ANALYTIC REVIEW

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Iron Status of Vegetarian Adults: A Review of Literature

Abstract: *The goal of this study was to review published data on iron status among vegetarian adults. Thirteen original articles met the inclusion criteria. Among female vegetarians, the percentage of the sample with ferritin <12 µg/L or <12 ng/mL ranged from 12% to 79%. An inadequate hemoglobin concentration ranged from 6% to 30.3%. Among males, the range of ferritin <12 µg/L across studies was from 1.7% to 29%. The prevalence of hemoglobin below deficiency cutoff ranged from 0% to 15.3%. A higher percentage of vegetarian females, compared to nonvegetarian participants, had ferritin below deficiency cutoff in all but one study (34% vs 0%, 47% vs 42%, 18% vs 13%, 27.8% vs 6.5% among Catholic nuns and 19.4% among college students, 79% Indian, and 56% Caucasian vegetarian vs 27% of nonvegetarian). Serum ferritin was lower in male vegetarians than male nonvegetarians in each study (11% among vegans and 21% among vegetarians compared to 6% and 7% among high and moderate meat consumers, 3% of vegetarians, and 25% vegans vs 0% of nonvegetarians, 29% vs 7%, 9% vs 0%). Vegetarians have a high prevalence of depleted iron stores. A higher proportion of vegetarians, compared to nonvegetarians, had iron deficiency anemia. This is especially true for premenopausal vegetarian women.*

Keywords: vegetarians; iron; hemoglobin; ferritin; adults

Vegetarian diets are dietary patterns that are devoid of all flesh foods but may include egg or dairy products. Vegan diets are free from all flesh foods, eggs and dairy products, and sometimes honey. Pesco-vegetarian is a dietary pattern with intake of fish and sea food, while semi-vegetarian (flexitarian) is a dietary pattern with occasional beef, pork, poultry, or fish intake.

The benefits of consuming vegetarian diets have been well established. Vegetarians have lower incidences of several health conditions including ischemic heart disease, total incidence of cancer, and type 2 diabetes.[1,2] They also have lower body mass indexes compared to omnivores.[2]

Despite the above-mentioned advantages, vegetarians also are at a high risk of a deficiency of some nutrients, such as vitamin B_{12} and iron.[3,4] In vegetarians, vitamin B_{12} deficiency results from low intake of this nutrient, while risk of iron deficiency is related to both inadequate iron intake and low bioavailability of iron from plant foods.[5] Since vegetarians, except for pesco- and semi-vegetarians, do not ingest meats, poultry, or fish, they only consume the less-absorbable non-heme iron found in plant foods.[5] The reason why non-heme iron is less bioavailable, compared to heme iron, is because of the naturally occurring absorption inhibitors, which mainly include phytate, oxalate, and polyphenols.[5] Phytate is one of the most potent absorption inhibitors and is found in whole grains, legumes, and nuts.[6] It has been estimated that more than 50% of phytate intake comes from grain products.[7] This is significant because, for

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many vegetarians, grain products are also the most significant source of dietary iron.[8] It is for the above-mentioned reasons that the Institute of Medicine stated that iron requirements for vegetarians are 1.8 times higher, compared to the requirement for nonvegetarians.[5]

Iron deficiency is defined as the noticeable reduction of iron supply to tissues in the body due to depleted iron stores.[5] Iron deficiency can lead to iron deficiency anemia, which is the final/most severe stage of iron deficiency.[5,9] Iron deficiency anemia results in microcytic erythrocytes and inadequate synthesis of hemoglobin (Hb).[5] The result of this abnormality causes inadequate oxygen supply to cells, tissues, and organs.[5,9] Poor iron status can lead to the development of iron deficiency anemia and associated symptoms. These symptoms may include decreased cognition, fatigue, less than optimal immune function, pregnancy complications, and even an increased risk of lead poisoning.[5]

Although several reviews of the literature on iron status among vegetarians were published to date,[6] none included a comprehensive evaluation of iron status based on all available published studies that reported percentage of deficiency in the studied samples. Thus, the goal of this article is to assess iron status among vegetarian adults. The objectives included (1) evaluation of iron status among vegetarian adult males and females; (2) assess prevalence of iron deficiency using ferritin concentration and hemoglobin levels below cutoff values; and (3) compare iron status and prevalence of iron deficiency among vegetarians with nonvegetarians.

Methods

A literature search was conducted using the PubMed database. Several key words were used to identify relevant articles. They included vegetarian [Title]) AND iron [Title/Abstract], vegan [Title]) AND iron [Title/Abstract], vegetarian [Title] AND hemoglobin [Title/Abstract], vegan [Title]) AND hemoglobin [Title/Abstract], vegetarian [Title]) AND ferritin, and vegan [Title]) AND ferritin [Title/Abstract]. In addition, a search using PUBMED electronic cross-referencing, called "similar articles," was used. Articles were excluded if they did not report original findings (eg, reviews, position papers, commentaries); articles that reported data on children, reports on iron intake but not biochemical iron status; articles that reported iron status for male and female vegetarians combined as one group rather than separately; and articles that did not report incidence of iron deficiency.

Findings

A total of 725 articles were identified. Of these, 712 were excluded based on our exclusion criteria. Detailed findings are found in Tables 1 and 2. Studies were conducted in Australia,[10,16,17] Canada,[11,20] China,[18] England,[12] Germany,[4] Korea,[13] New Zealand,[8,19] South Africa,[14] and the United States.[15] All of the vegetarians were ≥18 years old. Iron status of exclusively female vegetarians was assessed in 6 of the 13 studies.[4,10,12-14,20] Two reports were based exclusively on male vegetarians,[16,17] while 5 of the 13 studies included both males and females.[8,11,14,15,19] Ten of the 13 studies reported iron status among both vegetarians, including vegans and nonvegetarians,[8,10,12-19] while the remaining 3 studies assessed iron status in vegetarians only.[4,11,20]

Iron status using ferritin was assessed in 10 studies (Table 1)[4,8,10-17] and Hb in 8 studies (Table 2).[4,11-13,15,18-20] All other assessment methods, such as hematocrit, serum iron, and total iron binding capacity, were excluded from the analyses because they were reported in a very limited number of studies (hematocrit in 2 studies,[10,13] total iron binding capacity in 1 study,[20] and serum iron in 1 study[20]). Ferritin values were reported as the mean with standard deviation (SD),[8,10,14-20] geometric mean with 95% confidence limits (CL),[12] median with 95th percentile,[4] median with 90th percentile,[11] and median with 1 to 3 interquartile.[13]

Iron Status Among Vegetarians

Ferritin. Serum ferritin values among vegetarians varied considerably. Vegetarian females had much lower mean/geometric mean/median ferritin concentrations, compared to vegetarian males. The lowest serum ferritin values were reported among Indian vegetarian females from England, who did not use supplements (geometric mean [CL] = 6.4 [3.8-11.8] µg/L)[12] and among Caucasian participants from the same country, who also did not use supplements (10.4 [5.8-18.4] µg/L).[12] The highest mean serum ferritin was reported among 15 vegan female participants from the United States (mean [SD] = 27 [16] µg/L[15]) and among 25 female vegans, age ≥50 years, from Germany (median = 28 µg/L).[4] In 4 of the 10 studies that assessed iron status among vegetarian females, the mean and/or geometric mean ferritin concentrations were <15 µg/L.[4,8,11,12]

A high variation in ferritin concentrations were found among participants across studies indicated by a high standard deviation of the mean and by ranges of ferritin concentration. For example, findings reported by Ball and Bartlett, among Australian female vegetarians, showed a mean ferritin of 25 µg/L, with standard deviation of 16.2 µg/L and range of 4 to 89 µg/L.[10]

Male vegetarians had even greater variability in ferritin concentrations. The lowest reported ferritin was found among participants from New Zealand (mean [SD] = 36.6 [36] µg/L; median = 22.5 µg/L).[8] The highest ferritin level was found among 10 vegans from the United States (mean [SD] = 72 [32] µg/L).[15] In none of the samples the mean or median ferritin concentration was <15 µg/L. The variability in ferritin concentration among participants is illustrated by findings reported by Alexander et al. Their results showed a range of 8 to 122 in ferritin concentration among male study participants.[8]

Hemoglobin. Hb values were reported as the mean with SD,[8,10,11,13-20] mean with standard error,[12] and median with 95th percentiles.[4] Consistent with the ferritin status, vegetarian female participants had

Table 1.

Iron Status Among Vegetarian and Nonvegetarian Adults Using Ferritin Concentrations.

Study	Country	Sample (Number, and Age)	Diet Inclusion Criteria and/or Length of Adherence	Iron Deficiency Criteria	Prevalence of Iron Deficiency in Vegetarians	Prevalence of Iron Deficiency in Nonvegetarians	Iron biomarker Status in Vegetarians
Women							
Ball and Bartlett[10]	Australia	Vegetarian N = 50 (lacto-ovo vegetarians n = 48, vegans n = 2) and nonvegetarians N = 24 females	Inclusion criteria: ≥6 months of dietary pattern	<12 µg/L	18%	13%	Mean (SD) ferritin (µg/L): vegetarians: 25 (16.2); nonvegetarian: 45.5 (42.5)
		Age range: 18-45 years	Mean (range) period of diet adherence: 5.2 (1-17) years				
Bindra and Gibson[11]	Canada	East Indian lacto-ovo vegetarians N = 50 females (younger n = 37, older n = 22)	Not reported	<12 µg/L	41.2%	N/A	Median (range) ferritin (µg/L): younger females: 14.8 (2.0-117.2); older females: 18.3 (8.6-140.0)
		Age range: younger 18-39 years and older 40-64 years					
Reddy and Sanders[12]	England	East Indian vegetarians N = 23, Caucasian vegetarians N = 18, Caucasian nonvegetarians N = 22 females	Not reported	<12 µg/L	79% of Indian vegetarian, 56% of Caucasian vegetarians	27%	Geometric mean (95% confidence limit) ferritin (µg/L): Indian vegetarians: 6.4 (3.8-11.8); Caucasian vegetarians: 10.4 (5.8-18.4); nonvegetarian: 18 (11.2-29.2)
		Age range: 25-40 years					

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Table 1. (continued)

Study	Country	Sample (Number, and Age)	Diet Inclusion Criteria and/or Length of Adherence	Iron Deficiency Criteria	Prevalence of Iron Deficiency in Vegetarians	Prevalence of Iron Deficiency in Nonvegetarians	Iron biomarker Status in Vegetarians
Waldmann et al[4]	Germany	Vegan N = 75 (younger and N = 50 and older N = 25) females (43 following strict and 32 following moderate vegan diet)	Inclusion criteria: ≥1 years of dietary pattern	<6 ng/mL; <12 ng/mL	12% of women 19 to <50 years old, 8% of women ≥50 years old with ferritin <6 ng/mL 40% of women 19 to <50 years old, 12% of women ≥50 years old	N/A	Median ferritin (μg/L) with 95th percentiles: younger vegans: 14 (5-84.6); older vegans: 28 (5-70.5)
		Age range: younger 19-50 years and older ≥50 years	Mean (SD) period of diet adherence: younger 5.23 (3.6) years, older 6.98 (4.95) years				
Lee and Krawinkel[13]	Korea	Vegetarians N = 54, nonvegetarians nuns (N = 31), and nonvegetarian college students (N = 31) females	Inclusion criteria: ≥3 years of dietary pattern	<150 μg/mL	27.8%	6.5% nonvegetarian nuns, 19.4% nonvegetarian college students	Median (1-3 interquartile) ferritin (μg/mL): vegetarians: 206 (138-328); nonvegetarian nuns: 373 (243-574); nonvegetarian college students: 239 (165-471)
		Age range 18-44 years					
Alexander et al[8]	New Zealand	Vegetarians N = 36 (vegetarian n = 31 and vegan n = 5) and nonvegetarians N = 36 females	Mean (range) period of diet adherence: vegetarians 5.9 (1-9) years, vegans 6.6 (1-12) years	<12 μg/L	47%	42%	Mean (SD) ferritin (μg/L): vegetarian: 13.6 (7.5); nonvegetarian: 33.6 (54.3)
		Mean age: 26 years					
Faber et al[14]	South Africa	Lacto-ovo vegetarians N = 19 and nonvegetarian N = 12 females	Inclusion criteria: ≥2 years of dietary pattern	<12 μg/L	34%	0%	Mean (SD) ferritin (μg/L): vegetarian: 16.1 (12.9); nonvegetarian: 47.3 (35.7)
		Age range: 18-40 years					

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Table 1. (continued)

Study	Country	Sample (Number, and Age)	Diet Inclusion Criteria and/or Length of Adherence	Iron Deficiency Criteria	Prevalence of Iron Deficiency in Vegetarians	Prevalence of Iron Deficiency in Nonvegetarians	Iron biomarker Status in Vegetarians
Haddad et al[15]	USA	Vegans N = 15 and nonvegetarian N = 10 females	Inclusion criteria: ≥1 year of dietary pattern	≤12 µg/L	27%	20%	Mean (SD) ferritin (µg/L): vegan: 27 (16); nonvegetarian: 22 (13)
		Age range: 20-60 years	Mean (range) period of diet adherence: 12.1 (1-37) years				
Men							
Wilson and Ball[16]	Australia	Vegan N = 10, lacto-ovo-vegetarian N = 39, and nonvegetarian N = 25 males	Inclusion criteria: ≥6 months of dietary pattern	<25 µg/L—deficient	30% vegans, 20.5% lacto-ovo vegetarians with ferritin <25 µg//L; 25% vegans, 3% lacto-ovo vegetarians with ferritin <12 µg//L	0% for ferritin <12 or 25 µg/L	Mean (SD) ferritin (µg/L): vegans: 65 (50); lacto-ovo vegetarians: 64 (47); nonvegetarian: 121 (73)
		Age range: 20-50 years	Mean (range) period of diet adherence: lacto-ovo vegetarians 11 (0.5-44) years, vegans 6 (1.5-14) years	<12 µg/L—very deficient			
Li et al[17]	Australia	Vegan N = 18, lacto-ovo vegetarians N = 46, moderate meat intake nonvegetarians N = 65, high meat intake nonvegetarians N = 18 males	Inclusion criteria: ≥6 months of dietary pattern	<12 µg/L	11% of vegans 21% of lacto-ovo vegetarians	7% of moderate meat nonvegetarian, 6% of high meat nonvegetarian	Mean (SD) ferritin (µg/L): vegans: 50 (29); lacto-ovo vegetarians: 48 (29); moderate meat nonvegetarians: 111 (86); high meat nonvegetarians: 153 (117)
		Age range: 20-55 years					

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Table 1. (continued)

Study	Country	Sample (Number, and Age)	Diet Inclusion Criteria and/or Length of Adherence	Iron Deficiency Criteria	Prevalence of Iron Deficiency in Vegetarians	Prevalence of Iron Deficiency in Nonvegetarians	Iron biomarker Status in Vegetarians
Bindra and Gibson[11]	Canada	Lacto-ovo vegetarians N = 59 (younger n = 37 and older n = 22) males	Not reported	<12 ng/mL	1.7% of males	N/A	Median (ng/mL) with 90th percentiles: younger males: 70 (13.1, 258.8); older males: 91.4 (14.8, 176.6)
		Age range: younger 18-39 years, older 40-64 years					
Alexander et al[8]	New Zealand	Vegetarian N = 14 and nonvegetarian N = 14 males	Mean (range) period of diet adherence: vegetarians 5.9 (1-9) years	<12 µg/L	29%	7%	Mean (SD) ferritin (µg/L): vegetarian: 36.6 (36); nonvegetarian: 105.4 (78.7)
		Mean age: 28 years					
Faber et al[14]	South Africa	Lacto-ovo vegetarians N = 14 and nonvegetarian N = 10 males	Inclusion criteria: ≥2 years of dietary pattern	<12 µg/L	19%	0%	Mean (SD) ferritin (µg/L): vegetarian: 60.7 (103.9); nonvegetarian: 146.8 (82.5)
		Age range: 18-40 years					
Haddad et al[15]	USA	Vegan N = 10 and nonvegetarians N = 10 males	Inclusion criteria: ≥1 year of dietary pattern	≤12 µg/L	0%	0%	Mean (SD) ferritin (µg/L): vegan: 72 (32); nonvegetarian: 141 (93)
		Age range: 20-60 years	Mean (range) period of diet adherence: 12.1 (1-37) years				

Table 2.

Iron Status Among Vegetarian and Nonvegetarian Adults Using Hemoglobin Concentrations.

Study	Country	Sample (Number and Age)	Diet Inclusion Criteria and/or Length of Adherence	Iron Deficiency Criteria	Prevalence of Iron deficiency in Vegetarians	Prevalence of Iron Deficiency in Nonvegetarians	Hb Concentration
Women							
Waldmann et al[4]	Germany	Vegan N = 75 females (younger n = 50 and older n = 25)	Inclusion criteria: ≥1 years of dietary pattern	Hb <120 g/L	6% of younger, 8% of older	N/A	Median Hb (g/L) with 95th percentiles: younger vegans: 132 (117-151); older vegans: 134 (117-151)
		Age range: younger 19-50 years, older ≥50 years	Mean (SD) period of diet adherence: younger 5.23 (3.6) years and older 6.98 (4.95) years				
Bindra and Gibson[11]	Canada	Lacto-ovo East Indian vegetarian N = 55 (younger n = 38 and older n = 12) females	Not reported	Hb <12 g/dL	17.7%	N/A	Mean (SD) Hb (g/dL): younger females: 13.1 (1.6); older females: 13.6 (1.4)
		Age range: younger 18-39 years, older 40-64 years					
Anderson et al[20]	Canada	Vegetarian N = 56 (vegans n = 9 and lacto-ovo vegetarians n = 47) females	Mean (SD) period of diet adherence: 19 (17) years	High risk: Hb < 10 g/dL	0% high risk	N/A	Mean (SD) Hb (g/dL): vegetarians: 13.1 (1)
		Age range: 37-68 years		Moderate risk: Hb range 10-12 g/dL	22% moderate risk		

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Table 2. (continued)

Study	Country	Sample (Number and Age)	Diet Inclusion Criteria and/or Length of Adherence	Iron Deficiency Criteria	Prevalence of Iron deficiency in Vegetarians	Prevalence of Iron Deficiency in Nonvegetarians	Hb Concentration
Reddy and Sanders[12]	England	East Indian vegetarians N = 23, Caucasian vegetarians N = 18, nonvegetarians N = 22 females	Not reported	Hb < 110 g/L	9% of Indian, 0% of Caucasian	0%	Mean (standard errors) Hb (g/L): Indian vegetarians: 126 (2.3); Caucasian vegetarians: 136 (1.7); nonvegetarian: 136 (2)
		Age range: 25-40 years					
Haddad et al[15]	USA	Vegans N = 25 and nonvegetarian N = 10 females	Mean (range) period of diet adherence: 12.1 (1-37) years	Hb ≤ 120 g/L	13%	10%	Mean (SD) Hb (g/L): vegan: 132 (10); nonvegetarian: 133 (10)
		Age range: 20-60 years					
Lee and Krawinkel[13]	Korea	Vegetarian N = 54 and nonvegetarians N = 62 (31 nuns and 31 college students)	Inclusion criteria: ≥3 years of dietary pattern	Hb < 120 g/L	22.2%	6.5% nuns, 12.9% college students	Mean (SD) Hb (g/L) with and median: vegetarians: 129 (90); nonvegetarian nuns: 131 (95); nonvegetarian college students: 129 (93)
		Age range: 18-44 years					
Woo et al[18]	China	Vegetarian N = 106 and nonvegetarian N = 228 females	Diet adherence >10 years	Hb < 12 g/dL	30.3%	10%	Mean (SD) Hb (g/dL): vegetarian: 12.3 (1.4); nonvegetarian: 13.4 (1.1)
		Mean age for vegetarians: 65 years; mean age for nonvegetarian = 70.7 years					

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Table 2. (continued)

Study	Country	Sample (Number and Age)	Diet Inclusion Criteria and/or Length of Adherence	Iron Deficiency Criteria	Prevalence of Iron deficiency in Vegetarians	Prevalence of Iron Deficiency in Nonvegetarians	Hb Concentration
Men							
Harman and Parnel[19]	New Zealand	Vegetarians N = 11 and nonvegetarian N = 12 males	Not reported	Hb < 115 g/L	0%	0%	Mean (SD) Hb (g/L): vegetarian = 150.6 (11.2); nonvegetarian = 142 (8.7)
		Age range: 20-65 years					
Bindra and Gibson[11]	Canada	Lacto-ovo vegetarian East Indian N = 59 (younger n = 37 and older n = 22) males	Not reported	Hb < 14 g/dL	15.3%	N/A	Mean (SD) Hb (g/dL): younger = 15.5 (1.4); older = 15.4 (1.8)
		Age range: young 18-39 years, old 40-64 years					
Haddad et al[15]	USA	Vegans N = 10 and nonvegetarian N = 10 males	Inclusion criteria: ≥1 year of dietary pattern	Hb ≤ 120 g/L	0%	0%	Mean (SD) Hb (g/L): vegan = 154 (7); nonvegetarian = 156 (7)
		Age range: 20-60 years	Mean (range) period of diet adherence: 12.1 (1-37) years				

lower Hb levels, compared to male participants. Specifically, the mean (SD) of Hb level among female vegetarians were 12.3 (1.4) g/dL,[18] 13.1 (1) g/dL,[20] 13.1 (1.6) g/dL,[11] 13.6 (1.4) g/dL,[11] 123 (14.9) g/L,[19] 129 (90) g/L,[13] and 132 (10) g/L.[15] The values for the mean (standard error [SE]) of Hb were 126 (2.3) g/L[12] and 136 (1.7) g/L[12]; and the median (5th to 95th percentile) was 132 (117-151) g/L among women 19 to <50 years of age[4] and 134 (117-151) g/L among women ≥50 years old.[4] For male vegetarians, the mean (SD) Hb were 15.4 (1.8) g/dL,[11] 15.5 (1.4) g/dL,[11] 150.6 (11.2) g/L,[19] and 154 (7) g/L.[15]

Prevalence of Ferritin Below Cutoff Criteria. The deficiency criteria for studies that used ferritin to assess iron status included <6 ng/mL,[4] <12 ng/mL,[4] <12 µg/L,[8,10-12,14-17] <25 µg/L,[16] and <150 µg/mL.[13] Low ferritin concentrations among vegetarians were found in all studies. The percentage of participants with low ferritin varied and were higher among female than male vegetarians. Specifically, among females, the prevalence of ferritin <6 ng/mL was 12% and 8%, for women 19 to <50 years old and those ≥50, respectively.[4] For ferritin level <12 µg/L or <12 ng/mL, it was 12%,[4] 18%,[10] 27%,[15] 34%,[14] 40%,[4] 41.2%,[11] 47%,[8] 56,[12] 79%.[12] In addition, 27.8% of female participants had ferritin level <150 µg/mL.[13]

Among males, one study reported none of the participants having ferritin level <12 µg/L.[15] The prevalence of low ferritin reported in other studies were 1.7%,[11] 3%,[16] 11%,[17] 19%,[14] 21%,[17] 25%,[16] 29%[8] for deficiency defined as <12 µg/L and 20.5%,[16] 30%[16] for ferritin <25 µg/L.

Prevalence of Low Hemoglobin Status. A variety of deficiency criteria based on Hb levels were set in different studies including 10 g/dL,[20] 12 g/dL,[11,18,20] 14 g/dL,[11] 110 g/L,[12] 115 g/L,[19] and 120 g/L.[4,13,17] The deficiency prevalence among vegetarian female participants was 0% for deficiency defined as <10 g/dL,[20] 0%[12] for Caucasian and 9%[12] for Indian vegetarians, deficiency defined as <110 g/L, 17%[19] for deficiency defined as <115 g/L, 6%,[4] 8%,[4] 13%,[15] 17.7%,[11] 22%,[20] 22.2%,[13] and 30.3%[18] for deficiency defined as <12 g/dL or <120 g/L. For males, the deficiency prevalence was 0%[19] for deficiency defined as <115 g/L, 0%[15] for deficiency defined as <120 g/L, and 15.3%[11] for deficiency defined as <14 g/dL.

Comparison of Iron Status Among Vegetarians and Nonvegetarians. Eight studies assessed iron status among both vegetarians and nonvegetarians.[8,10,12-17] Among the 6 studies in which ferritin among vegetarian and nonvegetarian participants was reported, 5 studies reported female vegetarians to have lower mean/geometric mean/median serum ferritin values than female omnivores (Table 1).[8,10,12-14] Haddad et al was the only study in which female vegans had a higher mean ferritin values than female nonvegetarians (mean [SD] = 27 [16] µg/L vs 22 [13] µg/L).[15] However, even in that study the prevalence of ferritin below deficiency cutoff (12 µg/L) among female participants was higher among vegetarians, compared to nonvegetarians (27% vs 20%).[15] Similarly, higher percentage of vegetarian female, compared to nonvegetarian, participants had ferritin below deficiency cutoff in all other studies (34% vs 0%,[14] 47% vs 42%,[8] 18% vs 13%,[10] 27.8%[13] vs 6.5% among Catholic nuns[13] and 19.4% among college students,[13] 79% Indian and 56% Caucasian vegetarian vs 27% of nonvegetarian).[12]

The mean/geometric mean/median serum ferritin values were lower in male vegetarians than male nonvegetarians in each of the 5 studies (Table 1).[8,14-17] This prevalence reached 11% among vegans and 21% among vegetarians compared to 6% and 7% among high and moderate meat consumers in a study by Li et al.[17] Likewise, the prevalence was 3% of vegetarians and 25% vegans versus 0% of nonvegetarians below ferritin <12 ng/mL.[16] A similar pattern was seen in other studies (29% vs 7%,[8] 9% vs 0%[14]).

Among the 8 studies that assessed iron status with Hb, 5 studies assessed iron status in both vegetarians and nonvegetarians.[12,13,15,18,19] Three studies[12,13,18] assessed only females, and 2 studies[15,19] assessed both females and males. A comparison of Hb values among vegetarian versus nonvegetarians showed relatively low deficiency rates among males, which were similar to the prevalence among nonvegetarians. For females, the deficiency prevalence was higher among vegetarian, compared to nonvegetarian (Table 2). The difference in deficiency prevalence was as wide as 30% versus 10% among vegetarians and nonvegetarians in China[18] and as small as 13% versus 10% among vegans and nonvegetarians in the United States.[15]

Discussion

In this review, we assessed iron status among vegetarian adults based on 13 published studies with participants from 10 countries. Some studies reported iron status exclusively among vegetarians, while other studies reported iron biomarkers among vegetarians and nonvegetarians. The findings were reported for female and male vegetarians separately. This is the most comprehensive literature review on iron status of vegetarian adults.

Authors used a variety of different cutoff criteria for what constituted iron depletion (eg, ferritin <12 µg/L, <25 µg/L) or a deficiency (eg, Hb <115 g/L, <120 g/L). Likewise, a variety of different definitions of what constituted a vegetarian diet was used. For example, Ball et al defined a vegetarian as "an individual who consumed red meat no more than once a month, consumed chicken or fish no more than once a week."[10] Quite similar definition was used by Alexander et al. They defined a vegetarian as "someone who never consumed red meat and consumed chicken or fish no more than once a week."[8] In contrast, other authors defined lacto-ovo-vegetarians and lacto-vegetarians as individuals who "ate no meat, meat products, fish or poultry but consumed both dairy products and eggs or dairy products respectively."[19] Similarly, vegans were defined as those who "excluded meat, fish poultry, dairy products and eggs."[15]

We summarized findings based on serum ferritin and Hb, since other biomarkers of iron status were reported in very limited number of articles. Serum ferritin levels provide the most specific and sensitive assessment of iron stores, while according to the World Health Organization (WHO), serum Hb <120 g/L in females and <130 g/L in males indicate anemia. Low ferritin concentrations indicate a depletion of iron stores, which is a result of inadequate iron intake, malabsorption, and/or high volume of blood loss. Low ferritin levels usually reflect a gradual iron depletion, and it reflects poor iron status over a long period of time. Eventually, the progressive depletion of iron stores will negatively affect the body's iron availability that may lead to abnormal values of other biomarkers, such as hemoglobin.[6]

The findings based on ferritin levels showed a high prevalence of iron depletion among vegetarian participants, especially among females. Ferritin concentrations for female vegetarians was reported in 8 studies for 10 different groups. In 6 of the 10 groups the prevalence was higher than one third of the sample. The lowest prevalence of ferritin <12 µg/L was 12% of participants in one sample[4] and the highest reached 79% in another group.[12] Ferritin values among vegetarian men were reported for 8 different groups in 6 studies. The prevalence of iron depletion ranged from 0%[15] to 29%.[8] The prevalence of low ferritin was higher among both vegetarian males and females, compared to their nonvegetarian counterparts (Table 1).

Iron status among vegans, separately of other vegetarians, was reported in 3 studies. Data published by Wilson and Ball[16] showed much higher prevalence of ferritin depletion among vegan, compared to both vegetarian and nonvegetarian male participants (30%, vs 20.5% and 0% for vegans, vegetarians and nonvegetarians, deficiency defined as <25 ng/mL and 25%, 3%, and 0% for deficiency defined as <12 ng/mL).[16] On the other hand, the prevalence of deficiency among American vegan and nonvegetarian females was somewhat comparable (27% vs 20%).[15] Similarly, none of the vegan or nonvegetarian American males was found to have low ferritin.[15] In addition, Waldmann et al reported iron status exclusively among German vegan females with no comparison group. A considerably high prevalence of ferritin <12 ng/mL was found among both young and older groups of women (40% for 19 to <50 years old and 12% for 50 years and older).[4] The Hb level <120 g/L among the same participants was 6% and 8% for the younger and older groups, respectively.[4] Detailed data are found in Tables 1 and 2.

The high percentages of low ferritin concentrations among vegetarian women was not exclusive to a specific geographical location or country. In fact, findings conducted in some affluent countries showed higher prevalence of low ferritin, compared to findings among vegetarians from a developing country. For example, 56% of Caucasian females from North London, England,[12] and 47% of those from New Zealand[8] had ferritin <12 µg/L. These figures are somewhat higher than 34% of those from South Africa[14] having low ferritin based on the same cutoff criteria. The only one sample with a higher prevalence of inadequate ferritin concentration was reported among Indian women who lived in North London, England (79%).[12] The prevalence of iron depletion among vegan women in the United States reached 27%,[15] which, although lower than the prevalence reported in research from other countries, should be of concern.

As expected, in comparison to the prevalence of ferritin-depleted individuals, a smaller percentage of the samples had Hb concentration below the respective cutoffs. For example, only 6% of female vegetarians 19 to <50 years of age had Hb <120 g/L, even though 40% of the sample had depleted iron stores (ferritin <12 µg/L).[4] Likewise, 13% of vegan participants included in a study by Haddad et al had Hb values <120 g/L, although more than twice as high percentage (27%) had depleted iron stores (ferritin <12 µg/L).[15] In this study, the percentage of anemic vegan individuals (Hb < 120 g/L) was comparable to that of nonvegetarians (13% vs 10%). However, in all other studies, Hb values below the deficiency cutoffs were considerably higher among vegetarian versus nonvegetarian participants (Table 2).[12,13,18,19]

Nutritional deficiencies develop in staging, beginning with inadequate intake, through depletion of stores, occurrence of hematological abnormalities, and last, onset of overt deficiency symptoms. Since nutrient stores get depleted before hematological abnormalities occur and since ferritin reflects the level of stored iron, it is normal to see lower prevalence of inadequate Hb status compared to inadequate ferritin status.

At least 4 studies reported data from participants who were members of the Seventh-Day Adventists Church (Adventists).[14,15,19,20] Ferritin concentrations and percentages of the sample below deficiency cutoff were reported in 2 studies and Hb data were reported in 3 studies. Twenty-seven percent of female vegan participants in the study with Adventists living in the United States had ferritin <12 µg/L and 13% had Hb levels <120 g/L.[15] Among Adventists from South Africa, 34% of females had ferritin <12 µg/L.[14] Findings from Adventists from New Zealand showed 17% of female Adventists having Hb <115 g/L.[19] Among Canadian female vegetarian Adventists, 22% of the sample had Hb below 12 g/dL.[20] All male vegetarian Adventists had Hb above deficiency cutoff in both the United States and New Zealand.[15,19] All 10 vegan males who participated in a study by Haddad et al had ferritin above 12 µg/L.[15] In contrast, 9% of Adventist male vegetarians from South Africa had ferritin below this cutoff value.[19]

It has been previously concluded that the incidence of iron deficiency anemia among vegetarians is similar to that of nonvegetarians.[21] This conclusion may hold true for vegetarian males but a considerably higher percentage of vegetarian females, compared to their

nonvegetarian counterparts, were found having Hb concentration indicative of anemia (Table 2). Our findings also question another widely accepted belief that serum ferritin of vegetarians are usually within the normal range.[21] The reviewed data showed that this conclusion is not correct for a substantial proportion of vegetarians, especially female vegetarians.

Iron status among vegetarians is likely a result of (1) ingesting mainly non-heme iron, which is a subject to several iron absorption inhibitors found in plant foods,[5,6] and (2) inadequate dietary iron intake. Non-heme iron from plant foods is less bioavailable compared to heme iron.[5] Phytate is the principle iron absorption inhibitor found in grains, especially whole grains, legumes, and nuts.[6] Polyphenols can be found in many cereals, vegetables, and some beverages (eg, tea, coffee).[5,6] Oxalate is found in some green leafy vegetables. Some of these food items actually contain fair amounts of iron but its absorption rate is low.

According to the Institute of Medicine, vegetarians have 1.8 times higher requirement for iron compared to nonvegetarians.[5] Thus, even though in some studies intake of iron was somewhat higher among vegetarians than nonvegetarians, (1) it was often below the current recommended dietary allowance for vegetarian females and (2) it still fell short to compensate for the high needs.[10,14,15,19] Coupled with iron loss during the menstrual periods these factors contribute to high prevalence of iron depletion (ferritin 12 µg/L) among female participants.

Vegetarians can benefit from education on ways to improve iron status. In addition to the government-mandated iron fortification of staple foods, practiced in many developed and developing countries, in some countries food manufactures are allowed to practice voluntary food fortification programs. In the United States, for example, a variety of products, such as cereal, are fortified with iron. Some iron-fortified cereal, such as General Mills Total, contain 30 to as much as 60 mg of iron in a 3.5 oz serving.[22] Cereal that contain bran are also a significant source containing more than 15 mg of iron in 3.5 oz of the product.[22] Some beans, such as soybeans, lentils, and garbanzo beans contain up to 5 mg of iron per 3.5 oz of cooked product.[22] In both industrialized and developing countries utilizing iron casts for cooking can add a significant iron intake. The use of iron casts have also been shown to be an effective treatment for iron deficiency anemia.[23]

Absorption of iron can be enhanced when a significant source of vitamin C and/or other organic acids is added to a meal. Thus, cereal and other grain products should be ingested with fresh fruits, such as strawberries, blueberries, currants, and or citrus fruits. Similar if not better effect may be achieved if fresh fruit juices are regularly served with breakfast cereal. On the other hand, beverages such as tea and/or coffee should be limited. Although a routine use of iron supplements is not recommended due to their potential detrimental effect, it may be advisable to periodically use iron supplements on a short-term basis.

Iron absorption can be further improved by cooking, fermentation, and germination of foods. These food preparation techniques reduce the phytic acid content. Since grains are a major source of iron in many societies, appropriate use of these food preparation methods may have a significant impact on iron status. In addition, since tea and coffee are a major source of tannins, which inhibit iron absorption, the WHO suggested to limit drinking these beverages 1 to 2 hours after a meal instead of with a meal.[9] Last, since calcium also inhibits iron absorption, the WHO recommended to ingest calcium-rich foods, at meals with lowest iron content.[9]

Conclusion

The findings of this review showed that vegetarians have a high prevalence of depleted iron stores, indicative by ferritin values below specified cutoffs. In most cases, the used cutoff values were below the WHO's criteria for iron depletion (ferritin <15 µg/L).[24] Vegetarians also have a higher risk for developing low iron stores, iron depletion, and associated iron deficiency anemia, compared to nonvegetarians. These findings are consistent with a conclusion made by the authors of the Institute of Medicine's report on iron, who stated, "Serum ferritin concentrations have been observed to be markedly lower in vegetarian men, women, and children than in those consuming a nonvegetarian diet."[5] It has also been concluded in the past that "iron deficiency anemia appears to be no more prevalent among vegetarian women than among nonvegetarian women."[25] Based on this review, we conclude that the above statement may be accurate for vegetarian males. However, in all studies except for one with female Adventist vegans,[15] vegetarian women had a considerable higher prevalence of anemia (Hb <120 g/L).[12,13,17,19] Thus, iron is rightly considered a nutrient of concern for vegetarians. This is especially true for premenopausal vegetarian women.

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