frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 19 March 2025
DOI 10.3389/fsufs.2025.1531273

Check for updates

OPEN ACCESS

EDITED BY
Rakesh Bhardwaj,
Indian Council of Agricultural Research (ICAR), India

REVIEWED BY
Diane Zimmermann,
Independent Scholar, Switzerland
Sukyoung Jung,
Korea Institute for Health and Social Affairs, Republic of Korea

*CORRESPONDENCE
Farah Naja
fnaja@sharjah.ac.ae
Lara Nasreddine
ln10@aub.edu.lb

RECEIVED 20 November 2024
ACCEPTED 20 February 2025
PUBLISHED 19 March 2025

CITATION
Hwalla N, Deeb N, Naja F and Nasreddine L (2025) Developing sustainable food-based dietary guidelines for Lebanon: integrating health, economic resilience, and sustainability.
*Front. Sustain. Food Syst.* 9:1531273.
doi: 10.3389/fsufs.2025.1531273



# Developing sustainable food-based dietary guidelines for Lebanon: integrating health, economic resilience, and sustainability

Nahla Hwalla[1], Nour Deeb[1], Farah Naja[2,3]* and Lara Nasreddine[1]*

[1]Department of Nutrition and Food Sciences, Faculty of Agricultural and Food Sciences, American University of Beirut, Riad El Solh, Beirut, Lebanon, [2]Department of Clinical Nutrition and Dietetics, College of Health Sciences, Research Institute of Medical and Health Sciences (RIMHS), University of Sharjah, Sharjah, United Arab Emirates, [3]Faculty of Agricultural and Food Sciences, American University of Beirut, Riad El Solh, Beirut, Lebanon

**Background:** Developing Sustainable Food-Based Dietary Guidelines (SFBDGs) aligned with sustainable healthy diets (SHDs) is critical for addressing food and nutrition insecurity, mitigating diet-related diseases, improving public health, and promoting environmental sustainability. Lebanon, a low-middle-income Eastern Mediterranean country, faces significant challenges including high prevalence of food insecurity, wide-spread noncommunicable diseases, limited natural resources and ongoing economic, social and environmental crises.

**Objective:** To develop culture-specific SFBDGs for Lebanon aligned with recommendations for SHDs, integrating nutrition, health, economic, and environmental factors.

**Methods:** The SFBDGs were formulated using a diet optimization mathematical tool, Optimeal®, which generates patterns resembling current diets while satisfying nutritional, health, cost, and environmental footprint (EFP) constraints. Data from the latest national food consumption survey of Lebanese adults served as the reference for current food consumption pattern. Nutritional and health constraints were based on EAT-Lancet and World Health Organization (WHO) recommendations and Dietary Reference Intakes (DRIs). Cost constraints were maximized to match the cost of food groups within the current consumption pattern, while EFP constraints were based on the environmental impact of these food groups. The optimized consumption was later translated into SFBDGs.

**Results:** Compared to current national consumption, the optimized diet recommended increases in whole grains (+287%), dairy products (+61%), legumes (+50%), and fish (+26%) and reductions in refined grains (−66%), red meat (−65%), poultry (−32%), and added sugars and fresh fruit juices (−12%). Diet optimization led to a reduction in calorie intake (−6%) and EFPs, including greenhouse gas emissions (−24%), energy use (−7%), and water use (−6%), while maintaining cost.

**Conclusion:** The developed optimized diet and resulting Lebanese SFBDGs addressed nutrition, health, economic, and environmental sustainability of current food consumption pattern, providing a scientific foundation for policies promoting SHDs that are affordable and culture-specific, which can mitigate food insecurity and malnutrition and alleviate some of the country's challenges.

KEYWORDS

sustainable food-based dietary guidelines, sustainable diet, food security, diet optimization, dietary pattern

## 1 Introduction

The development of national Sustainable Food-Based Dietary Guidelines (SFBDGs) has become crucial in addressing the growing challenges of food insecurity, nutritional adequacy, environmental degradation, and public health (Food and Agriculture Organization of the United Nations, 2015; Food and Agriculture Organization and World Health Organization, 2019). Globally, around 30% of the population is experiencing moderate or severe food insecurity (Food and Agriculture Organization of the United Nations, 2024b), and 88% of countries grapple with a serious burden of either two or three forms of malnutrition (Food and Agriculture Organization of the United Nations, 2019). In 2023, approximately 9.1% of the world's population was undernourished (Food and Agriculture Organization of the United Nations, 2024b), and in 2022, 43% of adults were overweight or obese (World Health Organization, 2024a). As global populations grow and resources dwindle, food systems fall under unprecedented pressure to deliver diets that are not only nutritionally adequate, but also economically feasible and environmentally sustainable (Moscatelli et al., 2016; Food and Agriculture Organization of the United Nations, 2018b; Aguirre-Sánchez et al., 2023). One approach to achieving this purpose is to foster the adoption of sustainable healthy diets (SHDs) through the development and implementation of SFBDGs (Gazan et al., 2018; Food and Agriculture Organization and World Health Organization, 2019; Wilson et al., 2019; Rocabois et al., 2022). By developing and adopting context-specific SFBDGs, countries can develop and adopt policies that foster resilient agriculture systems, support sustainable food availability, affordability, and nutritional adequacy, improve health, address economic constraints, and mitigate climate change (Food and Agriculture Organization and Food Climate Research Network, 2016; Ahmed et al., 2019; Brink et al., 2019; Food and Agriculture Organization and World Health Organization, 2019). This holistic approach contributes to achieving the Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Wellbeing), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) (United Nations, 2024b).

Lebanon, a lower-middle-income country in the Eastern Mediterranean region, is affected by intertwined public health, economic, political, social, and environmental crises, resulting in overwhelming food insecurity affecting 67% of the population, with 44% classified in phase 2 (stressed), and 23% in phase 3 and above (crisis or above) (Integrated Food Security Phase Classification, 2024). Key drivers of Lebanon's food insecurity include the triple-digit inflation, severe currency depreciation, decline in humanitarian food assistance, unsustainable food consumption habits, defective food system and policies, in addition to debilitating conflict and political instability (Integrated Food Security Phase Classification, 2024; Lebanese Parliament Department of Research and Studies, 2024). Concurrently, Lebanon is facing a double burden of malnutrition with 9.6% of its population being undernourished in 2021–2023 (Food and Agriculture Organization of the United Nations, 2024b), and 64.9% having overweight or obesity in 2016–2017 (Lebanese Ministry of Public Health and World Health Organization, 2017). In parallel, the country harbors a high burden of non-communicable diseases (NCDs), with a prevalence of 52.4% among adults in 2024 (El Haidari et al., 2024), accounting for 91% of all deaths among the population in 2016 (World Health Organization, 2018). This heavy burden of malnutrition and diet-related diseases is partly driven by the gradual change in food consumption, also known as the "nutrition transition," from the traditional Lebanese Mediterranean Diet to the Westernized dietary patterns (Naja et al., 2019; Hwalla et al., 2021). Besides the adverse health effects of Westernized diets, studies in Lebanon have also shown that they are associated with high environmental footprints (EFPs) (Naja et al., 2018). The shattered economic situation may also exacerbate these dietary shifts, as many households increasingly turn to cheaper, less nutritious food options due to rising food prices and diminished purchasing power (Iacoviello, 2019; American Society of Nutrition, 2021). This is particularly concerning given Lebanon's limited natural resources, including water and energy, along with soil degradation, pollution from agrochemical overuse, high production costs, and low plant productivity (Food and Agriculture Organization of the United Nations, 2021). Previous attempts to produce a SHD for Lebanon (Hwalla et al., 2021) did not result in the development of SFBDGs for the country.

It is in this context that this study was conducted, with the aim of developing a priority set of SFBDGs for Lebanese adults, by defining a nutritionally adequate, healthy, culturally acceptable, affordable, and sustainable dietary pattern, identifying modifications to current food consumption practices, and proposing feasible tradeoffs.

## 2 Methods

To identify and formulate the priority set of SFBDGs for adults in Lebanon, an optimization mathematical approach was employed, using the Optimeal® software version 3.0. Developed by Blonk Sustainability, Optimeal® is an advanced dietary optimization tool used in projects addressing multiple factors such as nutritional, health, and sustainability parameters (Blonk Sustainability, 2024). It integrates food consumption data, nutritional requirements, cost, and environmental constraints to generate optimized diets that maintain cultural dietary habits.

The objective function Z represents the goal of the optimization, expressed as:

$$Z = \sum_{i=1}^{n} c_i \cdot x_i$$

- n is the total number of food items,
- $c_i$ represents the environmental impact, the cost coefficient for each food or the nutrient content of the food item
- xi represents the quantity of each food item included in the diet.

In the model, the input data included current food consumption, while the constraints around the objective function Z are set to meet required limits for food groups consumption, nutritional adequacy, cost, and environmental footprints, as will be detailed in this section.

Quadratic programming was used in this study, because it tends to provide more realistic outcomes. Every deviation from the current diet incurs a penalty (Blonk Consultants, 2019). The optimization process aims to minimize these penalties. This approach is based on the idea that diets closer to the current are more achievable, as consumers are generally reluctant to make drastic changes to their dietary habits (Blonk Consultants, 2019). In linear programming, penalties are applied in a linear manner, meaning each change results in the same penalty. In contrast, quadratic programming results in penalties in a quadratic manner, so the penalty increases with the extent of the change. While linear programming typically results in large changes to a few products, quadratic programming leads to smaller changes across a wider range of products.

Current national food consumption data were retrieved from the most recent national food consumption cross-sectional survey conducted among Lebanese adults aged between 18 and 64 years old ($n = 444$) in year 2022 (Hoteit et al., 2024). Details about the protocols used in this survey are available elsewhere (Hoteit et al., 2024). This data reflects the cultural dietary habits of the population, aiming to generate a diet that closely resembles these patterns. By anchoring the model in actual dietary behaviors, the optimization process generates recommendations that are not only nutritionally adequate and sustainable but also practical within the Lebanese cultural context.

The nutritional adequacy constraints were operationalized according to macro and micronutrient intake. Macronutrient constraints used were derived from the Institute of Medicine (IOM) acceptable macronutrient distribution range (AMDR) (Institute of Medicine, 2005) with carbohydrate, fat, and protein intakes (g/day) being restricted to provide a maximum of 2,000 kcal/day, which is the current energy intake based on the latest food consumption survey excluding food groups that are not recommended in any amounts (sweets, sugar-sweetened beverages, salty snacks, and processed meat) that account for 11% of the total energy intake. Micronutrient constraints used were based on the Estimated Average Requirement (EAR) as minimum and the Tolerable Upper Intake Level (UL) as maximum (Table 1). Since Lebanon lacks national standards for nutrient adequacy, we adopted the IOM recommendations, which are internationally recognized and commonly used when country-specific guidelines are unavailable (Hwalla et al., 2021; Nasreddine et al., 2022). This also ensures comparability with global recommendations.

TABLE 1 List of energy and nutrient constraints used in the optimization calculations for the development of a sustainable healthy diet for Lebanese adults.

| Nutrient or energy | Minimum | Reason for minimum | Maximum | Reason for maximum |
|---|---|---|---|---|
| Energy | – | Health | 2000 kcal* | Health |
| Macronutrient | Lower value of recommended range† | Health | Higher value of recommended range† | Health |
| Total carbohydrates | 45% of energy | | 65% of energy | |
| Total protein | 10% of energy | | 35% of energy | |
| Total fat | 20% of energy | | 35% of energy | |
| Trans fatty acids | – | Health | 1% of energy‡ | Health |
| Saturated fatty acids | – | Health | 10% of energy‡ | Health |
| Unsaturated fatty acids | 10% of maximum energy constraint | Health | – | – |
| Fiber | 25 g‡ | Health | – | – |
| Nutrients with EAR and UL | EAR† | Health | UL† | Health & toxicity |
| Vitamin A | | | | |
| Vitamin C | | | | |
| Calcium | | | | |
| Folate | | | | |
| Zinc | | | | |
| Iron | | | | |
| Niacin | | | | |
| Nutrients without UL | EAR† | Health | – | – |
| Thiamin | | | | |
| Riboflavin | | | | |
| Vitamin B12 | | | | |

This table is adapted from Hwalla et al. (2021). *2000 kcal maximum energy constraint was used as the current energy intake after the exclusion of calories allocated to food groups that are not recommended in any amounts (sweets, sugar-sweetened beverages, salty snacks, and processed meat). †Food and Nutrition Board of the National Academies of Sciences, Engineering, and Medicine Dietary Reference Intakes (DRI) (Food and Nutrition Board of the National Academies of Sciences, 2024). ‡World Health Organization (2023b) recommendations. EAR, Estimated average requirements; UL, tolerable upper intake level.

Minimum and maximum constraints for daily food groups' intakes were set to align with the EAT-Lancet commission (Willett et al., 2019) and WHO recommendations (World Health Organization, 2020) (Table 2) which take into account the role of food groups in either protecting against (Reynolds et al., 2019; Chen et al., 2022; Mendes et al., 2023; World Health Organization, 2023a; Zhao et al., 2023; Torheim and Fadnes, 2024) or contributing to the development of NCDs such as cardiovascular disease, Type 2 diabetes, and certain cancers (Yang et al., 2022; Ma and Qi, 2023; Reynolds et al., 2022). As such, these constraints address major health considerations, particularly in Lebanon, where NCDs are highly prevalent. Economic feasibility (based on the cost of each food group), was also taken into consideration in the optimization exercise. Table 2 provides the list of food groups included in the dietary optimization, their daily constraints as well as the rationale for adopting these constrains.

In addition, the cost constraints for the overall optimized diet were set to match the cost of the current diet as the maximum limit (Table 3). The latter was calculated based on the "mini basket" report issued by the Lebanese Ministry of Economy and Trade (MoET) in May 2024 (Lebanese Ministry of Economy and Trade, 2024) and from averaging the cost of individual food items from many supermarkets in Lebanon for foods that were not reported by the MoET.

EFP constraints were set according to the EFPs of the current consumption pattern (Naja et al., 2019) (Table 3). Energy use (in Megajoule), water use (in Liter), and greenhouse gas (GHG) emissions (in Kilogram of carbon dioxide-equivalents) per kilogram of each food group or subgroup included in the national consumption were extracted from Hwalla et al. (2021), where EFPs were computed using Life Cycle Assessments (LCAs).

Using all the aforementioned constraints, the Optimeal® derived a dietary pattern which met the recommendations for food groups, macro and micronutrients, cost and EFPs. As such the optimized diet was considered a sustainable and healthy dietary pattern for Lebanese adults. Based on this dietary pattern, and in comparison with the current consumption, a set of priorities for the SFBDG was identified, using an expert panel consisting of a public health nutritionist, a food

TABLE 2 List of food groups daily constraints used in the optimization calculations for the development of a sustainable healthy diet for Lebanese adults based on their current consumption.

| Food group | Current consumption[§] (g/d) | Minimum (g/d) | Reason for minimum | Maximum (g/d) | Reason for maximum |
|---|---|---|---|---|---|
| Vegetables | 206.49 | 200 | Health[§§] | – | |
| Fruit | 254.33 | 200 | Health[§§] | – | |
| Whole grains | 24 | 92.8 | Health[#] | – | |
| Refined grains | 274 | 0 | Health[#] | 92.8 | Health[#] |
| Fish | 11.39 | 14.3 | Health* | 17.9 | Environmental impact* |
| Legumes | 66.85 | 100 | Health[†] | 200 | Health[†] |
| Red meat | 41.34 | 14.3 | Feasibility[‡] | 14.3 | Health[‡], environmental impact |
| Poultry | 34.21 | 23.2 | Health[†] | 46.4 | Health[†] |
| Eggs | 22.23 | 10.4 | Health[†] | 20 | Health[†] |
| Nuts and seeds | 5 | 5 | Current consumption** | 16.2 | Feasibility** |
| Dairy products | 184.5 | 200 | Health[†] | 400 | Health[†] |
| Starchy vegetables | 50.48 | 40 | Health[†] | 80 | Health[†] |
| Added sugar and fresh fruit juices | 56.97 | 0 | Health | 50 g (i.e., <10% of total energy) | Health[§§] |
| Unsaturated added fat[¶] | 11.51 | 11.51 | Current consumption | 64 | Health[‡‡] |
| Saturated added fat[††] | 0 | 0 | Current consumption | 9.44 | Health[‡‡] |

[§]2022 national food consumption data for Lebanese adults (Hoteit et al., 2024). [§§]WHO recommendations: Minimum constraint for vegetables and fruits followed the recommendation of a combined intake of at least 400 g/day (World Health Organization, 2023a), with fruits only including fresh and dried fruits; Maximum constraint for added sugar and fresh fruit juices was set according to the recommendation for free sugars (World Health Organization, 2020). [#]The minimum constraint for whole grains was set at half the EAT-Lancet average recommendation for whole grains (Willett et al., 2019), given the low current consumption of whole grains in Lebanon (Hoteit et al., 2024). The rationale within the dietary optimization exercise was to foster a partial shift from refined grains toward whole grains' consumption in Lebanon. *Fish constraints were set in line with the Dutch dietary guidelines (Brink et al., 2019) taking into consideration their low current consumption level in Lebanon, high cost ($1.49 per 100 g) compared to other protein sources such as poultry ($0.52 per 100 g), and sustainability concerns. This approach ensures feasibility within the local economic context. [†]For legumes, dairy, poultry, eggs, and starchy vegetables, the minimum constraints were set at their average EAT-Lancet recommendations, while the maximum constraints were set at the upper limit proposed by the EAT-Lancet (Willett et al., 2019). For legumes, the quantity was calculated based on the cooked weight of beans, lentils, and peas, along with soy foods, excluding peanuts, which were grouped with nuts and seeds. [‡]Minimum and maximum constraints for red meat were set as per Afshin et al. (2019), balancing feasibility with global burden of disease data and taking into consideration the high environmental footprint of red meat. **For nuts and seeds, the minimum constraint was set at current consumption levels, while the maximum constraint was set as per Afshin et al. (2019). These values which are lower than those proposed by the EAT-Lancet and by Afshin et al. (2019) were adopted in our study in order to minimize economic burden on Lebanese consumers given the high cost of nuts and seeds ($2.17 per 100 g) compared to more affordable protein sources such as legumes ($0.2 per 100 g) and to reflect the substantial decline in nuts and seeds consumption in Lebanon since 2008/2009. Given these economic factors, this approach maintains feasibility while ensuring nutritional adequacy. [¶]Unsaturated added fat includes olives, avocado, and oils that are liquid at room temperature (e.g., olive, sunflower, canola, and corn oil). [††]Saturated added fat includes butter, ghee, lard, coconut oil and palm oil. [‡‡]Maximum constraints for unsaturated added fat and saturated added fat were set at the upper limit proposed by the EAT-Lancet (Willett et al., 2019).

TABLE 3 Maximum constraints for cost and environmental footprints of the sustainable and healthy diet.

| | Unit | Maximum constraint* |
|---|---|---|
| Cost | Dollar ($) | 5.9 |
| GHG emissions | Kilogram of carbon dioxide-equivalents (kg CO2eq) | 2.21 |
| Energy use | Megajoule (MJ) | 21.6 |
| Water use | Liter (L) | 1,620 |

*Cost constraints were maximized to match the cost of food groups within the current consumption pattern, while environmental footprint (EFP) constraints were based on the environmental impact of these food groups. Both cost and EFP maximum constraints excluded food groups that are not recommended in any amounts (sweets, sugar-sweetened beverages, salty snacks, and processed meat).

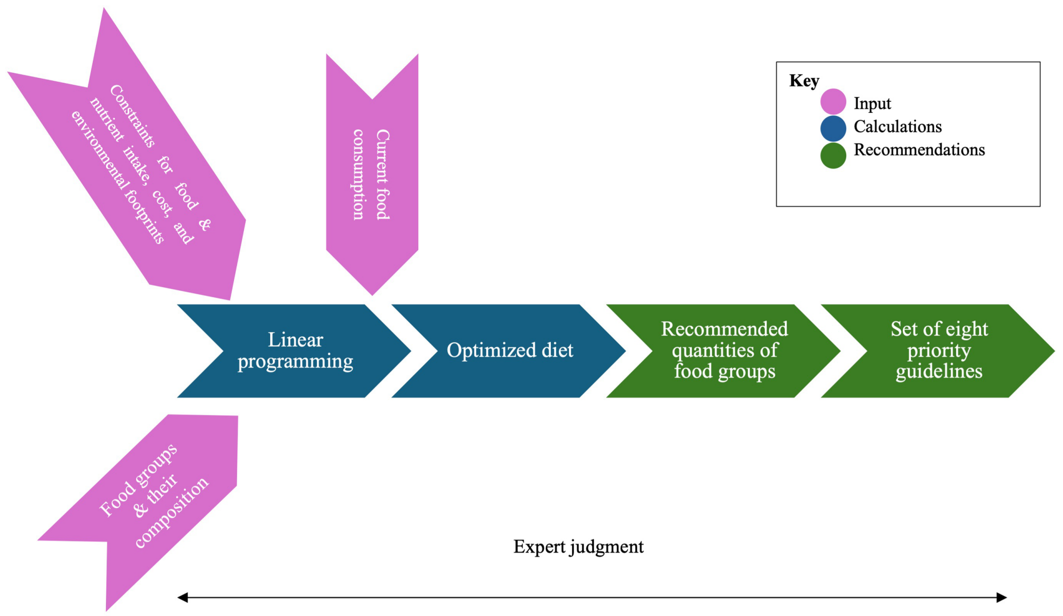


FIGURE 1
Outline of the development process of Lebanese SFBDGs. Source: Adapted from Brink et al. (2019), licensed under CC BY 4.0

policy expert, and a nutritional epidemiologist. The process began with clearly defining the study objectives. They reviewed the data on current food consumption and compared it with the output generated by the Optimeal® optimized diet. Through structured discussions, they critically assessed the differences, weighing different perspectives and potential strategies to bridge the gap between them. The panel then engaged in consensus-building, using their collective expertise to prioritize actionable recommendations. This collaborative and iterative approach ensured that the recommendations are both scientifically robust and practical for implementation. This process of defining a nutritionally adequate, healthy, culturally acceptable, affordable, and sustainable dietary pattern, was adapted from Brink et al. (2019), and is shown in Figure 1.

## 3 Results

Table 4 presents the optimized diet for Lebanese adults and identifies the recommended food groups for a sustainable and healthy diet. It presents the quantities of food groups to be consumed within the optimized diet and the percent change from the current consumption levels (when applicable). Accordingly, food groups that require change in their consumption levels are ranked in the table based on the magnitude of percent change.

Compared to the current consumption, the optimized diet revealed the need for a substantial increase in the intake of whole grains (+287%), as well as dairy products (+61%), legumes (+50%), and fish (+26%), while indicating the need for reductions in the consumption of refined grains (−66%), red meat (−65%), poultry (−32%), and added sugars and fresh fruit juices (−12%). Notably, the optimized diet recommended 185.6 g/day of grains, divided equally between refined and whole grains (92.8 g/day each).

Table 5 presents the energy (kcal), nutrient composition, environmental footprints, and cost of the optimized diet as well as percent change from current consumption levels. The optimized diet resulted in a 6% reduction in total calorie intake, with a 13% decrease in carbohydrate intake and an 11% increase in total fat intake. Protein intake increased slightly by 5%. The optimized diet also showed a notable decrease in trans-fat (−58%) while increasing fiber (+11%) and calcium (+40%) intakes. The decrease in some micronutrient levels, such as iron (−22%) and vitamin B12 (−23%), remained within recommended limits ensuring adequate consumption. The optimized

TABLE 4 Quantities of food groups that comprise the optimized diet for the Lebanese adults and percent change from current consumption.

| Food group | Current consumption (g/day) ‡ | Optimized diet (g/day) | Percent change from current consumption (%) |
|---|---|---|---|
| Whole grains | 24 | 92.8 | +287% |
| Dairy products | 184.5 | 298 | +61% |
| Legumes | 66.85 | 100 | +50% |
| Fish | 11.39 | 14.3 | +26% |
| All vegetables | 206.49 | 222 | +7% |
| Nuts and seeds | 5 | 5.17 | +3% |
| All starchy vegetables | 50.48 | 51.4 | +2% |
| Refined grains | 274 | 92.8 | -66% |
| Red meat | 41.34 | 14.3 | -65% |
| Poultry | 34.21 | 23.2 | −32% |
| Eggs | 22.23 | 20 | −10% |
| Added sugars and fresh fruit juices | 56.97 | 49.9 | −12% |
| Fruits | 254.33 | 243 | −5% |
| Unsaturated added fat* | 11.51 | 11.51 | No change |
| Saturated added fat† | 0 | 0 | No change |

*Unsaturated added fat includes olives, avocado, and oils that are liquid at room temperature (e.g., olive, sunflower, canola, and corn oil). †Saturated added fat includes butter, ghee, lard, coconut oil and palm oil. ‡Current consumption (g/day) reported by Hoteit et al. (2024).

TABLE 5 Energy, nutrient composition, environmental footprints, and cost of the optimized diet and percent change from current consumption.

| | Unit | Current consumption | Optimized diet quadratic | Change from current consumption |
|---|---|---|---|---|
| Calories | kcal | 1983.31 | 1857.12 | −6% |
| Carbs | g | 305.43 | 266.23 | −13% |
| Protein | g | 94.37 | 99.15 | +5% |
| Fat | g | 54.54 | 60.33 | +11% |
| Trans fat | g | 0.32 | 0.13 | −58% |
| Saturated fat | g | 15.88 | 18.93 | +19% |
| Unsaturated fat | g | 25.72 | 25.64 | No change |
| Fiber | g | 29.01 | 32.08 | +11% |
| Calcium | mg | 713.99 | 1,000 | +40% |
| Folate dietary folate equivalents (DFE) | mcg | 602.86 | 654.9 | +9% |
| Vitamin A | mcg | 1320.90 | 1397.85 | +6% |
| Vitamin C | mg | 102.45 | 107.26 | +5% |
| Iron | mg | 18.56 | 14.47 | −22% |
| Zinc | mg | 10.78 | 9.86 | −9% |
| Niacin | mg | 19.26 | 16.07 | −17% |
| Vitamin B12 | mcg | 3.81 | 2.94 | −23% |
| Thiamin | mg | 2.31 | 1.79 | −22% |
| Riboflavin | mg | 2.55 | 2.14 | −16% |
| Cost/day | $ | 5.9 | 5.9 | No change |
| GHG emissions | Kg $CO_2$ eq | 2.21 | 1.69 | −24% |
| Energy use | MJ | 21.56 | 20 | −7% |
| Water use | L | 1615.01 | 1512.45 | −6% |

diet maintained an overall cost at $5.90 per day (similar to the current diet), while reducing the environmental impact. Greenhouse gas emissions decreased by 24%, energy use by 7%, and water use by 6%.

The developed key messages of the SFBDGs are summarized in Table 6. These guidelines emphasize partially shifting the consumption of refined to whole grains, increasing the intake of legumes and dairy products, reducing red meat and poultry consumption, incorporating more fish into the diet, and limiting added sugars and fresh fruit juices' consumption. The recommendations were translated into practical serving sizes to facilitate adherence among Lebanese adults.

Detailed information on the conversion of the optimized daily amounts of food groups from grams to practical servings in the SFBDGs for Lebanese adults is shown in Supplementary Table 1.

# 4 Discussion

This paper presents the process, rationale and results of the development of SFBDGs for Lebanon, which to our knowledge, is the first country from the MENA region to develop culture-specific SFBDGs that holistically address nutritional adequacy, health challenges, economic factors, and environmental constraints. The originality of the study lies in the fact that it adopted a process which integrated model-based and data-driven components with expert judgment, thus providing a framework that can be adopted by other countries in the region that share similar local socioeconomic and health contexts. The proposed SFBDGs include a set of eight priority guidelines.

The results of the diet optimization underscore the need for a substantial increase in the consumption of whole grains, dairy products, and legumes, coupled with reductions in the consumption of refined grains, red meat, and added sugars and fresh fruit juices. These findings are in line with results reported by other diet optimization studies conducted in France (Clerfeuille et al., 2013), Sweden (Vieux et al., 2018), Tunisia (Verger et al., 2018; Perignon et al., 2019), and globally (Liu et al., 2024b), and with available research showing that dietary patterns that are richer in plant-based foods — such as whole grains and legumes—can improve health and reduce environmental footprints (Dietary Guidelines Advisory Committee, 2015; Willett et al., 2019). Growing evidence indicates that, unlike refined grains (United States Department of Agriculture, 2023), the consumption of whole grains, rich in dietary fiber, vitamins, minerals, phytochemicals, and other bioactive compounds (Zong et al., 2016), is associated with a reduced risk of all-cause mortality and various NCDs (Reynolds et al., 2019; Liu et al., 2024a). In a recent systematic review, Reynolds et al. (2019) reported clear dose–response relationships between whole grain intake and decreased incidence of coronary heart disease, type 2 diabetes, and colorectal cancer (Reynolds et al., 2019). In our study, the optimized diet recommended an increase in the consumption of whole grains by 68.8 g which could be achieved by shifting an equivalent amount from the consumption of refined grains. Accordingly, the optimized intake level of whole grains as obtained in our study (92.8 g/day) is closely aligned with the recent Nordic Nutrition Recommendations (90 g/day) (Blomhoff et al., 2023).

The optimized diet also showed the need to increase the consumption of legumes paralleled by decreases in meat intakes compared to current consumption levels. This is aligned with numerous studies that highlighted the positive health benefits of partly replacing meat with legumes (Röös et al., 2020; Gazan et al., 2021; Würtz et al., 2021; Kaartinen et al., 2022). The optimized reduction in meat, coupled with an increased intake of legumes aligns with the EAT-Lancet recommendations for legumes and meat (Willett et al., 2019). In addition, the quantities of both meat and legumes included in our optimized diet are in line with the EAT-Lancet dietary recommendations, hence indicating an overall adequate protein intake. Recent studies have also highlighted legumes as a "one of the most promising sources of sustainable alternative animal proteins," especially when consumed within a varied and balanced diet (Zhang et al., 2024). Besides their protein content, legumes are also rich in dietary fiber and various bioactive compounds, including phytosterols and polyphenols (Ganesan and Xu, 2017). Given their anti-inflammatory, antihypertensive, and antioxidant properties (Juárez-Chairez et al., 2022; Naureen et al., 2022), legumes were in fact shown to improve insulin sensitivity, promote healthier cardiometabolic profile and enhance gut microbial diversity (Marinangeli et al., 2020;

TABLE 6 Key messages of the sustainable food-based dietary guidelines for Lebanese adults.

| Key messages | Description* |
|---|---|
| Partially shift your consumption of grains from refined to whole | Aim to increase whole grain consumption to reach 3 servings per day and limit refined grains' intake to 3 servings per day. |
| Decrease your intake of red meat and partially replace it by legumes | Consume 2 servings of legumes per day and limit red meat to no more than 3 servings per week. |
| Increase your consumption of low-fat dairy products | Consume 2 servings of low-fat dairy products every day. |
| Decrease your consumption of poultry | Limit poultry consumption to 5 servings per week. |
| Include more fish in your weekly diet, preferably oily fish | Consume one serving of fish per week, while favoring fatty fish.<br>Learn to identify and choose fish types that are not overfished or are cultivated in an ecofriendly manner. |
| Limit your intake of sweets, sugar sweetened beverages, and fruit juices | Cap your intake of sugars from jams, honey, molasses, sweets, sugar sweetened beverages, and fruit juices to 10% of energy intake. |
| Enjoy a variety of fruits and vegetables | Maintain an intake of 6 servings of fruit and vegetables daily. |
| Maintain the consumption of heathy fats and oils in moderation | Limit your intake of solid fats and replace with olive oil and other vegetable oils. |

*Consult supplementary table 1 for the definition of a serving for the various food groups.

Yanni et al., 2023). Meta-analyses have consistently demonstrated an association between higher legume consumption and a reduced risk of mortality, obesity, and NCDs, including cancer (Torheim and Fadnes, 2024). The decrease in the consumption of red meat, is supported by numerous recent studies showing that the overconsumption of red meat carries "the greatest combined negative impact on environmental and human health" (Rust et al., 2020). It was in fact estimated that the environmental impact of producing ruminant meat—considering factors like land use, eutrophication, energy consumption, GHG emissions, and acidification potential—is 100 times higher than that of a plant-based diet (Clark and Tilman, 2017).

Although dairy production can also cause considerable adverse environmental effects (including water, soil, GHG emissions and air pollution) (Hoang et al., 2023), our study results recommended to increase the intake of dairy products as part of a sustainable and healthy diet, given that dairy products play an essential role in meeting nutrient recommendation, that are not easily met by other foods (such as Calcium), reducing the risk of certain chronic diseases (Chen et al., 2022), strengthening bones and muscles, lowering blood pressure and blood lipids, and helping to prevent diabetes and obesity (Rizzoli, 2014; United States National Heart Lung and Blood Institute, 2021; Mulet-Cabero et al., 2024). It is important to acknowledge that the recommended increases in dairy products reached a level of approximately 300 g/day, which is still in line with the EAT-Lancet recommendation of 0–500 g/day for a 2,500 kcal diet (or 0–400 g for a 2000 kcal diet, i.e., the reference diet in our study) (Willett et al., 2019). In this study, the optimized diet provided 100 g/week fish, which falls within the range of 100–125 g/week that was specified by Brink et al. (2019) in the Netherlands, while exceeding the current consumption levels in Lebanon (80 g/week). Although fish exerts numerous positive health effects (Zhao et al., 2023), its consumption is also associated with a high ecological burden, which constrains further increases in its intake levels. According to the Food and Agriculture Organization (2024), the fisheries and aquaculture sector faces critical challenges, including climate change, natural disasters, water scarcity, pollution, biodiversity loss, and rising consumption. Increased demand has led to intensified production, contributing to unsustainable practices, illegal, unreported, and unregulated fishing, and overfishing. In line with global sustainability efforts, this study highlights the importance of consuming fish species that are not overfished or that are farmed through environmentally sustainable methods. This approach supports Sustainable Development Goal 14, "Life Below Water" (United Nations Goal 12, 2024a) reinforcing the need for responsible and sustainable fish consumption. Additional constraints in relation to fish were related to its cost in the local context of Lebanon, where approximately 90% of the fish and seafood market depends on imports (United Nations Development Programme, 2023). Similarly, given that the prioritization of specific food groups in this study was driven by nutritional, economic, and environmental considerations, while also resembling, as much as possible, current food consumption patterns in Lebanon, the minimum constraint for nuts and seeds was set at 5 g (to mirror the current consumption level and avoid increasing the economic burden on the Lebanese consumers) while the maximum was set at 16.2 g, as identified by Afshin et al. (2019) based on the global burden of disease data.

Overall, this study identified necessary adjustments to current food consumption patterns based on new dietary data obtained amidst Lebanon's severe and compounded economic and societal crises. Over the past 13 years (since the last food consumption survey in 2008/2009), Lebanon has endured a devastating economic downturn, leading to a sharp rise in the cost of living—most notably in food prices (Integrated Food Security Phase Classification, 2024). As a result, food choices have shifted toward more accessible and affordable options. Previous research on sustainable diets in Lebanon (Hwalla et al., 2021) relied on the 2008/2009 national food consumption data collected before the crises, making it an unsuitable basis for developing SFBDGs. However, one persistent dietary hallmark can be seen in both studies, which is the low consumption of whole grains. Despite recommendations stemming from both the 2008/2009 and 2022 data to increase whole grain intake, refined grains continue to dominate Lebanese diets, highlighting an ongoing dietary challenge.

In terms of nutrients, the optimized diet resulted in a 58% decrease in trans-fat intake compared to the current diet. This is particularly important, as the WHO recommends that trans-fat intake should be <1% of total energy (World Health Organization, 2023b) given its adverse effects on blood lipids and the risk of cardiovascular disease (Islam et al., 2019; World Health Organization, 2024b). Another benefit of the optimized diet is an increase in fiber intake, a nutrient that has been consistently linked to significant reductions in the risk of obesity and NCDs (Partula et al., 2020; Waddell and Orfila, 2023), as well as all-cause and cause-specific mortality (Ramezani et al., 2024). Plausible mechanisms include reducing carcinogen exposure in the intestinal lumen by accelerating transit time, promoting satiety through cholecystokinin stimulation, and modifying the composition and function of the gut microbiome (Ramezani et al., 2024). The optimized diet also increased calcium intake to meet the EAR level, thus supporting cardiometabolic, neuronal, and bone health (Harvard School of Public Health, 2023). It is important to note that, while some micronutrient levels were found to decrease in the optimized diet, their intake levels remained within the established constraints, ensuring that nutritional needs are met. This is in line with studies showing that diet optimization can design a range of diets that meet individual micronutrient requirements (Leonard and Kiely, 2024).

In this study, the same cost of the current national diet was used to develop a healthier, economically feasible, and sustainable diet. This corroborates previous research demonstrating that a healthier and more environmentally friendly diet does not have to be more costly (Conforti and D'Amicis, 2000; Germani et al., 2014; Masset et al., 2014; Perignon et al., 2017; Hwalla et al., 2021; Springmann et al., 2021; Pais et al., 2022). The proposed diet in our study was associated with an overall 6% decrease in water use, 7% decrease in energy use, and 24% decrease in GHG emissions, highlighting its potential to promote sustainability without increasing financial burden on consumers. This is consistent with previous studies indicating that diet optimizations using nutritional and environmental parameters, with minimum deviation from current food consumption patterns, can lead to decreases in carbon and water footprints (ranging from 8.3 to 27% for water footprint and up to 15% for GHG emissions, depending on the stringency of the constraints) (Yin et al., 2021; Verly-Jr et al., 2022; Liu et al., 2024b).

Based on the diet optimization exercise, SFBDGs were proposed in this study and included a priority set of eight dietary guidelines. These guidelines are largely similar to those included in SFBDGs from other countries, in that they promote higher intakes of legumes and whole grains, while limiting the intake of red meat, poultry, added sugars and fruit juices (Food and Agriculture Organization and Food Climate Research Network, 2016; Brink et al., 2019). Besides its contribution to environmental sustainability, a dietary pattern in line with the proposed SFBDGs plays an essential role in supporting long-term health for reasons that go beyond the benefits of each food group alone (Tapsell et al., 2016; Natarajan et al., 2019). In fact, the interactions and potential synergies between the nutrients provided by the various food groups play a crucial role in enhancing nutritional status, overall health outcomes, and disease prevention (Townsend et al., 2023). Unlike other published SFBDGs (Food and Agriculture Organization and Food Climate Research Network, 2016; Konde et al., 2015; Brink et al., 2019), the priority set of SFBDGs developed in this study did not recommend an increase in fruits and vegetables' intakes. This is because current consumption levels of fruits and vegetables among Lebanese adults align with the recommendations, highlighting the Mediterranean qualities of the Lebanese diet, which is notably abundant in fresh produce (Naja et al., 2015). Transitioning from the current consumption pattern to one that aligns with the proposed SFBDGs is also essential for food security and is crucial for achieving the SDGs, which emphasize responsible consumption and production patterns to ensure food and nutrition security within sustainable food systems (United Nations, 2024b; Hwalla et al., 2021). The derivation of the optimized diet incorporates environmental sustainability, which is now acknowledged as the fifth dimension of food security (El Bilali et al., 2019; Fanzo, 2019; Clapp et al., 2022), and is particularly important for Lebanon, a country that has a high burden of food insecurity (Integrated Food Security Phase Classification, 2024) and harbors a double burden of malnutrition (Lebanese Ministry of Public Health and World Health Organization, 2017; Food and Agriculture Organization of the United Nations, 2024b). The SFBDGs developed in this study provide quantified recommendations with practical serving sizes to enhance adherence among Lebanese adults. Incorporating environmental sustainability into FBDGs has gained global recognition in recent years. A 2022 Lancet review found that 37 out of 83 countries (45%) explicitly mention environmental sustainability in their FBDGs, covering approximately 17% of the world's population (James-Martin et al., 2022). However, the extent of sustainability integration varies significantly, with most guidelines offering only general descriptions of sustainable diets rather than concrete, actionable recommendations. Few FBDGs provide detailed guidance on the implementation of sustainable dietary practices, underscoring the need for more comprehensive and practical approaches in future guideline development.

In light of these findings, it is crucial to emphasize the need for coordinated efforts to promote a dietary pattern aligned with the SFBDGs. This requires the involvement of all stakeholders—local, national, regional, and global—encompassing both public and private sectors and spanning multiple areas, including agriculture, trade, policy, health, and education, among others (Food and Agriculture Organization of the United Nations, 2018b). As such, adopting a food-systems approach that involves thinking and acting holistically, considering the entire food system—including all its elements, their interconnections, and their impacts, is warranted (Food and Agriculture Organization of the United Nations, 2018b). This approach emphasizes leveraging key entry points within the food system to promote SHDs (Food and Agriculture Organization of the United Nations, 2018a; International Food Policy Research Institute, 2024). This study provides SFBDGs for the Lebanese population and thus sets the stage for a food system transformation, the identification of intervention entry points (Food and Agriculture Organization of the United Nations, 2024a), and the prioritization of policy options through a consensus-building process with key stakeholders, thus paving the way for "better diet-related practices and, subsequently, better health, better nutrition, and more sustainable and equitable food system" (Food and Agriculture Organization of the United Nations, 2024a).

This study has several strengths, notably being the first to develop SFBDGs in the MENA region, while taking into account health, economic and environmental considerations. Additionally, this study used Optimeal®, a diet optimization tool that employs advanced mathematical techniques to generate diets based on a range of complex parameters. This tool has been validated and successfully implemented in various contexts (Temme et al., 2015; Kramer et al., 2017; Kramer et al., 2018; Brink et al., 2019; Broekema et al., 2020). Furthermore, this study used the latest available national food consumption data for Lebanese adults, published in 2024. However, the study's findings ought to be considered in light of the following limitations. Notably, Vitamin D was excluded as a nutritional constraint from the diet optimization process due to its naturally low levels in available foods and beverages, and the limited fortification of vitamin D in dietary products on the Lebanese market (Diana et al., 2016). Moreover, the EFPs used in this study were estimated using LCAs from other countries due to the lack of data specific to Lebanon. Despite that, efforts were made to use LCAs from neighboring MENA countries or from countries with similar climate and environmental conditions to Lebanon. Finally, the developed SFBDGs focused on food-related aspects and it was beyond the scope of this study to address other aspects such as body weight, physical activity or food safety that are usually included in FBDGs.

## 5 Conclusion

This study provided SFBDGs for Lebanese adults, integrating health, economic, and environmental factors. These findings provide a scientific basis for interventions and policy development that can partially mitigate the country's challenges. Adopting a multi-sectoral food system approach, is warranted to ensure comprehensive and sustainable improvements in dietary practices in line with SFBDGs.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

NH: Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Software, Supervision, Visualization, Writing – original draft, Writing – review & editing. ND: Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. FN: Formal analysis, Methodology, Visualization, Writing – review & editing. LN: Conceptualization, Formal analysis,

Methodology, Visualization, Writing – original draft, Writing – review & editing, Supervision.

## Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This work was fully supported by the University Research Board (Grant number: 104397) at the American University of Beirut (AUB).

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

## Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

## Publisher's note



## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1531273/full#supplementary-material

## References

Afshin, A., Sur, P. J., Fay, K. A., Cornaby, L., Ferrara, G., Salama, J. S., et al. (2019). Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet*, 393, 1958–1972. doi: 10.1016/S0140-6736(19)30041-8

Aguirre-Sánchez, L., Teschner, R., Lalchandani, N. K., El Maohub, Y., and Suggs, L. S. (2023). Climate change mitigation potential in dietary guidelines: a global review. *Sust. Prod. Consumpt.* 40, 558–570. doi: 10.1016/j.spc.2023.07.015

Ahmed, S., Downs, S., and Fanzo, J. (2019). Advancing an integrative framework to evaluate sustainability in national dietary guidelines. *Front. Sust. Food Syst.* 3:76. doi: 10.3389/fsufs.2019.00076

American Society of Nutrition (2021). When the economy goes down, so does the quality of our diets. Available online at: https://nutrition.org/when-the-economy-goes-down-so-does-the-quality-of-our-diets/#:~:text=A%20new%20study%20suggests%20dietary,added%20sugar%20during%20the%20recession (Accessed September 23 2024).

Blomhoff, R., Andersen, R., Arnesen, E. K., Christensen, J. J., Eneroth, H., Erkkola, M., et al. (2023). Nordic nutrition recommendations 2023. Copenhagen: Nordic Council of Ministers.

Blonk Consultants (2019). Demo Optimeal 3.0 [online]. Available online at: https://website-production-s3bucket-1nevfd7531z8u.s3.eu-west-1.amazonaws.com/public/website/download/0b577448-5790-4480-b0ca-6665f6de95c4/Demo-Optimeal-3.0-website.pdf (Accessed January 27, 2025).

Blonk Sustainability (2024). Sustainable nutrition. Available online at: https://blonksustainability.nl/consulting/sustainable-diets (Accessed October 18 2024).

Brink, E., van Rossum, C., Postma-Smeets, A., Stafleu, A., Wolvers, D., van Dooren, C., et al. (2019). Development of healthy and sustainable food-based dietary guidelines for the Netherlands. *Public Health Nutr.* 22, 2419–2435. doi: 10.1017/s1368980019001435

Broekema, R., Tyszler, M., Kok, F. J., Martin, A., and Lluch, A. (2020). Future-proof and sustainable healthy diets based on current eating patterns in the Netherlands. *Am. J. Clin. Nutr.* 112, 1338–1347. doi: 10.1093/ajcn/nqaa217

Chen, Z., Ahmed, M., Ha, V., Jefferson, K., Malik, V., Ribeiro, P. A. B., et al. (2022). Dairy product consumption and cardiovascular health: a systematic review and Meta-analysis of prospective cohort studies. *Adv. Nutr.* 13, 439–454. doi: 10.1093/advances/nmab118

Clapp, J., Moseley, W. G., Burlingame, B., and Termine, P. (2022). The case for a six-dimensional food security framework. *Food Policy* 106:102164. doi: 10.1016/j.foodpol.2021.102164

Clark, M., and Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environ. Res. Lett.* 12:064016. doi: 10.1088/1748-9326/aa6cd5

Clerfeuille, E., Maillot, M., Verger, E. O., Lluch, A., Darmon, N., and Rolf-Pedersen, N. (2013). Dairy products: how they fit in nutritionally adequate diets. *J. Acad. Nutr. Diet.* 113, 950–956. doi: 10.1016/j.jand.2013.04.002

Conforti, P., and D'Amicis, A. (2000). What is the cost of a healthy diet in terms of achieving RDAs? *Public Health Nutr.* 3, 367–373. doi: 10.1017/S1368980000000410

Diana, M., Souheil, H., and Pascale, S. (2016). Assessment of vitamin D levels, awareness among Lebanese pharmacy students, and impact of pharmacist counseling. *J. Epidemiol. Global Health* 7, 55–62. doi: 10.1016/j.jegh.2016.09.001

Dietary Guidelines Advisory Committee (2015). Scientific report of the 2015 dietary guidelines advisory committee: advisory report to the secretary of health and human services and the secretary of agriculture. Washington, DC: Dietary Guidelines Advisory Committee, 2019–2009.

El Bilali, H., Callenius, C., Strassner, C., and Probst, L. (2019). Food and nutrition security and sustainability transitions in food systems. *Food Energ. Secur.* 8:e00154. doi: 10.1002/fes3.154

El Haidari, R., Hoballa, M., Cheato, A., Baydoun, K., Husseini, A., Chahrour, M., et al. (2024). Prevalence and determinants of non-communicable diseases and risk factors among adults in Lebanon: a multicentric cross-sectional study. *Public Health* 229, 185–191. doi: 10.1016/j.puhe.2024.01.033

Fanzo, J. (2019). Healthy and sustainable diets and food systems: the key to achieving sustainable development goal 2? *Food Ethics* 4, 159–174. doi: 10.1007/s41055-019-00052-6

Food and Agriculture Organization (2024). Food-based dietary guidelines - Denmark. Available online at: https://www.fao.org/nutrition/education/dietary-guidelines/regions/denmark/en/ (Accessed November 4, 2024).

Food and Agriculture Organization and Food Climate Research Network (2016). Plates, pyramids, planet. Available online at: https://openknowledge.fao.org/server/api/core/bitstreams/4986aec2-a354-4497-8afc-94b562a53e53/content (Accessed July 29, 2024).

Food and Agriculture Organization and World Health Organization (2019). Sustainable healthy diets: Guiding principles [online]. Available online at: https://iris.who.int/bitstream/handle/10665/329409/9789241516648-eng.pdf?sequence=1 (Accessed May 7, 2024).

Food and Agriculture Organization of the United Nations (2015). Climate change and food security: Risks and responses [online]. Available online at: https://openknowledge.fao.org/server/api/core/bitstreams/a4fd8ac5-4582-4a66-91b0-55abf642a400/content (Accessed September 30, 2024).

Food and Agriculture Organization of the United Nations (2018a). Strengthening sector policies for better food security and nutrition results. Available online at: https://openknowledge.fao.org/server/api/core/bitstreams/f575d336-8868-4c9d-9b29-a120532462f0/content (Accessed September 13, 2024).

Food and Agriculture Organization of the United Nations (2018b). Sustainable food systems concept and framework. Available online at: https://openknowledge.fao.org/server/api/core/bitstreams/b620989c-407b-4caf-a152-f790f55fec71/content (Accessed September 13, 2024).

Food and Agriculture Organization of the United Nations (2019). Food-based dietary guidelines. Available online at: https://www.fao.org/nutrition/education/food-dietary-guidelines/background/en/ (Accessed August 13, 2024).

Food and Agriculture Organization of the United Nations (2021). Lebanon's agricultural sector: Challenges and opportunities [online]. Available online at: https://

openknowledge.fao.org/server/api/core/bitstreams/ca5c0eea-8447-468a-8dd0-abb7ce84b6de/content (Accessed January 21, 2025).

Food and Agriculture Organization of the United Nations (2024a). Food systems-based dietary guidelines: An overview. Available online at: https://openknowledge.fao.org/server/api/core/bitstreams/20b9fd77-47f5-46f0-bdd9-94f798620368/content (Accessed January 30, 2025).

Food and Agriculture Organization of the United Nations (2024b). Suite of food security indicators. Available online at: https://www.fao.org/faostat/en/#data/FS (Accessed August 12 2024).

Food and Nutrition Board of the National Academies of Sciences. (2024). Nutrient Recommendations and Databases. Available online at: https://ods.od.nih.gov/HealthInformation/nutrientrecommendations.aspx (Accessed September 21, 2024).

Ganesan, K., and Xu, B. (2017). Polyphenol-rich lentils and their health promoting effects. *Int. J. Mol. Sci.* 18:2390. doi: 10.3390/ijms18112390

Gazan, R., Brouzes, C. M. C., Vieux, F., Maillot, M., Lluch, A., and Darmon, N. (2018). Mathematical optimization to explore tomorrow's sustainable diets: a narrative review. *Adv. Nutr.* 9, 602–616. doi: 10.1093/advances/nmy049

Gazan, R., Maillot, M., Reboul, E., and Darmon, N. (2021). Pulses twice a week in replacement of meat modestly increases diet sustainability. *Nutrients* 13:3059. doi: 10.3390/nu13093059

Germani, A., Vitiello, V., Giusti, A. M., Pinto, A., Donini, L. M., and del Balzo, V. (2014). Environmental and economic sustainability of the Mediterranean diet. *Int. J. Food Sci. Nutr.* 65, 1008–1012. doi: 10.3109/09637486.2014.945152

Harvard School of Public Health (2023). Calcium. Available online at: https://nutritionsource.hsph.harvard.edu/calcium/ (Accessed September 25, 2024).

Hoang, V., Saviolidis, N. M., Olafsdottir, G., Bogason, S., Hubbard, C., Samoggia, A., et al. (2023). Investigating and stimulating sustainable dairy consumption behavior: an exploratory study in Vietnam. *Sust. Prod. Consumption* 42, 183–195. doi: 10.1016/j.spc.2023.09.016

Hoteit, M., Khattar, M., Malli, D., Antar, E., Al Hassani, Z., Abdallah, M., et al. (2024). Dietary intake among Lebanese adults: findings from the updated LEBANese natiONal food consumption survey (LEBANON-FCS). *Nutrients* 16:1784. doi: 10.3390/nu16111784

Hwalla, N., Jomaa, L., Hachem, F., Kharroubi, S., Hamadeh, R., Nasreddine, L., et al. (2021). Promoting sustainable and healthy diets to mitigate food insecurity amidst economic and health crises in Lebanon. *Front. Nutr.* 8:697225. doi: 10.3389/fnut.2021.697225

Iacoviello, L. (2019). Socio-economic determinants of nutrition transition in southern European countries. *Eur. J. Pub. Health* 29:198. doi: 10.1093/eurpub/ckz185.198

Institute of Medicine (2005). Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington, DC: National Academies Press.

Integrated Food Security Phase Classification (2024). Lebanon: Acute food insecurity projection update for April-September 2024. Available online at: https://www.ipcinfo.org/fileadmin/user_upload/ipcinfo/docs/IPC_Lebanon_Acute_Food_Insecurity_Projection_Update_Apr_Sep2024_Report.pdf (Accessed September 17 2024).

International Food Policy Research Institute (2024). The 2024 global food policy report food systems for healthy diets and nutrition. Available online at: https://www.ifpri.org/global-food-policy-report-2024/#:~:text=IFPRI's%202024%20Global20Food20Policy,food%20systems%20for%20better%20nutrition (Accessed September 6, 2024).

Islam, M. A., Amin, M. N., Siddiqui, S. A., Hossain, M. P., Sultana, F., and Kabir, M. R. (2019). Trans fatty acids and lipid profile: a serious risk factor to cardiovascular disease, cancer and diabetes. *Diabetes Metab. Syndr. Clin. Res. Rev.* 13, 1643–1647. doi: 10.1016/j.dsx.2019.03.033

James-Martin, G., Baird, D. L., Hendrie, G. A., Bogard, J., Anastasiou, K., Brooker, P. G., et al. (2022). Environmental sustainability in national food-based dietary guidelines: a global review. *Lancet Planetar. Health* 6, e977–e986. doi: 10.1016/S2542-5196(22)00246-7

Juárez-Chairez, M. F., Meza-Márquez, O. G., Márquez-Flores, Y. K., and Jiménez-Martínez, C. (2022). Potential anti-inflammatory effects of legumes: a review. *Br. J. Nutr.* 128, 2158–2169. doi: 10.1017/s0007114522000137

Kaartinen, N. E., Tapanainen, H., Maukonen, M., Päivärinta, E., Valsta, L. M., Itkonen, S. T., et al. (2022). Partial replacement of red and processed meat with legumes: a modelling study of the impact on nutrient intakes and nutrient adequacy on the population level. *Public Health Nutr.* 26, 303–314. doi: 10.1017/s1368980022002440

Konde, Å. B., Bjerselius, R., Haglund, L., Jansson, A., Pearson, M., and Färnstrand, J. S., (2015). Swedish dietary guidelines.

Kramer, G. F., Martinez, E. V., Espinoza-Orias, N. D., Cooper, K. A., Tyszler, M., and Blonk, H. (2018). Comparing the performance of bread and breakfast cereals, dairy, and meat in nutritionally balanced and sustainable diets. *Front. Nutr.* 5:51. doi: 10.3389/fnut.2018.00051

Kramer, G. F. H., Tyszler, M., Veer, P. V. T., and Blonk, H. (2017). Decreasing the overall environmental impact of the Dutch diet: how to find healthy and sustainable diets with limited changes. *Public Health Nutr.* 20, 1699–1709. doi: 10.1017/S1368980017000349

Lebanese Ministry of Economy and Trade (2024). Mini-basket (weekly). Available online at: https://www.economy.gov.lb/en/services/center-for-pricing-policies/mini---basket-weekly- (Accessed May 17, 2024).

Lebanese Ministry of Public Health and World Health Organization (2017). WHO Stepwise Approach for Non-Communicable Diseases Risk Factor Surveillance. Available online at: https://cdn.who.int/media/docs/default-source/ncds/ncd-surveillance/data-reporting/lebanon/steps/lebanon-steps-report-2016-2017.pdf?sfvrsn=b67a627f_3&download=true (Accessed August 13, 2024).

Lebanese Parliament Department of Research and Studies (2024). Lebanon food system transformation pathway building Back better: The recovery of a fragile food system. Available online at: https://www.unfoodsystemshub.org/docs/unfoodsystemslibraries/national-pathways/lebanon/2024-03-01-national-pathway-lebanon-eng.pdf?sfvrsn=b3a6dad2_3 (Accessed October 18, 2024).

Leonard, U. M., and Kiely, M. E. (2024). Can micronutrient requirements be met by diets from sustainable sources: outcomes of dietary modelling studies using diet optimization. *Ann. Med.* 56:2389295. doi: 10.1080/07853890.2024.2389295

Liu, X., Xin, L., and Li, X. (2024b). The global nutrition can be greatly improved with diet optimization. *Resour. Conserv. Recycl.* 202:107343. doi: 10.1016/j.resconrec.2023.107343

Liu, H., Zhu, J., Gao, R., Ding, L., Yang, Y., Zhao, W., et al. (2024a). Estimating effects of whole grain consumption on type 2 diabetes, colorectal cancer and cardiovascular disease: a burden of proof study. *Nutr. J.* 23:49. doi: 10.1186/s12937-024-00957-x

Ma, H., and Qi, X. (2023). Red meat consumption and Cancer risk: a systematic analysis of global data. *Food Secur.* 12:164. doi: 10.3390/foods12224164

Marinangeli, C. P. F., Harding, S. V., Zafron, M., and Rideout, T. C. (2020). A systematic review of the effect of dietary pulses on microbial populations inhabiting the human gut. *Benef Microbes* 11, 457–468. doi: 10.3920/bm2020.0028

Masset, G., Vieux, F., Verger, E. O., Soler, L. G., Touazi, D., and Darmon, N. (2014). Reducing energy intake and energy density for a sustainable diet: a study based on self-selected diets in French adults. *Am. J. Clin. Nutr.* 99, 1460–1469. doi: 10.3945/ajcn.113.077958

Mendes, V., Niforou, A., Kasdagli, M. I., Ververis, E., and Naska, A. (2023). Intake of legumes and cardiovascular disease: a systematic review and dose-response meta-analysis. *Nutr. Metab. Cardiovasc. Dis.* 33, 22–37. doi: 10.1016/j.numecd.2022.10.006

Moscatelli, S., El Bilali, H., Gamboni, M., and Capone, R. (2016). Towards sustainable food systems: a holistic, interdisciplinary and systemic approach. *Agrofor* 1:1103. doi: 10.7251/AGRENG1601103M

Mulet-Cabero, A.-I., Torres-Gonzalez, M., Geurts, J., Rosales, A., Farhang, B., Marmonier, C., et al. (2024). The dairy matrix: its importance, definition, and current application in the context of nutrition and health. *Nutrients* 16:2908. doi: 10.3390/nu16172908

Naja, F., Hwalla, N., Itani, L., Baalbaki, S., Sibai, A., and Nasreddine, L. (2015). A novel Mediterranean diet index from Lebanon: comparison with Europe. *Eur. J. Nutr.* 54, 1229–1243. doi: 10.1007/s00394-014-0801-1

Naja, F., Itani, L., Hamade, R., Chamieh, M. C., and Hwalla, N. (2019). Mediterranean diet and its environmental footprints amid nutrition transition: the case of Lebanon. *Sustain. For.* 11:6690. doi: 10.3390/su11236690

Naja, F., Jomaa, L., Itani, L., Zidek, J., El Labban, S., Sibai, A. M., et al. (2018). Environmental footprints of food consumption and dietary patterns among Lebanese adults: a cross-sectional study. *Nutr. J.* 17:85. doi: 10.1186/s12937-018-0393-3

Nasreddine, L., Hwalla, N., Al Zahraa Chokor, F., Naja, F., O'Neill, L., and Jomaa, L. (2022). Food and nutrient intake of school-aged children in Lebanon and their adherence to dietary guidelines and recommendations. *BMC Public Health* 22:922. doi: 10.1186/s12889-022-13186-w

Natarajan, T. D., Ramasamy, J. R., and Palanisamy, K. (2019). Nutraceutical potentials of synergic foods: a systematic review. *J. Ethnic Foods* 6:27. doi: 10.1186/s42779-019-0033-3

Naureen, Z., Bonetti, G., Medori, M. C., Aquilanti, B., Velluti, V., Matera, G., et al. (2022). Foods of the Mediterranean diet: garlic and Mediterranean legumes. *J. Prev. Med. Hyg.* 63, e12–e20. doi: 10.15167/2421-4248/jpmh2022.63.2S3.2741

Pais, D. F., Marques, A. C., and Fuinhas, J. A. (2022). The cost of healthier and more sustainable food choices: do plant-based consumers spend more on food? *Agric. Food Econ.* 10:18. doi: 10.1186/s40100-022-00224-9

Partula, V., Deschasaux, M., Druesne-Pecollo, N., Latino-Martel, P., Desmetz, E., Chazelas, E., et al. (2020). Associations between consumption of dietary fibers and the risk of cardiovascular diseases, cancers, type 2 diabetes, and mortality in the prospective Nutri net-Santé cohort. *Am. J. Clin. Nutr.* 112, 195–207. doi: 10.1093/ajcn/nqaa063

Perignon, M., Sinfort, C., El Ati, J., Traissac, P., Drogué, S., Darmon, N., et al. (2019). How to meet nutritional recommendations and reduce diet environmental impact in the Mediterranean region? An optimization study to identify more sustainable diets in Tunisia. *Glob. Food Sec.* 23, 227–235. doi: 10.1016/j.gfs.2019.07.006

Perignon, M., Vieux, F., Soler, L. G., Masset, G., and Darmon, N. (2017). Improving diet sustainability through evolution of food choices: review of epidemiological studies on the environmental impact of diets. *Nutr. Rev.* 75, 2–17. doi: 10.1093/nutrit/nuw043

Ramezani, F., Pourghazi, F., Eslami, M., Gholami, M., Mohammadian Khonsari, N., Ejtahed, H.-S., et al. (2024). Dietary fiber intake and all-cause and cause-specific mortality: an updated systematic review and meta-analysis of prospective cohort studies. *Clin. Nutr.* 43, 65–83. doi: 10.1016/j.clnu.2023.11.005

Reynolds, A.N., Hodson, L., de Souza, R., Tran Diep Pham, H., Vlietstra, L., and Mann, J (2022). Saturated fat and trans-fat intakes and their replacement with other macronutrients: a systematic review and metaanalysis of prospective observational studies. Geneva: World Health Organization; Licence: CC BY-NCSA 3.0 IGO.

Reynolds, A., Mann, J., Cummings, J., Winter, N., Mete, E., and Te Morenga, L. (2019). Carbohydrate quality and human health: a series of systematic reviews and meta-analyses. *Lancet* 393, 434–445. doi: 10.1016/S0140-6736(18)31809-9

Rizzoli, R. (2014). Dairy products, yogurts, and bone health123. *Am. J. Clin. Nutr.* 99, 1256S–1262S. doi: 10.3945/ajcn.113.073056

Rocabois, A., Tompa, O., Vieux, F., Maillot, M., and Gazan, R. (2022). Diet optimization for sustainability: INDIGOO, an innovative multilevel model combining individual and population objectives. *Sustain. For.* 14:12667. doi: 10.3390/su141912667

Röös, E., Carlsson, G., Ferawati, F., Hefni, M., Stephan, A., Tidåker, P., et al. (2020). Less meat, more legumes: prospects and challenges in the transition toward sustainable diets in Sweden. *Renew. Agric. Food Syst.* 35, 192–205. doi: 10.1017/S1742170518000443

Rust, N. A., Ridding, L., Ward, C., Clark, B., Kehoe, L., Dora, M., et al. (2020). How to transition to reduced-meat diets that benefit people and the planet. *Sci. Total Environ.* 718:137208. doi: 10.1016/j.scitotenv.2020.137208

Springmann, M., Clark, M. A., Rayner, M., Scarborough, P., and Webb, P. (2021). The global and regional costs of healthy and sustainable dietary patterns: a modelling study. *Lancet Planetar. Health* 5, e797–e807. doi: 10.1016/S2542-5196(21)00251-5

Tapsell, L. C., Neale, E. P., Satija, A., and Hu, F. B. (2016). Foods, nutrients, and dietary patterns: interconnections and implications for dietary guidelines. *Adv. Nutr.* 7, 445–454. doi: 10.3945/an.115.011718

Temme, E. H. M., Bakker, H. M. E., Seves, S. M., Verkaik-Kloosterman, J., Dekkers, A. L., van Raaij, J. M. A., et al. (2015). How may a shift towards a more sustainable food consumption pattern affect nutrient intakes of Dutch children? *Public Health Nutr.* 18, 2468–2478. doi: 10.1017/S1368980015002426

Torheim, L. E., and Fadnes, L. T. (2024). Legumes and pulses - a scoping review for Nordic nutrition recommendations 2023. *Food Nutr. Res.* 68:10484. doi: 10.29219/fnr.v68.10484

Townsend, J. R., Kirby, T. O., Sapp, P. A., Gonzalez, A. M., Marshall, T. M., and Esposito, R. (2023). Nutrient synergy: definition, evidence, and future directions. *Front. Nutr.* 10:1279925. doi: 10.3389/fnut.2023.1279925

United Nations (2024b). The 17 goals. Available online at: https://sdgs.un.org/goals (Accessed September 17, 2024).

United Nations Development Programme (2023). UNDP and the UK support Saida's fishing sector in partnership with Ministry of Social Affairs and Ministry of public works and transport [online]. Available online at: https://www.undp.org/lebanon/press-releases/undp-and-uk-support-saidas-fishing-sector-partnership-ministry-social-affairs-and-ministry-public-works-and-transport (Accessed October 11, 2024).

United Nations Goal 12. (2024a). Goal 12: Ensure sustainable consumption and production patterns. Available online at: https://www.un.org/sustainabledevelopment/sustainable-consumption-production/ (Accessed September 13, 2024).

United States Department of Agriculture (2023). What are refined grains? Available online at: https://ask.usda.gov/s/article/What-are-refined-grains#:~:text=Refined%20grains%20have%20been%20milled,white%20bread%2C%20and%20white%20rice (Accessed September 25, 2024).

United States National Heart Lung and Blood Institute (2021). Description of the DASH eating plan. Available online at: https://www.nhlbi.nih.gov/education/dash-eating-plan (Accessed October 11, 2024).

Verger, E. O., Perignon, M., El Ati, J., Darmon, N., Dop, M.-C., Drogué, S., et al. (2018). A "fork-to-farm" multi-scale approach to promote sustainable food systems for nutrition and health: a perspective for the Mediterranean region. *Front. Nutr.* 5:30. doi: 10.3389/fnut.2018.00030

Verly-Jr, E., de Carvalho, A. M., Marchioni, D. M. L., and Darmon, N. (2022). The cost of eating more sustainable diets: a nutritional and environmental diet optimisation study. *Glob. Public Health* 17, 1073–1086. doi: 10.1080/17441692.2021.1900315

Vieux, F., Perignon, M., Gazan, R., and Darmon, N. (2018). Dietary changes needed to improve diet sustainability: are they similar across Europe? *Eur. J. Clin. Nutr.* 72, 951–960. doi: 10.1038/s41430-017-0080-z

Waddell, I. S., and Orfila, C. (2023). Dietary fiber in the prevention of obesity and obesity-related chronic diseases: from epidemiological evidence to potential molecular mechanisms. *Crit. Rev. Food Sci. Nutr.* 63, 8752–8767. doi: 10.1080/10408398.2022.2061909

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al. (2019). Food in the Anthropocene: the EAT-lancet commission on healthy diets from sustainable food systems. *Lancet* 393, 447–492. doi: 10.1016/s0140-6736(18)31788-4

Wilson, N., Cleghorn, C. L., Cobiac, L. J., Mizdrak, A., and Nghiem, N. (2019). Achieving healthy and sustainable diets: a review of the results of recent mathematical optimization studies. *Adv. Nutr.* 10, S389–S403. doi: 10.1093/advances/nmz037

World Health Organization (2018). Noncommunicable diseases country profiles 2018. Geneva: World Health Organization.

World Health Organization (2020). Healthy diet. Available online at: https://www.who.int/news-room/fact-sheets/detail/healthy-diet (Accessed October 18, 2024).

World Health Organization (2023a). Increasing fruit and vegetable consumption to reduce the risk of noncommunicable diseases. Available online at: https://www.who.int/tools/elena/interventions/fruit-vegetables-ncds (Accessed February 4, 2025).

World Health Organization (2023b). WHO updates guidelines on fats and carbohydrates. Available online at: https://www.who.int/news/item/17-07-2023-who-updates-guidelines-on-fats-and-carbohydrates (Accessed October 23, 2024).

World Health Organization (2024a). Obesity and overweight. Available online at: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight#:~:text=Worldwide%20adult%20obesity%20has%20more,16%25%20were%20living%20with%20obesity (Accessed August 13, 2024).

World Health Organization (2024b). Trans fat. Available online at: https://www.who.int/news-room/fact-sheets/detail/trans-fat (Accessed September 13, 2024).

Würtz, A. M. L., Jakobsen, M. U., Bertoia, M. L., Hou, T., Schmidt, E. B., Willett, W. C., et al. (2021). Replacing the consumption of red meat with other major dietary protein sources and risk of type 2 diabetes mellitus: a prospective cohort study. *Am. J. Clin. Nutr.* 113, 612–621. doi: 10.1093/ajcn/nqaa284

Yang, B., Glenn, A. J., Liu, Q., Madsen, T., Allison, M. A., Shikany, J. M., et al. (2022). Added sugar, sugar-sweetened beverages, and artificially sweetened beverages and risk of cardiovascular disease: findings from the Women's Health Initiative and a network Meta-analysis of prospective studies. *Nutrients* 14:226. doi: 10.3390/nu14204226

Yanni, A. E., Iakovidi, S., Vasilikopoulou, E., and Karathanos, V. T. (2023). Legumes: a vehicle for transition to sustainability. *Nutrients* 16:98. doi: 10.3390/nu16010098

Yin, J., Zhang, X., Huang, W., Liu, L., Zhang, Y., Yang, D., et al. (2021). The potential benefits of dietary shift in China: synergies among acceptability, health, and environmental sustainability. *Sci. Total Environ.* 779:146497. doi: 10.1016/j.scitotenv.2021.146497

Zhang, X., Zhang, Z., Shen, A., Zhang, T., Jiang, L., El-Seedi, H., et al. (2024). Legumes as an alternative protein source in plant-based foods: applications, challenges, and strategies. *Curr. Res. Food Sci.* 9:100876. doi: 10.1016/j.crfs.2024.100876

Zhao, H., Wang, M., Peng, X., Zhong, L., Liu, X., Shi, Y., et al. (2023). Fish consumption in multiple health outcomes: an umbrella review of meta-analyses of observational and clinical studies. *Ann. Transl. Med.* 11:152. doi: 10.21037/atm-22-6515

Zong, G., Gao, A., Hu, F. B., and Sun, Q. (2016). Whole grain intake and mortality from all causes, cardiovascular disease, and cancer: a meta-analysis of prospective cohort studies. *Circulation* 133, 2370–2380. doi: 10.1161/circulationaha.115.021101