

Nutrition-related health effects of organic foods: a systematic review^{1–4}

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ABSTRACT

Background: There is uncertainty over the nutrition-related benefits to health of consuming organic foods.

Objective: We sought to assess the strength of evidence that nutrition-related health benefits could be attributed to the consumption of foods produced under organic farming methods.

Design: We systematically searched PubMed, ISI Web of Science, CAB Abstracts, and Embase between 1 January 1958 and 15 September 2008 (and updated until 10 March 2010); contacted subject experts; and hand-searched bibliographies. We included peer-reviewed articles with English abstracts if they reported a comparison of health outcomes that resulted from consumption of or exposure to organic compared with conventionally produced foodstuffs.

Results: From a total of 98,727 articles, we identified 12 relevant studies. A variety of different study designs were used; there were 8 reports (67%) of human studies, including 6 clinical trials, 1 cohort study, and 1 cross-sectional study, and 4 reports (33%) of studies in animals or human cell lines or serum. The results of the largest study suggested an association of reported consumption of strictly organic dairy products with a reduced risk of eczema in infants, but the majority of the remaining studies showed no evidence of differences in nutrition-related health outcomes that result from exposure to organic or conventionally produced foodstuffs. Given the paucity of available data, the heterogeneity of study designs used, exposures tested, and health outcomes investigated, no quantitative meta-analysis was justified.

Conclusion: From a systematic review of the currently available published literature, evidence is lacking for nutrition-related health effects that result from the consumption of organically produced foodstuffs. *Am J Clin Nutr* 2010;92:203–10.

INTRODUCTION

There is increasing global demand for organic food (1), and there is evidence that some consumers purchase organic foodstuffs on the understanding that they are healthier than conventionally produced foodstuffs (2–5). To our knowledge, there is currently no independent, systematic, evidence-based statement on the potential nutrition-related health effects of consuming organic foods.

Organic foodstuffs are produced according to specified standards that emphasize the protection of the environment and control of the use of chemicals in crop production and medicines in animal production (6, 7). A recent systematic review of peer-reviewed evidence published in the past 50 y concluded that organically and conventionally produced foodstuffs are broadly comparable in their nutrient content (8).

The current systematic review was designed to assess the strength of evidence of the nutrition-related benefits to human health of consumption of organic foodstuffs. This review does not address potential health effects of differences in contaminant content (such as herbicide, pesticide, and fungicide residues) of organically and conventionally produced foodstuffs or of potential wider environmental or occupational health effects of different agricultural practices. Establishing the strength of the existing evidence base that relates to nutrition-related health benefits of organic food consumption will assist policymakers in the development of evidence-based statements on potential public-health gains or risks that result from organic food consumption and support consumers to make informed choices.

METHODS

We conducted a systematic review of peer-reviewed literature published in the past 50 y from 1 January 1958 to 15 September 2008. Before publication, we updated our systematic review to 10 March 2010 to ensure that we included the latest research reports. As far as possible, we adhered to the guidelines for the reporting of systematic reviews (9).

Search strategy

Search strategies were developed in PubMed (<http://www.ncbi.nlm.nih.gov/pubmed/>) by using Medical Subject Headings and title/abstract terms to identify relevant exposures (organic compared with conventional production methods) and outcomes (health and health-related measures). The exposure terms searched (including all headings, subheadings, and title/abstract terms of the Medical Subject Headings) were as follows: organic, health food, conventional combined with food, agricultural crop, livestock,

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agriculture, production, nutrition, diet, and consumption. These terms were combined with a list of terms that describe relevant health outcomes that fall under the following categories: respiratory diseases, inflammatory diseases (including allergy/immune-related diseases), nutrient status and micronutrient deficiencies, reproductive health, eye diseases, noncommunicable chronic diseases, weight gain and obesity, diabetes, cardiovascular disease, cancer, dental diseases, and osteoporosis (*see* supplemental material under “Supplemental data” in the online issue for a full list of search terms). Multiple-database searching [PubMed, ISI Web of Science (http://isiwebofknowledge.com/products_tools/multidisciplinary/webofscience/), CAB Abstracts (<http://www.cabi.org/cababstracts>), and Embase (<http://www.embase.com/>)] was used to ensure comprehensive article retrieval in the original systematic review (to 15 September 2008), and 2 key databases (PubMed and CAB Abstracts) were searched in the systematic review update (to 10 March 2010).

Selection criteria and data extraction

The full texts of all potentially relevant articles were retrieved and assessed in duplicate for inclusion by 2 independent reviewers (AA and AH), and any disagreement was resolved in discussion with the project lead (ADD). All studies with an English abstract published in peer-reviewed journals in any language were included if they reported a comparison of health outcomes resulting from consumption of or exposure to foodstuffs from organic (reported by authors as organic, ecologic, and bioorganic) or conventional (reported by authors as conventional and intensive) farming systems. Articles were excluded if they were concerned with occupational health outcomes unrelated to consumption of organic or conventional foodstuffs (eg, the health of organic compared with conventional farmers), investigated animal health from an exclusively veterinary perspective (eg, the effect of agricultural practice on animal reproductive health), or were primarily concerned with the effects of nonnutrient contaminant content (eg, chemical residues and heavy metals). A hand search of reference lists of studies included in the review was conducted to check the completeness of the initial electronic searches. Subject experts ($n = 23$) identified from relevant publications were contacted by e-mail; we received 12 responses and were sent 11 publications that were all either not relevant ($n = 1$) or had previously been identified ($n = 10$). Gray literature (conference abstracts and unpublished studies) was not included. Data extraction was performed in duplicate for all included articles by 2 independent reviewers (AA and AH), and any inconsistencies were corrected as necessary in consultation with the project lead (ADD).

Study designs

We considered 3 main study types for inclusion in the review: human studies including randomized and nonrandomized controlled trials and studies with cohort, case-control, and cross-sectional designs; in vitro and ex vivo studies in human or animal cell lines and serum used to investigate human-related cell mechanisms; and animal studies that were explicit models of physiologic, biochemical, or other processes in humans.

Study quality

Each study included in the review was assessed for quality on the basis of the following 4 criteria that were defined a priori as essential to answer the research question: a clear definition of the organic production methods for the foodstuffs including the name of the organic certification body, a statement on the nature (ie, type, amount, or proportion) of the organic component of the foodstuff or diet under investigation, a clear definition of the health outcome and how it was measured, and a statement of the statistical methods used for data analyses. Studies were defined as being of satisfactory quality if they met all 4 criteria.

Data analyses

A statistical meta-analysis was not justified because of the marked heterogeneity of the included studies. We followed guidance from the Cochrane handbook, which supports the use of a systematic, narrative approach when a meta-analysis is inappropriate (10). We synthesized the results according to study hypothesis, study design, exposure, and health outcome.

External review

An independent, expert review panel was created to oversee and advise on the conduct of the review. The review panel comprised a subject expert (Julie Lovegrove, University of Reading, Reading, United Kingdom) and an expert in public health nutrition with systematic review experience (Martin Wiseman, University of Southampton, Southampton, United Kingdom, and World Cancer Research Fund International, London, United Kingdom). The expert independent review panel and experts at the Food Standards Agency (London, United Kingdom) provided feedback on the review protocol that was incorporated into the version posted online on 18 April 2008 (<http://www.lshtm.ac.uk/nphiru/research/organic/>). An updated version of the protocol, which was modified on the basis of the experience of conducting an earlier review (8) was finalized on 21 October 2008 and posted online on 30 January 2009. Relevant subject experts and external bodies were alerted to the review process and the availability of the review protocol. A draft of the final report was reviewed and approved by the expert, independent review panel and by 2 subject experts selected by the funders. Relevant peer-review comments were incorporated into this report.

RESULTS

Overview of studies identified

The original systematic search strategy identified 91,989 unique citations of which 45 articles were included as potentially relevant. An examination of the full text of these articles resulted in the exclusion of 37 studies that did not meet the inclusion criteria (**Figure 1**). The systematic review update identified an additional 6738 unique citations of which 17 articles were included as potentially relevant, and an examination of article full texts resulted in the exclusion of 14 studies (**Figure 1**). There were several reasons for the exclusion of potentially relevant articles, which included the lack of a study outcome of direct relevance to human public health ($n = 22$) and the absence of

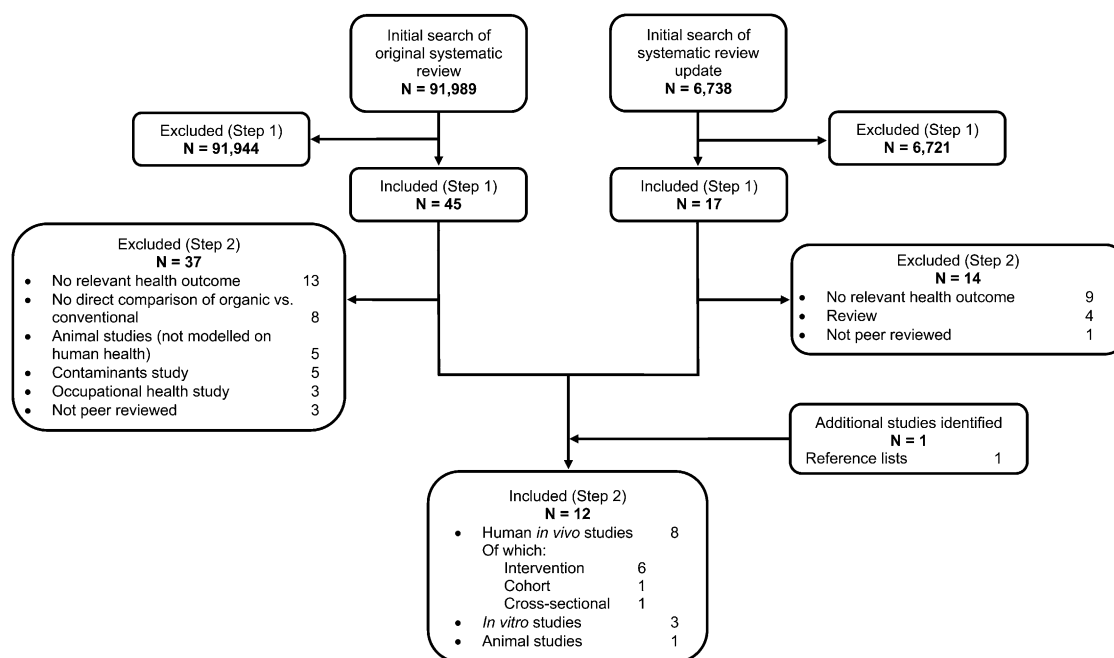


FIGURE 1. Flow chart of study selection process for the original systematic review (1 January 1958 to 15 September 2008) and the systematic review update (16 September 2008 to 10 March 2010) of the available evidence of nutrition-related health benefits of organic food.

a direct comparison of the health effects of organic compared with conventional foodstuff consumption or exposure ($n = 8$) (see supplemental material under “Supplemental data” in the online issue). A hand search of reference lists of the 63 potentially relevant articles identified one additional relevant study (11).

A final total of 12 publications [8 human *in vivo* studies (11–18), 3 human *in vitro* studies (19–21), and one animal study (22)] were included in the review (**Table 1**). Four of the 12 studies included in the review (33%) met the predefined quality criteria (12, 17, 18, 22), 7 studies failed to specify the certification body under which the organic foodstuffs that were studied were produced (11, 13–16, 19, 20), and one publication did not provide sufficient information on the nature of the organic foodstuff under investigation (21). In the largest human study conducted to date, the proxy-reported consumption of strictly organic dairy products was associated with a reduced risk of proxy-reported eczema in infants (15). The majority of the remaining studies showed no evidence of differences in nutrition-related health outcomes that resulted from exposure to organic or conventionally produce foodstuffs (Table 1). Given the small amount of studies identified in this review, all studies were included in the narrative synthesis independent of quality grading.

Study hypotheses

Eight of the 12 studies (67%) were predicated on the hypothesis that organic production methods result in higher nutrient concentrations in foodstuffs and that these compositional differences would result in different health responses (11, 13, 15, 16, 19–22). The remaining 4 studies hypothesized that agricultural production methods differentially affect markers of carcinogenesis (12) or the bioavailability of carotenoids (17) or polyphenolic substances (14, 18).

Study designs

There were 8 human studies that included 6 clinical trials (11–14, 17, 18), 1 cohort study (15), and 1 cross-sectional survey (16) and 4 reports of experiments conducted in animals (rats) (22) or human cell lines (20, 21) or serum (19). The clinical trials were generally small (sample sizes ranging from 6 to 43 in total) and short (an exposure period ranging from 1–28 d). The cross-sectional (16) and cohort (15) studies were considerably larger (sample sizes: 312 and 2764, respectively) and were both derived from the KOALA [Kind, Ouders en gezondheid: Aandacht voor Leefstijl en Aanleg (Child, Parent and Health: Lifestyle and Genetic Constitution)] Birth Cohort Study, which investigated influences of lifestyle and genetic constitution on the health of children and parents (23). These 2 studies had some design shortcomings, which included self- or proxy-reported measures of exposure (15, 16), a lack of information on the duration of exposure (16), and proxy-reported measures of primary outcomes (15). The 4 remaining studies used contrasting approaches to test different biological materials in animal or human samples (19–22).

Exposures

The majority of included articles (10 of 12 studies; 83%) studied the effects of specific foodstuffs: in 7 articles, fruit or vegetables were studied (12, 13, 17–20, 22), in 2 articles, wine was studied (11, 21), and in one article, livestock products were studied (16). Nine studies (75%) specifically investigated foodstuffs known to be rich in antioxidants such as tomatoes, grapes, apples, carrots, and strawberries (11–13, 17–22). Only 2 studies investigated organic foodstuffs as part of the whole diet (14, 15). The methods used for the measurement of exposure also varied. The majority of studies (10 of 12 studies;

TABLE 1Description of studies included in the systematic review of nutrition-related health benefits of organic foods¹

Reference	Study design	Sample size	Exposure	Duration	Outcome	Main results
Human in-vivo trials and cohort and cross-sectional studies						
Akçay et al, 2004 (11)	Crossover study	8 men and women (75% men)	100 mL (men) or 200 mL (women) organic or conventional Cabernet Sauvignon wine consumed in one sitting; organic samples consumed first; 6-wk washout between exposures	1 d	Total antioxidant activity, serum LDL oxidation, total phenol content	No significant differences between organic and conventional exposures.
Briviba et al, 2007 (12)	Double-blind randomized crossover trial	6 men	1 kg organic or conventional Golden Delicious apples + one white-bread roll consumed in one sitting; 1-wk washout between exposures	1 d	Serum glucose, triacylglycerol, and uric acid, LDL antioxidant capacity, lymphocyte DNA damage	No significant differences between organic and conventional exposures.
Caris-Veyrat et al, 2004 (13)	Single-blind randomized controlled trial	20 women	96 g organic or conventional tomato puree/d	21 d	Plasma concentrations of lycopene, beta-carotene, vitamin C	No significant differences between organic and conventional exposures.
Grinder-Pedersen et al, 2003 (14)	Double-blind randomized crossover study	16 men and women (38% men)	Controlled diets consisting of the same 4 organically or conventionally produced menus; 3-wk washout between exposures	22 d	Urinary excretion of 5 named flavonoids, plasma antioxidant activity measured using 8 methods	Quercetin and kaempferol urinary excretions were significantly higher after exposure to organic diets. Total plasma antioxidant capacity was significantly lower after exposure to organic diets.
Kummeling et al, 2008 (15)	Cohort study	2764 infants aged 0–2 y in the KOALA Birth Cohort	Reported habitual diet defined as conventional (<50% organic), moderately organic (50–90%), or strictly organic (>90%)	Parent report of infant diet in the second year of life	Parent report of occurrence of eczema and wheezing in all infants; total IgE antibodies and specific IgE concentrations in serum as measures of atopic sensitization in subsample (<i>n</i> = 815)	No significant differences between organic and conventional diets (or meat, fruit, vegetable, or egg food groups) and risk of eczema, wheezing, or atopic sensitization. Consumption of strictly organic dairy products was associated with a significantly lower risk of eczema; consumption of moderately organic dairy products was not associated with risk of eczema. No association of consumption of organic foods with total IgE antibodies or with IgE-specific measures of atopic sensitization.

(Continued)

TABLE 1 (Continued)

Reference	Study design	Sample size	Exposure	Duration	Outcome	Main results
Rist et al, 2007 (16)	Cross-sectional study	312 lactating women in the KOALA Birth Cohort	Self-reported habitual diet defined as conventional (<50% organic), moderately organic (50–90%), and strictly organic (>90%) at 34 wk of pregnancy	No data	Fatty acid composition of breast milk at 1 mo postpartum (including rumenic acid, 16 other conjugated linoleic acids, <i>trans</i> -vaccenic acid, and 14 other fatty acids)	After adjustment for dietary and lifestyle factors, rumenic acid was significantly higher in the breast milk of mothers who reported consumption of a strictly organic diet.
Stracke et al, 2009 (17)	Double-blind randomized controlled trial	36 men	200 g organic or conventional carrots/d	14 d (preceded by a 28-d depletion period)	Plasma carotenoid concentration, antioxidant activity, and LDL oxidation; peripheral blood mononuclear cell cytokine quantity, natural killer cell quantity, natural killer cell activity, carotenoid concentration, and DNA damage	No significant differences between organic and conventional exposures.
Stracke et al, 2009 (18)	Double-blind randomized controlled trial	43 men	500 g organic or conventional Golden Delicious apples/d	28 d (preceded by a 7-d depletion period)	Urinary and plasma polyphenol concentration and antioxidant activity	No significant differences between organic and conventional exposures.
Experimental animal or human in vivo/ in vitro studies						
Dani et al, 2007 (19)	Experimental in vitro and ex vivo human samples	No data	8 samples of grape juice (4 conventional and 4 organic)	3 min to 1 h	Antioxidant activity, serum lipid peroxidation	Statistical tests on differences between organic and conventional exposures were not reported.
Dani et al, 2009 (22)	Single-blind randomized controlled trial	24 male rats	7 μ L juice/g body weight, twice/d	30 d	Lipid peroxidation (TBARS) and antioxidant activity (SOD and CAT) in cerebral cortex, substantia nigra, hippocampus, striatum, liver, and plasma	Reduction of lipid peroxidation in most brain structures was significantly higher with organic juice; in plasma, reduction was significantly higher with conventional juice. Mixed results for antioxidant activity depending on tissue type.
Olsson et al, 2006 (20)	Experimental in vitro human cell cultures	Human colon and breast carcinoma cells	Extracts of 2 strawberry cultivars either organically or conventionally produced at 4 concentrations	24 h	Cell proliferation	Combined organic extracts inhibited cancer-cell proliferation to a significantly greater extent than combined conventional extracts at the 2 highest concentrations. Mixed results for individual cultivar extracts and for lower concentrations.

(Continued)

TABLE 1 (Continued)

Reference	Study design	Sample size	Exposure	Duration	Outcome	Main results
Yildirim et al, 2004 (21)	Experimental in vitro human samples	66 men and women (61% men)	Organic and conventionally produced wines	No data	Serum LDL oxidation	No data.

¹ IgE, immunoglobulin E; KOALA, Kind, Ouders en gezondheid: Aandacht voor Leefstijl en Aanleg (Child, Parent and Health: Lifestyle and Genetic Constitution) study; TBARS, thiobarbituric acid-reactive species; SOD, superoxide dismutase; CAT, catalase.

83%) compared a specified exposure or dose of a foodstuff as part of a controlled-exposure study. The 2 large population studies used measures of self- or proxy-reported exposure (15, 16) and proxy reports of diet when necessary (16% of study participants) (15).

Health outcomes

Most of the included articles did not study direct human health outcomes. In 10 of the included studies (83%), a primary outcome was the change in antioxidant activity (11–14, 17–22). Antioxidant status and activity are useful biomarkers but do not directly equate to a health outcome. Of the remaining 2 articles, 1 article recorded proxy-reported measures of atopic manifestations as its primary health outcome (15), whereas the other article examined the fatty acid composition of breast milk and implied possible health benefits for infants from the consumption of different amounts of conjugated linoleic acids from breast milk (16).

DISCUSSION

To our knowledge, this is the only systematic review to assess the strength of the totality of available evidence of nutrition-related health effects of consumption of organic foodstuffs. Despite an extensive search strategy, the review only identified 12 relevant articles that met our inclusion criteria and were published, with an English abstract, in peer-reviewed journals over the past ≥ 50 y. The identified articles were very heterogeneous in terms of their study designs and quality, study population or cell line, exposures tested, and health outcomes measured. This inherent variability prevented any quantitative meta-analysis of the reported results, and from our narrative review, we concluded that evidence of nutrition-related health effects from the consumption of organic food is currently lacking. The strength of evidence of other public and environmental health benefits that arises from the consumption of organic foods would warrant further systematic review but was beyond the scope of the current report.

Our review also systematically assessed the quality of research in this area and supports earlier nonsystematic reviews (24) in showing that the available research base is of a generally poor quality. The criteria we used to assess publication quality were identified as key methodologic components of study design that were specifically related to exposure (the certification of organic production and a definition of an organic diet) and outcome (statements on measurement of health outcomes and statistical methods), which we considered to be a minimum standard. We attempted no further grading within each quality

criterion. These criteria could be criticized for not being sufficiently rigorous because they did not include assessment of factors such as study design, sample size, quality of laboratory methods used, or suitability of statistical analysis. Despite the relatively low quality threshold used in this review, a disappointingly small number of studies were graded as being of satisfactory quality.

The articles included in our review used a wide range of study designs. Randomized controlled trials are the optimal design for determining the effect of an exposure on a specific outcome, but studies of all designs must be conducted and reported in accordance with recognized guidelines. None of the clinical trials in the review were reported according to CONSORT guidelines (<http://www.consort-statement.org/>), which are an evidence-based, minimum set of recommendations for reporting randomized controlled trials (25). The 6 human clinical trials in the review were conducted with samples of ≤ 43 participants, and none reported the power calculations used to determine sample-size requirements. Furthermore, poor reporting in some articles made it impossible to elucidate specific study methods. Most studies investigated the health effects of specific foodstuffs rather than the diet as a whole, and there was rarely any rationale provided for the quantity and duration of exposure to foodstuffs in clinical trials. Few studies investigated the health effects of livestock products. The nutritional composition of monogastric animal source foods has been shown to be sensitive to feeding practices (26), and this may have an effect on health (27).

Antioxidant activity (variously defined) was the most commonly reported primary outcome. Although antioxidant activity is a useful biomarker that may be relevant to human health, it is not a direct health outcome in itself. Numerous health benefits have been ascribed to antioxidants, but evidence linking antioxidant concentrations in foods, serum antioxidant concentrations after dietary consumption, and specific in vivo mechanisms of action for potential human health effects is mixed. It has been suggested that biomarkers may play an important role in measuring disease, but care must be taken in interpretation of such data.

This review has several strengths such as its systematic and exhaustive approach, its broad inclusion criteria, and its methodologic rigor. There are some potential limitations of the review process. First, it is possible that this review did not identify all relevant publications, although we attempted to minimize this possibility by using very broad search terms, repeating our search in multiple relevant scientific publication databases, hand searching reference lists and contacting relevant subject experts. Second, there are several factors that

may have introduced bias in our findings, specifically the exclusion of foreign language publications that did not have an English language abstract and gray literature. Finally, it is possible that peer-reviewed journals were less likely to publish articles reporting nonsignificant differences (10) and that authors did not report all analyses conducted in their research (10). A general limitation when comparing the nutrition-related health benefits of foodstuffs is that farmers select specific plant cultivars or animal breeds to provide an optimal output on the basis of the characteristics of their chosen agricultural system. Thus, direct comparison of nutrition-related health effects of organic compared with conventional foodstuffs can be complicated by varietal differences in the exposure under investigation.

This systematic review of the available published literature was designed to determine the strength of the evidence that nutrition-related health benefits in humans could be attributed to the consumption of organically produced foodstuffs. Taken together, the 12 included articles did not provide evidence of health benefits or harm from consuming organic foods. A surprising and important finding of this review is the extremely limited nature of the evidence base on this subject, both in terms of the number and quality of studies. This is particularly surprising given the increasing public and policy-level interest in the question of whether there are health benefits from the consumption of organic foods. The amount of research in this area is increasing, as evidenced by the fact that 4 studies included in this review (33%) were published since 2008. However, it is essential that future research (both human and in vitro studies) is better designed and, at the very least, meets the minimum quality criteria applied in this review.

Considerable efforts are currently underway to enhance the quality of research in this area. For example, the International Research Association for Organic Food Quality and Health aims to develop novel methods to study the effect of organic food on human health and has recently provided some useful guidelines on study design (28). Furthermore, ongoing work on animal models (29) may prove exceptionally helpful in providing insights for better targeted outcomes that may be relevant to human public health. Indeed, the use of animal models may permit a more diverse range of tests that are not possible in humans. We recommend that future, high-quality randomized controlled trials, whether in animals or humans, should be conducted that have sufficient sample sizes to reliably detect the presence of effects, longer and more realistic dietary exposures, and more accurate and objective approaches to measure dietary intake and outcomes of public health relevance. It is further recommended that the results of all studies and all analyses should be published to ensure that the reporting and publication biases of null findings are minimized. Finally, the reporting of future studies should follow internationally agreed approaches as outlined by the Equator Network (<http://www.equator-network.org>) to assist critical appraisal and interpretation (30). Evidence in this field may be improved if more interdisciplinary approaches to, and funding for, agricultural-health research were supported.

The authors' responsibilities were as follows—ADD, EA, KL and RU: participated in the design of the study; ADD: managed the study; AA and AH: conducted the literature search and data extraction; and all authors: contributed to the first and subsequent drafts of the article and approved the submitted

version. The review team held 7 progress meetings with the funder of this study. ADD had full access to all data and had final responsibility for the decision to submit the article for publication. None of the authors declared a conflict of interest.

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