmental impact are calculated but it should be expanded in future to also include other indicators such as human toxicity, air, water pollution, or impact on ecosystem services. A widespread adoption of lentil reformulated burger would entail cutting down on production of beef and increasing the production of lentils worldwide. A global scale feasibility study is therefore needed that can also model the consequences of such a production shift on social, environmental, and economic dimensions of sustainability. Instead of lentils, future studies might also explore the sustainability implications of incorporating other plant-based foods in beef burgers.

5. Conclusions

Overall, our analysis demonstrates the potential of food innovation and reformulation of existing recipes to contribute towards multiple sustainable development goals and complement other efforts such as reducing food waste [1], dietary behaviour change [4], and others [1]. Our multi-dimensional quantitative sustainability analysis can provide a template for future studies looking at benefits of partial or full substitution of animal sourced food products with plant-based products in different regions of the world. To conclude, inclusion of higher amounts of pulses in traditional meat-based products could bring substantial environmental advantages and a more nutritionally balanced diet without jeopardizing the affordability or nutrient composition.

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