Meta-Analysis

The effects of organic food on human health: a systematic review and meta-analysis of population-based studies

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Context: *Although the nutritional composition of organic food has been thoroughly researched, there is a dearth of published data relating to its impact on human health.* ***Objective:*** *This systematic review aimed to examine the association between organic food intake and health effects, including changes in in vivo biomarkers, disease prevalence, and functional changes.* ***Data Sources:*** *PubMed, EMBASE, Web of Science, the Cochrane Library, and ClinicalTrials.gov were searched from inception through Nov 13, 2022.* ***Data Extraction:*** *Both observational and interventional studies conducted in human populations were included, and association between level of organic food intake and each outcome was quantified as "no association," "inconsistent," "beneficial correlation/harmful correlation," or "insufficient". For outcomes with sufficient data reported by at least 3 studies, meta-analyses were conducted, using random-effects models to calculate standardized mean differences.* ***Data Analysis:*** *Based on the included 23 observational and 27 interventional studies, the association between levels of organic food intake and (i) pesticide exposure biomarker was assessed as "beneficial correlation," (ii) toxic metals and carotenoids in the plasma was assessed as "no association," (iii) fatty acids in human milk was assessed as "insufficient," (iv) phenolics was assessed as "beneficial", and serum parameters and antioxidant status was assessed as "inconsistent". For diseases and functional changes, there was an overall "beneficial" association with organic food intake, and there were similar findings for obesity and body mass index. However, evidence for association of organic food intake with other single diseases was assessed as "insufficient" due to the limited number and extent of studies.* ***Conclusion:*** *Organic food intake was found to have a beneficial impact in terms of reducing pesticide exposure, and the general effect on disease and functional changes (body mass index, male sperm quality) was appreciable. More long-term studies are required, especially for single diseases.* ***Systematic Review Registration:*** *PROSPERO registration no. CRD42022350175.*

Key words: *disease, health effect, meta-analysis, organic food, pesticide exposure.*

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INTRODUCTION

Organic agriculture is an ecological production management system that emphasizes rotating crops, managing pests naturally, diversifying crops and livestock, and improving the soil with compost additions and animal and green manures.[1] All food sold as organic must be certified as such by approved organic food control bodies according to defined criteria.[2] With an increase of 14 billion euros, in 2020 the global market for organic food saw its largest year of growth ever, surpassing 120 billion euros.[1]

Belief that organic food is healthier than conventional food is one of the key reasons why people consume it.[3] Organic farming imposes restrictions on the use of antibiotics and pesticides. Several research groups have explored differences in pesticide residue concentrations between organic and conventional products, their findings indicating that organic production results in lower levels of pesticide residues.[4–6] Moreover, organic food may contain more beneficial nutrients or phytochemicals. Organic milk has higher concentrations of beneficial fatty acids compared with conventional milk,[7,8] and higher levels of polyphenols have been detected in organically grown tomatoes, blue honeysuckle, and apples.[9,10]

However, the potential health benefits of organic food remain unclear. Previous systematic reviews have mostly focused on differences in nutrition or pesticide residue concentrations between conventionally produced foods and those produced using organic agriculture. Some meta-analyses have concluded that organic food has a lower risk of being contaminated with detectable pesticide residues, and that there are higher PUFA levels in organic meat.[4,11] Średnicka-Tobe et al aimed to determine the direct health effects of organic food intake, but were unable to perform a quantitative analysis due to the lack of studies and high level of heterogeneity in those studies.[11] Another systematic review expanded the breadth of the evidence examined related to human health outcomes, including potential changes in the preclinical stage, such as total antioxidant status, carotenoids, but no quantitative results were obtained.[12] A recent meta-analysis found that organic food consumption was associated with a modest reduction (11%) in the risk of obesity.[13] However, the meta-analysis only focused on obesity, and the 4 included studies were observational only and of moderate quality, with significant heterogeneity.

Thus, there is a need for further investigation of the potential health effects of organic food, especially given the growing consciousness among consumers of the environmental impacts of food production. The present study aimed to examine the direct clinical impact of organic food intake on human health by including assessment of potential preclinical biomarker changes in vivo, detectable functional changes, and disease outcomes. Furthermore, classification criteria were established to categorize the association between the consumption of organic food and health outcomes.

METHODS

Search strategy

The review was registered with PROSPERO (CRD42022350175) and reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[14] Four electronic databases (PubMed, EMBASE, Cochrane, and Web of Science) were searched for relevant studies from their years of inception up to November 13, 2022. The gray literature was searched on ClinicalTrials.gov to avoid publication bias. Individualized search strategies for the various databases included combinations of terms related to organic food and health outcomes. An example search strategy can be found in Appendix S1 in the Supporting Information online.

Inclusion and exclusion criteria

Both observational and interventional studies performed in humans were identified. The route of intervention/exposure to organic food was limited to dietary intake, and there was no restriction on the food type. For inclusion, studies needed to report differences in outcomes between groups, or risk estimates (odds ratio [OR], relative ratio [RR] or hazard ratio [HR]) for organic food intake. Outcomes studied included diseases (body mass index [BMI] and male sperm quality), in vivo biomarkers, and physiological biochemical parameters. Only English language articles were included. Studies were excluded if there was no description about the route of exposure to / intervention with organic food (Table 1).

Data extraction

Title scans and abstract reviews were conducted by 2 investigators independently, and the full text of all included studies was evaluated based on the inclusion and exclusion criteria. Discrepancies were resolved by discussion until a consensus was reached. Data were extracted by a research assistant (J.B.) and checked by another reviewer (L.X.). Information describing the study sample (sample size, age, sex, geographic region, and health condition), study design (study type, exposure or intervention duration, groups, and organic food

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Table 1 **PICOS criteria for inclusion of studies**

Parameter	Inclusion criterion	Exclusion criterion
Population	Humans	
Intervention	Organic food intake	No description about the route of exposure to / intervention with organic food
Comparison	Conventional food intake	Nutrient-fortified food
Outcomes	Diseases, in vivo biomarkers, or physiological biochemical parameters	Studies without available data
Study design	Interventional trials (including randomized controlled trials or self-controlled trials), cohort studies, case–control studies or cross-sectional studies	Systematic reviews, meta-analyses, reviews

types), and outcomes (specimen types, outcome indicators, and conclusions) were extracted. Moreover, the values of outcome indicators before and after the intervention in the single interventional study (at baseline and follow-up in cohort studies) were collected, including the subgroup data.

Risk-of-bias assessment

The risk of bias of the clinical trial study was assessed using the The Cochrane Risk of Bias Assessment Tool.[15] The observational studies were assessed using the Newcastle–Ottawa Quality Assessment Form and the Specialist Unit for Review Evidence (SURE) checklist.[16,17] Two reviewers participated in the assessment of bias risk, and any disagreement was settled by discussion.

Data synthesis and meta-analyses

Outcomes were categorized into 2 categories: (I) biomarkers (pesticide exposure; toxic metals; fatty acids in human milk; nutrients in plasma; serum parameters; and total antioxidant status) and (II) disease and functional change (BMI, male sperm quality).

The included studies were coded and the data subsequently classified and summarized to determine the associations between organic food intake and outcomes (Table 2); the coding and classification method used was first described by James.[18] Briefly, the evidence for an association was defined as "insufficient" if it was indicated by 3 or fewer studies. If the association was indicated by more than 3 studies, the results were classified based on the percentage of studies reporting statistically significant results as follows: (1) "no association" if less than 30% of the studies reported a significant association; (2) "inconsistent" if the significant association was reported in 34% to 59% of the studies; (3) "beneficial/harmful correlation" if over 60% of the studies reported a significant association. Whether the correlation was considered beneficial or harmful was based on the direction of the reported correlation. The "beneficial/harmful correlation" assessment was not completely equivalent to the assessment of "positive/negative correlation" between organic food and outcomes. For example, when the outcome was pesticide exposure, a "beneficial correlation" indicated that organic food consumption led to a reduction in pesticide exposure (a numerically negative correlation). The same coding was also applied to the subgroup analysis of study type to examine whether the findings were influenced or not.

Table 2 **Classifying criteria for association level between organic food intake and outcomes**

Number or percentage of studies supporting the association	Association level
Number of studies ≤ 3	Insufficient
Number of studies ≥ 4	
1%–33%	No association
34%–59%	Inconsistent
60%–100%	Beneficial correlation[a] Harmful correlation[a]

[a]The correlation was rated as a "Beneficial correlation" when the organic food was associated with a more favourable outcome; otherwise, it was rated as a "Harmful correlation".

All analyses were performed using Stata software version 14.2, and standardized mean differences (SMDs) were calculated using random-effects models for outcomes with at least 3 studies reporting sufficient data. Differences were calculated as levels for the organic diet group minus levels for the conventional diet group. Heterogeneity was determined using Cochran's Q statistic and I^2 values (I^2 values of 25, 50, and 75 were considered as indicating low, moderate, and high heterogeneity, respectively).

RESULTS

Literature search and study characteristics

A total of 13 060 relevant articles were identified after searching. Following the removal of duplicates and initial screening of titles and/or abstracts, 50 studies were

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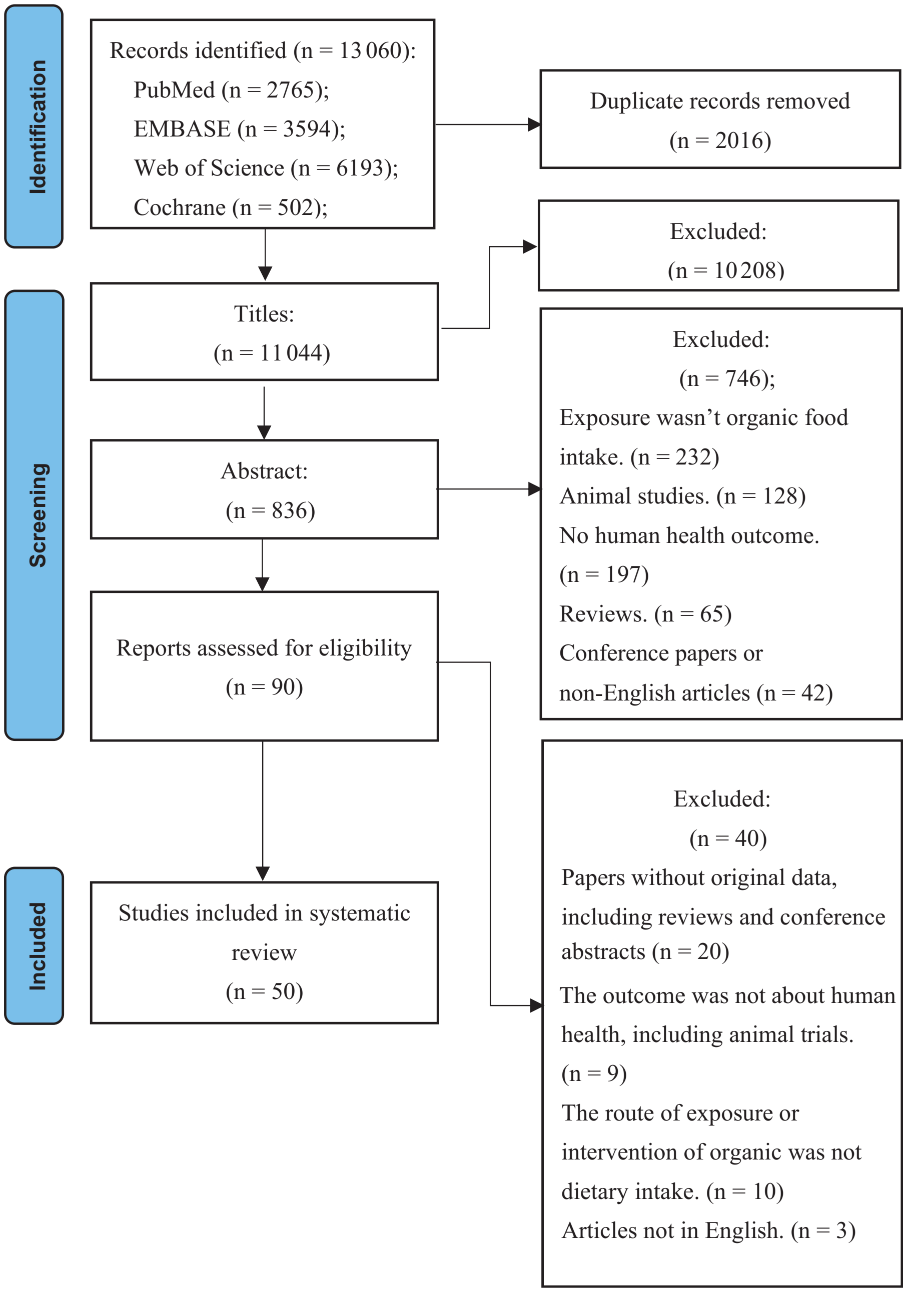

Figure 1 **Flowchart of search and selection process.**

included (Figure 1).[19–68] Twenty-seven of the included studies were interventional trials and used traditional food as a control diet.[18–30,46,49,52,53,55–58,60,61,63,65–67] Most of the studies were conducted in Europe[18–23,26–28,30–45,50–53,55,57,62,64,66,67] and the United States[24,25,45–48,54,59–61,63,65]; 2 were conducted in Brazil,[29,56] 1 in Japan,[58] and 1 in Australia.[49] Eleven studies were conducted in children,[24,25,40,41,46,48,53,60,64,65,67] 4 were in pregnant women,[35–37,51] and 2 were in senior men.[54,59] The main characteristics of the included studies are summarized (Table 3),[18–67] and the results of the classification of the association levels are shown in Table 4.[18–67] The subgroup analysis of the study types is presented in Table 5.[18–67] The results of the risk-of-bias assessment indicate that more than half of the trials had a high risk of bias in terms of blinding. The reporting bias of the majority of the trials was assessed as low risk (see Figure S1 in the Supporting Information online).

Pesticide exposure

Sixteen studies investigated changes in pesticide exposure biomarkers in response to organic food consumption (Table 4).[24,25,30,34,45–49,52,53,57,58,60,61,65] Overall, the

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Table 3 **Main characteristics of studies examining the health effects of organic food on humans**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
18	Caris-Veyrant et al (2004)	Parallel single-blind RCT; 20; France; Healthy nonsmoking females (21 y–39 y)	Tomato puree; Blood	Group 1: organic tomato puree; Group 2: conventional tomato puree	Subjects were randomly divided into 2 groups and the intervention lasted 3 wk.	Plasma vitamin C, β-carotene, and lycopene	Tomato puree increased plasma β-carotene and lycopene in both groups. There were no significant differences between groups for any outcome.	0
19	Stracke et al (2008)	Parallel double-blind RCT; 36; Germany; Healthy males (19 y–54 y)	Blanched carrots; Blood	Group 1: organic carrots; Group 2: conventional carrots; Group 3: followed the carotenoid-restricted diet	Subjects with a 4-wk low-carotenoid diet before baseline were randomly divided into 3 groups. The intervention lasted 14 d.	Plasma carotenoid, vitamin E, vitamin C, antioxidant activity (FRAP, ORAC, TEAC), and LDL oxidation; cytokine quantity, NK cell quantity and activity, DNA damage, plasma glucose, uric acid, TAG, cholesterol	No significant difference was detected in any outcome.	0
20	Stracke et al (2009)	Crossover double-blind RCT; 43; Germany; Nonsmoking healthy men (22 y–40 y)	Apple; Blood	Group 1 (n = 16): organic apples Group 2 (n = 16): conventional apples Group 3 (n = 11): maintained an apple- and polyphenol-restricted diet	A 1-wk depletion period and a 4-wk intervention period	Glucose, triacylglycerol, cholesterol, and uric acid; polyphenol; total antioxidant status; carotenoids, vitamins E and C; PBMC proliferation and lytic activity of NK cells	There were no significant differences in plasma glucose, uric acid, TAG, cholesterol, vitamin C, vitamin E, carotenoids, WBCs, polyphenol concentrations, or antioxidant markers between groups.	0
21	Briviba et al (2007)	Double-blinded, crossover RCT; 6; Germany; Nonsmoking healthy men (23 y–32 y)	Apple; Blood	Group 1: organic apples Group 2: conventional apples	Participants were randomly assigned to 2 groups and followed a polyphenol-restricted diet for 3 d before and during the intervention. Between 2 experimental days, there was a 1-wk wash-out.	Antioxidant activity, LDL oxidation, DNA damage.	There were no statistically significant differences between groups on DNA damage, antioxidant activity, or LDL oxidation.	0
22	Grinder-Pedersen et al (2003)	Double-blinded, crossover RCT; 16; Denmark; Healthy adults (21 y–35 y)	4 different menus including common vegetables, fruits, grains, a few eggs, and meat; Blood and urine	Group 1: organic diets followed by conventional diets; Group 2: conventional diets followed by organic diets	2 intervention periods were separated by a 3-wk wash-out with a habitual diet, and each intervention period lasted 22 d.	2-AAS, CAT, CPD, FRAP, GR, GSH-Px, MDA, OPD, PABA, SOD, TEAC	Quercetin, 2-AAS, urinary excretion of quercetin, and kaempferol were significantly higher in the organic phase. TEAC was significantly increased	+

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
							after intake of conventional diets compared with organic. No significant difference was seen for isorhamnetin or kaempferol.	
23	Akcay et al (2003)	Nonrandomized self-controlled interventional trials; 8; Turkey; Healthy non-smokers (24 y–45 y)	Wine; Blood	No groups; own overlapping comparison	Male subjects drank 200 ml and female subjects drank 100 ml of red organic wine, and after 6 wk the experiment was repeated with nonorganic red wine.	Total cholesterol, AOA, e-SOD, e-CAT, eTBARS, triglycerides, HDL, LDL, and total phenolics	No significant difference in outcome between the 2 types of wines was observed.	0
24	Lu et al (2006)	Nonrandomized self-controlled interventional trials; 23; United States; Children (3 y–11 y)	Fruits, vegetables, and grains; Urine	No groups; own overlapping comparison	During the 15-consecutive-day sampling period, organic food items were substituted for the conventional diet on days 4–8; for the remaining intervention time, subjects used the conventional diet.	MDA, TCPY, DEAMPY, IMPY, CMHC	After beginning the organic diet, the median urinary MDA and TCPY decreased to nondetectable levels immediately, where they remained until conventional diets were reintroduced ($P < .01$).	–
25	Lu et al (2008)	Nonrandomized self-controlled interventional trials; 23; United States; Children (3 y–11 y)	Fresh fruits and vegetables, juices, processed fruits or vegetables, and some wheat- or corn-based items; Urine and saliva	No groups; own overlapping comparison	A 15- and 12-consecutive-day sampling period in the summer (July–August) and fall (October–November), respectively; the intervention duration was consistent with that of study 24 (Lu et al 2006).	MDA, TCPY, IMPY, DEAMPY, CMHC	Reduction in malathion, chlorpyrifos, MDA, and TCPY metabolites in both the summer and fall were observed after beginning the organic diet.	–
26	Di Renzo et al (2007)	Nonrandomized self-controlled interventional trials; 10; Italy; Healthy nonsmoking men (30 y–65 y)	Fruits, vegetables, red wine, and milk; Blood	No groups; own overlapping comparison	Subjects consumed conventional food for 14 consecutive days, followed by a 14-consecutive-day period of consuming organic food. The prescriptions were the same for the 2 periods and all subjects.	ORAC	After the consumption of a Mediterranean organic diet for 14 d, a significant increase (21%) in the human plasma total antioxidant capacity was observed.	+

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
27	De Lorenzo et al (2010)	Cross-interventional trial; 150; Italy; Healthy nonsmokers (30 y–65 y) and CKD patients (42 y–54 y)	Organic vegetables and fruits; Italian Mediterranean Diet was used; Fasting blood and urine	Group 1 (n = 100): healthy subjects; Group 2 (n = 50): CKD patients	14 d consumption of conventional food products, followed by 14 d consumption of organic products	BMI; body composition, tHcy, blood glucose concentrations, serum phosphorus, lipid profile, inflammatory markers (TNF-α, IFN-γ, IL-1; IL-6)	Body composition analysis highlighted significant differences between the conventional and organic diets for the fat mass parameter. Significant decrease in cholesterol, calcium, and microalbuminuria after organic diet only in CKD patients. Inflammatory parameters decreased in both groups after the organic diet.	–
28	Soltoft et al (2011)	Double-blinded, cross-over RCT; 18; Denmark; Healthy, nonsmoking, adult men (18 y–40 y)	Crop foods, including fava beans, potatoes, rape seeds, and wheat; Fasting blood	Group 1 (n = 6): OA diet; Group 2 (n = 6): OB diet; Group 3 (n = 6): C diet	The interventions were 3 × 12-d periods with a wash-out period of 2 wk. There were 3 different agricultural systems: C, OA, and OB.	Carotenoid Content	No systematic differences in the plasma status of carotenoids between the agricultural production systems were observed.	0
29	Toaldo et al (2016)	Crossover RCT; 24; Brazil; Nonsmoking, healthy subjects (20 y–55 y)	400 ml red grape juices; Fasting blood	Group 1 (n = 8): organic red grape juice; Group 2 (n = 8): conventional red grape juice; Group 3 (n = 8): water	3 interventions and a run-in period of 14 d	GSH, glucose. uric acid, TAC, CAT, SOD, GPx	After the consumption of conventional and organic grape juices, the levels of GSH increased up to 8.2% and 7.0%, respectively, with no significant difference between juices.	0
30	Goen et al (2017)	Nonrandomized self-controlled interventional trials; 2; Switzerland; Adults (46 y–49 y)	Not explicitly stated; Urine	No groups; own overlapping comparison	2 subjects switched to an organic diet for 18 d after 11 d of a conventional diet.	Dialkylphosphates, pyrethroid metabolites, phenolic metabolites, 6-chloronicotinic acid, chlorinated phenoxy carboxylic acids, glyphosate, and AMPA	There were higher levels of the parameters in the samples taken during the conventional diet compared with those taken during the organic diet.	–
31	Jensen et al (1996)	Cross-sectional study; 196; Denmark;	Not explicitly stated; Sperm	Group 1 (n = 55): members of 2 associations promoting the	The subjects in group 1 consumed diets consisting of at least 25% organic products.	Sperm concentration, seminal volume, total sperm	The semen concentration was 43.1% higher among men eating organic food. Seminal volume, total	+

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
		Adult healthy men (mean age 33 y)		development of organic agriculture; Group 2 (n = 141): men working in an airline company		count, and sperm morphology	sperm count, and sperm morphology did not differ significantly between the two groups. The prevalence of previous genital disorders in group 1 was lower than that in group 2, but the incidence of cryptorchidism was higher.	
32	Juhler et al (1999)	Cross-sectional study; 256; Denmark; Male farmers (mean age 38 y)	Fruit, vegetables meat, milk, and bread; Sperm	Group N (n = 166): organic intake = 0%; Group M (n = 39): organic intake = 1%–49%; Group H (n = 46): organic intake = 50%–100%	Subjects were grouped by the percentage of organic food intake in their diet, which was reported by themselves in questionnaires.	Sperm concentration, seminal volume, total sperm count, and sperm morphology	The men in Group N had a lower proportion of normal sperms (N: 2.5% vs H: 3.7%,), but there were no other statistically significant between-group differences in semen parameters.	+
33	Baudry et al (2018)	Prospective observational cohort study; 68 946; France; Adults (mean age 44.2 y)	16 labeled organic products[b]; NS	No groups. Cox proportional hazards regression models were used to estimate the association of the risk of cancer with organic food consumption.	Volunteers completed self-administrated questionnaires monthly. Organic foods consumption frequencies were included in questionnaires, and scores were allocated for options; the maximum organic food score (OS) was 32 points.	All first primary cancers were considered cases except for basal cell skin carcinoma.	A high OS was inversely associated with the overall risk of cancer (hazard ratio for quartile 4 vs quartile 1, .75; 95% CI: .63, .88; *P* for trend = .001; absolute risk reduction = .6%; hazard ratio for a 5-point increase, .92; 95% CI: .88, .96).	–
34	Baudry et al (2018)	Cohort study; 300; France; Adults (mean age 58 y)	264 food and beverage items; Urine	Group 1 (n = 150): low organic food consumers; Group 2 (n = 150): high organic food consumers	Total and organic food consumption was assessed using an Org-FFQ. According to the proportion of organic food, which was reported by the subjects themselves, they were identified as low (below 10%) or high (above 50%) organic food consumers.	3-PBA, 4-F-3-PBA, CPMO, CPO, DAPs, DEAMP, DEDTP, DEP, DETP, DMDTP, DMP, DMTP, Eps, F-PBA, TCP	The mean concentrations of DETP, DMTP, and free 3-PBA were significantly higher in the conventional foods group compared with the organic foods one. When the population sample was restricted to pairs using <5% of organic food in the diet for conventional consumers, statistical	–

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
							significance was observed in total Eps.	
35	Brantsæter et al (2016)	Prospective pregnancy cohort study; 35 107; Norway; Pregnant women who delivered a singleton male infant	Vegetables, fruit, bread/cereal, milk/dairy products, eggs, and meat	Group 1 (n = 17 996): never/seldom consume organic food; Group 2 (n = 17 111): sometimes, often, or mostly consume organic food	Information on organic food consumption was collected by a FFQ that was designed specifically for assessing diet during the first 4 months of pregnancy: "never/seldom" vs "sometimes," "often," and "mostly" were defined as 2 groups.	Information about hypospadias and cryptorchidism was retrieved from MBRN, a national birth registry.	Women who consumed any organic food during pregnancy were less likely to give birth to a boy with hypospadias (OR = .42, 95% CI: .25, .70). No substantial association was observed between the consumption of organic food and cryptorchidism.	–
36	Torjusen et al (2016)	Prospective pregnancy cohort study; 28 192; Norway; Nulliparous pregnant females (mean age 28 y)	6 food groups: milk and dairy products, bread and cereal products, eggs, vegetables, fruit, and meat; NS	Group low (n = 25 699): never/seldom consume organic food; Group high (n = 2493): sometimes/often/mostly consume organic food	The subjects were from the same cohort of study 35 (Brantsæter et al 2016), and the method for collecting information on organic food consumption was consistent with study 35.	Pre-eclampsia was registered in the Medical Birth Registry of Norway.	Women who reported having eaten organic vegetables "often" or "mostly" had a lower risk of pre-eclampsia than those who reported "never/rarely" or 'sometimes" (crude OR = .76). The lower risk was evident also when adjusting for overall dietary quality.	–
37	Christensen et al (2013)	Retrospective case–control study; 612; Denmark; Mothers of boys	Milk, other dairy products, eggs, meat, fruit, and vegetables; NS	Group 1 (n = 306): mothers of boys operated on for hypospadias; Group 2 (n = 306): matching control group	Mothers were asked about their consumption of organic food items in the first trimester, and responses consisted of "often," "sometimes," "rarely," and "never," recoded to a binary variable ("often/sometimes" or "rarely/never").	Isolated hypospadias, collected through medical records.	Frequent current consumption of high-fat dairy products (milk, butter) while rarely or never choosing the organic alternative to these products during pregnancy was associated with increased odds of hypospadias.	–
38	Rist et al (2007)	Prospective birth cohort study; 312; Netherlands; Breastfeeding mothers (mean age 33 y)	Dairy and meat products; Breast milk samples collected 1 mo postpartum	Group 1 (n = 186): conventional, <50% organic food consumption; Group 2 (n = 33): 50%–90% organic food consumption;	The FFQ was included in a self-administered questionnaire in week 34 of the pregnancy. Subjects were asked for information on the consumption of dairy products, Meat, and certain other food	CLA, TVA, other conjugated linoleic acids, and other relevant fatty acids	The content of rumenic acid (the main CLA) increased in a statistically significant way while going from a conventional diet (.25 wt%) to a moderately organic diet	+

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
				Group 3 (n = 37): 90% organic food consumption	items, which are relevant dietary sources of CLA. Specific criteria for grouping are in the notes.[c]		(.29 wt%), to a strictly organic diet (.34 wt%).	
39	Mueller et al (2010)	Prospective birth cohort study; 310; Netherlands; Breastfeeding mothers (mean age 33 y)	Meat and dairy products; Breast milk samples collected 1 mo postpartum	Group 1 (n = 185): conventional, <50% MDOO; Group 2 (n = 33): 50%–90% MDOO; Group 3 (n = 37): >90% MDOO	The selection of population and data collection was consistent with that of study 38 (Rist et al 2007). Only the consumption of MDOO was documented.	Trans fatty acids	The 9(trans)18:1/11(trans)18:1-ratio, 10(trans)18:1/11(trans)18:1-ratio, and 10(trans)18:1/11(trans)18:1-ratio in human breast milk were lower with strict organic meat and dairy use compared with use of conventional-origin meat and dairy.	–
40	Buscail et al (2015)	Prospective observational cohort study; 1505; France; Infants (fetal period to 24 mo)	Not explicitly stated; Urine of mothers	Group 1 (n = 910): at least 1 otitis media (OM) episode; Group 2 (n = 408): at least 3 OM episodes	In the follow-up questionnaire, women were asked about the percentage of organic provenance for each food. A combined index of organic dietary consumption was defined and classified as low, medium, or high.	OM was identified from 4 questions from the 2-year follow-up questionnaire.	Children whose mothers reported an organic diet during pregnancy had a reduced risk of OM (at least 1 episode). The presence in maternal urine of dealkylated triazine metabolites (herbicide) was positively associated with recurrent OM (OR = 2.12, 95% CI: 1.01, 4.47).	–
41	Kummeling et al (2008)	Prospective birth cohort study; 2598; Netherlands; Children (mean age 2 y)	Meat, eggs, vegetables, fruit, dairy products, bread, and/or dry products; Blood	Group 1 (n = 2306): conventional diet (score below 21.0) Group 2 (n = 283): moderately organic food diet (score between 21.0 and 71.0); Group 3 (n = 175): strictly organic food diet (score above 71.0)	The subjects were from the same population of study 37 (Rist et al 2007). Organic food consumption of infants in the second year of life was reported by their parents. They were categorized according to total scores related to their consumption of 7 types of organic food: 0 (<50% organic food), .7	Eczema and wheeze occurrence was reported by parents in questionnaires, Total IgE antibodies in plasma.	Consumption of organic dairy products was associated with lower eczema risk (OR = .64), but there was no association of organic meat, fruit, vegetables, or eggs, or the proportion of organic products within the total diet with the development of eczema, wheeze, or atopic sensitization.	–

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
					(50%–90%), and 1 (>90%) scores.			
42	Kesse-Guyot et al (2017)	Prospective observational cohort study; 62 224; France; Adults (mean age 45 y)	16 labeled organic products; NS	No groups; the study estimated the association between OS (as quartiles) and weight change.	The population, data collection, and OS were consistent with those of study 33 (Baudry et al 2018).	Weight, height, and BMI were reported yearly.	A lower BMI increase was observed across quartiles of the OS (mean difference Q4 vs Q1 = –.16). An increase in the OS was associated with a lower risk of overweight and obesity.	–
43	Bradbury et al (2014)	Prospective cohort; 623 080; United Kingdom; Adult women (mean age 59 y)	Not explicitly stated; NS	Group 1 (n = 187 451): never consume organic food; Group 2 (n = 390 040): sometimes consumes organic food; Group 3 (n = 45 589): usually/always consume organic food	Women were asked the frequency of organic food consumption with 4 possible responses: "never," "sometimes," "usually," and "always" in questionnaires. Cox regression models (using attained age as the underlying time variable) were used to estimate RRs for incident cancer by the reported frequency of consumption of organic foods at baseline.	Women diagnosed with any cancer (except non-melanoma skin cancer) during the follow-up period, which was recorded in National Statistics, England, and the Information Services Division, Scotland.	Consumption of organic food was not associated with a reduction in the incidence of all cancer, soft tissue sarcoma, or breast cancer, but was associated with non-Hodgkin lymphoma (RR = .79).	–
44	Baudry et al (2017)	Prospective observational cohort study; 8174; France; Adults (mean age 45 y)	16 labeled organic products; Blood	No groups; the study estimated the association between OS (as three tertiles) and MetS.	The population, data collection, and OS were consistent with those of study 33 (Baudry et al 2018).	MetS is defined by 5 criteria according to the 2009 interim consensus statement.	Higher organic food consumption was associated with a lower probability of MetS and was negatively associated with prevalence (adjusted OR = .68, 95% CI: .61, .78).	–
45	McGuire et al (2016)	Cross-sectional study; 41; United States; Breastfeeding healthy women 1 mo–3 mo postpartum (mean age was 26.8 y)	Not explicitly stated; Urine and breast milk	Group 1 (n = 17): organic dietary pattern; Group 2 (n = 23): conventional dietary pattern;	The dietary pattern was reported by the subjects themselves.	Glyphosate and its metabolite AMPA.	No difference was found in urine glyphosate or AMPA concentrations between the groups.	0

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
46	Bradman et al (2015)	Nonrandomized self-controlled interventional trials; 40; United States; Children (3 y–6 y)	Fruits, bread, cereals, vegetables, dairy, eggs, juices, and snack foods; Urine	No groups; own overlapping comparison.	The study lasted 16 d, and the children consumed conventionally grown food for 4 d, organic food for 7 d, and then conventionally grown food for 5 d.	23 pesticide metabolites: specific and nonspecific metabolites for OP, pyrethrin, pyrethroid insecticides, and select herbicides	The geometric mean of total DMs, DAPs, and 2,4-D decreased during the organic diet phase compared with C1, the first conventional diet phase.	–
47	Curl et al (2015)	Cross-sectional study; 240; United States; Adults with subclinical cardiovascular disease (45 y–84 y)	Fruit and vegetables were specifically asked in questionnaires; Urine	Group 1 (n = 80): "rarely or never" consume organic produce; Group 2 (n = 80): "sometimes" consume organic produce; Group 3 (n = 80): "often or always" consume organic produce	Subjects were asked about their consumption of organic produce in a FFQ and classified into 3 groups of consumers: rarely or never, sometimes, often or always. Grouping according to estimated exposure ensured that any differences in DAP concentrations were not based on differences in produce intake.	4 DAP metabolites: DMP, DMTP, DEP, DETP	Among the conventional consumers, an increased tertile of estimated dietary OP exposure was associated with higher DAP concentrations. DAP concentrations were also significantly lower in groups reporting more frequent consumption of organic produce.	–
48	Curl et al (2003)	Cross-sectional study; 39; United States; Children (2 y–5 y)	Juice, fresh fruit, and vegetables; Urine	Group 1 (n = 18): organic; Group 2 (n = 21): conventional;	Children's consumption of juice and fresh produce was recorded by their parents in food diaries. The child was included in the "Organic" or "Conventional" category, respectively, if 75% or more of juice and produce servings were recorded as organic or conventional, respectively.	DMP, DMTP, DMDTP, DEP, and DETP.	The median total DMP concentration of the Conventional group was approximately 6 times higher than that of the Organic group; mean concentrations differed by a factor of 9.	–
49	Oates et al (2014)	Single-blinded, crossover RCT; 13; Australia; Nonsmoking adults (18 y–65 y)	Not explicitly stated; Urine	No groups; own overlapping comparison	Subjects consumed a diet of organic and conventional foods for 7 d.	DMP, DMTP, DMDTP, DEP, DETP, and DEDTP	Statistically significantly lower levels of urinary DMP and DMTP ($P < .05$), with a trend for DMDTP, during the organic phase. There was no significant difference for	–

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
							DEP, DETP, and DEDTP. Overall pesticide results in the organic phase were 89% lower than those measured in the conventional phase.	
50	Baudry et al (2019)	Prospective observational cohort study; 300; France; Adults (mean age 58 y)	16 labeled organic products; Fasting blood	Group 1 (n = 150): Nonorganic group (<10% of organic food in diet); Group 2 (n = 150): Organic group (>50% of organic food in diet)	The population and data collection were consistent with that of study 33 (Baudry et al 2018). The proportion of organic food in the whole diet was calculated by dividing the total organic food consumption by the total food consumption, and this was the basis of the grouping.	Iron status, magnesium, copper, cadmium, carotenoids, vitamins A and E, and fatty acids	Significant differences were observed between low and high organic food consumers with similar dietary patterns, with respect to plasma concentrations of magnesium, fat-soluble micronutrients (α-carotene, β-carotene, lutein, and zeaxanthin), fatty acids, and some fatty acid desaturase indices.	+
51	Simões-Wüst et al (2021)	Cross-sectional analysis; 2803; Switzerland Pregnant women	Meat; eggs; vegetables; fruit; milk and milk products; bread; and dried foods (dried legumes and cereals); NS	Group 1 (n = 2,766): women without GDM; Group 2 (n = 37): women with GDM;	The participants were asked to report the percentage of their purchased food products that were of organic origin: less than 50%, between 50 and 90%, or more than 90%.	GDM is defined as self-reported at week 34 and/or mentioned by midwife reports.	Organic food consumption tended to be lower in women with GDM compared with women without GDM, although the difference was not significant.	0
52	Rempelos et al (2021)	Randomized crossover interventional trial; 27; England; Healthy adults (21 y–36 y)	Fruit, vegetables, and cereal products; Urine and blood	Conventional group (n = 14): conventional MedDiet; Intervention group (n = 13): organic MedDiet	The study lasted 5 wk, and the 2-wk interventional MedDiet period was in weeks 2 and 3; before and after the intervention period, participants consumed the habitual Western diets.	CCC, 2,4-D, 2,4,5-T, GLY, AMPA, 4NP, TCHP, 3M-4NP, 6-CNA, Cl2CA, m-PBA, Br2CA, 3-PBA, t-CDCA, TTCA, Cu	Total UPRE (except TTCA and Cu) in the organic MedDiet intervention group was 91% lower ($P < .0001$) than in the conventional MedDiet group.	–
53	Makris et al (2019)	Cluster-randomized crossover trial; 149; Cyprus; Children (11 y–12 y)	Not explicitly stated; Urine	Group 1 (n = 43): organic diet followed by conventional diet; Group 2 (n = 106): conventional diet followed by an organic diet	2 periods (40-d of organic diet vs 40-d of conventional diet), with no wash-out period	3-PBA, 6-VNA, 8-iso-PGF2a, MDA, [8-iso-PGF2a], BMI *z*-scores	Children had lower pesticide exposures during the organic period. BMI *z*-scores were lower at the end of the organic period.	–
54	Ludwig-Borycz et al (2021)	Cross-sectional analysis;	Milk, eggs, meat, fruit, vegetables, bread or	Group 1 (n = 1,981): OF consumption (no);	Organic food consumption data was collected from	CRP, CysC	Log CRP and log CysC were inversely associated with	–

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
		3815; United States; Older adults (64.3 y ± .3 y)	cereals, frozen prepared meals, or other (specify); Blood	Group 2 (n = 1,738): OF consumption (yes)	a FFQ. The participants who said they ate any of the organic food types were classified as being in the organic food consumption group.		consuming organic food after adjusting for potential confounders (CRP: $\beta = -.096$; CysC: $\beta = -.033$).	
55	Hurtado-Barroso et al (2019)	Crossover RCT; 19; Spain; Healthy people (18 y–40 y)	Not explicitly stated; Blood and Urine	Group 1 (n = 11): organic food diet followed by conventional diet; Group 2 (n = 8): conventional food diet followed by organic diet.	Each volunteer consumed the organic food diet for 4 wk and the conventional food diet for 4 wk, and was encouraged to follow a healthy MedDiet with a similar food pattern. Organic products represented at least 80% of the organic food diet, and no organic foods were allowed in the conventional food diet.	Fe, As, Cu, Cd, U, Pb, Zn, Ca, Mg, K, Na, carotenoids, 3,4-HPPA, 4-HBA, 3,4-DHPAA, 3-HPAA, DHCA, hippuric acid, homovanillic acid, CA, m-Cou, p-Cou, and GA	A significant increase in excretion of 4-HBA was observed after the organic diet compared with the conventional diet, but no changes were detected for the remaining phenols.	+
56	de Oliveira et al (2022)	Double-blind RCT; 13; Brazil; Adults with dyslipidemia (20 y–59 y)	Juice made from BLS; Blood	Group 1 (n = 5): placebo; Group 2 (n = 6): BLS juice (low dose); Group 3 (n = 2): BLS juice (low dose).	3 stages, with a wash-out period of 1 wk; the volunteers received a high-fat breakfast after a 12-h fast, then a placebo of BSL juice was provided.	Phenolics, MDA, CAT, GPx activity; TNF-α	The high-fat meal induced postprandial hypertriglyceridemia and increased the concentration of MDA and GPx. This increase was attenuated in the group who received the highest dose of polyphenols when compared with the placebo.	–
57	Curl et al (2019)	Long-term randomized interventional trial;	Fruits and vegetables; Urine	Group 1 (n = 10): organic produce;	A parallel trial with a 1:1 allocation ratio, in which participants were	TCPY, IMPY, PNP, MDA, 4-F-3-PBA,	Pyrethroid biomarkers, including 3-PBA and trans-DCCA, were	–

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
		20; Idaho; Healthy pregnant women in early pregnancy (18 y–35 y)		Group 2 (n = 10): conventional produce	randomly assigned to either the "organic" or the "conventional" group, and the study lasted 24 wk.	3-PBA, and trans-DCCA	significantly higher in the conventional produce group compared with the organic produce group, but no statistically significant differences were observed in 4 biomarkers of OP exposure.	
58	Nimako et al (2022)	Nonrandomized interventional trial; 103; Japan; (<1 y–57 y)	Not explicitly stated; Urine	Group 1 (n = 36): organic diet for 5 d; Group 2 (n = 4): organic diet for 30 d; Group 3 (n = 63): conventional diet	The subjects in Groups 1–3 consumed a 5-d organic diet, 30-d organic diet, and conventional diet, respectively.	CLO, DIN, IMI, ACE, dm-ACE, THXM, NIT, and TCP	The %Df of NNIs, the rates of multiple NNI exposures, and the median cumulative levels of NNIs were significantly lower in the 5-d and 30-d organic diet consumers than in the conventional diet consumers.	–
60	Huynh et al (2020)	Cohort study; 271; United States; Senior men (mean age 53.3 y ± 17.6 y)	Not mentioned; NS	According to dietary patterns, subjects were divided into several groups, including the group "organic foods only" (n = 105).	The participants were recruited from a men's health clinic, and their dietary patterns were evaluated by questionnaires as: No specific diet, Organic foods only, No processed foods, Intermittent fasting, Whole foods only, Low-carb/Keto, Vegetarian/Pescatarian, Low-fat, and Other.	ED (IIEF-5 score of <22, ADAM data)	In multivariate analysis, after adjusting for age and BMI, patients reporting an organic diet were significantly less likely to have ED. After also accounting for comorbidities, patients adhering to an organic diet were approximately 1.8 times less likely to have ED.	–
59	Hyland et al (2019)	Nonrandomized self-controlled interventional trials; 16 participants from 4 families; United States; 7 adults (36 y–52 y) and 9 children (4 y–15 y)	All beverages except water, all food categories, and oils, condiments, and spices (organic phase); Urine	No groups; own overlapping comparison	The study lasted 12 d, and all family members were provided with certified organic food on days 6–11.	TCPY, MDA, total DMs, total DEs, 3-PBA, F-PBA, cDCCA, tDCCA, 5OH-Imd, 5OH-TBZ, Boscalid, Boscalid, 2,4-D	Significant reductions were observed in urinary levels of 13 pesticide metabolites and parent compounds representing OP, neonicotinoid, and pyrethroid insecticides and the herbicide 2,4-D following the introduction of an organic diet.	–
61	Fagan et al (2020)	Nonrandomized self-controlled interventional trials;	All beverages except water, all food categories, and oils,	No groups; own overlapping comparison	The study lasted 12 d; during days 6–11, all family members were provided	Glyphosate, AMPA	Mean urinary glyphosate and AMPA levels decreased 70.93% and	–

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
		16 participants from 4 families; United States; 7 adults (36 y–52 y) and 9 children (4 y–15 y)	condiments, and spices (organic phase); Urine		with certified organic food.		76.71%, respectively, within 6 d on an organic diet, and the decreases were also observed when the results for adults and children were analyzed separately.	
62	Corentin et al (2021)	Cross-sectional analysis; 1775 children and 2121 adults; France	12 food groups, including milk and dairy products, eggs, poultry, other meats, fish, fruits, vegetables, legumes, potatoes, bread and/or wheat, other cereals, and any other product	Linear regressions and logistic regression were performed to assess the association between organic index and BMI and obesity status.	Participants were asked to reported organic food frequency during the last 12 mo via questionnaires. For each food group, consumption was scored "always" = 3 points, "often" = 2 points, "rarely" = 1 point, "never" or "did not eat" = 0 points. The sum of the scores for 12 food groups constituted the index of organic food consumption.	Obesity and BMI for adults and children, and tri-ponderal mass index for children	There was a negative association between organic food consumption and both tri-ponderal mass index/BMI ($\beta = -.062$, $P = .001$ for children; $\beta = -.109$, $P < .001$ for adults) and obesity (OR = .935, $P = .010$ for children; OR = .944, $P < .001$ for adults), and the associations tended to remain statistically significant after controlling for several confounding variables concerning socio-economic status, quality of the diet, and physical activity.	–
63	Burns-Whitmore et al (2010)	A single-blind cross-over randomized trial; 20; United States; Healthy lacto-ovo-vegetarian adults (age 38 y ± 3 y)	Organic eggs; Blood	No groups; own overlapping comparison	Subjects received 3 × 8-wk dietary treatments (organic egg, n-3 fatty acid–enriched egg, or no egg) separated by 4-wk wash-out periods.	Serum β-carotene, lutein, and zeaxanthin	Compared with the control (no eggs), there was a significant increase ($P < .004$) in serum lutein after consuming either the organic egg or the n-3 fatty acid–enriched egg treatments; however, there was no difference between the 2 egg treatments for serum lutein.	0
64	Payet et al (2021)	Cohort study; 8081; France;	Not mentioned; NS	Group 1 (n = 3162): infrequent CCF/infrequent OFs;	Details of breastfeeding/infant formula feeding and complementary	Wheezing, asthma, and eczema	Feeding with OFs and/or CCFs during the complementary feeding period	+

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
		Infants (age 2 mo–5.5 y)		Group 2 (n = 1314): infrequent CCF/frequent OFs; Group 3 (n = 2631): frequent CCF/infrequent OFs; Group 4 (n = 963): frequent CCF/frequent OFs	feeding practices were collected. Parents monthly reported OFs (0, never; 1, sometimes; 2, often; and 3, always or almost always) and the frequency of feeding with CCFs.	between age 1 y and 5.5 y.	was not related to respiratory outcomes or eczema up to age 5.5 y; in adjusted analyses, children with frequent feeding with OFs but infrequent feeding with CCFs were more likely to have a food allergy from age >2 mo to 5.5 y. Children with frequent feeding with CCFs but infrequent feeding with OFs were less likely to have a food allergy from age >2 mo to 5.5 y.	
65	Qing Cheng et al (2022)	Crossover trial; 23; United States; Children (3 y–11 y)	Not mentioned; Urine	No groups; own overlapping comparison	Children participated in this study for both 15 and 12 consecutive days, respectively, consuming their normal conventional diets for the first 3 d, then switching to organic foods that the study provided for the following 5 consecutive days, and finally returning to their conventional eating regime for the remaining study days.	43 metabolites measured by global metabolomic profiling analysis, combining 3 independent analytical platforms, including measurement of the pesticide metabolite levels	Reduced oxidative stress and inflammatory responses and decreased detoxification demands when children switched their diets to mostly organic foods	–
66	Rempelos et al (2022)	Randomized crossover interventional trial; 27; England; Healthy adults (21 y–36 y)	Fruit, vegetables, and cereal products; Urine and blood	Conventional group (n = 14): conventional MedDiet; Intervention group (n = 13): organic MedDiet	The study lasted 5 wk, and the 2-wk MedDiet intervention period was in weeks 2 and 3. Before and after the intervention period, participants consumed habitual Western diets.	Urinary excretion and/or plasma concentrations of selected mineral micronutrients, toxic metals, and phenolic markers	The change of diet resulted in significant increases in urinary excretion of total phenolics, salicylic acid, mineral micronutrients Co, I, Mn, Ni, and plasma Se concentrations; however, no significant effects of food type (organic compared with conventional) were detected.	0
67	Agboola et al (2022)	Cluster-randomized crossover trial; 149;	Not mentioned; Urine	Group 1 (n = 43): organic diet followed by conventional diet;	2 periods (40 d of organic diet vs 40 d of	Cd, Pb, 8-iso-PGF2a, 8-OHdG, MDA	Percentage change between the conventional period and the	–

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Table 3 **Continued**

ID	Reference	Study type; Sample; Region; Population	Food type; Specimen	Groups	Duration and design	Outcome	Result	Association[a]
		Cyprus; Children (11 y–12 y)		Group 2 (n = 106): conventional diet followed by an organic diet	conventional diet); no wash-out period		organic food period was statistically significant only for creatinine-adjusted Pb (–3.9%); a significant negative interaction between days of treatment and the dietary organic intervention treatment was observed for creatinine-adjusted Pb (β = .021; 95% CI: .034, .008; *P*-adjusted = .01)	

[a]Whether there were statistically significant differences in outcomes before and after organic food intervention (or between the organic food group and the conventional food group): correlation between organic food and positive outcomes is indicated by "+", and correlation between organic food and negative outcomes is indicated by "–"; "0" indicates that there were no statistically significant differences between groups.

[b]Sixteen categories of labeled organic products: fruits; vegetables; soy-based products; dairy products; meat and fish; eggs; grains and legumes; bread and cereals; flour; vegetable oils and condiments; ready-to-eat meals; coffee, tea, and herbal tea; wine; biscuits, chocolate, sugar, and marmalade; other foods; and dietary supplements.

[c]Specific criteria for grouping: (1) conventional (ie, 50% of both the meat and dairy they consumed was of organic origin, or they ate no meat and 50% of the dairy they consumed was of organic origin, or they ate no dairy and 50% of the meat they consumed was of organic origin); (2) 50%–90% organic (ie, 50% of both the meat and dairy they consumed was of organic origin, but 90% of either meat or dairy was of organic origin, or they ate no meat and 50%–90% of the dairy they used was of organic origin, or they ate no dairy and 50%–90% of the meat they consumed was of organic origin); (3) 90% organic (ie, 90% of both the meat and dairy they consumed was of organic origin, or they ate no meat and 90% of the dairy they consumed was of organic origin, or they ate no dairy and 90% of the meat they consumed was of organic origin); (4) other (including any combination of 50% meat of organic origin and 50% dairy of organic origin or vice versa, and missing and inconsistent data). *Abbreviations*: BLS, beet leaves and stalks; BMI, body mass index; C, conventional agricultural system; CCF, commercial complementary food; CKD, chronic kidney disease; Cu, copper; ED, erectile dysfunction; GDM, gestational diabetes; HDL, high-density lipoprotein; IFN, interferon; IgE, immunoglobulin E; IL, interleukin; LDL, low-density lipoprotein; MDA, malondialdehyde; MDOO, meat and dairy products of organic origin; MedDiet, Mediterranean diet; MetS, metabolic syndrome; mo, month(s); NS, not stated; OA, organic agricultural system using animal manure; OB, organic agricultural system using cover crops; OM, otitis media; OP, organophosphate; OR, odds ratio; Org-FFQ, organic FFQ; OS, organic food score; Pb, lead; RR, relative risk; WBC, white blood cell; %Df, a decreasing detection frequency; 2,4,5-T, 2,4,5-Trichlorophenoxy acetic acid; 2,4-D, 2,4-Dichlorophenoxyacetic acid; 2-AAS, 2-aminoadipic semialdehyde; 3M-4NP, 3-Methyl-4-nitrophenol; 3-PBA, 3-phenoxybenzoic acid; 4-F-3-PBA, 4-fluoro-3-phenoxybenzoic acid; 4NP, Amino-methyl-phosphoric acid; 5OH-Imd, 5-Hydroxy-Imidacloprid; 5OH-TBZ, 5-Hydroxy-Thiabendazole; 6-CNA, 6-Chloronicotinic acid; 8-OHdG, 8-hydroxy-20-deoxyguanosine; ACE, acetamiprid; AMPA, aminomethylphosphonic acid; AOA, total antioxidant activity; BMI z-scores, age-and sex-standardized BMI z-scores; Br2CA, cis-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid; CAT, catalase; CCC, Chlormequat; Cd, cadmium; cDCCA, cis-2,2-(Dichloro)-2-dimethyl vinyl cyclopropane carboxylic acid; Cl2CA, cis-/trans-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid; CLA, conjugated linoleic acid isomers; CLO, clothianidin; CMHC, 3-chloro-4-methyl-7-hydroxycoumarin; CPMO, Chlorpyrifos-methyl-oxon; CPO, Chlorpyrifos-oxon; CRP, C-reactive protein; CysC, cystatin C; DAPs, dialkylphosphates; DEAMP, 2-(diethylamino)-6-methylpyrimidin-4-ol/one; DEAMPY, 2-diethylamino-6-methylpyrimidin-4-ol; DEDTP, diethyldithiophosphate; DEP, diethylphosphate; DETP, diethylthiophosphate; DIN, dinotefuran; dm-ACE, N-dm_acetamiprid; DMDTP, dimethyldithiophosphate; DMP, dimethylphosphate; Eps, diethylphosphates; FFQ, Food frquency questionnaire; F-PBA, 4-fluoro-3-phenoxybenzoic acid; GLY, N-(phosphonomethyl)glycine; GPx, glutathione peroxidase; GR, glutathione reductase; GSH, reduced glutathione; GSH-Px, glutathione peroxidase; IMI, imidacloprid; IMPY, 2-isopropyl-6-methyl-pyrimidin-4-ol; m-PBA, 3-Phenoxybenzoic acid; NIT, nitenpyram; ORAC, oxygen radical absorbance capacity; PABA, p-amino benzoic acid; PBMC, peripheral blood mononuclear cells; PNP, para-nitrophenol; SOD, superoxide dismutase; TAC, total antioxidant capacity; TAG, triglyceride; t-CDCA, trans-Chrysanthemumdicarboxylic acid; TCHP, 3,5,6-Trichloro-6-hydroxypyridine; TCP, thiacloprid; TCPY, 3,5,6-trichloro-2-pyridinol; tDCCA, trans-2,2-(Dichloro)-2-dimethyl vinyl cyclopropane carboxylic acid; TEAC, Trolox equivalent antioxidative capacity; tHcy, total plasma homocysteine; TNF, tumor necrosis factor; total DEs, total DEs = DEP+ DETP + DEDTP; total DMs, total DEs = DMP+ DMTP + DMDTP; TTCA, 2-Thio thiazolidin-4-carboxylic acid; TVA, trans-vaccenic acid; UPRE, urinary pesticide residue excretion; FRAP, ferric-reducing ability of plasma; ORAC, oxygen radical absorbance capacity; CAT, catalase; GSH-Px, glutathione peroxidase; eSOD, erythrocytesuperoxide dismutase; eCAT, erythrocyte catalase; eTBARS, erythrocyte thiobarbituric acid reactive substances; PBMC, peripheral blood mononuclear cells

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Table 4 **Summary of studies examining the relationship between organic food intake and potential health effects**

Outcome	Associated with organic food (reference ID)	Not associated with organic food (reference ID)	n/N[a]	Association level[b]
Biomarkers				
Pesticide exposure	24, 25, 30, 34, 46, 47, 48, 49, 52, 53, 57, 58, 60, 61, 65	45	15/16	Beneficial correlation
Toxic metals	67	50, 52, 55, 66	1/5	No association
Fatty acids in human milk	39, 40		2/2	Insufficient
Nutrients in plasma				
Phenolics	22, 24, 30, 55, 56	20, 23, 66	5/8	Beneficial correlation
Carotenoids	50	18, 19, 20, 28, 63	1/6	No association
Other nutrients[c]	38, 50, 55	18, 19, 20, 21, 66	3/8	No association
Serum parameters[d]	27, 54, 55, 56	19, 20, 21, 29	4/8	Inconsistent
Total antioxidant status[e]	22, 26, 56, 65	19, 20, 21, 23, 29	4/9	Inconsistent
Disease and functional change			16/17	Beneficial correlation
Body mass index or obesity	27, 42, 53, 62		4/4	Beneficial correlation
Metabolic syndrome	44		1/1	Insufficient[g]
Cancer	33, 43		2/2	Insufficient[g]
Allergy[f]	41, 64		2/2	Insufficient
Otitis media	40		1/1	Insufficient[g]
Pre-eclampsia	36		1/1	Insufficient[g]
Hypospadias or cryptorchidism	35, 37		2/2	Insufficient[g]
Gestational diabetes		51	0/1	Insufficient
Reproductive-related diseases	31, 32, 59		3/3	Insufficient[g]

ID refers to the included study's reference number.

Abbreviations: FRAP, ferric-reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TEAC, Trolox equivalent antioxidative capacity; CuZn-SOD, copper zinc-superoxide dismutase; CAT, catalase; GSH-Px, glutathione peroxidase; GR, glutathione reductase; MDA, malondialdehyde; 2-AAS, 2-aminoadipic semialdehyde; eSOD, erythrocytesuperoxide dismutase; eCAT, erythrocyte catalase; eTBARS, erythrocyte thiobarbituric acid reactive substances; PBMC, peripheral blood mononuclear cells.

[a]N = the total number of studies that include this outcome, n = the number of studies which reported statistical difference.

[b]The association level rated according to the criteria listed in Table 2.

[c]Including fatty acids in the plasma, vitamin A, vitamin C, vitamin E, and inorganic elements.

[d]Including glucose, triacylglycerol, cholesterol, urea, uric acid, high-density-lipoprotein cholesterol, low-density-lipoprotein cholesterol, C-reactive protein, cystatin C, and creatinine.

[e]Including FRAP, ORAC, TEAC, DNA strand breaks, CuZn-SOD, CAT, GSH-Px, GR, MDA, 2-AAS, eSOD, eCAT activities, eTBARS, PBMC proliferation, percentages of NK cells, the lytic activity of NK cells, cytokine secretion, and Tumor Necrosis Factor α.

[f]The directions of the results in these 2 studies were opposite; a detailed description has been provided in Table 3.

[g]There was a favorable association between organic food intake and this outcome.

level of association classification was rated as "beneficial", and this beneficial association was consistent for the interventional trials (Table 5). These studies measured various biomarkers related to pesticide exposure, including organophosphorus (11),[24,25,30,33,46–49,52,57,60] pyrethroid (6),[33,46,52,53,57,60] neonicotinoid (4),[52,53,58,60] glyphosate (2),[45,61] herbicides (3),[46,52,60] plant growth regulators (1),[52] and fungicides (1).[52]

Of these 16 studies, 12 were interventional trials,[24,25,30,46,49,52,53,57,58,60,61,65] 3 were cross-sectional studies,[45,47,48] and 1 was a cohort study.[34] All interventional trials reported statistically significant results. The interventions primarily involved the consumption of organic vegetables and fruits, and 5 studies did not specify the type of food used.[30,49,53,58,65] The duration of the interventions ranged from 5 days to 24 weeks.[46,57] Six trials were conducted in adults[30,34,45,47,49,52] and 5 in children.[24,25,46,48,53]

Due to the limited number of studies with sufficient data, meta-analysis was only carried out for 3,5,6-trichloro-2-pyridinol (TCPy), a biomarker for organophosphorus pesticide exposure, based on 3 studies.[24,57,60] The meta-analysis revealed no statistically significant difference in the urinary concentration of TCPy between the group consuming organic food and the group consuming conventional food (SMD: –.57, 95% CI: –1.38, .25) (Figure 2).

Other biomarkers

A total of 22 publications investigated the effect of organic food intake on biomarkers other than those indicating pesticide exposure,[18–23,26–30,38,39,50,52,54–56,63,65–67] including 18 trials,[18–23,26–30,52,55,56,63,65–67] 3 cohort studies,[38,39,50] and 1 cross-sectional analysis.[54] Only 2 investigations were conducted in children.[65,67] The range of intervention time in the trials ranged from several minutes to 4 weeks,[20,55] and most interventions involved single food items, including eggs, tomatoes, apples, carrots, red grape juice, etc.

The level of association of organic food with fatty acids in human milk was assessed as having "insufficient" evidence due to the limited number of studies. The levels of association of organic food intake

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Table 5 **Subgroup analysis of studies examining the relationship between organic food intake and potential health effects**

Outcome	Interventional trials		Cohort study		Cross-sectional study	
	Reference ID	n/N[a]	ID	n/N[a]	ID	n/N[a]
Biomarkers						
Pesticide exposure	24[g], 25[g], 30[g], 46[g], 49[g], 52[g], 53[g], 57[g], 58[g], 60[g], 61[g], 65[g]	12/12	34[g]	1/1	45, 47[g], 48[g]	2/3
Toxic metals	52, 55, 66, 67[g]	1/4	50	0/1		0/0
Fatty acids in human milk		0/0	39[g], 40[g]	2/2		0/0
Nutrients in plasma		0/0		0/0		0/0
Phenolics	20, 22[g], 23, 24[g], 30[g], 55[g], 56[g], 66	5/8		0/0		0/0
Carotenoids	18, 19, 20, 28, 63	0/5	50[g]	1/1		0/0
Other nutrients[b]	18, 19, 20, 21, 55[g], 66	1/6	38[g], 50[g]	2/2		0/0
Serum parameters[c]	19, 20, 21, 27[g], 29, 55[g], 56[g]	3/7		0/0	54[g]	1/1
Total antioxidant status[d]	19, 20, 21, 22[g], 23, 26[g], 29, 56[g], 65[g]	4/9		0/0		0/0
Disease and functional change		2/2		10/10		4/5
Body mass index or obesity	27[g], 53[g]	2/2	42[g]	1/1	62[g]	1/1
Metabolic syndrome		0/0	44[g]	1/1		0/0
Cancer		0/0	33[g], 43[g]	2/2		0/0
Allergy[e]		0/0	41[g], 64[g]	2/2		0/0
Otitis media		0/0	40[g]	1/1		0/0
Pre-eclampsia		0/0	36[g]	1/1		0/0
Hypospadias or cryptorchidism		0/0	35[g]	1/1	37[f,g]	1/1
Gestational diabetes		0/0		0/0	51	0/1
Reproductive-related diseases		0/0	59[g]	1/1	31[g], 32[g]	2/2

ID refers to the included study's reference number.

Abbreviations: FRAP, ferric-reducing ability of plasma; ORAC, oxygen radical absorbance capacity; TEAC, Trolox equivalent antioxidative capacity; CuZn-SOD, copper zinc-superoxide dismutase; CAT, catalase; GSH-Px, glutathione peroxidase; GR, glutathione reductase; MDA, malondialdehyde; 2-AAS, 2-aminoadipic semialdehyde; eSOD, erythrocytesuperoxide dismutase; eCAT, erythrocyte catalase; eTBARS, erythrocyte thiobarbituric acid reactive substances; PBMC, peripheral blood mononuclear cells.

[a]N = the total number of studies that include this outcome, n = the number of studies that reported statistical difference.

[b]Including fatty acids in plasma, vitamin A, vitamin C, vitamin E, and inorganic elements.

[c]Including glucose, triacylglycerol, cholesterol, urea, uric acid, high-density-lipoprotein cholesterol, low-density-lipoprotein cholesterol, C-reactive protein, cystatin C, creatinine.

[d]Including FRAP, ORAC, TEAC, DNA strand breaks, CuZn-SOD, CAT, GSH-Px, GR, MDA, 2-AAS, eSOD, eCAT activities, eTBARS, PBMC proliferation, percentages of NK cells, the lytic activity of NK cells, cytokine secretion, Tumor Necrosis Factor α.

[e]The directions of the results in the 2 studies was different; a detailed description has been provided in Table 3 or in the "Results."

[f]This study (ID 37) is a case–control study.

[g]Indicating that the outcome was associated with organic food.

Study or subgroup	Organic food Mean	SD	Total	Conventional food Mean	SD	Total	Weight	SMD IV, Fixed, 95% CI
Hyland (2019)	1.34	4.014	78	2.78	6.246	80	45.8%	−0.27 [−0.59, 0.04]
L. Curl (2019)	0.2	0.105	10	0.2	0.259	10	5.8%	0.00 [−0.88, 0.88]
Lu (2006)	1.7	2.7	116	7.2	5.8	87	48.4%	−1.27 [−1.58, −0.97]
Total (95% CI)			**204**			**177**	**100.0%**	**−0.74 [−0.95, −0.53]**

Heterogeneity: Chi² = 22.99, df = 2 ($P < 0.0001$); $I^2 = 91\%$
Test for overall effect: $Z = 6.84$ ($P < 0.00001$)

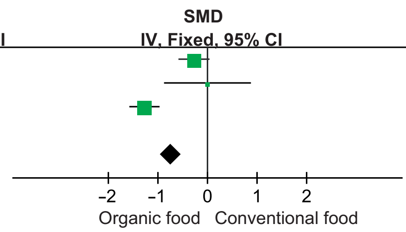

Figure 2 **Meta-analysis of the effect of organic food intervention on the concentrations of 3,5,6-trichloro-2-pyridinol (TCPy) in urine.** *Abbreviations*: IV, inverse variance; SD, standard deviation; CI: confidence interval; SMD, standardized mean difference.

with toxic metals and carotenoids were each classified as "no association", of organic food intake with phenolics was classified as "beneficial", and of organic food intake with serum parameters, and with total antioxidant status were each defined as "inconsistent" (Table 4). A beneficial association was identified between phenolics and organic food in the interventional trials (Table 5).

Diseases and functional change

Seventeen studies were identified that investigated the effect of organic food consumption on diseases or functional changes,[27,31–33,35–37,40–44,51,53,59,62,64] including 2 interventional studies,[27,53] 10 cohort studies,[33,35,36,40–44,59,64] 4 cross-sectional studies,[31,32,51,62] and a case–control study.[37] The overall correlations between organic

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food consumption and "diseases and functional change" and between organic food consumption and "BMI or obesity" were each classified as "beneficial" (Table 4).

Obesity/BMI. Four studies specifically reported on the effect of an organic food diet on obesity or BMI, and all concluded that increased organic food consumption was associated with a lower BMI or a reduced risk of obesity.[27,42,53,62]

Pregnant women study. Five studies investigated the association between organic food consumption in pregnant women and the risk of disease in the mother or offspring.[35–37,41,51] An association between organic food consumption and reduction in pre-eclampsia (OR = .79, 95% CI: .62–.99) and between organic food consumption and reduction in hypospadias (OR = .42, 95% CI: .25–.70) was observed in the same cohort, respectively.[36,37] Additionally, there was an association between rarely or never choosing organic high-fat dairy products during pregnancy and increased odds of hypospadias in offspring (OR = 2.18, 95% CI: 1.09–4.36).[38] A significant negative association was observed between an organic diet during pregnancy and at least 1 otitis media episode (OR = 2.12, 95% CI: 1.01–4.47).[42] Organic food consumption tended to be lower in women with gestational diabetes than in women without gestational diabetes, but the difference was not statistically significant.[52]

Allergy. Kummeling et al discovered that feeding infants with organic dairy products had a protective effect against eczema risk in the first 2 years of life (OR = .64,95% CI: .44–.93).[41] However, another cohort study reported that feeding with organic food during the complementary feeding period was not related to respiratory outcomes or eczema up to age 5.5 years; moreover, children fed frequently with organic food but infrequently with commercial complementary foods were more likely to have a food allergy.[65]

Reproductive functional change and disease. It was found that men who ate organic food had a higher sperm concentration, a reduced prevalence of previous reproductive disorders, a higher incidence of cryptorchidism,[32] and a higher proportion of normal sperm.[33] A cohort study conducted in senior men reported patients adhering to an organic diet were approximately 1.8 times less likely to have erectile dysfunction.[60]

Cancer. Two large cohort studies examined the association between the consumption of organic food and the risk of cancer.[33,44] It was reported that high organic food scores were inversely associated with the overall risk of cancer in a French population,[34] and a beneficial association of organic food with non-Hodgkin lymphoma was observed in British women (RR = .79, 95% CI: .65–.96).[45]

DISCUSSION

To our knowledge, this is the most comprehensive systematic review exploring the effects of organic food intake on health. Furthermore, we developed criteria for classifying the level of association between organic food and health effects, and assessed both the qualitative and quantitative impacts of organic food intake on various health outcomes. We found that there was a beneficial association between organic food intake and pesticide exposure reduction, overall burden of disease and functional changes, and BMI or obesity.

Pesticide exposure

The findings of the interventional trials indicated that an organic diet intervention can reduce pesticide exposure, though more research is needed to quantify the benefits of reducing exposure to particular pesticides. Pesticide residues in food have been a controversial topic of public discussion, and many consumers choose organic food to avoid them. Previous meta-analyses have shown that the risk of pesticide residues being detected in organic food production is 30% lower than that in conventional food production,[4] providing evidence for the benefits of consuming organic food. However, the present meta-analysis found no significant difference in the TCPy concentration in urine when comparing the organic and conventional groups. While pesticide residues detected in food produced organically were significantly lower, the level of correlation between pesticide residues detected in food samples and the absorbed pesticide dose measured in biological samples has rarely been determined, making it difficult to draw definitive conclusions.[69]

Previous research has largely focused on organophosphate pesticides, which were once the most frequently used.[67] However, the use of organophosphorus pesticides has declined in the United States since the passage of the Food Quality Protection Act in 1996, and this decrease reflects a shift toward the use of other classes of insecticides[58]; the use of pyrethroids and neonicotinoids has increased, and neonicotinoids are now the most widely used class of insecticides worldwide.[33] Further research is needed to assess the impact of exposure to individual pesticides.

Biomarkers in vivo

Based on the findings of this systematic review, the impact of organic food intake on physiological

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parameters, including immune and endocrine biomarkers, is unclear and may vary with food type, population health status, and intervention duration. The nutritional quality of food is influenced by factors such as food type, season, and environment, which could explain why organically produced food has a higher nutritional quality.

However, the impact of organic food intake may vary depending on the type of food and the duration of the intervention. More than half of the included interventional trials focused on single food interventions, mainly involving fruits. While these trials may be useful for investigating the health effects of specific organic foods, they do not reflect the diversity of foods in a typical diet. For instance, the NutriNet-Santé study found that individuals with different organic food consumption patterns tended to consume different types of food, and intake of plant-based foods increased with the proportion of organic foods in the diet.[70] Additionally, most intervention durations in the included studies were relatively short, around 2 weeks, making it challenging to assess the long-term impact of an organic diet. Stracke et al did not observe any health benefits after short-term (several minutes) or long-term (4 weeks) organic apple interventions,[21] likely due to the rapid elimination of apple polyphenols from the body. Conversely, Akçay et al concluded that the long-term consumption of organic red wine may have more potent antioxidant activity than a single dose,[24] possibly due to the storage capacity for flavonoids in the body. Therefore, future long-term intervention studies should consider the absorption, metabolism, and excretion of the various phytochemicals from the human body to better assess the health impact of organic foods.

The health status of study participants is also an important consideration. Most of the included studies selected healthy adults as subjects; however, some studies have reported that a reduction in C-reactive protein (a pro-inflammatory plasma marker) after consuming organic food was only observed in patients with chronic kidney disease,[28] and the modulating effect of enzymatic antioxidant protection from organic beet leaves and stalks (BLS) was only found in individuals with dyslipidemia.[57] Hughes et al suggested that supplementation with carotenoids might be appropriate for undernourished or less healthy individuals, particularly among the elderly.[71] Therefore, changes in biological function associated with organic food intake may be more clinically significant in unhealthy populations.

Organic food intake and disease

The majority of the included studies reporting disease outcomes were observational in nature. Multiple disease outcomes were reported in the included studies, including allergy, hypospadias, erectile dysfunction, preeclampsia, obesity, metabolic syndrome, and cancer. Although the evidence for an effect on each individual disease may be insufficient, these findings suggest a beneficial association between organic foods and overall disease and functional changes. One possible explanation for this overall beneficial association is the lower levels of pesticide residues and higher nutrient concentrations in organic food. Higher levels of n-3 PUFAs have been reported in organic milk,[4] which might explain the beneficial association with a lower eczema risk.[41]

Pesticides may interfere with the development of the male reproductive system, through their estrogenic or anti-androgenic activity, and animal studies support their role in the development of male reproductive disorders.[72] Pesticides also act on membrane receptors and enzymes in the steroid biosynthetic pathway, which can be delivered through the placenta during fetal development and lead to pregnancy disorders such as preeclampsia.[71] In addition, pesticides can impair glucose metabolism and induce insulin resistance, resulting in an increased risk of obesity and other chronic diseases. Moreover, pesticides can have a significant impact on human health by altering the composition and diversity of the gut microbiota, leading to abnormal intestinal barrier function and the development of diseases.[73] Possible underlying mechanistic pathways for the carcinogenicity of pesticides include structural DNA damage and functional damage through epigenetic mechanisms.[34,45]

Furthermore, it is important to consider reverse causation bias and confounding bias when making causal inferences about the health effects of organic food. Payet et al reported that a history of allergy strongly affects feeding with organic food during the complementary feeding period.[65] Meanwhile, organic food consumption could be associated with increased odds of food allergy later in childhood. Similar confusion arises when examining the association of organic food with other diseases such as obesity and cancer. Organic food consumers tend to be younger and thinner, with diets of higher nutritional quality, and they tend to be followers of a healthy lifestyle.[70] It is worth exploring whether the beneficial effects of organic food are the results of the general characteristics of the consumers or of the intake of organic food itself.

Finally, it is worth noting that the populations in the studies included in this review vary widely, and the studies cover topics ranging from allergies in infants to reproductive function in the elderly. This suggests that an organic food diet may be beneficial for people of all ages. However, given the special physiological states of children and the elderly, and the high cost of organic food, it

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may be more cost-effective to investigate the health effects of an organic diet among these special populations. Moreover, most of the included studies were conducted in economically advanced countries, with only 2 being conducted in Brazil. Given the current increasing environmental consciousness of consumers,[74] it would be worthwhile launching studies on the health effects of organic diets in developing countries.

LIMITATIONS

First, language bias could not be avoided, because only English articles were included; however, our review covers studies undertaken in a wide range of non-English-speaking countries. In addition, although we took measures to avoid omitting relevant literature, reporting and publication biases remain potential limitations of systematic reviews. Second, the limited number of studies for any particular outcome prevented us from examining the dose–response relationship of organic food intake with outcomes. Similarly, we were only able to conduct a meta-analysis for TCPy, as few studies were identified for other outcomes. Third, the conclusions regarding the association between organic food and disease were largely based on observational studies, and only a limited number of trials were included. Therefore, there is a need for more interventional trials to further investigate this association. Moreover, caution should be exercised when interpreting the findings, due to the heterogeneity among the included studies in terms of study design, population characteristics, organic food types, and statistical and analytical approaches employed.

CONCLUSION

The beneficial relationship between organic food intake and pesticide exposure is comparatively robust. There are indications of an overall positive association between an organic diet and improved health outcomes and physiological changes, but further research is needed to establish a definitive link with individual diseases beyond obesity.

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Supporting Information

The following Supporting Information is available through the online version of this article at the publisher's website.

Appendix S1 **Search strategy in EMBASE**
Table S1 **Abbreviated list**
Figure S1 **Bias assessments of interventional trials**

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