

Nutritional quality of organic foods: a systematic review^{1–4}

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ABSTRACT

Background: Despite growing consumer demand for organically produced foods, information based on a systematic review of their nutritional quality is lacking.

Objective: We sought to quantitatively assess the differences in reported nutrient content between organically and conventionally produced foodstuffs.

Design: We systematically searched PubMed, Web of Science, and CAB Abstracts for a period of 50 y from 1 January 1958 to 29 February 2008, contacted subject experts, and hand-searched bibliographies. We included peer-reviewed articles with English abstracts in the analysis if they reported nutrient content comparisons between organic and conventional foodstuffs. Two reviewers extracted study characteristics, quality, and data. The analyses were restricted to the most commonly reported nutrients.

Results: From a total of 52,471 articles, we identified 162 studies (137 crops and 25 livestock products); 55 were of satisfactory quality. In an analysis that included only satisfactory quality studies, conventionally produced crops had a significantly higher content of nitrogen, and organically produced crops had a significantly higher content of phosphorus and higher titratable acidity. No evidence of a difference was detected for the remaining 8 of 11 crop nutrient categories analyzed. Analysis of the more limited database on livestock products found no evidence of a difference in nutrient content between organically and conventionally produced livestock products.

Conclusions: On the basis of a systematic review of studies of satisfactory quality, there is no evidence of a difference in nutrient quality between organically and conventionally produced foodstuffs. The small differences in nutrient content detected are biologically plausible and mostly relate to differences in production methods. *Am J Clin Nutr* doi: 10.3945/ajcn.2009.28041.

INTRODUCTION

The demand for organically produced food is increasing. In 2007 the organic food market in the United Kingdom was estimated to be worth >£2 billion, an increase of 22% since 2005 (1), and the global estimate was £29 billion (2). Organic foodstuffs are produced according to specified standards, which, among other factors, control the use of chemicals in crop production and medicines in animal production and emphasize a minimal environmental impact (3, 4). Previous nonsystematic reviews have concluded that organically produced foods have a nutrient composition superior to that of conventional foods (5–7), although this finding has not been consistent (8, 9). To date, there has been no systematic review of the available published literature on this topic.

All natural products vary in their composition of nutrients and other nutritionally relevant substances (10). Different cultivars of the same crop may differ in nutrient composition, which can also vary depending on fertilizer and pesticide regimen, growing conditions, season, and other factors. The nutrient composition of livestock products can similarly be affected by factors such as the age and breed of the animal, feeding regimen, and season. This inherent variability in nutrient content may be further affected during the storage, transportation, and preparation of the foodstuffs before they reach the plate of the consumer. (See Supplemental Figure 1 under “Supplemental data” in the online issue.) An understanding of the factors that affect nutrient variability in crops and livestock products is important for the design and interpretation of research on differences in the nutrient content of organically produced and conventionally produced foodstuffs.

Notwithstanding the current uncertainty in the available evidence on the nutrient composition of foods produced under different agricultural regimens, consumers appear willing to pay a higher price for organic foods based on their perceived health and nutrition benefits (11, 12). Establishing the strength of existing evidence relating to the nutrient content of organic food will enable the development of evidence-based statements on content and potential nutrition-related public health gains or risks resulting from its consumption, which will allow consumers to make informed choices.

We present the results of a systematic review of studies that report the chemical analysis of foodstuffs produced under organic or conventional methods. The outcome was restricted to the nutrient and nutritionally relevant content of foodstuffs. We did not address differences in contaminant contents (eg, herbicide,

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pesticide, or fungicide residues) or the possible environmental consequences of organic and conventional agricultural practices because this was beyond the scope of our review.

METHODS

The quality and heterogeneity of the available data meant that we could not undertake a formal meta-analysis of the reported numerical results. We adhered, as much as possible, to the guidelines for the reporting of systematic reviews of observational studies (13).

Search strategy

We developed a search strategy in PubMed (<http://www.ncbi.nlm.nih.gov/pubmed/>) using Medical Subject Heading [MeSH] and title abstract [tiab] terms. The exposure terms searched (including all MeSH, headings, subheadings, and tiab terms) were “organic,” “health food,” and “conventional” combined with “food,” “agricultural crop,” and “livestock,” and “agriculture.” These terms were combined with terms for nutrients and nutritionally relevant substances from a recent global report on diet, nutrition, and prevention of cancer (14). (See Supplemental Table 1 under “Supplemental data” in the online issue.) The databases PubMed, Web of Science (http://isiwebofknowledge.com/products_tools/multidisciplinary/webofscience/), and CAB Abstracts (<http://www.cabi.org/cababstracts>) were searched for a period of 50 y from 1 January 1958 to 29 February 2008. Titles and available abstracts were scanned for relevance, and articles requiring further consideration were identified. Reference lists of relevant articles were hand-searched to identify additional publications. Subject experts ($n = 40$) identified from relevant publications were contacted by E-mail; we received 29 responses and were sent 36 publications, 25 of which were either not relevant or had previously been identified.

Selection criteria and data extraction

Studies with an English abstract published in peer-reviewed journals in any language were included if they reported a direct comparison of the composition of nutrients or nutritionally relevant substances in foodstuffs from organic (reported by authors as organic, ecologic, and bioorganic) and conventional (reported by authors as conventional and intensive) farming systems. Studies reporting comparisons of organic with either integrated ($n = 10$) or biodynamic ($n = 1$) farming practices were excluded, because these farming practices are specifically not conventional. Studies were also excluded if they were primarily concerned with the impact of different fertilizer regimens ($n = 6$) or nonnutrient (eg cadmium, lead, and mercury) contaminant content ($n = 37$) or were authentication studies describing techniques to identify the agricultural production method of the foodstuffs ($n = 11$). Gray literature (conference abstracts and unpublished studies) was not included.

All searching and data extraction were conducted by 2 research assistants (SKD and AH), and any disagreement resolved in discussion with the project lead (ADD). Data were extracted into separate databases for studies reporting on crops and livestock products. Data from foreign language articles were extracted by native speakers using a standardized template in discussion with the review team. Data extraction was per-

formed in duplicate for the first 10 included articles, and inconsistencies were noted and corrected. For the remaining articles, one reviewer entered the data and the other checked all entries; any differences were discussed and a consensus was reached.

Study designs

Studies investigating the nutrient content of organically and conventionally produced foods were based on 3 distinct study designs: field trials, which compare samples originating from organic and conventional agricultural methods on adjacent parcels of land (fields); farm surveys, which compare samples originating from organic and conventional farms that may be matched for selected variables; and basket studies, which compare samples of organically and conventionally produced food as available to the consumer from retail outlets.

Study quality

The quality of research and reporting in this area is extremely variable. Each study included in the review was graded for quality based on 5 criteria addressing key components of study design: a clear definition of the organic production methods, including the name of the organic certification body; specification of the cultivar of crop or breed of livestock; a statement of which nutrient or other nutritionally relevant substance was analyzed; a description of the laboratory analytic methods used; and a statement of the methods used for statistical analyses. Studies were defined as being of satisfactory quality if they met all 5 criteria. We did not grade further the quality of organic certifying bodies or analytic methods used.

Quantitative data synthesis

To assess the totality of evidence, all study designs and all foodstuffs (agricultural produce, livestock products, foods, and drinks) were included in the analysis. The articles reported a chemical analysis on 100 distinct foodstuffs and presented data on 455 nutrients and nutritionally relevant substances, which we grouped into 98 nutrient categories to facilitate the analysis. (See Supplemental Tables 2 and 3 under “Supplemental data” in the online issue.) There was an insufficient number of studies on comparable foodstuffs to permit direct analysis by foodstuff; therefore, the analysis was conducted by nutrient category across all study designs. Given the large number of possible nutrients that could be analyzed, an a priori pragmatic decision was made to conduct statistical comparisons on nutrient categories reported in ≥ 10 studies on crops and ≥ 4 studies on livestock products for which there were considerably fewer studies.

A small number of included studies reported some ($n = 5$) or all ($n = 1$) relevant data only in graphic format; only numerical data were extracted for use in the analysis. All remaining studies presented levels of nutrients as mean values. When the results consisted of more than one mean (eg, by month of harvest), the mean of the means was calculated. Most of the studies contained no information on sample size or variability around central estimates. The analysis presented is therefore a pragmatic choice that permitted the available data to be used to its fullest extent.

We calculated the standardized percentage difference in the reported mean nutrient content, as follows:

$$\left[\frac{\text{Content of nutrient in organically produced foodstuff} - \text{content of nutrient in conventionally produced foodstuff}}{\text{content of nutrient in conventionally produced foodstuff}} \right] \times 100 \quad (1)$$

Positive differences suggested that there might be more of particular nutrients in organically produced foodstuffs, whereas negative differences suggested that there might be more of particular nutrients in conventionally produced foodstuffs. Given the intrinsic differences in the design of studies included in the analyses, the percentage differences are not translatable into specific nutrient differences. We used *t* tests with robust SEs (to account for clustering caused by multiple nutrient comparisons within studies) and a significance level of 5% to interpret the results. Extreme values thought to be unlikely ($n = 3$) and defined as values for which the absolute difference from the next largest value was ≥ 1 SD were excluded from the analyses. The analyses were conducted by using STATA version 10 (2007, *Stata Statistical Software: release 10*; StataCorp LP, College Station, TX).

External review

An independent expert review panel was constituted to oversee and advise on the conduct of the review. The panel comprised a subject expert (Julie Lovegrove, University of Reading, United Kingdom) and an expert in public health nutrition with systematic review experience (Martin Wiseman, University of Southampton, United Kingdom, and World Cancer Research Fund International, United Kingdom). The expert independent review panel provided feedback on the review protocol, which was incorporated into the final protocol posted online on 18 April 2008 at <http://www.lshtm.ac.uk/nphiru/research/organic/>. Relevant subject experts and external bodies were informed about the availability of the review protocol. Comments from the expert panel were incorporated into the final report, which was also sent by the funder for external peer review by 5 subject experts. Relevant peer review comments were incorporated into this report.

RESULTS

Overview of studies identified

Of the 52,471 articles included in the search, 292 with potentially relevant titles were identified. Full copies of 281 of these articles were obtained, and, after scrutiny, 145 (52%) were excluded. Full copies of the remaining 11 articles [6 (2%) potentially eligible and 5 (2%) of unknown peer review status] were unobtainable despite numerous attempts. (See Supplemental Table 4 under “Supplemental data” in the online issue.) An additional 15 relevant articles were identified through a hand-search and 11 through direct author contact, which resulted in a final list of 162 articles that were assessed for study quality (Figure 1).

Quality of the studies

More than one-half of the studies identified ($n = 87$; 54%) failed to specify the organic certifying body [in 12 cases (7.5%) for which no certifying body was specified, we inferred a body from the Methods section of the report], 20% of the studies ($n = 33$) failed to state the plant cultivar or livestock breed, all studies stated the nutrients analyzed, 1% of studies ($n = 2$) failed to state laboratory methods, and 14% of studies ($n = 22$) failed to state statistical methods (see Supplemental Table 5 under “Supplemental data” in the online issue). One-third ($n = 55$; 34%) of the studies identified were of satisfactory quality (see Supplemental Table 6 under “Supplemental data” in the online issue), consisting of 46 reports (20 field trials, 22 farm surveys, and 4 basket surveys) on the composition of crops (see Supplemental Table 7 under “Supplemental data” in the online issue) and 9 reports (4 field trials and 5 farm surveys) on the composition of livestock products (see Supplemental Table 8 under “Supplemental data” in the online issue).

Comparison of content of nutrients and other substances

We extracted 1149 nutrient content comparisons from 46 satisfactory quality-crop studies, and data on 11 nutrient categories were reported in ≥ 10 studies. Analysis of satisfactory quality-crop studies found no evidence of a difference in 8 of the 11 nutrient categories (vitamin C, phenolic compounds, magnesium, potassium, calcium, zinc, copper, and total soluble solids) (Table 1). Nitrogen contents were significantly higher in conventionally produced crops, and contents of phosphorus and titratable acidity were significantly higher in organically produced crops. We extracted 125 nutrient comparisons from 9 satisfactory quality-livestock-product studies, and data on only 2 nutrient categories were reported in ≥ 4 studies. Analysis of the very limited database found no evidence of a difference between production method in either fats (unspecified) or ash (Table 2).

DISCUSSION

This report presents the results of the first published systematic review investigating differences in nutrient content of organically and conventionally produced foodstuffs. The review includes peer-reviewed publications published with an English abstract over the past 50 y. The organic movement has a long history (15), and the large proportion of articles identified in this review published after 2000 highlights the high level of current scientific interest.

The analysis presented suggests that organically and conventionally produced foods are comparable in their nutrient content. For 10 of 13 nutrient categories analyzed, there were no significant differences between production methods. Differences that were detected in crops were biologically plausible and were most likely due to differences in fertilizer use (nitrogen and phosphorus) (3) and ripeness at harvest (titratable acidity) (16). It is unlikely that consumption of these nutrients at the levels reported in organic foods in this study provide any health benefit. An important corollary is that organically produced foods are not inferior to conventionally produced foods with respect to their nutrient content.

Unlike all previous reviews that were nonsystematic, we conducted a rigorous literature search and identified a large

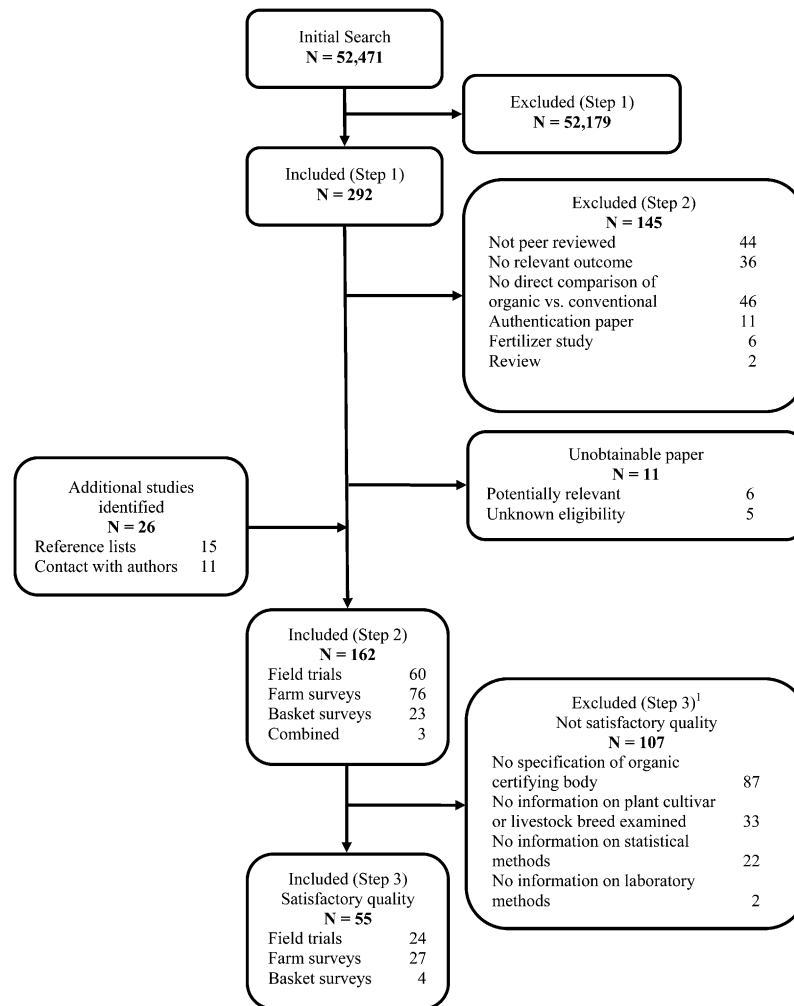


FIGURE 1. Study selection process for systematic review of the nutrient content of organic foodstuffs. ¹Reasons for exclusion at step 3 were not mutually exclusive.

number of studies conducted over the past 50 y. Our systematic approach, which focused on studies of satisfactory quality, agrees with some (higher contents of phosphorus in organic foods) but not all (higher contents of vitamin C and magnesium in organic foods) findings from previous reviews (5, 7, 9).

Results of analyses on >450 different nutrients or nutritionally relevant substances were identified in our review, and, whereas many articles appeared to have focused objectives guiding the analysis conducted and presented, others reported information on a considerable number of disparate substances. Given the large number of nutrients reported, we decided to group them into distinct nutrient categories for further analysis. We provided the totality of the data extracted from all satisfactory quality studies as a future resource for nutrition and agricultural researchers. (See Supplemental Tables 7 and 8 under “Supplemental data” in the online issue.)

Our review again highlighted the heterogeneity and generally poor quality of research in this area (11). The criteria we used to assess publication quality were identified as key methodologic components of study design, specifically relating to exposure (certification of organic production and definition of foodstuff) and outcome (statements on laboratory and statistical analysis methods). We attempted no further gradings within each quality

criterion; eg, organic certifying bodies have differing production regulations, and laboratory methods have different sensitivities (17). Despite the relatively low threshold used in this review to define satisfactory quality studies, a disappointingly low number of studies was graded as being of satisfactory quality. We urge researchers investigating nutritional characteristics of organic food to improve the scientific quality of their work and propose our 5 criteria as the bare minimum when reporting studies. To enable assessment of the nutritional quality of the foodstuffs in relation to their growing environment and mode of production, well-controlled long-term field trials, which provide explicit and detailed information on production methods, would be particularly valuable. An additional analysis including all 162 studies identified, irrespective of quality, similarly concluded that there was no evidence of important differences in nutrient content between organically and conventionally produced foodstuffs (data not shown).

This review had several strengths, such as its systematic and exhaustive nature, its broad inclusion criteria, and its methodologic rigor. However, because of the limitations of the extracted data, no formal meta-analysis was possible. To make best use of the available data, we elected to combine results from different study designs and calculated standardized differences across foods by

TABLE 1

Comparison of content of nutrients and other nutritionally relevant substances in organically and conventionally produced crops as reported in satisfactory quality studies

Nutrient category ¹	No. of studies	No. of comparisons	Results of analysis		Higher levels in organic or conventional crops?
			Standardized difference ²	<i>P</i>	
			%		
Nitrogen	17	64	6.7 ± 1.9	0.003	Conventional
Vitamin C	14	65	2.7 ± 5.9	0.84	No difference
Phenolic compounds	13	80	3.4 ± 6.1	0.60	No difference
Magnesium	13	35	4.2 ± 2.3	0.10	No difference
Calcium	13	37	3.7 ± 4.8	0.45	No difference
Phosphorus	12	35	8.1 ± 2.6	0.009	Organic
Potassium	12	34	2.7 ± 2.4	0.28	No difference
Zinc	11	30	10.1 ± 5.6	0.11	No difference
Total soluble solids	11	29	0.4 ± 4.0	0.92	No difference
Copper	11	30	8.6 ± 11.5	0.47	No difference
Titrateable acidity	10	29	6.8 ± 2.1	0.01	Organic

¹ Nutrient categories are listed by numeric order of the included studies.

² All values are means ± SEs (robust).

nutrient category. This will have resulted in the loss of the more nuanced findings from individual studies on specific foods but was chosen to be the most effective method for including and reporting all available data in a standardized form.

This review also had some limitations, which relate more specifically to the review process. We excluded gray literature and foreign language publications without English abstracts, and we were unable to locate a small number ($n = 11$) of potentially relevant publications, which may have resulted in us not including some relevant data in the review. Reporting bias, which occurs when authors do not report all analyses conducted in their research, and publication bias, which occurs when journal editors favor the publication of statistically significant findings are also potential limitations of systematic reviews (18). We are aware of 2 studies (19, 20) published after the review cutoff date.

All natural products vary in their composition of nutrients and other nutritional relevant substances for a wide variety of reasons (10), including production method. Production methods, especially those that regulate the use of chemical fertilizer, herbicides, and pesticides may also affect the chemical content of foodstuffs. Certified organic regimens specify the production of foodstuffs with the strictly controlled use of chemicals and medicines. The potential for any benefits to public and environmental health of these actions would certainly warrant further systematic review, but was beyond the scope of the current report.

The current analysis suggests that a small number of differences in nutrient content exist between organically and conventionally produced foodstuffs and that, whereas these differences in content are biologically plausible, they are unlikely to be of public health relevance. One broad conclusion to draw from this review is that there is no evidence to support the selection of organically produced foodstuffs over conventionally produced foodstuffs to increase the intake of specific nutrients or nutritionally relevant substances. It is also clear that research in this area would benefit considerably from greater scientific rigor and a better understanding of the various factors (apart from production regimen) that determine the nutrient content of foodstuffs.

We gratefully acknowledge technical support from Andrea Aikenhead. The funding organization had no role in study design, data collection, analysis, interpretation, or writing of the report. The review team held 6 progress meetings with the funding organization. The corresponding author had full access to all data and had final responsibility for the decision to submit for publication.

The authors' responsibilities were as follows—ADD, EA, KL, and RU: participated in the design of the study; ADD: managed the study, had full access to all of the data, and had final responsibility for the decision to submit for publication; EA: conducted the statistical analysis; and SKD and AH: conducted the literature search and data extraction. All authors contributed to the first and subsequent drafts of the report and approved the submitted version. All authors stated that they had no conflicts of interest to declare.

TABLE 2

Comparison of content of nutrients and other nutritionally relevant substances in organically and conventionally produced livestock products as reported in satisfactory quality studies

Nutrient category ¹	No. of studies	No. of comparisons	Results of analysis		Higher levels in organic or conventional livestock products?
			Standardized difference ²	<i>P</i>	
			%		
Fats (unspecified)	6	13	13.0 ± 14.6	0.42	No difference
Ash	4	8	13.7 ± 7.8	0.18	No difference

¹ Nutrient categories are listed by numeric order of the included studies.

² All values are means ± SEs (robust).

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