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Original Research Article

Life expectancy gains from dietary modifications: a comparative modeling study in 7 countries

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ABSTRACT

Background: Eating healthier is associated with a range of favorable health outcomes. Our previous model estimated the impact of dietary changes on life expectancy gains but did not consider height, weight, or physical activity.

Objectives: We aimed to estimate the increase in life expectancy resulting from the transition from typical national dietary patterns to longevity-optimizing dietary changes, more feasible dietary modifications, and optimized vegan dietary changes in China, France, Germany, Iran, Norway, the United Kingdom, and the United States.

Methods: Our modeling study used data from meta-analyses presenting dose-response relationships between intake of 15 food groups and mortality. Background mortality data were from the Global Burden of Disease Study. We used national food intake data and adjusted for height, weight, and physical activity level.

Results: For 40-y-olds, estimated life expectancy gains ranged from 6.2 y (with uncertainty interval [UI]: 5.7, 7.5 y) for Chinese females to 9.7 y (UI: 8.1, 11.3 y) for United States males following sustained changes from typical country-specific dietary patterns to longevity-optimized dietary changes, and from 5.2 y (UI: 4.0, 6.5 y) for Chinese females to 8.7 y (UI: 7.1, 10.3 y) for United States males following changes to optimized vegan dietary changes.

Conclusions: A sustained change from country-specific typical dietary pattern patterns to longevity-optimized dietary changes, more feasible dietary changes, or optimized vegan dietary changes are all projected to result in substantial life expectancy gains across ages and countries. These changes included more whole grains, legumes, and nuts and less red/processed meats and sugars and sugar-sweetened beverages. The largest gains from dietary changes would be in the United States.

Keywords: food groups, diets, life expectancy, mortality, longevity

Introduction

Reducing morbidity and mortality due to unhealthy eating is essential to achieve Sustainable Development Goal target 3.4 to reduce premature mortality from noncommunicable diseases by one-third by 2030 [1–4]. Diets rich in fruits, vegetables, legumes, nuts, whole grains, and fish and low in red meat, processed meat, and foods and drinks high in added sugars are associated with improved health and longevity [2,4]. Life expectancy (LE) is a measure of the expected years an individual has left to live, and LE at birth is commonly used as a measure of overall population health.

Recently, we presented an initial Food4HealthyLife model that found that a sustained change from a typical Western dietary pattern to longevity-optimized dietary changes could increase the LE of young adults by more than a decade [2]. Even making more feasible dietary changes (i.e., to a diet that was halfway between a typical Western dietary pattern and longevity-optimized dietary changes) could result in an increase of 6–7 y [2]. The first Food4HealthyLife model was

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Abbreviations: HR, hazard ratio; LE, life expectancy; UI, uncertainty interval.

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developed for an overall adult population and did not take individual differences in height, weight, and physical activity levels into account when estimating energy requirements, intake levels, and gains in LE. Further, although mortality rates were country-specific, the baseline dietary pattern used to illustrate the estimated gains from dietary changes was the typical Western dietary pattern and not country-specific dietary patterns. However, because dietary patterns vary between countries, we expect the potential health gains following sustained dietary changes to vary correspondingly [5]. Further adding to the diversity in eating patterns, many people choose dietary patterns for reasons that go beyond health, such as vegetarian and vegan lifestyles often chosen for ethical reasons [6–8].

In this study, our aim was to estimate the potential increase in LE in 7 culturally varied countries, spanning both high- and middle-income economies, namely China, France, Germany, Iran, Norway, the United Kingdom, and the United States. This evaluation focused on the impact of shifting from typical dietary patterns in each of the countries to 3 different dietary strategies: a diet optimized for longevity, feasible dietary adjustments, and a vegan diet with a longevity emphasis. We also conducted a comparative analysis of the projected LE improvements in these countries.

Methods

First, we summarize the model approach to estimate the change in LE by sustained change from the baseline dietary pattern in a country to a new diet (further details in the Supplementary Text S1 and S2). This study used a definition of diet as the quantities of different foods groups consumed [9]. Only publicly available data sources were used, including data from meta-analyses and the Global Burden of Disease, and thus no ethical permission was required.

Country-specific baseline dietary patterns

Because dietary patterns vary between individuals and settings, the Food4HealthyLife model 2.0 considers typical dietary patterns in China, France, Germany, Iran, Norway, the United Kingdom, and the United States. The countries were chosen based on data availability for the food groups at the adult population level and to have a spread of high- and middle- income countries, some of them undergoing nutrition transition (Iran and China) [10]. The rationale for not presenting low-income countries in the model is that the studies used to estimate associations between food intakes and health outcomes are sparse in these countries. The dietary patterns in each of the countries are summarized in Table 1, and the sources for the dietary pattern for each country are explained in Supplementary Text S2. Estimates of dietary patterns and mean energy intakes for males and females with different age, height, weight, and activity levels are also presented (Supplementary Tables S1–S13). We used 15 food group categories (whole grains, fruits, vegetables, nuts, legumes, fish, eggs, milk/dairy, refined grains, red meat, processed meat, white meat, sugar-sweetened beverages, added sugar in foods, and added oils). Foods not categorized within these food groups (e.g., food items such as cakes, sandwiches, and pizza, with unclear conversion to food groups) were categorized as uncategorized foods. The higher the proportion of uncategorized foods, the higher the uncertainty about the impact of dietary changes. Because a large and physically active person has higher energy needs than a small and inactive person, we allowed for the adjustment of these output dietary patterns based on height, weight, and physical activity

TABLE 1

Typical intakes of each food group (in grams/d) in China, France, Iran, Norway, Germany, the United Kingdom, and the United States[1] as well as a longevity-optimized dietary changes, more feasible dietary changes, and optimized vegan dietary changes.

Food groups (g/d)	China	France	Iran	Norway	Germany	United Kingdom	United States	Feasibility-approach	Optimized	Optimized vegan
Whole grain (product weight)	🟥 20	🟥 8	🟨 70	🟨 61	🟥 24	🟥 16	🟥 30	🟩 138	🟩 225	🟩 275
Vegetable	🟩 262	🟨 131	🟩 229	🟩 255	🟨 139	🟨 135	🟩 249	🟩 325	🟩 400	🟩 600
Fruit	🟨 130	🟨 130	🟨 142	🟩 244	🟨 161	🟨 102	🟩 184	🟩 300	🟩 400	🟩 500
Nuts	🟥 7	🟥 3	🟥 4	🟥 11	🟥 4	🟥 0	🟥 11	🟨 13	🟩 25	🟩 25
Legumes	🟥 23	🟥 8	🟥 19	🟥 6	🟥 8	🟥 8	🟥 9	🟨 100	🟩 200	🟩 200
Fish	🟥 32	🟥 23	🟥 8	🟨 82	🟥 25	🟥 16	🟥 17	🟩 125	🟩 200	🟥 0
Egg	🟩 26	🟩 13	🟩 22	🟩 36	🟩 12	🟩 27	🟨 44	🟩 38	🟩 25	🟨 0
Milk	🟩 33	🟩 183	🟩 286	🟩 225	🟩 204	🟩 95	🟩 434	🟩 250	🟩 200	🟨 0
Refined grains (dry weight)	🟨 138	🟩 99	🟨 143	🟥 172	🟩 88	🟨 145	🟥 159	🟩 100	🟩 50	🟩 75
Red meat	🟥 81	🟨 47	🟩 22	🟨 66	🟥 70	🟨 44	🟨 41	🟨 50	🟩 0	🟩 0
Processed meat	🟩 10	🟥 27	🟩 7	🟥 71	🟥 40	🟥 34	🟥 27	🟨 25	🟩 0	🟩 0
White meat	🟩 24	🟩 26	🟩 94	🟩 53	🟩 26	🟩 25	🟩 43	🟩 63	🟩 50	🟩 50
Sugar-sweetened beverages	🟩 102	🟩 111	🟩 50	🟥 425	🟨 210	🟩 71	🟥 621	🟨 250	🟩 0	🟩 0
Added oil	🟩 16	🟩 8	🟩 60	🟩 30	🟩 19	🟩 19	🟩 21	🟩 25	🟩 25	🟩 50
Added sugar	🟩 3	🟥 50	🟥 51	🟥 71	🟥 50	🟥 52	🟥 52	🟨 25	🟩 0	🟩 0
Calculated energy (kJ/d)	4864	4693	7799	9927	5783	5475	8211	8275	7615	7875
Uncategorized (%)	53	55	25	4	44	47	21	20	27	24

Example of reference female: age 40 y, height 1.65 m, weight 60 kg, moderately active (1.2). Example of reference male: age 60 y, height 1.70 m, weight 65 kg, inactive (1.05). The color coding assumes that the uncategorized proportion is distributed in the same proportion as the other food groups, with green associated with the most favorable life expectancy estimates (0%–33% gain potential), red with the least favorable life expectancy estimates (67%–100% gain potential), and yellow in between these estimates (33%–66% gain potential). Typical food consumption is estimated mean food intakes derived mostly from national dietary intake surveys.

[1] Presented for reference person (with typical energy requirement within the given scenario).

level. Estimates of dietary energy requirements are based on energy expenditure prediction equations suggested by Heymsfield et al. [11].

Mortality rates

We used location-, age-, and sex-specific mortality estimates from the Global Burden of Diseases and Injuries study to calculate LE under typical conditions for each category of age, sex, and country [12]. To avoid data affected by the initial stages of the COVID-19 pandemic, we used pre-COVID data from 2019.

Dose-response relationships

We used recent and comprehensive meta-analyses to obtain quantitative information on dose-response relationships between intake of the food groups and their associations with all-cause mortality [13–18] (Figure 1). When more than one meta-analysis was available, we used the most comprehensive (usually the latest) with dose-response relationship data, unless later, less comprehensive meta-analyses argued well for excluding the studies. Most of the underlying studies included in the meta-analyses were adjusted for factors such as smoking, physical activity, BMI, age, and sex, and many also adjusted for intake of other food groups. To be conservative in our main estimates, we reduced the effect estimates per food group on mortality by 25% to account for the fact that not all studies included in the meta-analyses were adjusted for all confounders and that there could be correlation between food groups and the estimates of LE [19]. There are few studies assessing dietary interventions and reversal of key morbidities such as cardiovascular diseases and cancer, but one study has examined intensive lifestyle changes over 5 y and changes in coronary artery disease [20]. This indicated a relative difference in coronary artery stenosis between the intervention of 11% (3.9% in controls compared with −6.8% in the intervention) during the first year and 37.2% for the 5-y period (27.5% in controls compared with −9.7% in the intervention). Thus, the model assumed a gradually increasing reduction in cardiovascular disease risk, with full effect at 20 y (in the form of an inverse S-shaped curve, see Supplementary Text S1).

We assessed the overall quality of evidence using NutriGrade scores for each of the different food groups and weighting the mean of these based on the absolute contribution of each food group to the LE change [21]. The quality of the meta-analyses was rated with AMSTAR-2 and considered as high for all included meta-analyses [13–16,18] except for white meat, for which the meta-analysis was rated as moderate quality [17].

Food4HealthyLife model 2.0 summary

Johansson et al. [22] presented a framework for measuring LE from disease onset for specific conditions, and this methodology was modified by Fadnes et al. [2,19] to assess the impact of sustained changes in the intake of different dietary factors on LE. In brief, the methodology is based on multiplying the age- and sex-specific background mortality by the hazard ratios (HRs) corresponding to the intake of each food group. For example, if the HR was 0.8 for one food group and 1.2 for another, the combined impact on mortality of the 2 groups is $0.8 \times 1.2 = 0.96$, yielding a decrease in mortality of 4%.

To calculate uncertainty intervals (UIs) for the gains or losses in LE from a certain intake of one food group, we sampled from a normal distribution with a mean corresponding to the logarithm of the HR from the Cox regression analyses [i.e., log(HR)] and a SD corresponding to the SE of log(HR). Then, the number was transformed back to HR. Repeating this process 200 times, the upper and lower limits were the 2.5 and 97.5 percentiles of the ranked numbers. To obtain the overall UI, this procedure was repeated for all the food groups, and these simulated HRs were multiplied as described in the previous paragraph. Again, repeating this procedure 200 times, the upper and lower limits were the 2.5 and 97.5 percentiles. See Supplementary Text S1 for more details.

Target diet

The values for the food groups in longevity-optimized dietary changes were set such that the dose-response relationships indicated no additional reduction in mortality from further increases or decreases in intake of each food group (i.e., the impact on mortality had plateaued). The vegan dietary changes (or strictly vegetarian without dairy and eggs) were optimized in a similar way but without animal products and choosing the higher part of the optimal spectrum for included food groups to balance the energy difference from excluded food groups. A more feasible dietary change was defined as being at the midpoint between what was defined as a typical Western diet (Table 1) and the longevity-optimized dietary changes. The feasible dietary changes

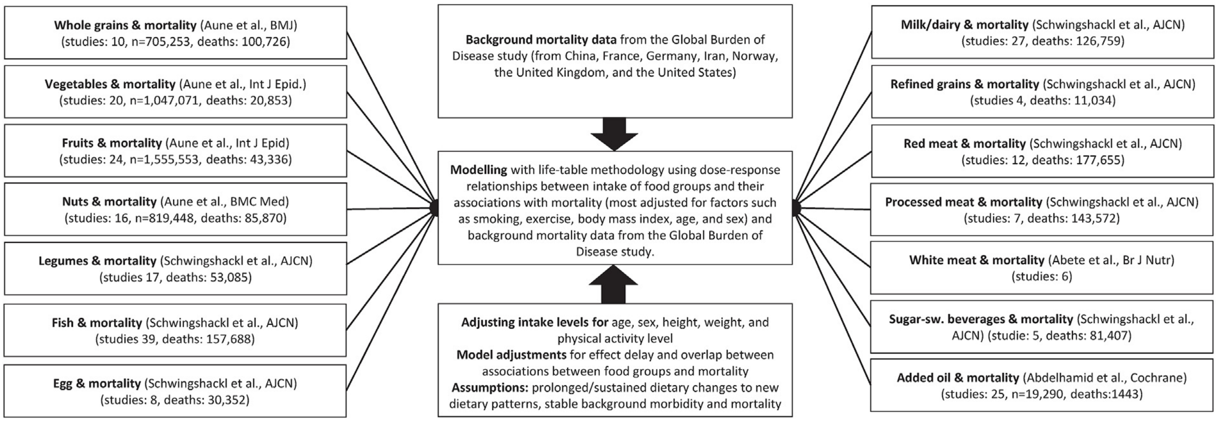

FIGURE 1. Participant and data flow chart summarizing input data with number of participants, studies, and deaths outcomes for each food group exposure as well as summarizing model assumptions and background mortality data.

correspond relatively well with guidelines such as the Eatwell Guide [23], which recommends consuming ≥5 portions of a variety of fruit and vegetables daily; basing meals on potatoes, bread, rice, pasta, or other starchy carbohydrates; choosing higher fiber wholegrain varieties; including some dairy or alternatives to dairy such as soya drinks and yogurts; and choosing lower-fat and lower-sugar products where possible.

Online calculator

We used the R package *Shiny* to create a web application that enables the estimation of the effect of sustained dietary change on LE (http://v2.food4healthylife.org/) [24,25]. In the left food panel (i.e., the diet before change), the defaults are set to the typical dietary patterns in the respective countries. The right food panel represents diet after change. Clicking the "*New diet: Optimal*," "*New diet: Feasible*," or "*New diet: Vegan*" button, the right panel of sliders are adjusted to the longevity-optimized diet, more feasible diet, and optimized vegan diets. We estimated gain in LE for each country when changing from a typical dietary pattern to a longevity-optimized diet, a more feasible diet, and an optimized vegan diet in 20-, 40- and 60-y-old females and males from China, France, Germany, Iran, Norway, the United Kingdom, and the United States. Plots were made using the R package *Highcharter* [26]. We also conducted sensitivity analyses with delays of 5 –50 y to achieve the full benefit in LE from sustained dietary change, and modified model adjustments where the effect is reduced by 50% or 0% rather than the 25% mentioned in the paragraph on dose-response relationships. We adhered to the transparent reporting of a multivariable prediction model for individual prognosis or diagnosis (see TRIPOD Checklist S1) [27].

Results

In most countries, the typical dietary patterns were low in whole grain (except Norway and Iran, with moderate intake), moderate to high in vegetables, and moderate in fruits (high in Norway and the United States) (Table 1). Further, the typical dietary patterns were low in nuts, low in legumes, and low in fish (moderate in Norway). The intake levels of refined grains were generally high but slightly lower in China, Iran, and Germany. Typical consumption of red meats ranged from low in Iran; moderate in France, Norway, the United States, and the United Kingdom; to high in Germany and China. Intakes of processed meats were low in China and Iran and high in the other countries. Consumption of sugar-sweetened beverages were low in China, France, Iran, and the United Kingdom; moderate in Germany; and high in Norway and the United States. Consumption of added sugar was low in China and high in the other countries.

LE for 20-y-old females with typical eating patterns ranged from 59.1 y in Iran to 62.4 y in France (Table 2). For 60-y-old females, the corresponding LEs were 20.9 and 23.7 y. For 20-y-old males, LE under typical dietary pattern conditions ranged from 55.5 y in China to 59.6 y in Norway while corresponding values for 60-y-old males were 18.6 and 21.2 y. Typical dietary patterns in Iran and China were associated with higher LE than typical dietary pattern in countries such as the United Kingdom and Germany (Table 2, Figure 2, and Supplementary Figures S1–S174).

Among 40-y-old females/males, estimated gains in LE from a sustained change from the typical dietary patterns in the respective countries to longevity-optimized dietary changes were in the range of 6.2 y (UI: 5.7, 7.5 y) to 6.3 y (UI: 5.3, 7.9 y) in China to 9.3 y (UI: 7.7, 10.8 y) to 9.7 y (UI: 8.1, 11.3 y) in the United States. The largest gains would be made by eating more legumes, whole grains and nuts, and less processed meat (Figure 3). However, because of differences in typical dietary patterns between countries, the relative rank and magnitude in gains differed slightly between countries. For example, for 40-y-old females in China, the 3 most impactful changes were increasing the intake of whole grains (1.5 y; UI: 1.2, 1.9 y) and legumes (1.1 y; UI: 0.6, 1.8 y) while limiting red meats (0.8 y; UI: 0.7, 0.9 y). Correspondingly, for Norway, the greatest benefit would be obtained by increasing intake legumes (1.3 y; UI: 0.7, 2.1 y), limiting intake of processed meats (1.4 y; UI: 1.2, 1.5 y), and increasing the intake of whole grains (0.9 y; UI 0.6, 1.3 y). For the United States, the top 3 changes were projected to be increasing the intake of whole grains (1.7 y; UI: 1.3, 2.1 y) and legumes (1.3 y; UI: 0.7, 2.1 y) while limiting sugar-sweetened beverages (1.0 y, UI: 0.2, 1.6 y). Similarly, for the United Kingdom, the top 3 projected changes were increased intake of whole grains (1.8 y; UI: 1.4, 2.2 y), legumes (1.2 y; UI: 0.6, 2.0 y), and nuts (1.0 y; UI: 0.9, 1.2 y).

We also estimated energy requirements (kJ/d), and age-, sex-, height-, weight-, and physical activity-specific diet adaptations for different scenarios (Table 2), with energy requirements and intake levels approximately double for large and highly active 20-y-old males compared with smaller and inactive 60-y-old females.

Sensitivity analyses showed that when decreasing time-to-full-effect to 5 y, gains in LE were increased by 1%–3% among 20-y-old females and males, 3%–8% among 40-y-olds, and 19%–27% among 60-y-olds. Conversely, when increasing time-to-full-effect to 50 y, gains in LE were reduced by 6%–9% among 20-y-old females and males, by 21%–25% among 40-y-olds, and by 50%–58% among 60-y-olds. In sensitivity analyses of the model adjustment, setting the model more conservatively (reducing effects by 50% due to potential overlap or confounding) resulted in estimates of LE being reduced by one-third across all age groups. Conversely, when not accounting for residual confounding (assuming no overlap or confounding), estimates of gain in LE were increased by one-third across all age groups. The overall quality of evidence was assessed as moderate for all 3 diets under consideration. The uncertainty was higher for countries such as France and Germany, which had a higher proportion of foods not categorized within the food groups we present.

Discussion

In this study, we estimate the gain in LE that could be expected following sustained changes from typical eating patterns in China, France, Germany, Iran, Norway, the United Kingdom, and the United States to longevity-optimized dietary changes, a more feasible option, and an optimized vegan option. This shows that for 40-y-old adults, changing to a longevity-optimized diet is projected to result in LE gains in the range of 6–8 y. Similarly, LE gains of 5–7 y would be expected when changing to optimized vegan dietary changes, and gains of 2–4 y for more feasible dietary changes. Our analyses also indicate that the projected gains in LE from typical dietary to optimization of dietary patterns in Iran and China are lower than those in the United Kingdom and Germany, with up to a 2–3-y difference in LE when initiated from early adulthood. In addition, across all ages and in all countries, projected gains in LE following sustained dietary change are greater for males than for females.

TABLE 2

Life expectancy estimates for 20-, 40-, and 60-y-old female and male adults from China, France, Germany, Iran, Norway, the United Kingdom, and the United States, and estimated life expectancy gains for each of the adult populations that changes from a typical dietary pattern within the country (TD) to a more feasible changes (FD), optimized vegan (VD), or longevity-optimized dietary changes (OD)

	Age	Life expectancy (added years from age)				Life expectancy gain from sustained dietary pattern change in years (with uncertainty intervals[1])		
		TD	FD	VD	OD	TD->FD	TD->VD	TD->OD
China females (1.65 m, 60 kg)	20	59.9	61.7	65.5	66.4	1.8 (0.3, 3.3)	5.5 (4.2, 6.8)	6.5 (5.2, 7.9)
	40	40.3	42.0	45.6	46.5	1.7 (0.3, 3.1)	5.2 (4.0, 6.5)	6.2 (5.0, 7.5)
	60	21.4	22.8	25.7	26.5	1.4 (0.3, 2.6)	4.3 (3.4, 5.4)	5.1 (4.2, 6.3)
China males (1.75 m, 70 kg)	20	55.5	57.4	61.3	62.4	2.0 (0.5, 3.6)	6.0 (4.7, 7.6)	7.1 (5.8, 8.6)
	40	36.3	38.1	41.6	42.6	1.7 (0.4, 3.2)	5.3 (4.2, 6.9)	6.3 (5.3, 7.9)
	60	18.6	19.8	22.3	23.1	1.2 (0.3, 2.3)	3.7 (3.1, 5.1)	4.5 (3.9, 5.8)
France females (1.65 m, 60 kg)	20	62.4	66.3	69.7	70.5	3.5 (2.4, 4.2)	7.3 (6.0, 8.5)	8.1 (6.7, 9.4)
	40	42.4	46.4	49.7	50.4	3.3 (2.3, 4.0)	7.2 (6.0, 8.5)	8.0 (6.7, 9.3)
	60	23.7	26.9	29.8	30.5	2.6 (1.8, 3.2)	6.1 (5.1, 7.2)	6.8 (5.7, 7.9)
France males (1.75 m, 70 kg)	20	58.4	62.6	66.6	67.6	4.3 (3.2, 5.7)	8.3 (6.9, 9.7)	9.3 (7.8, 10.8)
	40	39	43	46.7	47.6	4.0 (3.1, 5.5)	7.7 (6.4, 9.2)	8.7 (7.3, 10.2)
	60	20.7	24	26.9	27.6	3.0 (2.2, 4.3)	5.9 (4.9, 6.9)	6.6 (5.6, 7.7)
Germany females (1.65 m, 60 kg)	20	60.9	65.1	68.6	69.5	4.2 (3.2, 5.5)	7.7 (6.4, 9.0)	8.6 (7.2, 10.0)
	40	40.9	45.1	48.5	49.4	4.2 (3.2, 5.7)	7.6 (6.4, 8.9)	8.5 (7.1, 9.9)
	60	22.2	25.6	28.5	29.2	3.4 (2.4, 4.6)	6.3 (5.3, 7.4)	7.0 (5.9, 8.2)
Germany males (1.75 m, 70 kg)	20	57.8	62.2	66.1	67.1	4.3 (3.0, 5.9)	8.3 (6.9, 9.8)	9.3 (7.8, 10.9)
	40	38.3	42.4	46.1	47.1	4.1 (3.1, 5.5)	7.8 (6.5, 9.3)	8.7 (7.3, 10.3)
	60	20.1	23.2	26	26.8	3.1 (2.4, 4.1)	5.9 (5.0, 7.1)	6.6 (5.6, 7.8)
Iran females (1.65 m, 60 kg)	20	59.1	61.1	64.8	65.8	2.0 (0.7, 3.8)	5.7 (4.3, 7.3)	6.7 (5.3, 8.2)
	40	39.7	41.5	45.1	46	1.8 (0.6, 3.6)	5.4 (4.1, 7.0)	6.3 (5.0, 7.9)
	60	20.9	22.3	25.2	25.9	1.4 (0.5, 2.9)	4.3 (3.3, 5.7)	5.1 (4.1, 6.4)
Iran males (1.75 m, 70 kg)	20	56.5	58.8	63.1	64.2	2.3 (0.8, 4.3)	6.6 (4.8, 8.2)	7.7 (5.9, 9.2)
	40	37.7	39.9	43.8	44.8	2.2 (0.9, 4.1)	6.1 (4.6, 7.7)	7.1 (5.6, 8.7)
	60	20.1	21.5	24.4	25.1	1.4 (0.5, 2.9)	4.3 (3.3, 5.6)	5.0 (4.0, 6.3)
Norway females (1.65 m, 60 kg)	20	61.8	65.7	69.2	70	3.0 (1.7, 4.4)	7.4 (5.9, 8.8)	8.2 (6.5, 9.6)
	40	41.8	45.8	49.2	50	3.0 (1.7, 4.4)	7.4 (5.9, 8.8)	8.2 (6.5, 9.6)
	60	22.8	26.2	29.1	29.8	2.7 (1.5, 3.8)	6.3 (5.1, 7.6)	7.0 (5.7, 8.2)
Norway males (1.75 m, 70 kg)	20	59.6	63.4	67.1	68.1	3.8 (2.2, 5.5)	7.5 (6.0, 9.1)	8.5 (6.7, 10)
	40	40.2	43.7	47.3	48.2	3.5 (2.0, 5.1)	7.1 (5.7, 8.6)	8.0 (6.4, 9.5)
	60	21.2	24.3	27.2	27.9	3.1 (1.9, 4.3)	5.9 (4.8, 7.2)	6.7 (5.4, 8.0)
United Kingdom females (1.65 m, 60 kg)	20	60.5	65.2	68.8	69.6	4.7 (3.3, 6.3)	8.3 (6.9, 9.7)	9.1 (7.8, 10.6)
	40	40.6	45.3	48.7	49.5	4.7 (3.4, 6.3)	8.1 (6.9, 9.5)	9.0 (7.7, 10.4)
	60	21.9	25.7	28.6	29.3	3.8 (2.8, 5.1)	6.7 (5.6, 7.8)	7.4 (6.4, 8.6)
United Kingdom males (1.75 m, 70 kg)	20	58.1	62.9	66.7	67.7	4.7 (3.3, 6.5)	8.6 (7.2, 10.1)	9.6 (8.2, 11.2)
	40	38.6	43.1	46.8	47.7	4.6 (3.3, 6.2)	8.2 (6.9, 9.6)	9.1 (7.8, 10.6)
	60	20.3	23.8	26.7	27.4	3.5 (2.5, 4.7)	6.4 (5.3, 7.4)	7.1 (6.0, 8.2)
United States females (1.65 m, 60 kg)	20	59.6	64.3	68.1	69	4.7 (2.8, 6.8)	8.5 (6.8, 10.1)	9.4 (7.6, 11)
	40	39.7	44.6	48.2	49	4.9 (3.2, 7.0)	8.4 (6.8, 10.0)	9.3 (7.7, 10.8)
	60	21.6	25.5	28.4	29	3.9 (2.6, 5.6)	6.7 (5.5, 7.9)	7.4 (6.1, 8.6)
United States males (1.75 m, 70 kg)	20	56.1	60.9	65.2	66.2	4.8 (2.9, 7.2)	9.1 (7.2, 10.8)	10.2 (8.3, 11.9)
	40	36.9	41.8	45.6	46.6	4.8 (3.2, 7.1)	8.7 (7.1, 10.3)	9.7 (8.1, 11.3)
	60	19.7	23.2	26	26.7	3.5 (2.4, 5.1)	6.3 (5.2, 7.5)	7.0 (5.9, 8.2)

[1] Uncertainty intervals are calculated using 200 Monte Carlo simulation selecting the 5th and 195th values when arranged from lowest to highest.

We also present a method for estimating the impact of sustained changes in dietary patterns on LE while adjusting for age, sex, height, weight, and activity level, which is integrated into the online calculator Food4HealthyLife 2.0 (http://v2.food4healthylife.org/). We use this to present associations between dietary changes and longevity for a range of comparison scenarios, including intake and energy adaptations for physically inactive and highly active people in different age groups and of different heights.

Eating more legumes, whole grains, and nuts, and eating less red meat and processed meats and sugar-sweetened beverages were projected to produce the biggest increases in LE, but with slightly different ranking between the countries due to between-country differences in current habitual dietary patterns. Thus, although intake of fruits and vegetables is strongly inversely associated with mortality [13,16], in most countries, intake of fruits is closer to the optimal level than that of whole grains and legumes, so there is less benefit by further increasing fruit intake. It is likely that there will be variation in health outcomes associated with differences in specific foods within each of the food groups and in food processing and preparation methods. For example, added oils such as olive oil, which are rich in MUFAs, seem to be more beneficial than other added oils [18,28,29]. A comparison of dietary guidelines among 96 countries worldwide published in 2021 indicated that 90 had recommendations on fruits and vegetables, 79 on sugar, 59 on grains/cereals, 58 on fish, 50 on legumes, but only 19 on nuts [30]. This indicates that there might be more potential in highlighting nuts but also whole grains, fish, and legumes in dietary guidelines.

Although sustained changes to the optimized vegan dietary changes were estimated to produce slightly lower LE gains than those following sustained change to the longevity-optimized diet, the differences were

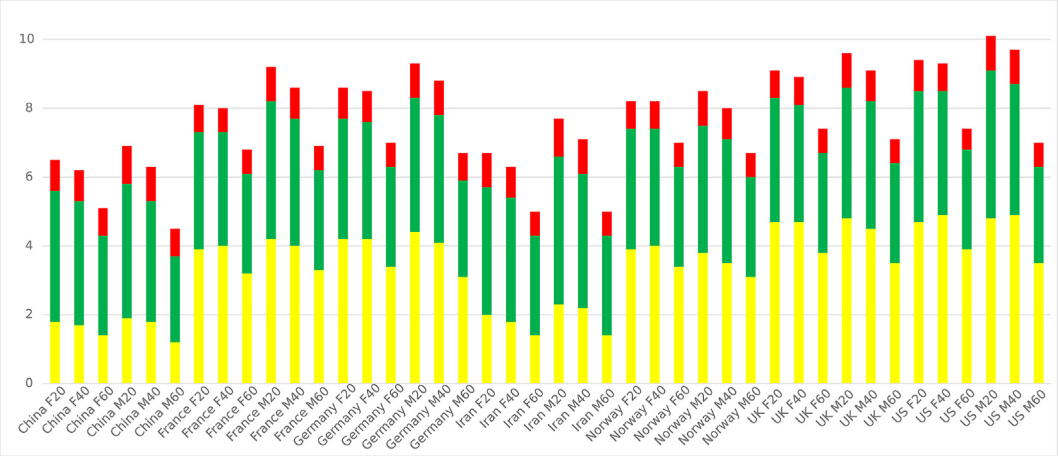

FIGURE 2. Life expectancy gains in 7 geographically diverse countries among 20, 40, and 60-y-old females (F) and males (M). The yellow bars indicate gain from sustained, more feasible dietary changes of country-specific dietary patterns. The green bars indicate additional gain from more feasible dietary changes to optimized vegan dietary changes, and the red bars indicate additional gain from optimized vegan dietary changes to longevity-optimized dietary changes. Based on Food4HealthyLife modeling. UK, United Kingdom; US, United States.

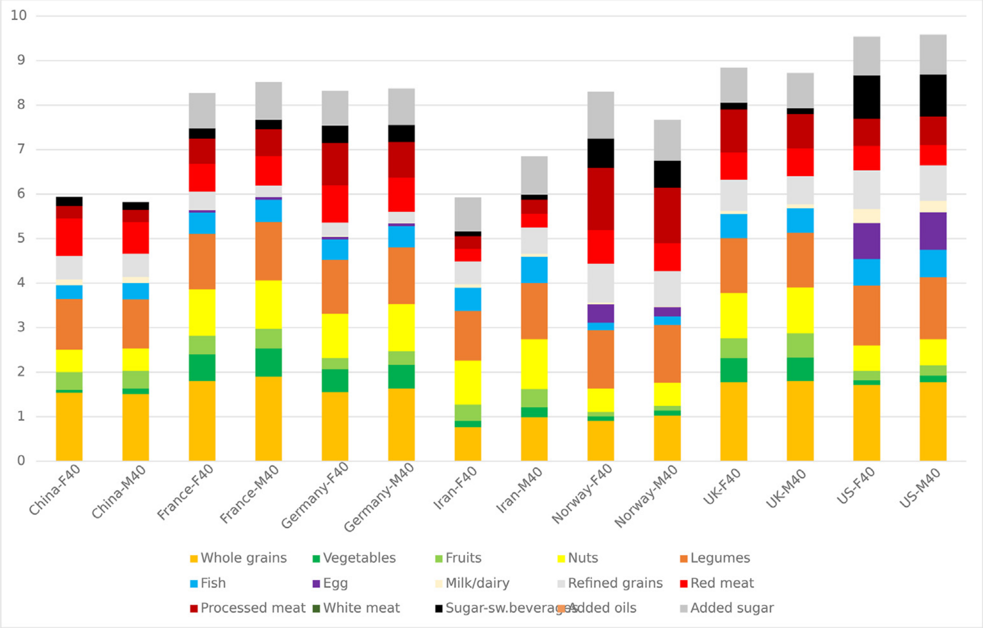

FIGURE 3. Estimated food-specific life expectancy gains in years from sustained change from typical dietary patterns in 7 geographically diverse countries to optimized dietary changes among females (F) and males (M) aged 40 y. Gains are associated with increased intake of whole grains (light orange), vegetables (dark green), fruit (light green), nuts (yellow), legumes (brown), fish (blue), and reduction in red and processed meat (red and dark red), sugar-sweetened beverages (black), refined grains (grey), and in some settings, also slight reduction in intake of eggs (purple), and milk/dairy (light yellow). Based on Food4HealthyLife modeling. UK, United Kingdom; US, United States.

not large. The projected longevity difference between these diets was mainly attributable to gains from the consumption of fish. Plant-based dietary patterns have benefits beyond human health and, for example, have a substantially smaller carbon footprint and require less land use [7,8] and may offer cost benefits [31].

Our study has some limitations. Meta-analyses combine studies that often involve heterogeneity between the studies, with overall estimates not necessarily accounting for the heterogeneity in settings and with different extents of adjustment for potential confounders. Nevertheless, meta-analyses are often the best evidence available, and most adjust for a range of potential confounders. For studies presenting outcome measures with and without adjustment for other food groups, these generally indicate minimal changes in the estimates of mortality risk [32–34]. Our estimates do not take past morbidity into consideration, nor do they consider other risk factors such as genetic vulnerability, or progress in development of medical treatments or lifestyle [35]. Thus, the methodology is not intended to provide individualized forecasting of life-years gained, but rather adult-relevant population estimates under given assumptions. Although the estimates are population-based, it might be useful for individuals and clinicians to be aware of dietary patterns typically associated with beneficial outcomes, as long as the limitations are taken into consideration. A meta-analysis on the association between consumption of different food groups and risk of obesity/overweight indicates that the intake levels we report in the longevity-associated dietary pattern are associated with reduced risk of obesity/overweight [36]. The dietary adaptations to height, weight, and activity level also assume a proportionally similar intake of food groups based on energy requirements. Further, we have not considered any long-term health consequences due to excessive intake of food with high levels of toxins [37,38]. We do not account for micronutrient levels, which are also essential when assessing dietary patterns. It could be noted that suboptimal intakes of several micronutrients is the rule rather than the exception, even in high-income countries [39,40]. For some dietary patterns such as vegan dietary patterns, ensuring sufficient levels of key micronutrients such as vitamin B12 from supplements or fortified foods would be essential to avoid negative health outcomes due to deficiencies [41]. Our methods have several strengths. Our model uses the most comprehensive meta-analyses with dose-response data investigating associations between intakes of food group and risk of all-cause mortality. We also have developed methodology that integrates time between change to full longevity effect and model adjustments that accounts for correlation with residual overlap in risk estimates. Our model adjustments have been chosen to provide conservative estimates, reducing the risk of overestimating longevity gains. In addition, we present several sensitivity analyses showing generally similar patterns. We have further added adaptations based on height, weight, and physical activity level, in addition to age and sex. The meta-analyses used in this study were of high quality [42], with quality of evidence grading for the associations with food groups ranging from very low for eggs and white meat to high for whole grains, and most were in the moderate category [21]. The overall quality of evidence was estimated as moderate. Our sensitivity analyses indicate that, with even the most conservative approaches, the estimates of gains in LE from eating healthier are substantial.

In conclusion, changing from typical eating patterns to a longevity-optimized diet, more feasible dietary changes, or optimized vegan dietary changes are all associated with substantial gains in LE in geographically and culturally diverse countries including China, France, Germany, Iran, Norway, the United Kingdom, and the United States. Higher intakes of legumes, whole grains, and nuts and lower intakes of red and processed meats and sugar-sweetened beverages contributed most to these gains. The largest health gains from sustained dietary changes were projected in the United States and second largest in the United Kingdom. For 40-y-old adults with typical dietary patterns, projected gains in LE following sustained longevity-optimized dietary changes are in the range of 6–8 y, and correspondingly, 5–7 y when changing into an optimized vegan option, and 2–4 y for a more feasible dietary pattern change. Across all countries and age groups, projected gains in LE are greater for males than for females, which may help to address the current sex-dependent inequality in lifespan in most countries.

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Author contributions

The authors' responsibilities were as follows – LTF, JMØ, ØAH, KAJ: designed the study; LTF, EJA, JMØ, RB, ØAH: analyzed the data; LTF: principal investigator and wrote the first draft of the manuscript; and all authors: participated in interpretation of the data, reviewed the manuscript for intellectual content, and read and approved the final version of the manuscript.

Conflict of interest

The authors report no conflicts of interest.

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Data availability

The data used in this study are available through various online sources (see Supplementary data and references for a range of sources).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajcnut.2024.04.028.

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