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MINI REVIEW

Health and sustainability outcomes of vegetarian dietary patterns: a revisit of the EPIC-Oxford and the Adventist Health Study-2 cohorts

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Abstract

Knowledge in the role of plant-based diets on health had been shaped in part by cohort studies on vegetarians. We revisited publications from two ongoing longitudinal studies comprising large proportions of vegetarians—the Adventist Health Study-2 (AHS-2) and the European Prospective Investigation into Cancer and Nutrition-Oxford (EPIC-Oxford)—to describe the food and nutrient intake, health effects, and environmental sustainability outcomes of the dietary patterns identified in these studies. The vegetarian diet groups in both cohorts have essentially no meat intake, lower intake of fish and coffee, and higher intakes of vegetables and fruits compared to their non-vegetarian counterparts. In the AHS-2 cohort, vegetarians have higher intake of whole grains, legumes, nuts, and seeds. Vegans in AHS-2 have 16% reduced risk while vegans, vegetarians, and fish-eaters in EPIC-Oxford have 11–19% lower risk for all cancers compared to non-vegetarians. Pesco-vegetarians in the AHS-2 cohort had significantly lower mortality risk from all causes and ischemic heart disease while EPIC-Oxford fish-eaters had significantly lower all-cancers mortality risk than their non-vegetarians counterparts. Morbidity risks and prevalence rates for other chronic diseases were differentially reported in the two cohorts but vegetarians have lower risk than non-vegetarians. Greenhouse gas emissions of equicaloric diets are 29% less in vegetarian diet in AHS-2 and 47–60% less for vegetarian/vegan diets in EPIC-Oxford than non-vegetarian/meat-eating diets. The beneficial health outcomes and reduced carbon footprints make the case for adoption of vegetarian diets to address global food supply and environmental sustainability.

Introduction

The roots of vegetarianism can be traced back to the beginning of human history. Since then, adoption of vegetarian diets had been associated with various reasons including ethical and religious beliefs [1], lifestyles and health, and in some cases, socio-economic constraints. Most recently, growing concerns regarding the impact of food production on the environment have influenced some meat-eaters to switch to plant-based diets. Vegetarians continue to be a small minority in all countries except India, where a third of the population are vegetarians [2]. However, in many parts of the world, particularly some western countries, the growth in food establishments that cater to vegetarians and vegans points to the growing popularity of such diets. In the United States, recent estimates indicate that 3.3% of the population are vegetarians, with slightly more females (3.5%) than males (3.2%) and a larger percentage being 18–34 years old (5.3%); when eating out, 37% always or sometimes eat vegetarian meals and 15% sometimes or always eat vegan meals [3]. In the United Kingdom, the National Diet and Nutrition Survey in their 2012 report shows that 2% of both adults and children self-reported being vegetarian while less than 1% reported to be vegans [4].

Earlier concerns about vegetarian diets revolved around inadequacy associated with plant protein, but it is now scientifically established that well-planned vegetarian diets are healthful, nutritionally adequate, and may prevent and treat certain diseases; they are also deemed appropriate for all life cycle stages [5]. Perhaps findings from studies done on the large vegetarian cohorts in North America (Adventist Health Studies 1 and 2) and the United Kingdom (Oxford Vegetarian Study and the European Prospective

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Investigation into Cancer-Oxford) set the impetus to look more closely into the benefits of vegetarian diets. Results of epidemiological investigations from these cohorts show the favorable influences of vegetarian diets on longevity, overall health, and indicators of lifestyle and nutrition-related issues. In this paper, our aim is to describe side by side the dietary intake (food and nutrients), health effects, and environmental sustainability outcomes of the dietary patterns identified in the two ongoing longitudinal cohort studies that include large proportions of vegetarians, the Adventist Health Study-2 (AHS-2) and the European Prospective Investigation into Cancer and Nutrition-Oxford (EPIC-Oxford).

Vegetarian cohorts: the EPIC-Oxford and AHS-2

The EPIC-Oxford and AHS-2 are the largest of known ongoing prospective studies that include high proportions of vegetarians. Previous to these two studies were the Adventist Health Study 1, which followed up a cohort of 34,198 members composed of Seventh-day Adventists in California for 6 years (1977–1982) [6], and the Oxford Vegetarian Study which followed up 11,000 members from 1980 to 1984 [7].

The EPIC-Oxford is one of the many cohorts in the European Prospective Investigation into Cancer and Nutrition. It specifically targeted a population with a wide range of dietary patterns and was designed to recruit as many vegans and vegetarians in the United Kingdom. A total of 65,429 participants (14,606 males and 50,823 females) aged 20–97 years were recruited. Participants were categorized into a diet group based on responses to the following items in the questionnaire: (1) “Do you eat any meat (including bacon, ham, poultry, game, meat pies, sausages)?”; (2) “Do you eat any fish?”; (3) “Do you eat any dairy products (including milk, cheese, butter, yogurt)?”; and, (4) “Do you eat any eggs (including eggs in cakes and other baked foods)?” [8] (see Table 1). The cohort comprised of 52% meat-eaters (i.e., non-vegetarians), 15% fish-eaters, 29% vegetarians, and 4% vegans [8].

The AHS-2 which began in 2002 was designed to encompass a representative sample of Seventh-day Adventists all over North America and aimed to investigate diet-cancer associations. It has a total of 96,194 participants (62,500 females and 33,694 males; 25,500 Blacks and 62,814 Whites) aged 30–112 years at the time of recruitment [9]. A self-administered quantitative food frequency questionnaire was used to determine dietary intake, and dietary patterns were defined relative to frequency of intake of animal-based foods using an algorithm shown in Table 1. Based on the nutrient validation report published in

Table 1 Definition of dietary patterns in the EPIC-Oxford and the AHS-2

EPIC-Oxford		Adventist Health Study-2	
Dietary pattern	Definition[a]	Dietary pattern	Definition[b]
Meat-eater	Eats meat	Non-vegetarian	Eats meats (red meat and poultry) once or more times a month and all meats combined (fish included) more than once a week
		Semi-vegetarian	Eats meats (red meat and poultry) once or more times a month, and all meats combined (fish included) once a month to less than once a week
Fish-eater	Eats fish but not meat	Pesco-vegetarian	Eats fish one or more times a month but all other meats less than once a month
Vegetarian	Eats dairy and/or eggs but not meat or fish	Lacto-ovo vegetarian	Eats eggs/dairy one or more times per month but all meats (fish included) less than once a month
Vegan	Do not eat meat, fish, eggs, or dairy products	Vegan	Eats eggs/dairy, and all meats (fish included) less than once a month

[a]Based on definitions given by Davey et al. [8]

[b]Based on definitions given by Orlich et al. [13]

2010, the cohort comprised of 48% non-vegetarian, 10% semi-vegetarian, 6% pesco-vegetarian, 28% lacto-ovo vegetarian, and 8% vegan members [10].

What vegetarians eat: the vegetarian dietary patterns

A vegetarian diet is mainly plant-based but since there is no single vegetarian eating pattern, vegetarian diets vary only according to the extent of avoidance of animal products. Vegetarian diets can be totally plant-based (i.e., plant-only), such as in strict vegetarian or vegan diets, or plant-based with limited types and/or amounts of foods of animal origin. Lacto-ovo vegetarian, which includes milk, dairy products, and eggs, is the most widely practiced form of vegetarian diet. Semi-vegetarian—which can comprise pesco-vegetarian (includes fish) and flexitarian (occasionally includes small amounts of meat in a plant-rich diet)—is a relatively new term that may broaden the accessibility of vegetarian diets to the general public.

Any diet devoid of animal food sources can be claimed to be a vegetarian diet; thus, it is important to determine the intake profile of vegetarians. In the succeeding two sections, intake profiles of the two cohorts are placed side by side for foods and nutrients that have been published in common for both cohorts.

Food intake patterns of vegetarians

Table 2 shows the mean daily intake of selected foods/food groups for both cohorts. Two published reports for the

Table 2 Food intake of the EPIC-Oxford and AHS-2 diet groups

Food group	EPIC-Oxford dietary patterns[a, b]					AHS-2 dietary patterns[c, d]				
	Vegan	Vegetarian	Fish-eaters	Low meat-eaters	Regular meat-eaters	Vegans	Lacto-ovo vegetarian	Pesco-vegetarian	Semi-vegetarian	Non-vegetarian
Total meat, g/d[a]	—	—	—	35.2	108.5	0.0	0.0	18.2	9.1	59.2
Red meat, g/d[a]	—	—	—	21.4	73.8	0.0	0.0	0.0	1.6	16.1
Poultry, g/d[a]	—	—	—	14.6	34.6	0.0	0.0	0.0	5.2	21.7
Total processed meat, g/d[a]	—	—	—	8.2	25.9	0.0	0.0	0.0	0.3	2.7
Total fish g/d[a]	—	—	38.6	40.6	43.5	0.0	0.0	18.2	2.1	18.6
Oily fish, g/d[a]	—	—	16.0	15.8	14.5	0.0	0.0	7.5	0.8	6.3
Whole grains[e]						292.8	214.0	210.6	197.8	157.9
Legumes[e]						84.4	73.4	75.2	65.5	52.5
Nuts and seeds[e]						36.0	27.5	25.0	23.4	18.8
Eggs, g/d[a]	0.0	7.0	7.0		7.0	0.0	7.6	8.3	10.6	14.1
Dairy milk, g/d[b]	0.0	293.0	293.0		293.0	0.7	99.1	96.8	152.2	174.6
Dairy cheese, g/d[b]	0.0	27.5	23.0		15.2	1.4	21.3	17.7	25.6	25.7
Vegetables, g/d[b]	309.0	267.1	254.6		223.5	424.1	347.2	386.0	337.0	319.9
Fruits, g/d[a]	270.2	234.1	248.3		210.6	483.1	357.0	400.3	343.0	298.8
Sweetened beverages, ml/d[b]	72.4	95.0	60.2		66.7	123.7	216.4	225.4	295.9	373.3
Coffee, ml/d[b]	84.0	311.4	223.6		475.8	9.9	36.1	50.6	99.0	134.4
Tea, ml/d[b]	147.3	475.0	475.0		475.0	37.2	25.8	56.2	30.0	41.8
Alcohol, g/d[b]	7.6	10.9	11.8		10.6	0.2	1.0	2.3	3.3	8.4

[a]Values are unadjusted computed weighted means of 14,944 female and 5380 male vegan/vegetarians, 6926 female and 1590 male fish-eaters, 10,128 female and 2911 male low meat-eaters and 13,396 female and 5035 male regular meat-eaters in the Oxford Vegetarian Study and the EPIC-Oxford [11]

[b]Values are unadjusted computed weighted means assuming that median intakes of 256 female and 168 male meat-eaters, 257 female and 168 male fish-eaters, 255 female and 167 male vegetarians, and 255 female and 167 male vegans reported in a cross-sectional analysis of the EPIC-Oxford cohort approximate mean values [12]

[c]Values are means adjusted for age, gender, and race standardized to an 8368 kJ (2000 kcal) diet [13] in AHS-2

[d]Consumption of each food/food group in all the four vegetarian diets in AHS-2 are significantly different than that of the non-vegetarian dietary pattern ($p < .0001$)

[e]No report on EPIC-Oxford

EPIC-Oxford were used for the table: a recent report by Appleby et al. [11] collapsed the vegans and vegetarians into one group and re-categorized meat-eaters into low and regular meat-eaters; Schmidt et al. [12] used a sample of vegans, vegetarians, fish-eaters, and meat-eaters who were matched in age and gender. Mean values of intake for the foods reported in the articles were stratified by gender so to simplify, we computed weighted means assuming that median values reported by Schmidt et al. were near the mean values due to large enough sample sizes for each diet group. In the AHS-2, the mean intake for the selected foods was from an average of 89,455 subjects after multiple imputation analysis [13]. To unify the units for beverages, gram units for fruit drinks, soda, coffee, and tea were converted to volume in milliliters using an assumed density of 1 g/ml.

For both cohorts, the vegetarian diet groups had lower intakes of meat, fish, and coffee, and higher intakes of vegetables and fruits compared to their non-vegetarian counterparts. It is interesting to note that fish-eaters in the EPIC-Oxford and pesco-vegetarians in the AHS-2 cohorts ate less fish than meat-eaters/non-vegetarians. The two cohorts differed in consumption patterns of dairy milk, dairy cheese, tea, and alcohol across the dietary pattern groups: eggs, dairy cheese, and dairy milk intake had increasing intake trends from vegans to non-vegetarians in the AHS-2 while in EPIC-Oxford, vegetarians, fish-eaters, and meat-eaters ate similar amounts. The EPIC-Oxford cohort also drank relatively similar amounts of alcohol across all dietary pattern groups except for the vegan group; on the other hand, intake increased across the dietary pattern groups in the AHS-2 cohort. Although intake of alcohol in the EPIC-Oxford group was higher, it was very minimal in both cohorts. Intake of sweetened beverages was higher among vegans and vegetarians compared to fish- and meat-eaters in the EPIC-Oxford cohort, whereas the trend was opposite for the AHS-2 cohort, with non-vegetarians being the highest consumers. In terms of differences between the two cohorts, intakes of fruits, vegetables, and sweetened beverages were higher in AHS-2 while intakes of dairy products, coffee, and tea were higher in EPIC-Oxford. These may be attributed to differences in dietary assessment methodologies and/or food availability.

Food consumption of the different vegetarian groups relative to non-vegetarians for both the AHS-2 and EPIC-Oxford cohort is shown in Fig. 1. Differences in the intake of eggs, dairy products, and alcohol between the two cohorts are noticeable. Overall, the food intake profile of

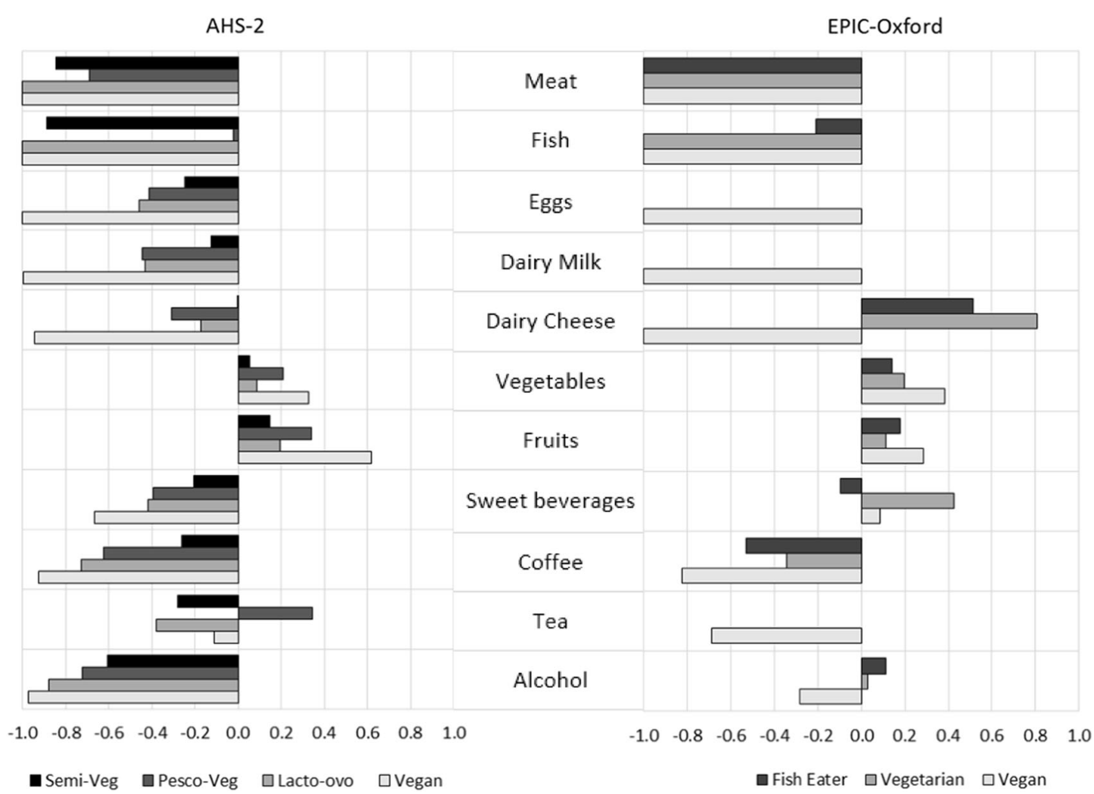

Fig. 1 Food intake in vegetarian diets relative to non-vegetarian/meat-eating diet in the AHS-2 and the EPIC-Oxford. Negative values (left of 0.0) indicate lesser proportion of intake while positive values (right of 0.0) indicate higher proportion of intake in the vegetarian relative to non-vegetarian/meat-eating diets. This figure was created using the data from Appleby et al. [11], Schmidt et al. [12], and Orlich et al. [13]

vegetarian diets reflects higher amounts of foods considered anti-inflammatory (fruits and vegetables) and lesser amounts of foods associated with increased cardio-metabolic risk (meat, eggs, and dairy). A comprehensive description of food intake by the different dietary patterns in AHS-2 [13] reported further that intake of whole grains relative to total grains was high for the whole cohort: 79% for vegans, 68% for lacto-ovo vegetarians, 66% for pesco-vegetarians, 65% for semi-vegetarians, and 55% for non-vegetarians. Plant sources of protein consumed by vegetarians in AHS-2 were soy foods (soybeans, tofu, soymilk, and meat analogs), legumes, nuts/peanuts/nut butters, and seeds.

Analysis of food intake can partially explain why certain dietary patterns reduce the risk for chronic diseases. For instance, plant foods are not only made up of nutrients but also bioactive compounds, such as polyphenols [14] and phytosterols [15, 16], with antioxidant and/or cholesterol-lowering properties that may act in synergy with nutrients to confer beneficial health effects.

Nutrient intake patterns of vegetarians

Reported nutrient intakes for the different defined dietary patterns in the EPIC-Oxford are based on the dietary data obtained from 30,251 participants aged 30–90 years who responded to the third follow-up questionnaire administered in 2010 [17] and from a cross-sectional analysis that focused on protein and amino acid intake of a subsample of 392 males aged 30–49 years in EPIC-Oxford [18]. For the AHS-2, nutrient intake reports were based on 71,751 participants in the original cohort (mean age = 59 years) who responded to the validated quantitative food frequency questionnaire [19]. Table 3 shows a summary of the nutrient intakes for both cohorts. Marked differences in intake of certain nutrients could be attributed to differences in assessment methodologies and nutrient databases for foods in the two cohorts. In the AHS-2, vitamin and mineral supplements were included in the reported values but only dietary intake was reported in EPIC-Oxford. Thus, no comparisons were made between the two cohorts, but only the trends of intake relative to the other dietary patterns

Table 3 Nutrient intake profile of the dietary patterns in EPIC-Oxford and AHS-2

Nutrient	EPIC-Oxford dietary patterns[a]				AHS-2 dietary patterns[b]				
	Vegan n = 803	Vegetarian n = 6673	Fish-eaters n = 4531	Meat-eaters n = 18,244	Vegans n = 5694	Lacto-ovo vegetarian n = 21,799	Pesco-vegetarian n = 6583	Semi-vegetarian n = 4042	Non-vegetarian n = 33,634
Energy, kJ	8127	8367	8486	8742	7924	7933	8088	7142	7920
% Carbohydrates	54.0	52.8	50.7	48.0	58.1	54.3	54.5	53.9	51.4
% Protein	13.1	14.0	15.5	17.2	13.6	13.7	14.2	13.7	14.7
% Plant protein	12.3[c]	7.8[c]	7.4[c]	6.0[c]	13.0	11.4	11.1	10.3	8.5
% Animal protein	—	4.6[c]	5.6[c]	8.4[c]	0.6	2.4	3.0	3.4	6.2
Soy protein, g[d]	2.8[c]	0.4[c]	0.3[c]	0.0[c]	13.1	10.2	10.5	8.0	4.9
% Fat	30.5	30.0	30.3	31.3	28.2	31.9	31.3	32.2	33.8
% SFA	6.9	9.5	9.4	10.4	5.0	7.0	6.7	7.7	8.6
% PUFA	10.3	7.8	7.9	7.1	9.5	9.8	9.4	9.4	8.8
% Alcohol[e]	2.2	3.2	3.5	3.4	—	—	—	—	—
Fiber, g	28.9	25.6	24.9	21.7	46.7	37.5	37.7	34.9	30.4
Vitamin B_6, mg	2.43	2.38	2.49	2.64	3.2	3.3	3.5	3.4	3.1
Vitamin B_{12}, mcg	0.78	3.09	6.36	7.88	6.3	8.0	8.5	8.3	7.1
Folate, mcg	504	452	446	413	723	729	766	731	672
Vitamin C, mg	190	174	174	167	293	271	308	273	250
Vitamin D, mcg	1.8	2.0	3.7	3.8	2.4	4.6	5.8	5.5	6.1
Vitamin E, mg	16.3	13.6	13.5	12.1	18.5	24.7	26.9	26.1	20.0
Calcium, mg	848	1117	1131	1083	933	1145	1125	1195	1072
Magnesium, mg	470	419	421	390	591	514	519	492	448
Potassium, mg	4115	4013	4140	4158	4120	3667	3853	3627	3487
Sodium, mg	2645	2631	2701	2624	3066	3432	3101	3346	3272
Iron, mg	18.3	16.7	16.7	16.3	22.2	22.1	22.4	21.7	20.0
Zinc, mg	8.7	10.3	10.2	10.5	11.3	11.5	11.5	11.6	11.9

[a]Mean values adjusted for age and gender; alcohol was included in determining total caloric intake [17]

[b]Mean values adjusted for age, gender and race for all macronutrients, except for % SFA and % PUFA, and unadjusted median values for all micronutrients due to skewed distributions; all values are standardized to 8368 kJ and reflect supplemental intake of vitamin B_{12} [19]

[c]Median values based on a subsample of 392 males: 98 meat-eaters, 98 fish-eaters, 98 vegetarians, and 98 vegans [18]

[d]Values are expressed as median % energy from soy protein for EPIC-Oxford and in mean weight (grams) for AHS-2

[e]No report in AHS-2

Table 4 Mortality and morbidity risks of the different dietary patterns of EPIC-Oxford and AHS-2 relative to non-vegetarians

	EPIC-Oxford					AHS-2				
	Regular meat-eaters	Low meat-eaters	Fish-eaters	Vegetarians	Vegans	Non-vegetarian	Semi-vegetarian	Pesco-vegetarian	Lacto-ovo vegetarian	Vegans
Mortality, hazard ratios[a]										
All causes	1.00	0.93 (0.86, 1.00)	0.96 (0.87, 1.06)	1.00 (0.93, 1.08)	1.14 (0.97, 1.35)	1.00	0.92 (0.75, 1.13)	**0.81 (0.69, 0.94)**	0.91 (0.82, 1.00)	0.85 (0.73, 1.01)
Ischemic heart disease	1.00	0.93 (0.76, 1.15)	1.00 (0.75, 1.34)	1.00 (0.80, 1.25)	0.85 (0.51, 1.44)	1.00	0.92 (0.57, 1.51)	**0.65 (0.43, 0.97)**	0.82 (0.62, 1.06)	0.90 (0.60, 1.33)
Cardiovascular disease	1.00	0.96 (0.84, 1.10)	1.22 (1.02, 1.46)	1.10 (0.95, 1.27)	1.16 (0.84, 1.59)	1.00	0.85 (0.63, 1.16)	0.80 (0.62, 1.03)	0.90 (0.76, 1.06)	0.91 (0.71, 1.16)
Cerebrovascular disease[b]	1.00	0.88 (0.68, 1.13)	1.36 (0.99, 1.86)	1.17 (0.90, 1.51)	1.63 (0.98, 2.69)	—	—	—	—	—
All cancers	1.00	0.96 (0.87, 1.08)	0.83 (0.70, 0.97)	0.91 (0.80, 1.03)	1.14 (0.88, 1.47)	1.00	0.94 (0.66, 1.35)	0.94 (0.72, 1.22)	0.90 (0.75, 1.09)	0.92 (0.68, 1.24)
Morbidity and risk factors, relative risks/odds ratios										
All cancers[c, d]		1.00[e]	**0.89 (0.81, 0.98)**	**0.89 (0.83, 0.96)**	**0.81 (0.66, 0.98)**	1.00	0.98 (0.82, 1.17)	0.88 (0.77, 1.01)	0.93 (0.85, 1.02)	**0.84 (0.72, 0.99)**
Colorectal[c, f]		1.00[e]	**0.67 (0.48, 0.92)**	1.00 (0.81, 1.24)	1.29 (0.81, 2.07)	1.00	0.86 (0.59, 1.24)	0.83 (0.66, 1.05)	**0.58 (0.40, 0.84)**	0.93 (0.62, 1.38)
Breast (female)[c, b]		1.00[e]	1.09 (0.93, 1.28)	0.96 (0.84, 1.10)	0.91 (0.61, 1.34)	—	—	—	—	—
Prostate[c, b]		1.00[e]	**0.89 (0.81, 0.98)**	**0.90 (0.84, 0.97)**	0.82 (0.68, 1.00)	—	—	—	—	—
Hypertension[g, h]	—		—	—	—	1.00	0.92 (0.70, 1.50)		**0.57 (0.36, 0.92)**	**0.37 (0.19, 0.74)**
Type 2 diabetes[i, h]	—		—	—	—	1.00	**0.49 (0.31, 0.76)**	0.79 (0.58, 1.09)	**0.62 (0.50, 0.76)**	**0.38 (0.24, 0.62)**
Diverticular disease[j, b]		1.00	0.90 (0.71, 1.16)	**0.73 (0.58, 0.92)**	**0.28 (0.10, 0.74)**	—	—	—	—	—
Metabolic syndrome (%)[k, h]	—		—	—	—	39.7	37.6		25.2	
BMI (kg/m^2)[l]		22.2[e]	22.9	22.8	23.7	28.6	27.2	26.2	25.9	24.0

[a]Hazard ratios for all-cause and other causes of mortality were estimated by Cox proportional hazards regression with attained age as time variable, and adjusted for several demographic and lifestyle covariates (smoking; alcohol intake; physical activity; marital status; regular use of nutritional supplements; study/method of recruitment; all possible combinations of sex, parity, oral contraceptive use, and hormone therapy use; prior diabetes, prior high blood pressure, and receipt of long-term medical treatment); values under EPIC-Oxford were pooled from the Oxford Vegetarian Study and the EPIC-Oxford cohorts [11]. Hazard ratios for the AHS-2 cohort are estimated by Cox proportional hazards regression with attained age as time variable and adjusting for sex, race, smoking, exercise, personal income, educational level, marital status, alcohol intake, region, sleep, and menopause and hormone therapy in women [21]. Bold values represent $p < 0.05$ when compared with reference group.

[b]No report or published findings in AHS-2

[c]Morbidity relative risks in the combined Oxford Vegetarian Study and EPIC-Oxford cohorts were estimated by Cox proportional hazards regression with age as underlying time variable and controlled for BMI and several demographic and lifestyle covariates (smoking; physical activity level; alcohol intake; for breast cancer, parity, oral contraceptive use; study/method of recruitment by using separate models for each end point; regular and low meat-eaters are combined as referent group [20]

[d]Hazard ratios in the AHS-2 were estimated by Cox proportional hazards regression with attained age as time variable and adjusted for race, family history of cancer, education, smoking, alcohol, age at menarche, pregnancies, breastfeeding, oral contraceptives, hormone replacement therapy, and menopausal status [23]

[e]Regular meat-eaters and low meat-eaters are combined as "meat-eaters"

[f]Hazard ratios in the AHS-2 cohort were estimated by Cox proportional hazards regression with attained age as time variable, and adjusted for race, gender, education, exercise level, smoking, alcohol use, family history of colorectal cancer; history of peptic ulcer, inflammatory bowel disease; treatment for diabetes mellitus within past year; use of aspirin, statins; prior colonoscopy or flexible sigmoidoscopy; use of supplemental calcium, vitamin D; energy intake; hormone therapy (women only); and BMI [24]

[g]Whites only, semi-vegetarians and pesco-vegetarians combined as one group; Odds ratios were estimated by logistic regression analysis and adjusted for age, sex, education, and physical activity [28]

[h]No report or published findings in EPIC-Oxford

[i]Odds ratios were estimated by multiple regression analysis and adjusted for age, sex, race, BMI, physical activity, education, income, sleep, television watching, smoking, and alcohol intake [30]

[j]Relative risk estimated by Cox proportional hazards regression stratified by sex, method of recruitment and region of residence and adjusted for smoking, educational level, Townsend deprivation index, self-reported hyperlipidemia, receipt of long-term medical treatment, use of oral contraceptives, use of hormone replacement therapy, and BMI [32]

[k]Prevalence rates for metabolic syndrome are given; semi-vegetarians and pesco-vegetarians were combined, lacto-ovo vegetarians and vegans were combined [31]

[l]Values for the EPIC-Oxford group are computed weighted age-adjusted means for 4318 male and 13,506 female meat-eaters, 1095 male and 5096 female fish-eaters, 2888 male and 9419 female vegetarians, and 570 male and 983 female vegans [25]; values for AHS-2 are age-standardized means [24]

within each cohort. Energy from alcohol was included in computing the macronutrient energy distribution for EPIC-Oxford but not in the AHS-2; energy proportions from fat and protein were largest for non-vegetarians in both cohorts. Vegans had markedly higher intakes of plant and soy proteins, dietary fiber, and magnesium compared to their counterparts in both cohorts. This diet group also had the lowest calcium and vitamin D intakes. Vitamin B_{12} intake in the EPIC-Oxford cohort reflected what was expected in diets that do not include animal food sources but values for the AHS-2-reflected dietary plus supplement intake [19].

Health outcomes of vegetarians

Table 4 shows the risk of death due to all causes, ischemic heart disease, cardiovascular or circulatory disease, cerebrovascular events, and all cancers in the combined cohorts of Oxford Vegetarian Study (OVS) and EPIC-Oxford [11, 20] and for the same causes except for cerebrovascular disease (no published report yet) in the AHS-2 cohort [21, 22]. Fish-eaters in the OVS/EPIC-Oxford cohort have significantly lower death risk due to cancers while their pesco-vegetarian counterparts in the AHS-2 cohort have significantly lower risk of death from all causes and ischemic heart disease [21] compared to the reference group, meat-eaters/non-vegetarians. It is notable that low meat-eaters have lower all-cause mortality compared to vegans and vegetarians in the EPIC-Oxford cohort but the opposite is true for AHS-2, with vegans and lacto-ovo vegetarians still having lower mortality compared to the semi-vegetarians.

Morbidity risks are also presented in Table 4. Compared to the non-vegetarians in the combined EPIC-Oxford and OVS cohort, fish-eaters, vegetarians, and vegans have significantly 11–19% lower risk for all cancers; in addition, fish-eaters and vegetarians are also significantly more protected from prostate cancers (10–11% reduced risk), and fish-eaters (23% reduced risk) from colorectal cancer [20]. Only the vegans and lacto-ovo vegetarians in the AHS-2 cohort have significantly reduced risk for specific cancers compared to non-vegetarians: 16% reduced risk from all cancers for vegans [23] and 42% reduced risk from colorectal cancer for lacto-ovo vegetarians [24]. There are no published findings on breast and prostate cancers in AHS-2 which are left blank in the table.

Although the BMI of the AHS-2 cohort [24] is relatively higher than that of the EPIC-Oxford cohort [25], it is clear that the vegetarian diet groups in both cohorts have lower BMI than non-vegetarians (see Table 4). The lacto-ovo vegetarians and vegans in AHS-2 have 43% and 63% significantly lower risk, respectively, from hypertension compared to non-vegetarians. In the EPIC-Oxford group report in 2002, prevalence of self-reported hypertension was higher in meat-eaters compared to their fish-eating and vegetarian counterparts: 20.7% in men and 16.5% in women meat-eaters, 12.1% in men and 10.7% in women fish-eaters, 9.8% in men and 8.5% in women vegetarians, and 5% in men and 6.8% in women vegans [26]. Among 3524 meat-eaters, 1404 fish-eaters, 3123 vegetarians, and 612 vegans with no self-reported hypertension, systolic (SBP) and diastolic (DBP) blood pressures were higher in meat-eaters than vegans, with age-adjusted mean differences of 4.2 mmHg and 2.6 mmHg SBP, and 2.8 mmHg and 1.7 mmHg DBP for men and women, respectively [26]. The significantly lower blood pressure or prevalence of hypertension among vegetarians and vegans were attributed to their lower body mass index (BMI) [27, 28].

In a cross-sectional analysis of 60,903 AHS-2 subjects with 3430 who reported type 2 diabetes (T2D), all vegetarian groups, including semi-vegetarians and pesco-vegetarians, were found to have 24–49% significantly lower risk from T2D compared to non-vegetarians [29]. In an updated report on incidence of T2D on 41,387 participants (which excluded prevalent cases of T1D/T2D, those who did not respond to the bi-annual hospitalization history, and had missing study variables) published 2 years later, the risk of developing type 2 diabetes was shown to be significantly reduced by 51%, 38%, and 62% among semi-vegetarians, lacto-ovo vegetarians, and vegans, respectively, compared to non-vegetarians [30]. Vegans and (lacto-ovo) vegetarians also had lower prevalences of metabolic syndrome [31] and diverticular [32] diseases as shown for AHS-2 and EPIC-Oxford, respectively.

Findings from both cohorts confirm that there is a vegetarian advantage when it comes to personal and population health. Discourses on the benefits, nutritional adequacy, and health effects of different dietary patterns are often based on the amount of plant foods in the diet. Globally, vegetarians have lower prevalence of cardio-metabolic risk, including overweight and obesity, and chronic diseases [33–35]. Vegetarians are also known for longevity. The absence or limited amounts of meat and the rich variety and quantity of plant foods in a vegetarian diet may independently account for its observed health benefits, since research shows mounting evidence of positive human health outcomes from plant foods [5] and injurious influences of meats [36]. However, balanced plant-based diets that include relatively small amounts of animal foods, such as eggs, dairy, and/or fish have been shown to also have health benefits.

Sustainability of vegetarian diets

The United Nations Food and Agriculture Organization characterized sustainable diets as "those diets with low environmental impacts that contribute to food and nutrition security and to healthy lives for present and future generations" [37]. Additional attributes of sustainable diets are to be "respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable, nutritionally adequate, safe, and healthy, and optimize natural and human resources" [37]. Producing plant foods require fewer natural resources than producing animal foods, thus, plant-based diets are more sustainable and less taxing on the environment [5, 38]. We recently examined the environmental impacts and the resources used in the production of commonly consumed plant sources (beans and almonds) and animal sources (eggs, chicken, and beef) of protein. Beef was found to dominate resource use: about 18 times more land, 11 times more water, and 12 times more fertilizers than that needed for the same amount of protein in beans (see Fig. 2) [39]. In addition, beef protein required about ten times more pesticides than beans and produced six times more animal waste than egg protein production [39]. At the dietary pattern level using data from AHS-1, the production of foods consumed by vegetarians required ~10,000 liters less water, 9900 kJ less energy, 186 g less fertilizers, and 5 g less pesticides than the production of non-vegetarian diets [40].

A comparison of greenhouse gas (GHG) emissions associated with a standard 8368 kJ (2000 kcal) diet among dietary patterns in the AHS-2 (vegetarian, semi-vegetarian, and non-vegetarian) [41] and in the EPIC-Oxford (vegan, vegetarian, fish-eaters, low meat-eaters, medium meat-eaters, and high meat-eaters) [42] using life cycle assessments is shown in Fig. 3. In both cases, reduction or elimination of meat in the diets can result in reduced GHG emissions: about 29% and 22% in vegetarian and semi-vegetarian, respectively, compared to non-vegetarian in the AHS-2, and from 22% with medium meat-eating (50–99 g meat/d) up to 60% with no meat or vegan compared to high meat-eating (≥100 g meat/d), in the EPIC-Oxford.

Consensus is increasing that plant-based diets are more sustainable because their production is more efficient and associated with lower environmental impact. Diets rich in plant-based foods and lower in animal-based foods are better at promoting health and have less adverse impact on the environment compared to the existing typical western diet [43-45].

Making the case for vegetarian diets at the global level

In the preceding sections, we have presented the food and nutrient intake, health effects, and sustainability parameters of vegetarian diets. It is noticeable that thousands of free-living vegetarians from the two leading research cohorts

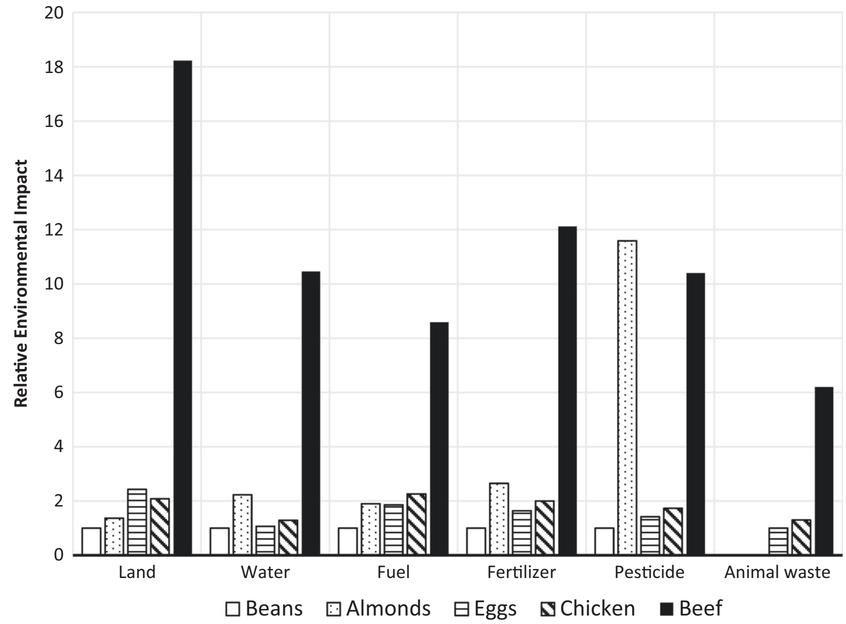

Fig. 2 Relative environmental impact of protein production from plant vs. animal sources of food. Beans are the reference food (impact set at 1). Figure was developed from data in Table 2 of Marlow et al. [40]

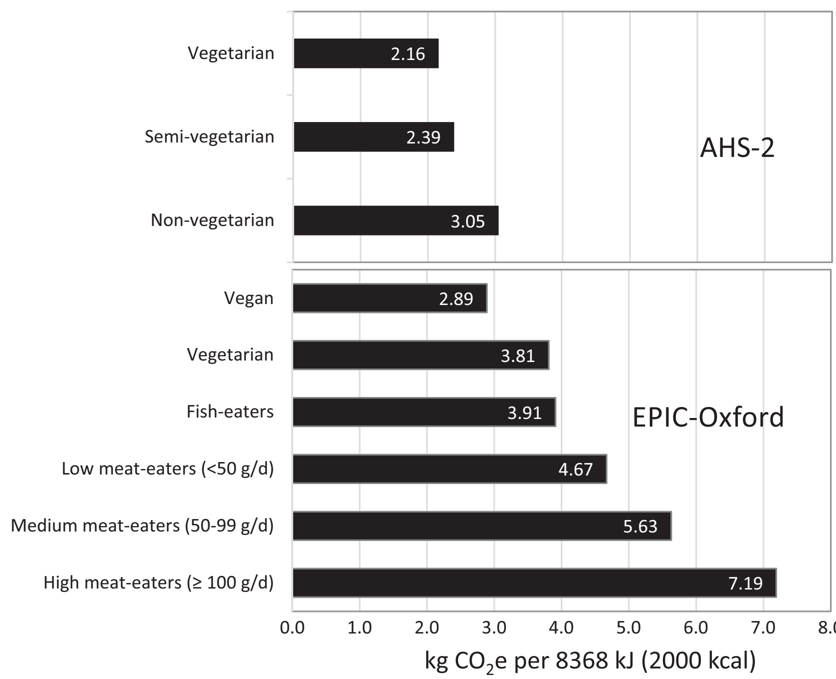

Fig. 3 Mean greenhouse gas emissions in kg CO_2 equivalents adjusted to 8368 kJ (2000 kcals) by type of diet in the AHS-2 and EPIC-Oxford cohorts. Figure was developed using data from Soret et al. [41] and Scarborough et al. [42]

have essentially no meat intake, low intake of dairy foods, and an expectedly higher intake of plant foods, with an apparent nutrient adequacy and better health outcomes signified by lower mortality and morbidity for most chronic diseases, including obesity. The production of such diets is more environmentally sustainable since they require less natural resources and emit less GHG. This contrasts with the current dramatic increase in the demand for foods of animal origin, particularly meat and dairy foods, at the global level. Increased demand of animal products is brought about by the worldwide demographic explosion [46] and the increasing wealth among large segments of populations in transitional and developing nations. Industrial livestock production is intrinsically resource inefficient and highly taxing on the environment, rendering the current food system environmentally unsustainable [38]. Furthermore, the shift from traditional plant-based to animal-based diets in many transitional and developing economies have contributed to the obesity epidemic and its concomitant comorbidities, creating a major public health and health care burden.

We posit that advocating for plant-based diets at the global level is timely. Shifting diets from animal-based to plant-based worldwide is of paramount importance in achieving food security and sustainability goals. Diminishing consumption of meat and other animal products will make substantial quantities of food available for direct human consumption, a more efficient and sustainable means to feed populations that could also abate food insecurity. Additionally, evidence connecting meat consumption, specifically red meat and processed meat, with detrimental health outcomes is growing [47–49]. From a strict health perspective, there is no need to consume meat. The downright adoption of meatless (vegetarian) diets at the global level has the potential to all at once optimize the food supply, improve health, increase environmental sustainability, and advance social justice outcomes [38].

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