Organic Food in the Diet: Exposure and Health Implications

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Annu. Rev. Public Health 2017. 38:295–313

First published online as a Review in Advance on December 15, 2016

The *Annual Review of Public Health* is online at publhealth.annualreviews.org

https://doi.org/10.1146/annurev-publhealth-031816-044437

Keywords

organic food, organic vegetables, naturalness, compositional differences, health effects

Abstract

The market for organic food products is growing rapidly worldwide. Such foods meet certified organic standards for production, handling, processing, and marketing. Most notably, the use of synthetic fertilizers, pesticides, and genetic modification is not allowed. One major reason for the increased demand is the perception that organic food is more environmentally friendly and healthier than conventionally produced food. This review provides an update on market data and consumer preferences for organic food and summarizes the scientific evidence for compositional differences and health benefits of organic compared with conventionally produced food. Studies indicate some differences in favor of organic food, including indications of beneficial health effects. Organic foods convey lower pesticide residue exposure than do conventionally produced foods, but the impact of this on human health is not clear. Comparisons are complicated by organic food consumption being strongly correlated with several indicators of a healthy lifestyle and by conventional agriculture "best practices" often being quite close to those of organic.

INTRODUCTION

Although traditional organic farming practices have prevailed for thousands of years, the modern organic movement began in Europe in the 1920s. The main motivations were to preserve and develop the fertility of the soil and to counteract the industrialization of agriculture. Over the following decades, avoiding the growing dependence on synthetic fertilizers and pesticides also became a motivation (65). From the outset, this avoidance was based on principle because substantial knowledge of the adverse effects of intensive use of fertilizers and pesticides first emerged during the 1960s, exemplified by the pesticide DDT (dichloro-diphenyl-trichloroethane), introduced in the 1940s. DDT was inexpensive to produce, effective in killing pests, and had low acute toxicity to vertebrates. The improved crop yields triggered widespread, unrestricted use (64). Over time, evidence of the adverse effects of DDT and other persistent chemicals on the environment and human health accumulated and eventually became a public concern. Rachel Carson's book *Silent Spring* (published in 1962) was instrumental in this assessment (64). As DDT was banned, more rapidly degradable pesticides were developed by the chemical industries. However, though less persistent, these were not necessarily harmless to the health of humans, animals, and the environment (105).

Although regulations and restrictions apply (110), the global use of pesticides is now more than two million tons per year and increasing (39). Use of pesticides and synthetic fertilizers combined with intensive irrigation and specialized crops have resulted in increased food production. Organic farming systems are often portrayed as an inefficient approach to meet future needs for global food production (92). Despite this perception, consumer demand and sales of organic food are growing rapidly, and global retail sales reached US$80 billion (more than €60 billion) in 2014. Growth is projected to continue (85).

The term organic farming was first used in the 1940s to describe the use of organic materials for soil fertility and comprises a holistic view of soil, crops, animals, and society (65). The core of organic agriculture is a systematic approach that includes crop rotations; diversity in crops and livestock; grazing; soil improvement, in part by the application of animal manures and compost; and pest management without the use of synthetic pesticides (92). The increasing popularity of organic food and farming has prompted the need for organic certification and standards. The International Federation of Organic Agricultural Movements (IFOAM) was founded in 1972, and 283 organic certification bodies are now operating in 170 countries worldwide (92). All food sold as organic must be certified as such by approved organic control bodies according to defined criteria (24, 78).

The overall aim of organic agriculture, whether in farming, processing, distribution, or consumption, is to sustain or improve the health of the soil and the ecosystem from the smallest organisms in the soil to human beings. The four principles of organic farming as formulated by IFOAM are health, ecology, fairness, and care (51). Organic farming allows no use of agrochemicals (artificial pesticides, growth regulators, and synthetic soluble fertilizers), no use of genetically modified organisms [i.e., plants, animals, or microorganisms in which the genetic material has been manipulated (113)], and restricted use of veterinary medicine and pesticides approved for use in organic farming (24, 78, 80). Furthermore, it emphasizes the use of diversity and the rotation of crops and livestock, improving soil and recycling materials and energy (51). The United Nations Food and Agriculture Organization states that "[o]rganic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity" (35). These aspects may place organic agriculture in a position to help improve crop diversity and environmental and human health (35, 51, 68).

The belief that organic foods are healthier than conventionally produced foods is an important reason why interest in organic food is increasing worldwide (43, 48, 85, 119). The majority of scientific studies, reviews, and meta-analyses agree that there are some compositional differences between organic and conventionally produced food (92). However, whether these differences are relevant for human health is not clear, and few studies have assessed the potential impact of organic compared to conventionally produced food on human health outcomes (46, 82, 99).

The aim of this review is to provide an update on market data and consumer preference for organic food and to assess the state of scientific evidence for compositional differences and health benefits of organic compared with conventionally produced food. Recommendations for policy and future research are also provided.

MARKET DATA AND CONSUMER PREFERENCES

Organic production ranges from small-scale farms to large-scale high-technology enterprises. The latest survey, in 2014, on certified organic agriculture worldwide included data from 172 countries (36). Australia, Argentina, and the United States had the largest land area for organic agriculture. The average share of organic agricultural land in the countries included in the survey was 1%; however, agricultural land in 11 countries was more than 10% organic (36). Data on retail sales and international trade were available for about one-third of the countries included in the 2016 report and showed that the countries with the largest retail sales value for organic food in 2014 were the United States (€27.1 billion; US$35.9 billion), followed by Germany (€7.9 billion; US$10.5 billion), France (€4.8 billion; US$6.8 billion), China (€3.7 billion; US$4.9 billion), Canada (€2.7 billion; US$3.6 billion), and the United Kingdom (€2.3 billion; US$3.1 billion). Market growth has been noted in all countries. The countries with the largest organic share of the food market were Denmark (7.6%), followed by Switzerland (7.1%), Austria (6.5%), and the United States (5%) (36). The fresh produce food categories, i.e., organic vegetables, fruit, eggs, and dairy, comprise most sales, but North America also has a range of processed organic ready meals, carbonated drinks, and frozen foods (36, 88). More than 90% of organic food sales occur in North America and Europe, yet these regions have only one-third of the organic farmland, and a large portion of organic crops grown in other parts of the world are destined for export (36).

Although organic products make up a minor share of the world food market, the increase in certified commodities and their availability in mainstream supermarkets have made organic food the fastest growing segment of the food industry (36). In the wake of the rising demand for organic foods, a number of studies have aimed to identify characteristics of organic consumers, motives for choosing organic food, and factors driving organic food consumption. A summary of these studies is outlined below.

Characteristics of Organic Consumers

Defining organic consumers and assessing organic diets, e.g., what type of food, and the contribution of organic food to the total diet are major challenges in population studies (9, 88). There are no methods to measure the habitual diet in individuals without significant error (114). Research describing lifestyle and socioeconomic characteristics of organic food consumers has shown that organic consumption is a complex phenomenon involving diverse groups that do not fit into typically defined consumer segments. Most studies report that organic consumption is closely linked to other health and lifestyle indicators, e.g., consumers often have higher education and income, have lower body-mass index (BMI), are more physically active, and have healthier diets than those who do not or seldom use organic food (32, 34, 58, 107, 108). However, this pattern does not necessarily apply when organic food consumption is related to an alternative lifestyle that includes vegetarianism, environmentalism, or other ideologies (10, 48, 89, 107). Studies show that frequent organic consumption does not follow a typical age gradient but is found in both young adult (<25 years) and older adult (>40 years) age groups (81, 107) and that organic consumers more often belong to households with children than do nonorganic consumers (48).

The impacts of age, education, and income in explaining differences in the purchasing behavior of those who buy or do not buy organic products are not consistent among studies (9, 31, 32, 48). A study of household demographic information and grocery purchase records for a large number of US households showed that higher-income households were more likely to try organic vegetables and that African American households were less likely to purchase organic vegetables than were white households; however, when African American households did purchase organic foods, they spent a greater share of their vegetable budget on organic vegetables (31). A study in a large population of pregnant women in Norway showed that frequent organic consumers more often participated in regular exercise and had lower BMI, characteristics associated with a healthy lifestyle. However, frequent organic consumption was also associated with higher prevalence of smoking and use of alcohol, characteristics that are not typical of a health-conscious lifestyle (107).

Factors Driving Organic Food Consumption

The latest survey from the Organic Trade Association in the United States showed that health motivation is the main reason for choosing organic food (85), which is consistent with the results of organic food choice determinants in studies in developed as well as developing countries (31, 43, 48, 71, 81, 86, 119). The purported health benefits of choosing organic food include reduced exposure to contaminants (48, 71, 85, 96, 109, 117) or increased nutritional value (48, 85, 109). Consumers seem to value the lower risk of exposure to contaminants as more important than higher content of nutrients (44).

Animal welfare (40, 96) and environmental concerns (48, 116) are other important motives for choosing organic food. Organic livestock production differs from conventional systems. For example, organic animals are allowed larger housing areas, outdoor access, and straw bedding; they are fed organic feed; the use of antibiotics is restricted; no preventive medical treatment is allowed; and clipping of tail, teeth, and beaks is prohibited (59). Consumers perceive this as more natural and less intensive than conventional animal production, but potential differences in disease occurrence have been little studied (59). The prevalence of mastitis did not differ between organic and conventional dairy farms (38, 59). For some consumers, ethical considerations related to animal welfare result in abstaining from meat and/or animal products (95), and studies consistently show that organic consumers include a larger share of vegetarians than conventional consumers (48, 107).

Other motives are factors relating to environmental concerns, including soil and water quality, biodiversity, greenhouse gas emissions, and resource efficiency (yield). A meta-analysis of differences in environmental impacts between organic and conventional farming concluded that organic farming systems have higher content of organic matter in soils, contribute positively to biodiversity, and have lower emissions of greenhouse gases (GHGs) per hectare of farming (74, 92). The GHG effect is less pronounced and may even be reversed when expressed per unit of product. Leaching of nitrates and phosphorous from agricultural production systems to ground and surface water is a huge environmental problem and occurs, on average, much less in organic than in conventional farming (74). Although organic farming systems yield less food, recently estimated to be ~19%, the gap can be reduced or even abolished with further research and development work, as indicated in recent publications (90, 92). Export/import and transport may also be important for sustainability (5). Organic vegetables, fruits, and herbs grown in low-income countries, particularly in Africa, are produced almost exclusively for the export market. International organic organizations argue that there need to be local markets for organic products if the industry is to be more sustainable (36).

Naturalness is a concept frequently used in marketing of organic food. There is no formal definition of this concept, and it tends to be interpreted differently by producers, traders, consumers, and critics of organic food (111). Commitment to foods perceived to be natural was a major determinant of increasing the consumption of certified organic foods by Australian consumers, who perceived natural as a contrast to contemporary food characteristics such as genetic modification, radiation, and the use of pesticides, preservatives, animal growth hormones, and antibiotics (63). Along with the perception of naturalness, many consumers perceive organic food as having better taste, color, and flavor than conventional foods, although actual blind tests show little or no difference (41, 120). With the rapid growth in organic food consumption, the market for processed organic products also increases. The term processing implies activities such as cleaning, cutting, heating, canning, and freezing as well as the addition of preservatives, flavors, or other substances approved for use in food products, such as preservatives, salt, sugars, and fats (37). According to organic regulations in the European Union and the United States, organic foods must be processed without irradiation or chemical food additives (24), but certification systems do not restrict the addition of salt, sugars, and fats. From a public health perspective, it is important to distinguish between processed and ultraprocessed, energy-dense products (75). If processing of organic food results in ultraprocessed convenience foods, then the value of naturalness of such organic food items may be disrupted.

Availability of organic alternatives to conventional food is another important determinant of organic food consumption. Consumers want organic products to be easily available in all shops, and there is also an increasing market for home delivery of boxes of organic fruit and vegetables (20). Consumers are prepared to pay more for products that involve less processing and that are grown free of pesticides and genetically modified organisms, perhaps by local farmers considered worthy of support (8, 48, 70). Insufficient availability, convenience concerns, and high prices for organic food are identified as factors that limit the consumption of organic food (5, 31, 48, 63).

COMPOSITIONAL DIFFERENCES

Consumer preference for organic food is motivated in part by a general perception that organic foods are healthier and more natural than conventional alternatives. This perception may be motivated in large part by the compositional differences between organic and conventional food. The production system affects the chemical composition of plants and animal products; a number of reviews document compositional differences from various production systems (6, 7, 11, 14, 17, 18, 28, 49, 61, 69, 87, 93, 99, 100, 115, 118). The differences relate to concentrations of nutrients and other bioactive compounds (secondary plant metabolites/plant defense agents), pesticides, other contaminants, mycotoxins, and microorganisms, including plant pathogens (**Table 1**). Fewer data are available for animal products; the observed compositional differences relate to fatty acid profile, iodine, and selenium (102, 103) (**Table 1**). Various study designs are used when comparing the composition of organic and conventional crops and include field trials (comparison of nutrient or substance concentrations in organic and conventional crops grown on different lots of the same field), farm-pairing studies (comparison of nutrient or substance concentrations in organic and conventional crops grown on neighboring farms), market-basket studies (comparison of nutrient or substance concentrations in organic and conventional fresh

Table 1 Outline of compositional differences between organic and conventionally produced food according to systematic reviews

Parameters	Food produce	Organic versus conventional	References
Vitamins: e.g., vitamin C, vitamin E, and carotenoids	Fruit, vegetables	Higher (most studies)	7, 11, 17, 49, 115
Minerals: calcium, potassium, phosphorous, magnesium, iron	Fruit, vegetables, cereals	Higher	11, 14, 28, 49, 93, 99, 118
Nitrate	Fruit, vegetables, cereals	Lower	7, 17, 61, 69, 115, 118
Antioxidant activity	Fruit, vegetables, cereals	Higher	7, 11, 17, 49, 61, 93
Phenolic compounds (total)	Fruit, vegetables, cereals	Higher	7, 18, 99
Protein, amino acids, nitrogen	Fruit, vegetables, cereals	Lower	7, 28
Beneficial fatty acids, i.e., eicosapentaenoic acid, docosapentaenoic acid, docosahexaenoic acid, α-linolenic acid, and conjugated linoleic acid	Milk, meat	Higher	61, 87, 102, 103
Iodine and selenium	Milk	Lower	102, 103
Cadmium	Fruit, vegetables, cereals	Lower in cereals	7
Pesticide residues	Fruits, vegetables, and grains	Lower risk for contamination	6, 14, 61, 69, 99
Fusarium toxins	Cereals	Similar or lower in organic	99
Microorganisms, antibiotic-resistant bacteria	Chicken and pork		99

and processed foods sampled at the consumer end of the distribution chain), and biomarker studies (comparison of nutrient or substance concentrations in human tissue, e.g., urine or blood following consumption of organic and conventional foods).

The eventual public health implication of the various compositional differences is under active scientific debate (21, 45, 99). During the past two decades, several reviews, meta-analyses, and scientific reports evaluated the clinical relevance of these compositional differences. In the following sections, we give a brief overview of the available evidence on compositional differences and possible relevance for human health.

Differences in Content of Nutrients, Other Bioactive Substances, and Contaminants

A review from February 2016 summarized 15 scientific reviews or meta-analyses comparing nutritional differences between organic and conventional products; 12 concluded that organic foods have higher concentrations of vitamin C, total antioxidants, and total omega-3 fatty acids (92). In addition, two other systematic reviews, also from February 2016, concluded respectively that (*a*) organic milk has substantially higher concentrations of long-chain polyunsaturated n-3 fatty acids and lower concentrations of iodine and selenium than does conventional milk (103) and (*b*) differences in fat composition (more n-3 fatty acids, α-linolenic acid, and conjugated linoleic acid) were also indicated for organic meat (102). Although there are discrepancies between some of the included results, these reports generally agree that the overall picture shows compositional differences mostly in favor of organic foods (**Table 1**). Similar conclusions have been reached by research institutes and governmental bodies such as the UK Food Standard Agency (27), the Swedish University of Agricultural Sciences (73), the Norwegian Committee for Food Safety (82), and the French Food Safety Agency (2).

Compositional differences between organic and conventional alternatives vary between food groups. For fruit and vegetables, the reviews and meta-analyses show that organic fruits and vegetables have lower concentration of nitrate and higher concentrations of dry matter, minerals (e.g., iron, magnesium, phosphorous, and zinc), vitamins C, and other bioactive compounds such as carotenoids and tocopherols. Furthermore, organically produced fruit and vegetables have been shown in some cases to have higher concentrations of some naturally occurring secondary plant metabolites such as phenols and flavonoids, some of which are natural defense agents for plants and may also be of importance for human health (7, 17, 73, 82, 99).

For cereals, lower concentrations of proteins and amino acids are found in organic than in conventional crops, which is linked to lower nitrogen input and availability in organic crop production (7, 11, 118). A major concern regarding cereal crops is contamination by mycotoxins, fungal metabolites that have adverse effects in humans, animals, and crops. Despite conventional agriculture's use of fungicides to control fungal contamination, most studies show no difference in the Fusarium toxin deoxynivalenol (DON) between organic and conventional cereals, and the rest show lower concentrations in organically produced cereals (13, 99). For other Fusarium mycotoxins, i.e., T2 and HT2, most studies show lower concentrations in organically produced cereals. Organic cereal farming systems using systematic crop rotation, more intensive surface treatment, and lower plant density than conventional farming systems may contribute to this lower concentration (73, 82, 99). With regard to toxic metals, studies have found no differences between organic and conventional crops for arsenic and lead, and organic crops had significantly lower concentrations of cadmium (7).

For animal foods, the compositional differences reflect primarily differences in feed. For milk and dairy, organic livestock husbandry requires that a large fraction of the feed should be locally produced grass and clover, which are rich in omega-3, whereas conventional feed consists of soy, palm kernel cake, and cereals with lower omega-3 content (24). Organic milk consistently contains more omega-3 fatty acids and has a more beneficial ratio between omega-6 and omega-3 than do conventional dairy products (12, 87, 103). On the other hand, organic milk generally contains less iodine than conventional milk (103). Similarly, compositional differences between organic and conventional eggs and meat reflect differences in feeding regimens.

In organic farming, the animals are required to have access to outdoor areas, which may increase the risk of parasites and infection. Studies show little difference with regard to bacterial contamination between organic and conventional produce (70, 82), but one study reported higher occurrence of bacteria resistant to antibiotics in conventional as compared with organic chicken and pork (99).

Biomarker Studies of Compositional Differences

Biomarkers studies are studies in humans or animals where analyses of biological markers are used as proxies of health effects. These studies are carried out because it is virtually impossible to conduct well-designed experimental dietary studies with the true health outcomes as the endpoint; the time and expenses required are out of scope. The Norwegian Scientific Committee for Food Safety identified eleven studies which examined antioxidant levels (e.g., carotenoid concentrations or antioxidant capacity), fatty acid composition, or absorption of copper and zinc with organic compared to conventional food consumption (82). Only one study found higher antioxidant capacity in blood when participants consumed organic food, and there was no difference in the intake or absorption of zinc or copper, while two studies found higher concentrations of anti-inflammatory and growth stimulating fatty acids in breast milk from mothers who consumed diets composed of more than 90% organic meat and dairy products. With the exception of the two breast-milk studies, the biomarker studies were limited by small study populations (6–36 participants) (82).

Pesticide Residues in Organic and Conventionally Produced Food

The principles of organic farming ensure no use of synthetic pesticides, although some natural substances are approved for use as pesticides in organic agriculture (91). Pesticides approved for use in organic agriculture comprise extracts from plants or microorganisms with low persistence and are evaluated according to the same regulations as other pesticides (110). Exposure to pesticides in the general population, with the exception of occupational and accidental exposure, is mainly via residues on food (66). Some of the pesticides that have been approved for organic production are not without known health consequences; for example, rotenone, an insecticide from the seeds and stems of certain plants, is known to cause Parkinson Disease in animal models and possibly also in humans (56). At the time of writing, use of rotenone has been prohibited in European organic agriculture (24), is registered only for restricted use in the US (80), but may still be used in other parts of the world.

Reports from surveillance programs for pesticide residues in plant foods both in Europe and the United States have shown that although the levels of detected residues were low, pesticide residues are detected almost exclusively in conventional food samples (6, 33, 72, 79). Likewise, systematic reviews consistently conclude that organic foods are less likely than conventional food samples to have detectable pesticide residue (7, 91, 99). Controlled feeding experiments in children and adults have confirmed that consumption of organic food resulted in lower urinary concentrations of pesticide metabolites than consumption of conventional alternatives (16, 26, 67, 84). These studies and a study that estimated dietary pesticide exposure (25) provide convincing evidence that consumption of organic foods reduces the exposure to synthetic pesticide metabolites. The crucial point of debate when comparing organic and conventional foods is whether low-level dietary pesticide residue exposure is of clinical relevance (45, 76, 83). The available evidence on adverse human health effects associated with exposure to pesticide metabolites in food is limited. Most studies to date have focused on individuals exposed to the parent pesticide (i.e., the active ingredient) to evaluate health effects, though there continues to be concern about the effects of low-level, often long-term, exposure on human growth and development (77, 94, 112).

In summary, there are compositional differences in nutrients and some other substances between organically and conventionally produced food, but the differences are small and the relevance for human health is subject to debate (21, 45). Higher intakes of vitamins, minerals, beneficial fatty acids, and plant defense agents from organic foods are not likely to impact the health of populations with ample nutrient supply. Studies of the potential health impacts of organic food consumption are all conducted in well-nourished populations (**Table 2**). Pesticide residue exposure is clearly lower with organic foods as compared with conventional foods, but the potential impact of this difference on human health is not clear.

HEALTH BENEFITS LINKED TO ORGANIC FOOD CONSUMPTION

Although numerous studies have compared the nutrient, antioxidant, and pesticide residue content of organic and conventional foods, few scientific studies in animals or humans have examined

Table 2 Overview of human studies of health outcomes associated with consumption of organic versus conventionally produced food

End point	Study population and design	Exposure	Result	References
Atopy	Cross-sectional study in 295 children from families with anthroposophic lifestyle and 380 children from control families in Sweden	Organic food consumption as part of an anthroposophic lifestyle	Less atopy in the children coming from anthroposophic families	4
Allergies and atopic sensitization	Cross-sectional study including 14,893 children aged 5–13 years from anthroposophic families and reference children from five European countries (Austria, Germany, the Netherlands, Sweden, and Switzerland)	Organic food consumption as part of an anthroposophic lifestyle	Fewer allergies in families with anthroposophic lifestyle	3
Hay fever and asthma-like symptoms	Cross-sectional study in 593 organic and 1,205 conventional farmers in the Netherlands	Organic versus conventional farming practice	No difference in respiratory disease associated with farming practice/organic consumption	98
Eczema and/or wheeze occurrence	Prospective follow-up of 2,700 children in the KOALA birth cohort in the Netherlands. Blood samples from 815 infants at 2 years of age were analyzed for total and specific immunoglobulin-E	Organic consumption in six food groups and proportion of organic within the total diet	No difference in atopic sensitization. Less eczema with consumption of organic dairy products but not with other organic foods or proportion of organic food	60
Allergic sensitization	Prospective study of 330 children from families with anthroposophic, partly anthroposophic, or nonanthroposophic lifestyle in Sweden. Allergen-specific immunoglobulin-E sensitization measured in blood	Organic food consumption as part of an anthroposophic lifestyle	Immunoglobulin-E sensitization to common allergens was lower among children of families with an anthroposophic lifestyle	104
Hypospadias	Case-control study in mothers of 306 boys who were operated on for hypospadias and 306 mothers of healthy boys	Retrospective recall of organic consumption in six food groups during pregnancy	No difference with any organic consumption but higher prevalence with nonorganic milk/dairy combined with frequent consumption of high fat dairy products	23
Hypospadias and cryptorchidism	Prospective study in 35,107 mothers of singleton male infants in Norway 2002–2008	Organic food in six food groups assessed by FFQ grouped into frequent versus sometimes	Lower prevalence of hypospadias with any organic consumption, and in particular organic vegetables. No difference for cryptorchidism	19

(*Continued*)

Table 2 (*Continued*)

End point	Study population and design	Exposure	Result	References
Preeclampsia	Prospective study in 28,192 first time singleton pregnant mothers in Norway 2002–2008	Organic food in six food groups assessed by FFQ grouped into any versus seldom/never	Lower prevalence of preeclampsia with frequent organic vegetables, no difference for other food groups or any organic consumption	106
Sperm quality	Cross-sectional study in 30 members of organic farming organizations and 73 blue-collar workers as controls in Denmark in 1994	Organic farmers had a high proportion of organic food in their diets	Higher sperm density in organic farmers	1
Sperm quality	Cross-sectional study in 55 members of organic farming organizations (age 20–45 years) and 141 controls working in an airline company (age 23–43 years) in Denmark in 1996	The organic farmers had at least 25% organic food in their diets	Higher sperm quality in organic food consumers	54
Sperm quality	Cross-sectional study in 85 organic (mean age 40 years) and 171 conventional farmers (mean age 38 years) in Denmark in 1995/1996	Organic food consumption assessed by FFQ and grouped into 0%, 1–49%, and 50–100% organic fruits and vegetables	Lower concentration of morphologically normal spermatozoa in the group with no organic food intake. No differences in 14 other parameters	57
Sperm quality	Cross-sectional study in 85 organic (mean age 40 years) and 171 conventional farmers (mean age 38 years) in Denmark in 1995/1996	Comparison of pesticide exposure and sperm quality between organic and conventional farmers	No difference in sperm quality between organic and conventional farmers	62
Cancer incidence, overall and for 17 individual cancer sites	Prospective study in 623,080 British women with follow-up for 9.3 years from 2002 to 2011	Organic consumption (any food group) in four categories; never, sometimes, usually, or always	No differences for all cancer incidence between usually/always versus never organic	15
Risk factors for cardiovascular disease	Intervention study, crossover design with 150 Italian men (100 healthy and 50 patients with chronic liver disease) in 2006–2008. Outcomes: BMI by dexa scan and blood parameters	Two weeks intervention with Mediterranean conventional diet (T1) and Mediterranean organic diet (T2)	Significant reduction in risk factors for cardiovascular disease after the T2 period	30

Abbreviations: BMI, body-mass index; FFQ, Food Frequency Questionnaire; KOALA, Kind, Ouders en gezondheid: Aandacht voor Leefstijl en Aanleg (Child, parents and health, addressing lifestyle and constitution).

whether the consumption of organic food is associated with better health than consuming the corresponding conventional food. Some evidence from experimental animal studies indicates that organic feed ingredients may improve animal physiology such as immune parameters and hormone balance, but the findings are not consistent and the relevance for human health is unclear (22, 47, 52, 53, 97, 101).

Epidemiologic studies can demonstrate statistically significant associations between exposures and health outcomes, but that in itself does not imply a causal relationship. The criteria for objectively evaluating the level of causality of associations observed in epidemiology, as formulated by Sir Bradford Hill in 1965, include consistency, strength of association, dose–response relationship, time order, specificity, consistency on replication, predictive performance, biological plausibility, and coherence (42).

We have reviewed 14 epidemiologic studies published between 1994 and 2015, which examined organic food consumption with respect to various health outcomes (**Table 2**). The studies included end points ranging from atopy, eczema, and/or respiratory disease (3, 4, 60, 98, 104) to reproductive anomalies in boys, (19, 23), preeclampsia (106), sperm quality (1, 54, 57, 62), cancer (15), and risk factors for cardiovascular disease (30). All except one study were observational. Seven had a cross-sectional design, five were prospective cohorts, one was a case-control study, and one was an experimental study.

Atopy, Eczema, and/or Respiratory Disease

Three cross-sectional studies involving 17,000 participants in Europe (3, 4, 98) and two prospective studies involving ~3,000 children in the Netherlands and Sweden (60, 104) showed that children in families with an anthroposophic lifestyle, farmers involved in organic production systems, and children fed only organic dairy products during infancy and whose mothers consumed only organic dairy products during pregnancy had fewer allergies or fewer instances of eczema than did their respective controls. The outcomes were assessed as immunoglobulin-E sensitization to food allergens measured in blood samples (60, 104), and eczema occurrence was measured according to parental reports (60). The results were not consistent in the two studies, however. An anthroposophic lifestyle differs with regard to many characteristics, including regular consumption of fermented vegetables, which may influence the gut microbiota, and the effects observed in studies involving families with this lifestyle may not be associated with organic food consumption alone. Of the studies reporting allergic outcomes, the prospective study demonstrating a reduced risk of eczema in children fed only organic dairy products during infancy and whose mothers consumed only organic dairy products during pregnancy (60) can be considered to provide stronger evidence. The authors suggested a higher content of beneficial fatty acids in organic milk as a possible biological explanation for this finding.

Reproductive Anomalies in Boys

One case-control study (23) and one prospective study (19) examined associations between organic food consumption and male reproductive development. The case-control study in Denmark comprised 306 mothers of boys who were operated on for hypospadias and 306 mothers of healthy boys. This study suggested a protective association between hypospadias in the offspring and mother choosing the organic alternatives for butter and cheese (23). The mothers were asked to recall their intake of fruits, vegetables, milk, dairy products, eggs, and meat during pregnancy, and they were further asked whether organic alternatives were used often/sometimes or rarely/never. No associations were seen for other organic food groups. The authors suggested as an explanation that conventionally produced butter and cheese may contain more traces of pesticide residues than the organic equivalents, but they did not have measurements to support this (23).

In the Norwegian Mother and Child Cohort Study, organic food consumption during pregnancy was examined in relation to prevalence of hypospadias and cryptorchidism at birth (19). The study sample included 35,107 mothers who delivered a singleton male infant. The hypospadias and cryptorchidism outcomes were obtained from the Medical Birth Registry of Norway. Information about use of six groups of organically produced foods (vegetables, fruit, bread/cereal, milk/dairy products, eggs, and meat) was collected by a food frequency questionnaire in midpregnancy. Mothers who consumed any organic food during pregnancy were less likely to give birth to a boy with hypospadias than were women who never/seldom consumed organic food. Associations with the specific organic foods were strongest for vegetables and milk/dairy consumption. No substantial association was observed for consumption of organic food and cryptorchidism (19).

Sperm Quality

Sperm quality has been examined in relation to organic consumption in four cross-sectional studies (**Table 2**). Two of the studies found higher sperm concentrations when comparing sperm density in members of Danish Organic Farmers' associations and controls who were blue-collar workers or employees in an airline company (1, 54). The other two studies compared sperm quality in a population of 85 organic and 171 conventional farmers in Denmark (57, 62). One study examined the outcome according to intake of organic fruit and vegetables (57), and the other examined the outcome according to organic or conventional farming practice. No substantial differences were found with regard to organic consumption (57, 62).

Preeclampsia

In the Norwegian Mother and Child Cohort Study, using the subset of 28,000 first-time mothers, a modest but significant reduction in the prevalence of preeclampsia was seen in mothers who reported frequent consumption of organic vegetables, whereas no association was found for the other organic food groups. The observed effect of organic vegetables occurred in addition to the reduced prevalence of preeclampsia associated with a healthy diet in general (106). Although the investigators adjusted for a number of potential confounding factors, confounding still cannot be ruled out.

The two studies in the Norwegian Mother and Child Cohort Study (19, 106) asked only about frequency of organic food consumption within six food groups and not about actual amounts of organic food within each food group. The studies did not include biomarkers to assess whether women who reported organic food consumption had different exposure to pesticides, had higher levels of beneficial agents, or had generally healthier lifestyles. Furthermore, the number of exposed cases was low, and the use of organic foods may reflect factors of lifestyle and food selection that could not be adjusted for in statistical modeling. Therefore, replication in other studies and, preferably, studies that include biomarkers to verify differences in exposure is required to confirm or refute these findings.

Cancer

Associations between the use of any organic foods and incidence of cancer over 9.3 years was examined in a cohort of 623,080 British women (15). The women were asked, "Do you eat organic food?" and were given four possible categorical responses from which to choose: never, sometimes, usually, and always. Women who reported usually or always consuming organic foods had healthier dietary and lifestyle habits (e.g., more likely to exercise, and less likely to smoke or eat red and processed meat) than did women who reported never consuming organic foods. The results showed little or no decrease in cancer incidence with consumption of organic food, except a weak association with a lower incidence of non-Hodgkin lymphoma (15).

Risk Factors for Cardiovascular Disease

In an experimental study with a crossover design, investigators examined risk factors for cardiovascular disease, including body composition and biochemical parameters, in 150 healthy males and 50 male patients with renal disease in Italy. Outcome measures were obtained in all participants at baseline, after 14 days on a conventional diet, and after 14 days on an organic Italian Mediterranean diet. Study results indicated that the organic diet reduced cardiovascular risk factors in both healthy individuals and patients, but the study had numerous limitations, including the short intervention period, small number of participants, and inadequate reporting of results (30).

Summary of Health Effects Studies

With the exception of the two most recent studies from the prospective pregnancy cohort in Norway (19, 106), the remaining studies have been included in one or more of a number of scientific reviews and reports (7, 17, 27, 29, 46, 50, 55, 73, 82, 99). The human studies include only five prospective cohort studies, and there is a general consensus that the scientific evidence from human studies is insufficient to conclude whether organic food is more beneficial for health in some respects than are conventional food.

CONCLUSIONS: IS ORGANIC FOOD HEALTHIER?

The available evidence supports consumers' belief that organic food production and consumption result in lower pesticide exposure, are more environmentally friendly, and may be better for animal welfare. However, the impact on human health of the actual low-level pesticide exposure from conventionally produced foods is not clear. Some studies indicate better nutritional profiles in organic foods than in conventional foods, but the differences are mostly small and may not be of practical relevance in well-nourished populations. Few studies have investigated the possible health benefits of organic food consumption in humans. While providing some indications, the available evidence is limited and therefore insufficient to conclude whether organic food is healthier. The beneficial health effects of vegetables and fruits and other foods recommended in a balanced diet are well documented, but the jury is still out and not ready to conclude whether choosing the organic alternatives would provide additional benefits. The current dietary guidelines, which recommend more fruit, vegetables, and plant foods and less meat, are based on a large number of studies and are valid regardless of whether the produce is organic. It is important to highlight that consumers choose organic food for a variety of reasons beyond just for health. Organic production and consumption may, arguably, have other merits as complementary approaches to conventional food systems.

RECOMMENDATIONS FOR FUTURE RESEARCH

None of the human observational studies that examined health effects associated with the consumption of organic compared with conventional foods included biomarkers to indicate organic versus conventional exposure. In a strict sense, such biomarkers may not exist because there is no distinct demarcation line between organic and conventional agricultural practices; rather, the distinction has a wide border zone. Absence of markers of pesticide/other chemical use is not exclusive to consumers of organic foods, and while high levels of synthetic fertilizers may leave a biochemical fingerprint, conventional farmers often seek to limit the use of these products, not the least for economic reasons. Virtually all methods used in organic farming are, or could be, employed in conventional farming; the main difference lies in the restrictions applied. Therefore, any biochemical markers or patterns indicative of organic food consumption would indicate organic or near-organic food, rather than organic per se. More detailed assessment of organic consumption is needed to decrease the likelihood that observed associations are caused by factors other than the organic exposure. Investigators of many large prospective cohorts have collected biological material in addition to asking questions about the use of organic foods. Analyses of this material, with regard to the identification concern mentioned above, could provide valuable input to strengthen or refute reported findings. Studies of associations between the dietary qualities, including organic food consumption, pesticide exposure, and novel biomarkers, such as gut microbiota–based translational biomarkers in prospective observational studies, are therefore warranted.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

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Annual Review of
Public Health

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