Whole Grain Food Definition Effects on Determining Associations of Whole Grain Intake and Body Weight Changes: A Systematic Review

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ABSTRACT

Within epidemiological and intervention studies, whole grain consumption has generally shown positive associations with reductions in markers of overweight and obesity. However, studies use varied methods of determining whole grain intake, including different definitions of a whole grain food, which may explain varied results. This systematic review aimed to identify how different methods of reporting and calculating whole grain intake, including whole grain food definitions, affect reported associations between whole grain intake and body weight measures in adults. Systematic searching of PubMed, Scopus, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Cochrane Central Register for Controlled Trials (CENTRAL), and MEDLINE (all years to 11 June, 2020) identified eligible studies. Cohort and cross-sectional studies assessing whole grain intake and body weight measures in adults were included. Studies that did not specify methods used to calculate whole grain intake were excluded. Twenty-one cross-sectional studies (from 24 articles) and 9 prospective cohort studies (from 7 articles) were included in the review. Many cross-sectional studies showed whole grain intake was, to some degree, significantly associated with body weight measures, whereas associations varied greatly among cohort studies. Studies calculating whole grain intake using total grams of intake, USDA databases, or ≥25% whole grain in combination with listing specific foods, showed consistent beneficial effects of increasing whole grain intake on body weight. Studies with general lists of foods included as "whole grain foods" or lower cut-offs for whole grain content were inconsistent. The majority of studies reported whole grain intake as servings/day or grams whole grain/day. This review suggests that an association between whole grain and body weight measures remains likely, although precise associations are difficult to determine due to heterogeneity in methodologies and an inability to formally compare studies. Moving forward, application of a standardized methodology to calculate whole grain intake is essential. *Adv Nutr* 2021;12:693–707.

Keywords: whole grain, cereals, intake, whole grain food definition, Healthgrain Forum, body weight measures, adults, cross-sectional, prospective cohort

Introduction

The prevalence of overweight and obesity worldwide is currently at an astounding high, with an estimated 1.9 billion adults (39%) above a healthy weight in 2016 (1). This is concerning as overweight and obesity are associated with cardiovascular risk factors and cardiovascular disease (CVD) (2–5). The consumption of particular dietary patterns, namely the "prudent/healthy" dietary pattern (typically high in fruit, vegetables, whole grains, fish, and poultry) and individual dietary components within this pattern, are associated with reductions in the risk of obesity and CVD (6, 7).

Epidemiological and intervention studies have identified positive associations of whole grain consumption with reductions in the markers of overweight and obesity, including body weight, BMI, body fat percentage, waist circumference (WC), and weight gain (8–11). Systematic reviews and meta-analyses support positive associations of whole grain intake and body weight measures in observational trials (12), randomized control trials (13), and more recently in a combination of both (14). However, a recent meta-analysis on controlled trials reports conflicting evidence in which whole grain intake did not affect any measures of obesity (15). It is thought these results differ to previous reviews due to the exclusion of quasi-experimental studies and studies

The authors reported no funding received for this study.

Author disclosures: The authors report no conflicts of interest.

Supplemental Tables 1–6 and Supplemental Material 1 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/advances/.

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Abbreviations used: CVD, cardiovascular disease; MetS, metabolic syndrome; NOS, Newcastle–Ottawa Scale; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue; WC, waist circumference; WG, whole grain; WHR, waist to hip ratio; WMD, weighted mean difference.

 Adv Nutr 2021;12:693–707; doi: https://doi.org/10.1093/advances/nmaa122.

administering individual whole grain foods. The authors reason that individuals do not consume individual foods in their usual diet but rather follow dietary patterns.

It is also possible that the calculation of whole grain intake may be flawed, or at least inconsistent (16). In the absence of formal whole grain definitions by some agencies (including the FDA and USDA), variation in the definition of what constitutes a whole grain food is further problematic. For example, studies may specify a minimum proportion of whole grain in foods to be met (17, 18), some include bran despite not meeting recognized whole grain definitions (19, 20), whereas others include any amount of whole grain from any food (21, 22). Across the breadth of literature, there is no consideration for variations in whole grain food definitions between studies, despite acknowledgment that this omission may contribute to study weaknesses (12, 14). Recently, a secondary analysis of national dietary intake data in Australia identified a decrease in the calculation of whole grain intake of ≤8 g/(10 MJ.day) in adults when only contributions from foods meeting a precise definition were used in estimations, compared with measurements of absolute grams of intake (23). Furthermore, whole grain intake is often reported as serves per day, where whole grain content of a single serve varies depending on the food item. For example, a serve of 30% whole grain breakfast cereal contains less whole grain than a serve of porridge, as the porridge is made from 100% whole grain. Despite differing whole grain contents, the serves of each product are often viewed and treated equally. The impacts of utilizing these varied definitions on determining outcome effects is not clear. Therefore, the aim of this review was to investigate whole grain intake and body weight changes with a focus on methods of calculating whole grain intake. Specifically, this review attempts to identify how whole grain food definitions affect reported associations between whole grain intake and body weight measures in adults.

Methods

This review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statements (24) (**Supplemental Table 1**) and was guided by the Conducting Systematic Reviews and Meta-Analyses of Observational Studies of Etiology (COSMOS-E) guidelines (25). This review was registered in the International Prospective Register of Systematic Reviews (PROSPERO) in July 2019 under registration number CRD42019135244.

Search strategy

Electronic databases including PubMed, Scopus, Cumulative Index to Nursing and Allied Health Literature (CINAHL, via EBSCO), Cochrane Central Register for Controlled Trials (CENTRAL), and MEDLINE (via EBSCO) were systematically searched (all years to 19 June 2019, updated 11 June 2020). Search terms involved free text terms, subject headings (including Medical Subject Headings [MeSH]) and associated synonyms with no restrictions based on publication date or language. The following search terms were applied: wholegrain, whole grain, whole cereal, wholemeal, whole meal, whole wheat, body weight, weight gain, weight loss, body mass index, BMI, waist circumference (WC), obese, obesity, overweight, waist to hip ratio (WHR), waist to height ratio, body fat, abdominal fat, and adipose tissue. **Supplemental Table 2** illustrates an example of the search strategy utilized in PubMed. Reference lists of eligible studies were searched.

Selection criteria

Inclusion criteria were: *1*) study population consisted of adults aged ≥18 y, of any sex, with or without pre-existing conditions (e.g. diabetes, CVD, or cancer) and within normal, overweight, or obese BMI ranges. *2*) Cohort or cross-sectional studies comparing whole grain intake to no or low whole grain intake. Studies did not have to specify intake was derived from "whole grain foods" for inclusion but were required to define methods for calculation of whole grain intake. Studies investigating only dietary patterns that considered whole grain intake were excluded if the whole grain component could not be isolated from other components of the dietary pattern (for example the Mediterranean diet). *3*) Studies that assessed whole grain intake or dietary patterns against body weight measures (body weight, BMI, WC, hip circumference, WHR, waist to height ratio, body fat percentage, and adipose tissue measures). Studies investigating metabolic syndrome (MetS) were initially included as WC is a known component (26), but were excluded if WC could not be isolated from other MetS components. The following exclusion criteria were applied: *1*) study population aged <18 y ("children," "adolescents," or "pubescent"). *2*) Studies did not specify methods used to calculate whole grain intake or define whole grain/whole grain foods. *3*) Studies used refined grain intake as the sole comparator. *4*) Where anthropometric outcomes were reported according to whole grain intake only at baseline of cohort studies as a characteristic of the population. 5) Controlled trials and duplicates of the same study. Controlled trials were not included in this review as participants in these studies typically consume whole grain over short periods of time.

Study selection

The title and abstract of articles were screened independently by 2 review authors (1 author screened all articles [KRK], with 2 authors each completing half the duplicated screen [EPN and EJB]). Screening excluded studies investigating whole grain intake against other conditions, e.g. diabetes, CVD, or cancers, unless a measure of body weight was explicit in the title or abstract. Following this, full texts of potentially eligible articles were assessed independently by all authors (using the same method as title/abstract screening). For articles in a language other than English, Google Translate (27) was utilized prior to screening of the full text. Discrepancies at each screening stage were resolved through discussion with all review authors.

Where study duplicates were found, all relevant articles were thoroughly checked to avoid inadvertent exclusion. In the case that an outcome from 1 study was reported across multiple articles, the most recently reported article was included. If multiple articles were based on the 1 study but reported differing outcomes, all articles were included. Due to large heterogeneity between study methodologies, a meta-analysis was not feasible.

Data extraction

Data from eligible studies were extracted by a single review author (KRK) and summarized into separate tables based on study design (cross-sectional and cohort). The following data was extracted into summary tables: article citation, country, name of study/cohort, number of participants, sex, age range, number of data groups (if relevant), method of dietary intake collection, whole grain food definition utilized, whole grain reporting method, quantifiable whole grain intake for exposure/comparator groups, outcome of interest, results relating to outcome (including *P* value), and the covariates used within analysis. Information pertaining to potential confounders were extracted, including dietary fiber intake (including different types); total energy intake and other sources of energy such as alcohol; and dietary habits, considered through intake of specific food groups. Data based on the most adjusted model was utilized. The principal outcome measures consisted of β-coefficients for continuous data, and a combination of ORs, RRs, and means for categorical data. In the case of missing data or need for clarification, authors were contacted, and articles were excluded where no response was received.

Quality assessment

Two separate adaptations of the Newcastle–Ottawa Scale (NOS) (adapted for cohort and cross-sectional studies) were utilized by 2 authors for the quality assessment of eligible studies. The NOS tool assesses quality based on the selection of study groups, comparability of study groups, and ascertainment of the outcome of interest. For cohort studies, adaptations were made based on the original NOS (28), whereas for cross-sectional studies amendments were made to the adaptation by Herzog et al. (29). Key adjustments to the NOS tools were made to ensure applicability to the studies included in this review, particularly adjustment for energy intake (see **Supplemental Material 1** for further details). Discrepancies between authors for quality were resolved through discussion. A maximum of 8 and 9 stars can be achieved for cohort and cross-sectional studies, respectively. Studies obtaining 8/9 stars were considered of highest quality, whereas studies obtaining no stars were considered of lowest quality.

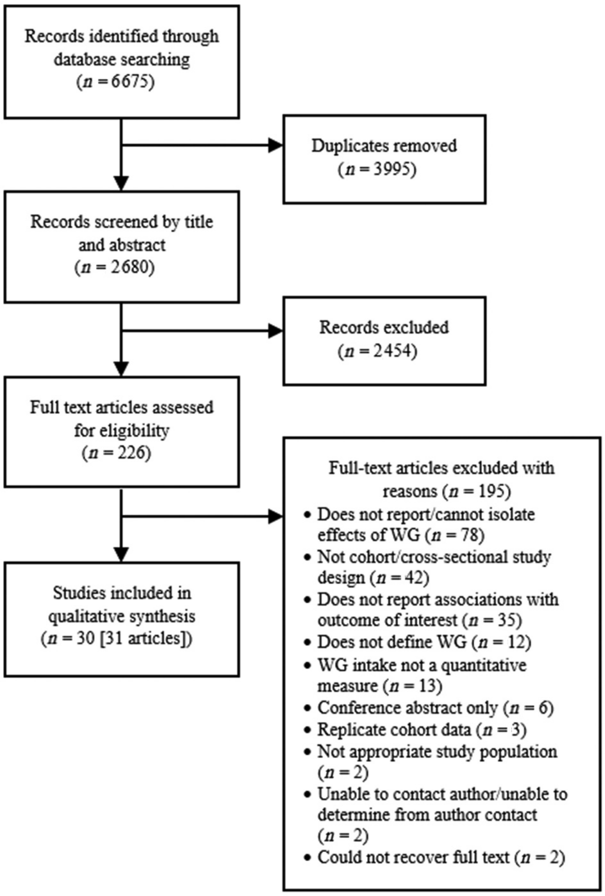

FIGURE 1 PRISMA flow diagram for systematic review study selection. WG, whole grain.

Results

Study characteristics

Initially, 6675 articles were returned, with 2680 articles screened by title and abstract after the removal of duplicates. After full-text assessment of 226 articles, 30 studies, across 31 articles were eligible. Primary reasons for exclusion at full-text assessment included not reporting or isolating the effects of whole grain, study design not cohort or cross-sectional, not reporting associations with the outcome of interest, whole grain intake not reported as a quantitative measure, and not defining whole grain foods where they were used in the determination of intake (**Figure 1**).

Each eligible article reported data based on a single study cohort with the exception of Mozaffarian et al. (30), where 3 separate study cohorts were reported. Furthermore, a small number of articles reported different, but relevant, outcomes based on the same study cohort (31–36). Of the 30 studies, 21 had a cross-sectional study design (from 24 articles; **Table 1**) and 9 were of prospective cohort design (from 7 articles; **Table 2**). Studies were conducted in the USA (18, 30, 33, 34, 37–46), Scandinavian countries (47–51), Iran (31, 32, 52), the UK (35, 36, 53), Spain (54, 55), Australia (56), France (57), Greece (58), and the Netherlands (59). Most

TABLE 1 Characteristics of cross-sectional studies examining the relation between whole grain intake and body weight measures in adults[1]

Article	Country	Study cohort	n[2]	Age, y	Number of intake groups	Method of dietary intake collection	Whole grain food definition[3]	Whole grain reporting method	Low/no whole grain intake	High whole grain intake	Outcome	Results	P value	Covariates used in analysis[4]
Albertson et al. (37)	USA	NHANES (2001–2012)	29,683 (M/F)	≥19	3	1 × 24-h recall	USDA MPED/FPED	oz eq/d	0 oz eq/d	>1 oz eq/d	BMI (kg/m^2)	T1 = 28.3 (SE: 0.1) vs. T3 = 27.6 (SE: 0.1)	<0.0001	A, S, R, E, AI, PA
											WC (cm)	T1 = 96.6 (SE: 0.3) vs. T3 = 94.7 (SE: 0.3)	<0.0001	
											Overweight/obese (BMI≥25)	Likelihood % T1 = 66.2 vs. T3 = 62.3	<0.0001	
											Obese (BMI≥30)	Likelihood % T1 = 33.0 vs. T3 = 31.0	0.0035	
Good et al. (38)	USA	NHANES (1999–2000)	1943 (F)	≥19	3	24-h recall	USDA MPED/FPED	Servings/d	0 servings/d	≥1 servings/d	BMI (kg/m^2)	Coefficient T1 = 0.046 (SE: 0.017) vs. T3 = 0	0.02	A, E, AI, DF, R, PA, Ed, Sm
											Overweight/obese (BMI≥25)	OR T1 = 1.47 (95% CI: 1.12, 1.94) vs. T3 = 1.00 (ref)	0.01	
			1930 (F)								WC (cm)	Coefficient T1 = 0.030 (SE: 0.010) vs. T3 = 0	0.03	
Kyrø et al. (47)	Norway, Sweden, Denmark	HELGA cohort (Norwegian Women and Cancer study 1999–2000 + Northern Sweden Health and Disease Study 1995–1998 + Diet, Cancer and Health Study 1995–1998)	3294 (M)/ 5408 (F)	30–65	—	24-h recall	List specific foods: breakfast cereals, WG bread, WG crisp bread, WG rice, WG flour and starch, other grains (100% cereal), salty biscuits, aperitif biscuits and crackers, cream dessert and puddings (milk based), cakes, sweet pies, pastries and puddings (nonmilk based), dry cakes and biscuits	g WG/d	—	—	Change in WG intake per 1kg/m^2 BMI increase	Male: % = −2 (95% CI: −3, −1)	0.002	A, C, MA
												Female: % = −1 (95% CI: −1, 0)	0.07	
Bakken et al. (48)	Norway	Norwegian Women and Cancer (NOWAC) study (2002–2005)	90,592 (F)	≥18	—	FFQ (semiquantitative)	List specific foods: WG bread (where proportion of WG estimated to be 40% of product weight)	Slices/d	<4 slices/d	≥4 slices/d	High WG bread consumption (≥4 slices WG bread/d)	OR BMI<20.0 = 1.20 (95% CI: 1.11,1.30) vs. BMI 20.0–24.9 = 1.00 (ref) vs. BMI 25.0–29.9 = 0.89 (95% CI: 0.85,0.92) vs. BMI≥30.0 = 0.96 (95% CI: 0.91,1.02)	<0.001	A, Re, Ed, HH, PA, Sm, HS
Andersen et al. (51)	Denmark	Diet, Cancer and Health - Next Generations (DCH-NG) (2015–2019)	38,553 (M/F)	≥18	—	FFQ (376-item, semiquantitative)	List specific foods: rolled oats, rye flakes, spelt flakes, oatmeal, WG porridges, rye bread, WG pasta, WG/brown rice and cereal breakfast products, wholemeal bread and crisp bread with the WG logo	g WG/d	<25 g/ (10 MJ.d)	≥75 g/ (10 MJ.d)	High whole grain intake (75 g/[10 MJ.d])	OR BMI<18.5 = 0.91 (95% CI: 0.78,1.07) vs. BMI 18.5–24.9 = 1.00 (ref) vs. BMI 25–29.9 = 0.79 (95% CI: 0.76,0.83) vs. BMI ≥30 = 0.61 (95% CI: 0.57,0.65)	Not given	Nil
											Low whole grain intake (<25 g/[10 MJ.d])	OR BMI<18.5 = 1.28 (95% CI: 0.93,1.77) vs. BMI 18.5–24.9 = 1.00 (ref) vs. BMI 25–29.9 = 1.25 (95% CI: 1.13,1.38) vs. BMI ≥30 = 1.76 (95% CI: 1.57,1.99)		
Egeberg et al. (49)	Denmark	Diet, Cancer and Health study (1993–1997)	26,175 (M)/ 28,545 (F)	50–64	—	FFQ (192-item, semiquantitative)	List specific foods: rye bread, WG bread, crisp bread, oatmeal, and corn	g WG food/d	—	—	Change in WG intake per 1 cm WC increase	Male: β = −0.2 (95% CI: −0.4, −0.1)	Not given	A, Ce, Fi, RM, Po, PM, D, F, V, RG, AI, Sm, PA, Fa, Supp, HRT, BMI, WC, Ed
												Female: β = 0.1 (95% CI: 0.0, 0.3)		

(*Continued*)

TABLE 1 (*Continued*)

Article	Country	Study cohort	n[2]	Age, y	Number of intake groups	Method of dietary intake collection	Whole grain food definition[3]	Whole grain reporting method	Low/no whole grain intake	High whole grain intake	Outcome	Results	P value	Covariates used in analysis[4]
Barrett et al. (56)	Australia	National Nutrition and Physical Activity Survey (NNPAS) (2011–2012)	6206 (M/F)	≥18	4	24-h recall	Nil definition (absolute intake)	g WG/d	0 g/ (10 MJ.d)	95.1 g/(10 MJ.d)	BMI (kg/m^2)	Nonconsumers = 26.7 (SE: 0.2) vs. T3 = 26.3 (SE: 0.2)	0.11	A, S, E, Al, Sm, PA, F, V, CF
			6214 (M/F)								WC (cm)	Nonconsumers = 92.0 (SE: 0.6) vs. T3 = 90.0 (SE: 0.4)	0.03	
Bellisle et al. (57)	France	Comportements et Consommations Allimentaires en France (CCAF) survey	1389 (M/F)	≥18	4	7-d food diary	Nil definition (absolute intake)	g WG/d	0 g/d	≥15.6g/d	Overweight/obese (BMI≥25)	OR Q1 = 1.7 (95% CI: 1.1, 2.5) vs. OR Q4 = 1.0 (ref)	0.0439	A, S, Ed, Re, PA, Sm, E
Esmaillzadeh et al. (31)	Iran	Tehran Lipid and Glucose Study (TLGS)	375 (M)/ 470 (F)	18–74	4	FFQ	Jacobs' definition and list specific foods: dark breads (sangak, barbari, taftoon), barley bread, popcorn, cornflakes, wheat germ, and bulgar	g WG food/d	<10 g/d	>143g/d	Obesity (BMI≥30)	OR Q1 = 1.0 (ref) vs. OR Q4 = 0.71 (95% CI: 0.54,1.09)	>0.05	A, E, E(fat), BPM, Es, Sm, PA, M, Fi, F, V
											Abdominal adiposity (M WC>102 cm; F WC>88 cm)	OR Q1 = 1.0 (ref) vs. OR Q4 = 0.90 (95% CI: 0.79,0.96)	0.04	
Esmaillzadeh et al. (32)			357 (M)/ 470 (F)	18–74	—	FFQ (168-item, semiquantitative)		g WG food/d	—	—	WC (cm)	$\beta = -0.413$ (SE: 0.117)	<0.05	A, BMI, HC, E, E(fat), F, V, M, Fi
Georgoulis et al. (58)	Greece	Untitled: NAFLD patients from outpatient liver clinics	73 (M/F)	18–65	—	FFQ (semiquantitative)	List specific foods: WG bread, WG crisp bread and rusks, WG pasta, brown rice, and WG breakfast cereals	g WG food/d	—	—	Obesity (BMI ≥30)	OR = 0.97 (95% CI: 0.95,0.99)	0.02	A, S, E, Se
											Increased WC (M>102 cm; F>88 cm)	OR = 0.98 (95% CI: 0.96, 0.99)	0.04	
											Abdominal fat level	$\beta = -0.24$	0.02	
Kimokoti et al. (39)	USA	Reasons for Geographic and Racial Differences in Stroke (REGARDS) study	4855 (M)	45–98	—	FFQ (107-item, semiquantitative)	List specific foods: WG bread	g WG food/d	—	—	WG bread consumption	Black men: normal weight metabolically healthy = 21.2 (SE: 5.0) vs. normal weight metabolically unhealthy = 29.2 (SE: 7.7) vs. overweight metabolically healthy = 20.4 (SE: 4.7) vs. overweight metabolically unhealthy = 22.4 (SE: 5.3) vs. obese metabolically healthy = 21.8 (SE: 5.0) vs. obese metabolically unhealthy = 21.8 (SE: 5.1) White men: normal weight metabolically healthy = 16.9 (SE: 1.7) vs. normal weight metabolically unhealthy = 12.8 (SE: 3.1) vs. overweight metabolically healthy = 13.7 (SE: 1.5) vs. overweight metabolically unhealthy = 12.6 (SE: 1.8) vs. obese metabolically healthy = 16.2 (SE: 2.0) vs. obese metabolically unhealthy = 15.1 (SE: 2.0)	Not given	A, MS, Re, Ed, In, Al, MV, Sm, PA, TV, CRP, F, V, RG, B, Fi, Po, RM, PM, Fr, D, FJ, SSB, BMI, E
Shah et al. (33)	USA	Multi-Ethnic Study of Atherosclerosis (MESA)	5079 (M/F)	≥18	—	FFQ (127-item, semiquantitative)	List specific foods: oatmeal, dark bread, bran muffin, brown rice, selected cereals	Servings/d	—	—	PAT (cm^3)	$\beta = -0.118$	<0.01	A, R, S, Wt, Sm, SBP, BG, TC, PA, E

(*Continued*)

TABLE 1 (*Continued*)

Article	Country	Study cohort	n[2]	Age, y	Number of intake groups	Method of dietary intake collection	Whole grain food definition[3]	Whole grain reporting method	Low/no whole grain intake	High whole grain intake	Outcome	Results	*P* value	Covariates used in analysis[4]
											SAT (cm^3)	$\beta = -0.057$	0.06	
											VAT (cm^3)	$\beta = -0.114$	<0.01	
Lutsey et al. (34)	USA		5496 (M/F)	45–85	5	FFQ (127-item)	Jacobs' definition and list specific foods: WG breakfast cereal, oatmeal, dark bread, bran muffins, brown or wild rice	Servings/d	1.39 servings/d	0.02 servings/d	BMI (kg/m^2)	Q1 = 28.2 (SE: 0.151) vs. Q5 = 27.6 (SE: 0.151)	<0.0001	A, S, R, Ed, Ce, E, Sm, Al, PA, F, V, RG, D, Fi, Po/M
Barrett et al. (36)	UK	National Diet and Nutrition Survey (NDNS) (2008–2014)	2658 (M/F)	≥18	4	4-d food diary	Nil definition (absolute intake)	g WG/d	3 g/ (10 MJ.d)	68.8 g/(10 MJ.d)	BMI (kg/m^2)	Q1 = 26.00 (SE: 0.27) vs. Q4 = 25.40 (SE: 0.26)	0.09	A, S, E, CF
			2107 (M/F)								Waist to hip ratio	Q1 = 0.872 (SE: 0.004) vs. Q4 = 0.857 (SE: 0.004)	0.04	
Mann et al. (35)	UK	National Diet and Nutrition Survey (NDNS) (2008–2011)	1521 (M/F)	≥18	4	4-d food diary	Nil definition (absolute intake)	g WG/d	0 g/d	61 g/d	Weight (kg)	Q1 = 78.1 vs. Q4 = 77.9	0.91	A, S
Thane et al. (53)	UK	National Diet and Nutrition Survey (NDNS) (2000–2001)	758 (M)/ 934 (F)	19–64	5	7-d weighed food diary	≥10% WG on dry weight basis	g WG/d	0 g/d	≥48 g/d	Weight (kg)	Male: Q1 = 83 (95% CI: 81, 85) vs. Q5 = 86 (95% CI: 83, 88)	0.98	A, O, Sm, Re, Sea, Mis
												Female: Q1 = 69 (95% CI: 67, 71) vs. Q5 = 72 (95% CI: 69, 75)	0.39	
											Normal weight (BMI<25)	Male: % Q1 = 36 vs. Q5 = 36	0.70	
												Female: % Q1 = 46 vs. Q5 = 42	0.74	
											Overweight (BMI≥25)	Male: % Q1 = 35 vs. Q5 = 51	0.11	
												Female: % Q1 = 32 vs. Q5 = 30	0.91	
											Obese (BMI≥30)	Male: % Q1 = 29 vs. Q5 = 23	0.16	
												Female: % Q1 = 22 vs. Q5 = 24	0.79	
											Normal WC (M<94cm; F<80 cm)	Male: % Q1 = 48 vs. Q5 = 43	0.51	
												Female: % Q1 = 42 vs. Q5 = 48	0.22	
											Increased risk WC (M = 94 to <102 cm; F = 80 to <88 cm)	Male: % Q1 = 20 vs. Q5 = 27	0.87	
												Female: % Q1 = 28 vs. Q5 = 29	0.91	
											Greatly increased risk WC (M≥102 cm; F≥88 cm)	Male: % Q1 = 32 vs. Q5 = 30	0.38	
												Female: % Q1 = 30 vs. Q5 = 23	0.14	
McKeown et al. (40)	USA	Framingham Offspring Study (1991–1995)	1338 (M)/ 1603 (F)	≥18	5	FFQ (126-item, semiquantitative)	Jacobs' definition and list specific foods: WG breakfast cereal, dark bread, popcorn, cooked oatmeal, wheat germ, brown rice, and other grains (bulgar, kasha, couscous)	Servings/wk	0.90 servings/wk	20.5 servings/wk	BMI (kg/m^2)	Q1 = 26.9 vs. Q5 = 26.4	0.06	A, S, E, HTN, Sm, Al, MV, Es, PA, PUFA, M, Fi, F, V
											Waist to hip ratio	Q1 = 0.92 vs. Q5 = 0.91	0.005	
McKeown et al. (41)	USA	Untitled: vitamin K supplementation intervention study	177 (M)/ 257 (F)	60–80	4	FFQ (126-item, semiquantitative)	Jacobs' definition and list specific foods: hot/cold WG breakfast cereal, dark bread, brown rice, other grains (bulgar, kasha, couscous)	Servings/d	0.21 servings/d	2.86 servings/d	BMI (kg/m^2)	Q1 = 26.8 (95% CI: 25.7,28.1) vs. Q4 = 25.8 (95% CI: 24.6,27.1)	0.08	A, S, E, E(fat), PA, Sm, Al, MV
											Body fat %	Q1 = 34.5 (95% CI: 32.7,36.3) vs. Q4 = 32.1 (95% CI: 30.1,34.1)	0.02	

(*Continued*)

TABLE 1 (*Continued*)

Article	Country	Study cohort	n[2]	Age, y	Number of intake groups	Method of dietary intake collection	Whole grain food definition[3]	Whole grain reporting method	Low/no whole grain intake	High whole grain intake	Outcome	Results	*P* value	Covariates used in analysis[4]
											Trunk fat mass (%)	Q1 = 43.0 (95% CI: 40.4,45.5) vs. Q4 = 39.4 (95% CI: 36.7,42.1)	0.02	
								g WG/d	Not given	Not given	BMI (kg/m^2)	Q1 = 26.9 (95% CI: 25.8,28.1) vs. Q4 = 25.4 (95% CI: 24.2,26.6)	0.006	
											Body fat (%)	Q1 = 34.4 (95% CI: 32.6,36.2) vs. Q4 = 31.7 (95% CI: 29.7,33.6)	0.007	
											Trunk fat mass (%)	Q1 = 42.4 (95% CI: 39.9,44.8) vs. Q4 = 38.4 (95% CI: 35.7,41.1)	0.002	
McKeown et al. (42)	USA	Framingham Heart Study	1434 (M)/ 1400 (F)	≥18	5	FFQ (126-item, semiquantitative)	Jacobs' definition and list specific foods: cold WG breakfast cereal, oatmeal, dark bread, brown rice, other grains (bulgar, kasha, couscous), popcorn, bran, and wheat germ	Servings/d	0.14 servings/d	2.93 servings/d	WC (cm)	Q1 = 97.0 (95% CI: 95.8,98.2) vs. Q5 = 93.7 (95% CI: 92.4,94.9)	<0.001	A, S, Sm, E, Al
											SAT (cm^3)	Q1 = 2895 (95% CI: 2772,3017) vs. Q5 = 2552 (95% CI: 2422,2682)	<0.001	
											VAT (cm^3)	Q1 = 1883 (95% CI: 1807,1959) vs. Q5 = 1563 (95% CI: 1482,1643)	<0.001	
Newby et al. (43)	USA	Baltimore Longitudinal Study of Ageing (BLSA)	1502 (M/F)	27–88	5	7-d weighed food diary	USDA MPED/FPED	g WG/d	0.65 g/d	46 g/d	Weight (kg)	Q1 = 75.0 (SE: 0.7) vs. Q5 = 72.6 (SE: 0.7)	0.004	A, S, E, De, R, Ed, Supp, Sm, E(fat), Al, RG
											BMI (kg/m^2)	Q1 = 25.5 (SE: 0.2) vs. Q5 = 24.8 (SE: 0.2)	<0.0001	
			1404 (M/F)						0.94 g/d	49.3 g/d	WC (cm)	Q1 = 87.4 (SE: 0.6) vs. Q5 = 85.0 (SE: 0.6)	0.002	
Rose et al. (44)	USA	Untitled: college students from a large state university	159 (M/F)	19.9[5]	—	7-d food diary ×2	First ingredient listed on label is WG	Servings/d	0.3 servings/d	0.8 servings/d	WG intake	Normal weight (BMI 18.5–24.99) = 0.8 (SD: 0.8) vs. overweight (BMI 25.0–29.99) = 0.6 (SD: 0.7) vs. obese (BMI≥30.0) = 0.3 (SD: 0.4)	<0.05	A, S, PA
Sahyoun et al. (18)	USA	Untitled: community living older adults	179 (M)/ 356 (F)	60–98	4	3-d food diary	USDA MPED/FPED	Servings/d	0.31 servings/d	2.90 servings/d	BMI (kg/m^2)	Q1 = 26.4 vs. Q4 = 25.2	0.03	A, S, R, Ed, MS, Sm, Al, PA, BMI, E, SF, BPM, LLM
Van de Vijver et al. (59)	Netherlands	Netherlands Cohort Study (NLCS)	2078 (M)/ 2159 (F)	55–69	—	FFQ (150-item, semiquantitative)	List specific foods: muesli, porridge (oats or whole wheat), brown rice, cooked grains (millet, buckwheat etc.)	g WG/d	—	—	BMI (kg/m^2)	Male: β = −0.03 (95% CI: −0.05, −0.02)	<0.01	A, E, Pro, Ed, Sm, F, V
												Female: β = −0.04 (95% CI: −0.06, −0.01)	<0.01	
											Overweight (BMI≥25)	Male: OR = 0.98 (95% CI: 0.96,0.99)	<0.01	
												Female: OR = 0.98 (95% CI: 0.96,0.99)	<0.01	
											Obese (BMI≥30)	Male: OR = 0.90 (95% CI: 0.84,0.98)	<0.05	
												Female: OR = 0.96 (95% CI: 0.93,0.99)	<0.05	

[1] NAFLD, nonalcoholic fatty liver disease; oz eq, ounce-equivalents; PAT, pericardial adipose tissue; Q1, quartile/quintile 1; Q4, quartile 4; Q5, quintile 5; ref, reference category; SAT, subcutaneous adipose tissue; T1, tertile 1; T3, tertile 3; VAT, visceral adipose tissue; WC, waist circumference; WG, whole grain.
[2] M, male; F, female.
[3] Jacobs' definition: breakfast cereals that contain ≥25% whole grain or bran by weight are classified as whole grain. USDA MPED/FPED: whole grain as classified in the USDA's My Pyramid Equivalents Database (MPED) and USDA's Food Pattern Equivalent Database (FPED).
[4] Covariates included in analysis: age (A), alcohol intake (Al), beans/legumes intake (B), fasting blood glucose (BG), blood-pressure medication use (BPM), center (Ce), country (C), cereal fiber (CF), C-reactive protein (CRP), dairy intake (D), decade of visit (De), dietary fiber intake (DF), energy intake (E), energy intake from fat (E(fat)), education (Ed), estrogen use (Es), use of fats during cooking (Fa), fish intake (Fi), fruit intake (F), fruit juice intake (FJ), fried food intake (Fr), hip circumference (HC), persons in household (HH), use of hormone replacement therapy (HRT), self-reported health status (HS), hypertension treatment (HTN), income (In), lipid-lowering medication use (LLM), meat intake (M), mutually adjusted (MA), marital status (MS), misreporting (Mis), multivitamin use (MV), occupation (O), physical activity (PA), processed meat intake (PM), poultry intake (Po), protein intake (Pro), PUFA intake (PUFA), race/ethnicity (R), area of residence/region (Re), refined grain intake (RG), red meat intake (RM), sex/gender (S), sedentary behavior (Se), season (Sea), saturated fat intake (SF), smoking status (Sm), sugar-sweetened beverages/soft drink (SSB), supplement use (Supp), systolic blood pressure (SBP), total cholesterol (TC), television viewing (TV), vegetable intake (V), weight (wt).
[5] Data presented as mean age.

TABLE 2 Characteristics of prospective cohort studies examining the relation between whole grain intake and body weight measures in adults[1]

Article	Country	Study cohort	n[2]	Age, y	Number of intake groups	Method of dietary intake collection	Whole grain food grain food definition[3]	Whole grain food grain reporting method	Low/no whole grain intake	High whole grain intake	Outcome	Results	*P* value	Covariates used in analysis[4]
Bazzano et al. (45)	USA	Physician's Health Study	17,881 (M)	40–84	4	FFQ (61-item, semiquantitative)	Jacobs' definition and list specific foods: breakfast cereals	Servings/d	Rarely/ never	≥1 serving/d	Weight gain (kg)	8-y weight gain Q1 = 1.55 (SE: 0.05) vs. Q4 = 1.13 (SE: 0.11)	0.003	A, Sm, BMI, Al, PA, HxHTN, HxCh, MV
												13-y weight gain Q1 = 2.18 (SE: 0.06) vs. Q4 = 1.83 (SE: 0.13)	0.08	
											Overweight (BMI ≥25)	8-y RR Q1 = 1.00 (ref) vs. Q4 = 0.83 (95% CI: 0.71, 0.98)	0.06	
												13-y RR Q1 = 1.00 (ref) vs. Q4 = 0.91 (95% CI: 0.79, 1.05)	0.13	
Bautista-Castano et al. (54)	Spain	Prevencion Con Dieta Mediterranea (PREDIMED) trial	2213 (M/F)	55–80 (M)/60–80 y (F)	4	FFQ (137-item, semiquantitative)	List specific foods: WG bread	g WG food/d	−55.43 g/d decrease	+57.17 g/d increase	Weight gain	>2 kg OR Q1 = 1.00 (ref) vs. Q4 = 1.03 (95% CI: 0.75, 1.42)	0.724	A, S, Ig, wt, T2DM, E, Al, Pro, SF, PF, MF, Sm, PA
											Weight loss	>2 kg OR Q1 = 1.00 (ref) vs. Q4 = 1.13 (95% CI: 0.84, 1.53)	0.436	
											WC gain	>2 cm OR Q1 = 1.00 (ref) vs. Q4 = 0.90 (95% CI: 0.65, 1.23)	0.692	A, S, Ig, WC, T2DM, E, Al, Pro, SF, PF, MF, Sm, PA
											WC loss	>2 cm OR Q1 = 1.00 (ref) vs. Q4 = 0.87 (95% CI: 0.62, 1.23)	0.493	
de la Fuente-Arrillaga et al. (55)	Spain	Seguimiento Universidad de Navarra (SUN) project	9267 (M/F)	18–101	4	FFQ (136-item)	List specific foods: WG bread	g WG food/d	1 g/d	162 g/d	Overweight/obesity (BMI ≥25)	2-y OR Q1 = 1.00 (ref) vs. Q4 = 0.66 (95% CI: 0.35, 1.24)	0.210	A, S, PA, TV, Se, Sm, BMI, DF, E, OO, SSB, FF
Hosseini-Esfahani et al. (52)	Iran	Tehran Lipid and Glucose Study (TLGS) (2005–2011)	378 (M)/473(F)	≥18	3	FFQ (168-item, semiquantitative)	List specific foods: barbari bread, sangak bread, taftoon bread, whole-wheat bread and biscuits, cooked barley	Servings/d	Male: ≤0.76 servings/d change	Male: >3.80 servings/d change	Weight gain	Male: OR T1 = 1.18 (95% CI: 0.64, 2.17) vs. T3 = 1.14 (95% CI: 0.62, 2.12)	Not given	A, wt, Ed, Sm, PA
									Female: ≤0.12 servings/d change	Female: >2.50 servings/d change		Female: OR T1 = 1.92 (95% CI: 1.11, 3.31) vs. T3 = 1.67 (95% CI: 0.97, 2.86)		
											Weight loss	Male: OR T1 = 0.92 (95% CI: 0.43, 1.96) vs. T3 = 0.89 (95% CI: 0.42, 1.89)		
												Female: OR T1 = 1.61 (95% CI: 0.81, 3.19) vs. T3 = 1.03 (95% CI: 0.52, 2.05)		
Kyrø et al. (50)	Denmark	The Danish Diet, Cancer and Health prospective cohort study (1993–1997) + follow-up study (1999–2002)	20,692 (M)/ 23,201 (F)	50–65	—	FFQ + 24-h recall	List specific foods: rye bread, WG bread, rolled oats, muesli, and crispbread	g WG/d	—	—	Weight change (g) per 25 g/d WG intake	Male: 5-y change = −42 (95% CI: −113, 30)	0.25	A, E, Sm, PA, Ed, PM, D, F, V, Pro, SF, BMI
												Female: 5-y change = 68 (95% CI: −11, 146)	0.09	
											WC change (cm) per 25 g/d WG intake	Male: 5-y change = 0.06 (95% CI: −0.03, 0.16)	0.21	A, E, Sm, PA, Ed, PM, D, F, V, Pro, SF, WC
												Female: 5-y change = 0.06 (95% CI: −0.08, 0.20)	0.39	
Liu et al. (46)	USA	Nurse's Health Study (NHS) (1984–1996)	74,091 (F)	38–63	5	FFQ (semiquantitative)	Jacobs' definition and list specific foods: dark breads, WG breakfast cereal, popcorn, cooked oatmeal, wheat germ, brown rice, bran and other grains (bulgur, kasha, couscous)	Servings/d	Little to no increase in WG intake	Increased WG intake	BMI change	2–4 y change Q1 = 0.56 (SE: 0.01) vs. Q5 = 0.46 (SE: 0.01)	<0.0001	A, PA, Sm, HRT, Al, Caf, E, SF, PF, MF, TF, Pro, BMI

(*Continued*)

TABLE 2 (*Continued*)

Article	Country	Study cohort	n[2]	Age, y	Number of intake groups	Method of dietary intake collection	Whole grain food grain food definition[3]	Whole grain food grain reporting method	Low/no whole grain intake	High whole grain intake	Outcome	Results	*P* value	Covariates used in analysis[4]
									−0.59 servings/1000 kcal/d change	+0.90 servings/1000 kcal/d change	Obesity (BMI ≥30)	12-y OR Q1 = 1.00 (ref) vs. Q5 = 0.81 (95% CI: 0.73, 0.91)	0.0002	
Mozaffarian et al. (30)	USA	Nurse's Health Study (NHS) (1986–2006)	50,422 (F)	52.2[5]	—	FFQ (semiquantitative)	List specific foods: bran, brown rice, cold breakfast cereal, cooked oatmeal, other cooked breakfast cereal, dark bread, wheat germ	Servings/d	—	—	Weight change (kg) per 1 serving increase	4-y change: −0.93 (95% CI: −1.13, −0.71)	<0.001	A, BMI, Sl, PA, Al, Sm, TV, F, D, PC, RG, SSB, Sw, PM, M, E(trans fat), Fr
		Nurse's Health Study II (NHS II) (1991–2003)	47,898 (F)	37.5[5]								4-y change: −0.53 (95% CI: −0.80, −0.27)	<0.001	
		Health Professionals Follow-up Study (HPFS) (1986–2006)	22,557 (M)	50.8[5]								4-y change: −0.96 (95% CI: −1.20, −0.71)	<0.001	

[1] Q1, quartile/quintile 1; Q4, quartile 4; Q5, quintile 5; ref, reference category; T1, tertile 1; T3, tertile 3; WC, waist circumference; WG, whole grain.
[2] M, male; F, female.
[3] Jacobs' definition: breakfast cereals that contain ≥25% whole grain or bran by weight are classified as whole grain.
[4] Covariates included in analysis: Age (A), alcohol intake (Al), baseline BMI (BMI), caffeine intake (Caf), dairy intake (D), dietary fiber intake (DF), energy intake (E), education (Ed), energy from trans fat intake (E[transfat]), fruit intake (F), fast food intake (FF), fried food intake (Fr), use of hormone replacement therapy (HRT), history of high cholesterol (HxCh), history of hypertension (HxHTN), intervention group (Ig), meat intake (M), monounsaturated fat (MF), multivitamin use (MV), olive oil intake (OO), physical activity (PA), potato chips/potato intake (PC), polyunsaturated fat (PF), processed meat intake (PM), protein intake (Pro), refined grain intake (RG), sex/gender (S), sedentary behavior (Se), saturated fat intake (SF), sleep duration (Sl), smoking status (Sm), sugar-sweetened beverages/soft drink (SSB), sweets/desserts intake (Sw), television viewing (TV), trans fat intake (TF), type 2 diabetes prevalence at baseline (T2DM), vegetable intake (V), baseline waist circumference (WC), baseline weight (wt).
[5] Presented as mean age.

studies included both male and female participants ($n = 22$), however, 3 studies were comprised of males only (30, 39, 45), whereas 5 studies included females only (30, 38, 46, 48). Of the prospective cohort studies, years of follow-up ranged from 2 to 20 y.

Studies reported a variety of body weight measures. In cross-sectional studies, the most prevalent outcomes included BMI ($n = 10$), WC ($n = 6$), obesity ($n = 5$), overweight/obesity ($n = 3$), abdominal adiposity ($n = 3$), weight ($n = 3$), overweight ($n = 2$), subcutaneous adipose tissue (SAT) ($n = 2$), visceral adipose tissue (VAT) ($n = 2$), and WHR ($n = 2$). In prospective studies the most prevalent outcomes were weight gain ($n = 3$), weight loss ($n = 2$), and weight change ($n = 2$). Furthermore, 6 cross-sectional studies (39, 44, 47–49) investigated reverse associations of whole grain intake determined by body weight measures.

Across studies, the method for reporting whole grain intake and the definition used to describe whole grain foods varied significantly. Whole grain foods were defined according to the USDA's My Pyramid Equivalent Database or Food Pattern Equivalent Database across 4 studies (18, 37, 38, 43). Fifteen studies (30, 33, 39, 47–52, 54, 55, 58, 59) listed specific foods to include as whole grain (with great variation of foods among these studies). In conjunction with listing specific foods, 7 studies (31, 32, 34, 40–42, 45, 46) also utilized a definition initially proposed by Jacobs et al. (20), which includes foods with ≥25% whole grain or bran. Additionally, 1 study defined whole grain foods as those containing ≥10% whole grain on a dry weight basis (53), and 1 study defined whole grain foods as those where whole grain is listed as the first ingredient on the product packaging (44). Finally, 3 studies did not utilize a whole grain food definition, but rather included all amounts of whole grain from any food (absolute amount) (35, 36, 56, 57). It is of note that 1 study (reported across 2 articles) (33, 34) utilized 2 different whole grain food definitions. The majority of studies reported whole grain intake as grams of whole grain per day (35, 36, 41, 43, 47, 50, 51, 53, 56, 57, 59) or servings per day (18, 30, 33, 34, 38, 41, 42, 44–46, 52), although serving sizes were not consistent and did not contain equal whole grain amounts. Some studies specified the serving size as those indicated in the USDA databases, others described or provided examples of a serving size for 1 or more included foods, whereas others did not report serve size at all. Other methods included grams of whole grain food per day (31, 32, 39, 49, 54, 55, 58), slices of whole grain bread per day (48), ounce equivalents per day (37), and servings per week (40).

Few studies accounted for other factors that may influence body weight measures in their analyses. Five articles accounted for total dietary fiber intake (38, 40, 42, 54, 55) where 1 additionally accounted for fiber from non-bread sources (55). Two articles accounted for cereal fiber intake (36, 56), 11 articles accounted for intake of various food groups (31, 32, 34, 39, 40, 42, 47, 49, 50, 56, 59), 21 accounted for total energy intake (18, 31–34, 36–43, 46, 50, 54–59), and 12 accounted for alcohol intake (38–43, 45–47, 49, 54, 56). Only 3 studies (40, 42, 56) accounted for all of these factors within the analyses exploring whole grain intake and body weight measures. Some studies considered these factors outside the context of whole grain intake and body weight measures, for example, associations between dietary fiber (41, 59) or specific food groups (30, 52) with body weight measures.

Overwhelmingly, whole grain intake was significantly associated with body weight measures to some degree. Although this was generally consistent across methods for the calculation of whole grain intake, inconsistent results tended to be where only a list of "whole grain foods" was used, or in the study (53) that defined whole grain foods as containing ≥10% whole grain (**Table 3**). Particularly in cross-sectional studies, significant inverse associations were found among all relevant studies for WC, overweight/obesity, and VAT (32, 33, 37, 38, 42, 43, 56, 57), although the classification of whole grain foods varied among the studies under each of these outcomes. For instance, studies assessing WC identified whole grain foods based on the definitions in the USDA's My Pyramid Equivalent Database and/or Food Pattern Equivalent Database (37, 38, 43), using a combination of Jacobs' definition and listing specific foods, where the specific foods listed differed (32, 42), or included the absolute grams of whole grain consumed (56). Interestingly, these studies all accounted for total energy intake in analyses, with some additionally accounting for alcohol intake, whereas only those utilizing the latter 2 definitions accounted for intake of specific food groups. The reporting of whole grain intake differed greatly across these studies such that oz eq/d, servings/d, g WG/d, and g WG food/d were reported. Nonetheless, methods using USDA databases or a 25% whole grain cut-off and lists of foods appeared consistent in demonstrating associations. Of note, lists of foods included bran, which does not meet accepted definitions of whole grain.

Additionally, significant inverse associations were present for the majority of studies investigating BMI. In 1 study by McKeown et al. (41), no significant associations were found when analyzing whole grain intake as servings per day (Q1 26.8 compared with Q4 25.8, $P = 0.08$), although when analyzing whole grain intake as grams per day a significant inverse association was present (Q1 26.9 compared with Q4 25.4, $P = 0.006$). In contrast, the 2 studies that did not show significant associations with BMI included absolute grams of whole grain intake in their analysis (36, 56). These studies accounted for both energy intake and cereal fiber. Only 1 of these studies showed significant associations with BMI prior to adjustment for cereal fiber intake (56). All other positive studies utilized a definition of whole grain foods that may have restricted the amount of whole grain included in analysis. Only some of these studies considered intake of specific food groups (4/10 studies) and dietary fiber (3/10 studies) as potential confounders. Conflicting evidence was present for the remaining outcomes including overweight, obesity, abdominal adiposity, SAT, weight, and WHR.

Considering the reverse association, varying evidence emerged for associations of whole grain intake determined by body weight measures. In the studies by Kyrø et al. (47) and Egeberg et al. (49), an increase in BMI for males and an increase in WC, respectively, was associated with lower whole grain intake. Both studies accounted for intake of alcohol and specific food groups. In addition, Bakken et al. (48) and Andersen et al. (51) found that those in a lower BMI range had greater odds of high whole grain intake, whereas no clear trends between BMI category and whole grain intake were seen in Kimokoti et al. (39).

Prospective cohort studies showed greater variation in associations than cross-sectional data. Significant inverse associations were found between whole grain intake and 8-y weight gain, but not for 13-y weight gain in Bazzano et al. (45). Bautista-Castano et al. found no significant associations with weight gain (54), whereas Hosseini-Esfahani et al. (52) showed reduced odds of weight gain with increased whole grain intake, although significance was not reported. Again, variation in the method of calculating whole grain intake was present, such that Bazzano et al. (45) utilized Jacobs' definition, whereas Bautista-Castano et al. (54) and Hosseini-Esfahani et al. (52) listed specific foods to be included in the calculation. Further differences in reporting whole grain and confounding factors in analyses were identified. Bazzano et al. (45) and Hosseini-Esfahani et al. (52) reported whole grain as servings/d and did not account for additional factors influencing body weight measures, whereas Bautista-Castano et al. (54) reported intake as grams of whole grain food/d and accounted for total energy intake in analyses. Bautista-Castano et al. (54) also found no significant associations between whole grain intake and weight loss, although interestingly, Hosseini-Esfahani et al. (52) found a decrease in odds of weight loss with an increase in whole grain. Both these studies list specific foods to be included in the whole grain intake calculation, although they vary greatly among their included foods. All other outcomes were assessed within a single study and therefore, the results cannot be compared.

In summary, significant associations with reduced body weight measures were found in studies including whole grain foods defined by USDA food databases in the calculation of whole grain intake, and in the majority of studies utilizing Jacobs' definition in conjunction with listing specific foods. However, there is great variation in associations among studies that list only specific foods to be included in estimations of whole grain intake.

Quality assessment

Following assessment using modified NOS tools, study quality among cross-sectional studies ranged from 3–7 stars out of a possible 9 stars, with the majority ($n = 21$) indicating moderate to higher quality (5–7 stars). Study quality among cohort studies ranged from 2–7 stars out of a possible 8 stars, with a large proportion ($n = 6$) of lower quality (2–4 stars) (**Supplemental Table 3–6**).

Discussion

Overall, this review confirms the results of previous reviews in that an association between whole grain intake and body

TABLE 3 Summary of the associations between whole grain intake and body weight measures in adults by whole grain food definition among cross-sectional and prospective cohort studies[1]

		Outcome																		
		With increasing WG intake																	With increasing BMI	With increasing WC
Whole grain food definition	Article	Over-weight /obesity	BMI[2] (kg/m²)	Weight[2] (kg)	Waist to hip ratio	WC[2,3] (cm)	Obesity	Over-weight	Body fat (%)	Trunk fat mass (%)	Abdo-minal fat level	PAT (cm³)	SAT (cm³)	VAT (cm³)	Weight gain	Weight loss	WC gain	WC loss	WG intake	WG intake
Grams from all foods	Barrett et al. (56)		-ve			-ve*														
	Bellilse et al. (57)	-ve*																		
	Barrett et al. (36)		-ve		-ve*															
	Mann et al. (35)			Ø																
USDA MPED/FPED	Albertson et al. (37)	-ve*	-ve*			-ve*	-ve*													
	Good et al. (38)	-ve*	-ve*			-ve*														
	Newby et al. (43)		-ve*	-ve*		-ve*														
	Sahyoun et al. (18)		-ve*																	
List specific foods	Andersen et al. (51)																		-ve	
	Kyrø et al. (47)																		-ve*[M]	
	Bakken et al. (48)																		-ve*	
	Egeberg et al. (49)																			-ve (M) +ve (F)
	Georgoulis et al. (58)					-ve*	-ve*				-ve*									
	Kimokoti et al. (39)																		Ø	
	Shah et al. (33)											-ve*	-ve	-ve*						
	Van de Vijver et al. (59)		-ve*				-ve*	-ve*												
	Bautista-Castano et al. (54)														+ve	+ve	-ve	-ve		
	de la Fuente et al. (55)	-ve																		
	Hosseini-Esfahani et al. (52)														-ve	-ve				
	Kyrø et al. (50)			-ve (M) +ve (F)		+ve														
	Mozaffarian et al. (30)			-ve*																
Jacobs' definition (≥25% whole grain or bran) + list specific foods	Esmaillzadeh et al. (31)					-ve*	-ve													
	Esmaillzadeh et al. (32)					-ve*														
	Lutsey et al. (34)		-ve*																	
	McKeown et al. (40)		-ve*		-ve*															
	McKeown et al. (41)		-ve (S) -ve* (G)						-ve* (S) -ve* (G)	-ve* (S) -ve* (G)										
	McKeown et al.(42)					-ve*							-ve*	-ve*						
	Bazzano et al. (45)							-ve							-ve*[4]					
	Liu et al. (46)		-ve*				-ve*													
≥10% dry weight basis	Thane et al. (53)			+ve																
First ingredient listed on label is whole grain	Rose et al. (44)																		-ve*	

[1] F, female; FPED, Food Pattern Equivalent Database; G, grams/d; M, male; MPED, My Pyramid Equivalents Database; PAT, percutaneous adipose tissue; S, serves/d; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue; WC, waist circumference; WG, whole grain.
[2] Includes change in outcome, i.e. change in BMI, change in weight, change in waist circumference.
[3] Includes increased waist circumference and abdominal adiposity outcomes. Both outcomes are related to waist circumference measures.
[4] Statistically significant association for 8-y data, although not statistically significant for 13-y data.
* Statistically significant association.
*[M] Statistically significant association for males only.
Ø, no association present.
+ve, indicates a positive association.
-ve, indicates a negative association.

weight measures is likely, with significant associations noted in the majority of studies. We aimed to build on previous reviews by considering the role of different methods of calculating whole grain intake and the effects on associations with body weight outcomes. Our findings highlight that determining the extent of these associations is limited firstly by the large heterogeneity related to methods of calculating and reporting whole grain intake, particularly in defining whole grain foods and serves, and secondly a lack of comprehensive consideration for other potential factors influencing associations with body weight.

Previous reviews on this topic also suggest that whole grain intake has beneficial associations with body weight measures. Specifically, Harland & Garton (12) found that within observational studies, high whole grain consumers had a BMI 0.630 kg/m^2 lower and a 2.7 cm decrease in WC in comparison to low whole grain consumers ($P = 0.0001$ and $P = 0.03$, respectively). Similarly, Maki et al. (14) found a significant inverse association with BMI (–0.0141 kg/m^2 per g WG/d, $P = 0.0001$) among cross-sectional studies, and a general inverse association with weight change among prospective cohort studies with follow-up periods ranging from 5 to 20 y. However, these effects are less prominent among controlled trials, where Maki et al. found nonsignificant associations with weight change (–0.049 kg, $P = 0.698$) or BMI in controlled trials ≤16 wk in intervention length. Additionally, Sadeghi et al. (15) found nonsignificant associations in randomized control trials with body weight, BMI, WC, body fat percentage, fat mass, and fat-free mass. This conflicts with evidence presented in Pol et al. (13), where even though no associations with body weight were found (weighted mean difference [WMD] 0.06, $P = 0.45$), a small association with body fat was indicated (WMD –0.48%, $P = 0.04$). It is important to note that Pol et al. (13) was based on earlier study publications and as a result may not reflect the current body of evidence. Conflicting evidence among these reviews may be linked to the use of different whole grain food definitions and this is acknowledged by authors (12, 14). Similar limitations are discussed among systematic reviews and meta-analyses of observational studies investigating whole grain intake among other outcomes including CVD, type 2 diabetes mellitus, cancer, and mortality (60–63).

Previous reviews have highlighted the variation in whole grain food definitions between studies. Multiple studies have acknowledged the difficulty in assessing the influence of differing definitions of whole grain foods on results, where US studies tend to use Jacobs' definition, and European studies generally do not provide a definition (60–62). Study heterogeneity, where most studies reported intake as the amount or frequency of whole grain food or product (including water content) is also noted, with few reporting intake as the actual amount of whole grain (dry weight) (61, 62). Only 1 past review aimed to reduce heterogeneity between studies through calculations and assumptions to standardize intake as grams of whole grain per day (62). Furthermore, some authors acknowledge that it may be difficult to consistently define and precisely estimate the intake of whole grain in observational studies leading to underestimation of the magnitude of associations (63).

The issues identified within past work and the current review have significant implications for both research methodologies and public health recommendations, as conclusions and recommendations drawn may vary due to study heterogeneity; particularly the variation in definitions used and assessment of other factors impacting body weight such as dietary habits. This is problematic as guidelines and recommendations depend on conclusions from these studies which are not necessarily comparable.

Many definitions specify a minimum proportion of whole grain, such as Jacobs' definition, where studies using these definitions often explore serves of intake against health outcomes. However, both a food containing 100% whole grain or only the minimum proportion of whole grain (such as 25% with the Jacobs' definition) are included equally as a "serve" of whole grain, and therefore the results become muddied. This is problematic as firstly, whole-grain-containing foods that are not classified as a "whole grain food" (such as a bread containing 20% whole grain when utilizing Jacobs' definition) are potentially consumed in large amounts and may contribute significantly to whole grain intake, and this intake is not counted. Secondly, this type of classification can affect public health messaging, implying that even a food lower in whole grain (but meeting a definition such as 25% whole grain) is an ideal food. It may be erroneous to encourage intake of these "serves" due to the overall nutrient profile of the food. Generally, the lower the percentage of whole grain, the increased likelihood of greater refined grain or deleterious components, such as sugar or saturated fat. Similarly, including absolute grams of whole grain captures whole grain intake from any food, and there is no consideration for the intake of deleterious components, which may be present in these foods. Irrespectively, using absolute grams of whole grain intake would allow for comparison of the values between studies, and potentially deleterious components can be adjusted for in analyses. In public health messaging, regulation can ensure whole grain claims are not allowed on "unhealthy" foods.

Another important consideration is the inclusion of bran in whole grain calculations despite not meeting recognized definitions of whole grain. As bran itself has shown beneficial associations with a variety of health outcomes (64–67), the studies utilizing this definition are measuring the combined effects of whole grain and bran on health associations.

In addition, differences in study outcomes are likely attributed to varied consideration for other influences on body weight measures. Dietary fiber is consistently shown to reduce body weight across studies (68), however, it is important to differentiate these effects by fiber source and potentially fiber type. Fiber derived from whole grain is associated with favorable effects on various body weight measures, however, fruit fiber, vegetable fiber, and other sources of cereal fiber also contribute to these effects, potentially inconsistently (69). Although different fiber types are shown to have different physiological effects (70), the studies included in this review mostly lack this consideration. Whole grain source is relevant to the types of fiber, which could include varied amounts of soluble and/or insoluble fiber. Here, only 2 articles (36, 56) accounted for the effects of cereal fiber in general, let alone the type of fiber. As expected, adjustment for cereal fiber attenuated associations with BMI and WC in an Australian cohort, and WHR in a UK cohort. Interestingly, associations with BMI within the UK cohort were strengthened, highlighting that something greater than the cereal fiber component within the whole grain may be responsible for these associations. Future studies should investigate effects differentiated by whole grain type due to varied quality and composition, particularly in fiber quantity and type.

Furthermore, associations can be influenced by dietary habits where intake of specific food groups may positively or negatively affect outcomes. For instance, the intake of vegetables is associated with decreased weight-related outcomes (71), whereas the intake of red meat is associated with an increase (72). Adjustment for energy intake was undertaken in the majority of included studies, although several studies did not make this adjustment. Failure to remove variation resulting from total energy intake can weaken associations (73).

Moving forward, a standardized approach including reporting the method of whole grain intake calculation and definitions of whole grain foods applied, is needed. As previously suggested in Ross et al. (74), for research, the intake of whole grain should be reported in grams of whole grain and on a dry weight basis, to enable better comparisons between studies and potentially lead to stronger meta-analyses. There is a strong need for the uptake of universal standards around the definition of a whole grain for greater consistency. Use of whole grain food definitions, serves of whole grain, and consideration of nutrient profile requirements for health labels may be better used to direct public health advice. Grams of whole grain does not necessarily translate well to public health messaging.

Strengths within the current study include data based on large sample sizes increasing generalizability to a broad population, and a systematic methodology to capture eligible studies and limit reporting bias. Limitations are primarily related to the study designs included. Firstly, there were a limited number of cohort studies investigating the effects of whole grain on body weight over time. However, numerous cross-sectional studies were included where associations are based upon a single time point and may not truly reflect causal effects. In addition, a large proportion of the included studies, particularly prospective cohort studies, used self-reported body weight measures, noted as an indicator of poorer quality. Bias related to participant reporting may be present and subsequently impact associations. Finally, as discussed earlier and within other studies (12, 14), the apparent association between whole grain intake and weight status may be due to residual confounding. It is often shown that those consuming whole grain have better dietary and lifestyle habits, which in turn may be the driving force influencing weight status.

Conclusion

It is evident that there is great inconsistency among studies in reporting and calculating whole grain intake, specifically defining whole grain foods. As such, observed associations of whole grain intake with health outcomes has the potential to be impacted by the heterogeneity in methods used. The evidence continues to support associations of increased whole grain intake with improved body weight measures. Further research applying a standardized methodology to calculate whole grain intake, which is defined by recognized groups, will assist the development of conclusions and recommendations based on sound evidence. Historical methods used in large cohort or cross-sectional studies must also be reconsidered.

Acknowledgments

The author's contributions were as follows—KRK, EPN, and EJB: contributed to the conceptual idea of the review, collected and analyzed the data, interpreted the data, and contributed to the manuscript preparation; and all authors: read and approved the final manuscript.

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