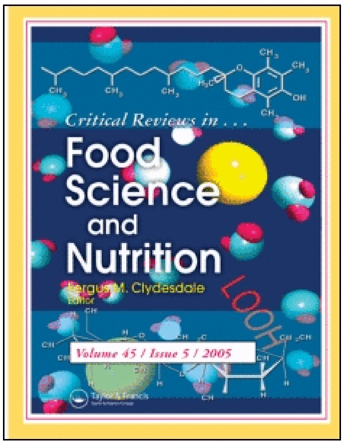

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A Comparison of the Nutritional Value, Sensory Qualities, and Food Safety of Organically and Conventionally Produced Foods

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A Comparison of the Nutritional Value, Sensory Qualities, and Food Safety of Organically and Conventionally Produced Foods

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Key Words: Organic food, sensory, nutritional value, food safety.

ABSTRACT: Given the significant increase in consumer interest in organic food products, there is a need to determine to what extent there is a scientific basis for claims made for organic produce. Studies comparing foods derived from organic and conventional growing systems were assessed for three key areas: nutritional value, sensory quality, and food safety. It is evident from this assessment that there are few well-controlled studies that are capable of making a valid comparison. With the possible exception of nitrate content, there is no strong evidence that organic and conventional foods differ in concentrations of various nutrients. Considerations of the impact of organic growing systems on nutrient bioavailability and nonnutrient components have received little attention and are important directions for future research. While there are reports indicating that organic and conventional fruits and vegetables may differ on a variety of sensory qualities, the findings are inconsistent. In future studies, the possibility that typical organic distribution or harvesting systems may deliver products differing in freshness or maturity should be evaluated. There is no evidence that organic foods may be more susceptible to microbiological contamination than conventional foods. While it is likely that organically grown foods are lower in pesticide residues, there has been very little documentation of residue levels.

I. INTRODUCTION

A. What is "Organically Grown Food"?

The term "organically grown food" denotes products that have been produced in accordance with the principles and practices of organic agriculture. Organic agricultural and food processing practices are wide ranging and overall seek to foster the development of a food production system that is socially, ecologically, and economically sustainable. The key principles and practices of organic food production aim to encourage and enhance biological cycles within the farming system to maintain and increase long-term fertility of soils, to minimize all forms of pollution, to avoid the use of synthetic fertilizers and pesticides, to maintain genetic diversity of the production system, to consider the wider social and ecological impact of the food production and processing system, and to produce food of high quality in sufficient quantity.[1]

Certified organic food and fiber products are those that have been produced according to documented standards. There are hundreds of organic certifying agencies around the world that establish their own production standards and certification processes. A small number of these agencies have gained accreditation from the International Federation of Organic Agricultural Movements (IFOAM), based on verification that the agencies are operating in accordance with the IFOAM Basic Standards. In addition, some certification agencies have gained ISO accreditation (e.g., ISO 65 for certifiers) and/or been audited by government agencies giving the certifiers another level of in-

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dependent verification of their standards and operating systems.

For the purposes of this review, terms such as "ecological" farming and "biological" farming have been considered to be synonymous with "organic" farming. However, a distinction needs to be made between organic and bio-dynamic farming systems. Bio-dynamic farming systems, based on the teachings of Rudolf Steiner, incorporate the principles and practices of organic agriculture but also include some unique practices. For example, bio-dynamic farmers may apply preparations of cow manure, herbs, minerals, etc. to composts and directly to the land and they commonly take into account the position of the planets and the moon in deciding what tasks to carry out at a particular time of the month.[2]

B. The Organic Food Industry

Over the last few years the organic food industry has been showing the highest levels of growth of all food sectors. In the USA, the market for organic foods increased 40-fold from 1986 to 1996, and at the end of 1999 estimated to be worth over $4.2 billion annually, and is predicted to continue to grow at a rate of more than 24% per year.[3] In the UK, the organic market is estimated to be worth over US$567 million[4] and accounts for 3 to 4% of all food sales.[5] Organic markets in some other European countries are considerably larger than that in the UK. For example, Germany has the largest of the European markets worth over US$1.92 billion in 1997.[4] In New Zealand, the value of the organic export market was estimated to be over NZ$70 million in 2000/2001,[6] close to a 3-fold increase from 1997.[7] The New Zealand domestic organic market was estimated to be worth NZ$50 million in 2000/2001.[6] It is predicted that the value of the total New Zealand organic industry (export and domestic markets) may increase to NZ$500 million by 2005.[6]

C. Why Do Consumers Choose Organic Food?

A number of studies have identified the reasons behind these considerable increases in consumer demand for organic foods, although the relative importance of factors influencing the purchase of organic foods may vary from country to country. Frequently, surveys report pesticide residues in food (i.e., concerns for own health) to be more important in the decision to purchase organic food products than concerns for the environment as a whole, although this factor is more important in some countries.[8-14]

For example, consumers in Germany have tended to be more concerned with environmental issues than those in the UK,[9,15] although this may be changing with more recent reports suggesting that approximately 70% of organic consumers cite health as the primary reason for purchasing organic food.[16] In the USA, consumers who considered organic foods to be better than conventional foods believed that the following characteristics (in decreasing order of importance) were important when they purchased organic foods: safety, freshness, general health benefits, nutritional value, effect on environment, flavor, and general product.[17] Goldman and Clancy[18] reported that organic food buyers at a cooperative in New York believed protection of wildlife and water supplies from pesticide contamination was the most important reason for supporting organic agriculture, followed by protection of drinking water supplies from fertilizer contamination and protection of consumers from pesticide residues in food. Frequent purchasers of organic products were less concerned with price and product appearance. A group of Norwegian organic consumers identified health and environmental reasons for purchasing organic foods.[19] In this study, the youngest age group (15 to 24 years) named consideration for the environment and animal welfare as key reasons for purchasing organic food, whereas in the older age groups concern for their own health was the most important reason.

In a comprehensive study investigating health-related determinants of organic food consumption in the Netherlands,[20] the importance of health and environmental factors in influencing the decision to purchase organic foods was found to vary with the frequency of purchase. Health was found to be a more important motive for "incidental" buyers, whereas environmental reasons were found to be a more important factor for "heavy" buyers of organic foods. This finding suggests that when surveys of organic purchasers are carried out, the study participants should be classified according to frequency of purchase.

Consumers have also been found to have specific reasons for not purchasing organically grown foods, including:

- Too expensive[12,21-24]
- Poor availability and lack of time to find retail outlets (when organic products are not readily available in supermarkets)[19,21-23,25]
- Unsatisfactory quality (possibly mainly focused on appearance of fresh produce)[21,22,24]
- Satisfaction with their current food purchases; do not think organic food is any better[22]
- Unfamiliarity with the term "organic", certification systems and organic logos.[19.21]

Some researchers have attempted to develop a profile of the consumer of organic foods. These consumers have been classified into four broad (and presumably overlapping) groups: (1) those who are concerned with the environment, (2) food phobics who are concerned about chemical residues in food, (3) humanists concerned with factory farming, and (4) hedonists who believe that a premium product must be better and more importantly taste better.[26] In an Irish study, the typical organic food purchaser was more likely to be female with a higher level of disposable income.[26] Secondary factors influencing organic food purchase were the presence of children and being in the 30 to 49 year age group, although unlike other studies age group was not found to be a particularly significant factor. In a Californian study,[27] organic food buyers were found to be older than nonbuyers and were more likely to be in service and white-collar occupations. Govindasamy and Italia[28] reported higher income earners and younger people were more willing to purchase Integrated Pest Management (IPM) produce than lower income earners and older people. Another American study reported that income and age were not important factors in distinguishing between organic food buyers and nonbuyers.[18] Wandel and Bugge[19] have also reported that interest in organic food in Norway was not related to income, occupation, age, or presence of children in the household.

Schifferstein and Oude Ophuis[20] suggest that organic food buyers tend to be health conscious and believe that the type of food they choose to eat affects their health. In addition, organic consumers are more willing to sacrifice some money, appearance, and ease of preparation when purchasing organic products. Overall, purchasing organic food is part of a way of life for such people and reflects a particular ideology and value system.

The way in which consumers decide to purchase organic products has also been investigated.[13,25,29,30,31] A model developed for the purchase of organic foods includes four stages: cue utilization (organically grown label, naturally processed, price); integration of cues to an overall quality perception (health and environmental concerns); trade-off of perceived quality and cost (higher prices may lead to higher perceived value but price is also sacrificed in the product purchase); influence of perceived value on willingness to buy (the willingness to pay more for organic products than for conventional products is in most cases fundamental for success of the market).[29] In this study, organic extra virgin olive oil was used to test the model and various marketing actions were identified that might increase the likelihood that the product would be purchased. For example, product labeling should indicate the naturalness of the product and that it has been produced in accordance with recognized standards and that overall the product promotion should strongly link its attributes to product benefits such as environmental friendliness.

Hutchins and Greenhalgh[13] suggest that because of confusion of consumers over the word "organic", such products may be more successfully marketed in a broader way as "environmentally friendly". These authors strongly recommend that a cohesive marketing strategy is needed in order to fulfill the increasingly complex needs of consumers. Store type and convenience of store location is another factor that can markedly influence the purchase of organic products, and this could be an important factor in understanding where potential growth in organic foods might occur.[23,25,31] A variety of distribution methods for organic produce are used around the world, including direct supply from farmers to consumers, health food shops, specialist organic retailers, supermarkets, farmers markets, and food cooperatives.[32-35] The relative importance or dominance of distribution method tends to vary from country to country.[36] In New Zealand, organic food has in the past been predominantly distributed directly from farmers to consumers and via health food shops. It is only comparatively recently that some supermarkets have taken an interest in stocking organic products, largely because of difficulties in securing regular supplies and also because significant consumer interest has only developed quite recently.

D. Comparisons of Organic and Conventional Food Production Systems

A wide range of factors has been investigated in studies comparing organic and conventional food production systems, including economics, crop yields, agronomic factors (soil chemical properties, soil physical properties, soil microbiological activity, pest and disease burdens etc), farm management practices, product quality (nutritional value, taste, shelf life), environmental impacts, biodiversity, farm nutrient inputs and social, trade, and political issues associated with food production.[2,37-54] Clearly, in order to make a valid comparison of the two production systems a broad perspective needs to be taken. Food quality and what is meant by quality in the context of organic food production systems is one area that has received much attention in the debate on differences between organically and conventionally produced foods.[37,55-60] Many people involved in the organic food industry believe that a broad perspective concerning food quality is required in order to ensure the provision of a sustainable food supply in years to come. Hence, a number of areas have been identified as important to consider — authenticity, functional properties (how well food is suited to specific purpose — storage, cooking, and processing quality), biological factors (how food interacts with the body's functioning), nutritional value, sensory characteristics, ethical issues, environmental issues, and social issues in relation to production and distribution.[16] Recently it also been argued that in the future eating locally produced food is going to be an important factor in ensuring a sustainable food supply[61-63] and that environmental issues in food production and food "quality" should not be the only factors to consider.

The purpose of this review is to evaluate studies that set out to compare the nutritional value, sensory quality, and food safety issues of organically and conventionally produced food. While both consumers and food producers appear to find these particular issues of increasing interest from food choice and food marketing perspectives, respectively, it is important to acknowledge that a discussion of these issues only provides a very limited comparison of organic and conventional food production systems. In order to fully evaluate the advantages and disadvantages of both systems of food production, a far broader discussion of the issues mentioned above is necessary.

II. THE NUTRITIONAL VALUE OF ORGANICALLY AND CONVENTIONALLY GROWN FOOD

A. Introduction

A large number of studies have been reported that attempt to investigate if there is a difference in the nutritional value of organically and conventionally grown food. There is considerable variation in the types of studies and study designs. However, the majority involve one of four main approaches:

1. The chemical analysis of organic and conventional foods purchased from retailers
2. The effect of different fertilizer treatments on the nutritional quality of crops
3. The analysis of organic and conventional foods produced on organically and conventionally managed farms
4. The effect of organic and conventional feed/foods on animal and human health (predominantly reproductive health)

Within each of the four approaches, it is extremely difficult to compare findings because of the varying study designs. In addition, the studies that focus on the effect of fertilizer type on nutritional value and those that involve the analysis of foods purchased from retailers do not enable clear conclusions to be made about the impact of organic and conventional production systems on nutritional value. In the former study type only one (although important) aspect of production is considered, while in the latter type little or nothing is known about the origin of the foods analyzed. However, given that fertilizer treatment studies are cheaper and easier to carry out than whole farm comparison studies, it is not surprising that this approach is commonly taken. While these studies do contribute to fundamental knowledge of fertilizer effects, they do not provide clear answers on the effect of different farming systems on nutritional value of crops. Potentially more useful information about any differences in nutritional value would be obtained from the analysis of food produced from organic and conventional farms, because the effect of whole systems of production (which are documented) on nutritional value are essentially being evaluated. Animal and human health studies, together with information on food composition, could ultimately reveal the clearest answer. Such studies are, of course, the most difficult and expensive to perform. Food composition data alone do not reveal much about how foods may be digested and metabolized in the body.

In the following sections a number of studies are reviewed. Since some of the early studies (pre 1960) have not been reported in sufficient detail and/or have used questionable analytical methods, the focus of the review is on more recently published work.

B. Retail Purchase Comparisons

Although only a small number of studies have taken the approach of measuring nutritional value of products purchased from retailers, it is often these studies that gain media attention (Table 1). For example, Smith[67] is periodically quoted in the popular media as proving that organic food is more nutritious than conventional food. The study design precludes any such conclusions being made because it appears that there was no effort made to verify that organically labeled products were, in fact, from organic production systems and also no details about the sampling system were reported.

Some researchers argue that the best way to evaluate what nutrients consumers are actually getting is to purchase the food, as they would from the retailers. However, this approach does not allow such variables as maturity at harvest, freshness, and cultivar to be controlled at all (as well as any growing conditions), so these variables could well confound any apparent differences in nutritional value.

A recent study commissioned by the Organic Retailers and Growers Association of Australia (ORGAA) claimed that organic vegetables (beans, tomatoes, capsicum, silverbeet) sampled from a certified organic farm may have considerably higher minerals content than similar foods purchased from a supermarket.[64] Although ORGAA recognize that this is only one very limited study, they believe that the very much higher levels in organic food justify further study in a more rigorous fashion. It is interesting to note that there were no major differences in vitamin C and carotene levels in the crops studied.

Perhaps a more worthwhile approach to take with this type of study would be to identify retail suppliers (i.e., growers) of organic and conventional produce that are located in a similar area and establish an experimental protocol that would enable farming systems to be well documented as well as harvest date, distribution chain conditions, storage conditions at the retailer, etc. In this way some of the variables could perhaps be controlled and so any differences in the nutritional composition of produce purchased at the retail stage could be more accurately evaluated. However, even with a more elaborate protocol such as this, there would need to be a large number of studies carried out in different areas in order to make any generalized conclusions.

C. Fertilizer Treatment Comparisons

It is well known that the application of fertilizers in crop production will affect the composition of plant material.[69-75] Considerable emphasis

Table 1
Summary of Studies Comparing the Nutritional Value and General Quality of Organically and Conventionally Grown Food as Purchased from Retailers

Study	Products Tested	Study Design	Nutrients Analysed	Key Results
Anon[64]	green beans, tomatoes, capsicum, silverbeet	samples from certified org. farm and supermarket; number of samples not reported	Ca, K, Mg, Na, Fe, Zn, vit C, carotene	vit C and carotene levels similar in org. and conv. produce; mineral levels considerably higher in all org. products
Conklin and Thompson[65]	tomatoes, potatoes, sweet peppers, carrots, lettuce (leaf and iceberg), apples, grapes	org. and conv. samples from 5 retail outlets each week over 18 week period; 5-10 samples collected each week; over 80% org. products labelled as certified org.	visible quality characteristics noted only (e.g. bruises, tearing, insect damage, discolouration etc)	visual quality of org. and conv. products often indistinguishable; on average org. carrots, leaf lettuce, peppers and potatoes had more defects but not sig.
Pither and Hall [66]	apples, carrots, green cabbage, potatoes, tomatoes	products purchased from a variety of retailers, 30 samples each of org. and conv.	moisture, total solids, vit C, sugar, starch, Fe, K, Zn	results variable e.g.apples: vit C higher in org. cf conv., sugar higher in conv. cf org.; carrots: dry matter and K higher in org. vs conv., glucose, fructose, total sugar, vit C (dry weight basis) higher in conv. cf org.
Smith [67]	apples, pears, potatoes, wheat, sweetcorn, baby food	samples purchased over two yrs; no attempt to verify labelling of samples in stores; 4-15 samples per food	range of minerals	sig. higher levels of some minerals in all org. products except baby food e.g. apples (higher levels of Ca, Mg, Fe, P, Mn, Na in org. cf conv.; no difference in K, Cu, Zn); wheat (higher levels of Ca, Mn, P, K, Cu in org. cf conv., Zn, Mn; lower levels of Na, Fe in org. cf conv.)
Stopes et al. [68]	lettuce, cabbage, beetroot, cress (samples collected over two winters); potato, carrots, mung bean sprouts (samples from one winter)	no attempt to standardize for variety, source of supply; variable sample size (range 8-42 for one product over one winter)	nitrate	no consistent difference bet. org. and conv.; considerable range of values

Abbreviations: org. – organic; conv. - conventional; biodyn. – biodynamic; tmt(s). – treatment(s); bet. – between; sig. – significant; yr(s) - year(s)

has been placed on the effect of nitrogenous fertilizers on crop nutritional value and yield.[76-88] The majority of studies indicate that the higher the amount of nitrogen available to the crops, the higher its uptake and as a consequence the higher the nitrogen and nitrate contents of the crop. Whether the use of organic fertilizers results in different responses to that of inorganic sources of nitrogen has been studied frequently (see later).

A number of other factors may also affect plant composition, and for this reason it is often difficult to isolate the effect of fertilizers. The main factors that can influence the nutritive value of crops include:[48,69,71-73,89,90]

1. Genetics (i.e., plant crop and cultivar)
2. Environment
   - soil type and structure
   - fertilizer type and application method
   - climate - light, temperature, rainfall, humidity
   - soil microbial populations
   - management practices — e.g., crop rotation, use of pesticides, irrigation, growth regulators, cultivation practices
3. Post-harvest practices
   - harvest time (crop maturity)
   - handling and storage
   - processing methods and conditions

Studies investigating the effect of inorganic and organic fertilizers on crop composition have been carried out for some time and researchers have made varying attempts to control some of these other factors that could affect nutritional value. In addition, sampling protocols and analytical methods used (particularly in the earlier studies) may have also affected nutrient concentrations reported. Consequently, interpretation can often be difficult. A number of early studies found no significant difference in the nutritional value of crops fertilized with manure-based composts compared with those treated with inorganic fertilizers.[91-93] In these studies, vitamin C in potatoes, vitamin A in sweet potatoes, and vitamin B_1 in wheat and barley were investigated. In a much larger and comprehensive study, the effect of fertilizer treatments (control vs. manure vs. chemical fertilizers) on the nutritional value of wheat and millet were studied by both analyzing the chemical composition of the crops and by feeding the crops to animals.[94] The author claimed that wheat grown in the manure had higher (10 to 17%) vitamin A levels than that grown in the chemically fertilized soil and that the "manured" millet had 15% higher levels of vitamin B compared with that grown on soil treated with chemicals. In addition, growth was considered to be better in animals fed the "manured" wheat. It is clearly difficult to ascertain the reliability of these results given the lack of statistics and the unclear way in which the studies were reported.

El Gindy et al.[95] investigated the effect of fertilizer treatment, variety and soil type on the protein, and mineral content of wheat. This study is of particular interest because it is one of few that have used appropriate statistical techniques to explore the relative importance of fertilizer treatment, soil type, and plant variety on crop composition. It was found that plant variety had more influence on protein and overall mineral content than either fertilizer treatment or soil type, although there were significant interactions between soil type and fertilizer treatment for some nutrients.

Table 2 presents a summary of some of the more recent studies that have compared the effect of inorganic and organic fertilizers on the nutritional value of crops. The most common crops investigated are carrots, lettuce, potatoes, and leafy green vegetables, particularly spinach. A number of studies have analyzed crops for a range of minerals; however, the most common nutrients analyzed are vitamin C, carotene, and nitrate. In addition, dry matter has been reported frequently. The majority of studies have used an accepted experimental design (randomized block with replicates), although there are a number that have not appeared to pay much attention to experimental design.[96,118] In fact, in a few cases authors have claimed significant differences when no statistical techniques have been used at all.[96,103,109,116] The studies by Schuphan[116] are frequently quoted in support for increased nutritional value of organic crops.[47] The studies were conducted over a 12-year period and are among the longest in duration reported to date. Although some of the claims of increased nutrient levels from organic

Table 2
Summary of Studies Comparing the Nutritional Value of Food Grown Using Different Types of Fertilizers

Study	Crops Tested	Study Design	Nutrients Analysed	Key Results
Ahrens et al.[96]	spinach	2 expts; Expt 1) field trial, no replicates, 9 tmts (control, NPK (4 levels), composted manure (4 levels) Expt 2) field trial, 2 replicates, 9 tmts (control, NPK (4 levels), composted manure plus biodyn. preparations (4 levels), NPK plus manure (2 levels)), no statistics	dry matter, nitrate, vit C	Expt 1) higher dry matter and higher nitrate from NPK cf compost, lower vit C from NPK cf compost; Expt 2) lower dry matter from NPK cf compost, compost plus NPK variable for dry matter, higher nitrate from NPK cf compost and compost plus NPK, slightly lower vit C from NPK cf compost and compost plus NPK
Alvarez et al.[97]	pineapple	glasshouse trial, randomized complete block, 2 tmts (NPK, compost)	free acids, sugars	no difference in sugars and acids bet. tmts
Barker[98]	spinach	pot trial in glasshouse, 3 yrs, 7 tmts (control, dried blood, castor pomace, cottonseed meal, sewage sludge, dried cow manure, ammonium nitrate), 2 spinach varieties	N, nitrate	N lower from org. (average of 5 treatments) cf ammonium nitrate for both varieties; nitrate no different from org. cf ammonium nitrate tmts; nitrate lowest from cow manure for one variety only
Clark et al.[99]	tomatoes	4 tmts (conv. 2-yr rotation, conv. 4-yr rotation, low input, org.), 4 replicates, randomized block split-plot design	N	N significantly greater in 2 conv. systems cf org. in 3 of 4 yrs; N significantly greater in low input cf org. in 2 of 4 yrs
Comis[100]	swiss chard, green beans	pots in glasshouse, 3 tmts - manure, sewage sludge compost, inorganic fertilizer	vitamin C	vit C decreased with increasing manure or compost or inorganic fertilizers (i.e. increasing N)
Evers[101]	carrot	comparison of inorganic fertilizer tmts with org. farms; fertilizer - randomized block, 10 tmts, 2 yrs; org. farms - samples collected from 2 fields	nitrate, N, P, K, Ca, Mg, ash, dietary fibre	org. carrots similar to inorganic fertilizer tmts for nitrate, N, Mg, ash; P, Ca higher in org. cf fertilizer tmts; K, fibre variable depending on location
Goh and Vityakon[102]	spinach, beetroot	pot trial; 5 tmts (ammonium sulphate, ammonium sulphate+N-serve, potassium nitrate, poultry manure, urea); 5 levels, 2 varieties of spinach	nitrate	increasing nitrate with increasing N application; poultry manure lowest N uptake, potassium nitrate - highest N uptake in spinach and beetroot; no difference in 2 spinach varieties

Kansal et al.[103]	spinach	field trial, randomized block, 3 replicates, 7 tmts (urea (4 levels), manure (3 levels)) plus combinations; no statistics	dry matter, N, protein, P, Zn, Cu, Mn, Fe, sugars, vit C	N lower from manure tmts cf urea and urea plus manure tmts; effect of manure on P not clear; no trends for Fe, Cu, sugars; Mn higher from manure cf urea; Zn lower from manure cf urea; protein highest with no manure; vit C, carotene lower from manure cf urea
Lairon et al.[104]	lettuce	field trial, randomized block with 7 replicates; 7 tmts (control, ammonium nitrate (2 levels), nitrate of soda (2 levels), org. N (2 levels); sample size - 5 lettuces per plot	dry matter, P, K, Ca, Mg, Na, Fe, Cu, Mn, nitrate, protein, amino acids	dry matter, protein, amino acids - not affected by tmts; variable effects on minerals; nitrate lower from org. tmts cf mineral fertilizers
Lairon et al.[105]	leeks, carrots, turnip, potato, kale, lettuce	pot and container trials - 5 replicates; field trial - leeks, kale, 2 yrs, 3 replicates (tmts for pots and field - control, NPK, blood meal, compost); farm comparison – conv. vs org. - lettuce, potato, leek, carrot; sample size - pot trial (leek (n=5), carrots (n=4)); container trial (leeks (n=10), turnips (n=10)); field trial (n=10 from each plot); farm comparison (n=30)	dry matter, P, Ca, Mg, Fe, Cu, Mn, vit C, nitrate	pot trials: nitrate in leeks and carrots higher with NPK cf compost; no sig. differences in minerals for leeks and carrots; container trials: no effect of treatment on vit C in leeks and turnips, nitrate lower in compost cf mineral fertilizers and blood meal in leeks and turnips, no sig. differences in minerals; field trials: higher nitrate from NPK cf compost in leeks and kale; farm comparison: dry matter, vit C levels not affected, K, Ca, Fe, Cu, Mn not affected, tendency for P, Mg higher from org. farm, nitrate variable depending on crop, season - in spring/summer - nitrate lower in org. lettuce and potatoes in 3 of 5 samples
Lieblein[38]	carrots	randomized 3 factor factorial design, 2 blocks at each of 2 locations over 2 yrs; 9 tmts (control, 4 levels of org. and mineral fertilizer); expts carried out on biodyn. farms; 25 roots per plot analysed	carotene, N, nitrate, dry matter, glucose, fructose, sucrose	increased N application, increased N in carrots for conv. only - but varied with yr and location - effect of yr and location influenced carrot N more than tmt; increased nitrate from mineral fertilizer cf org. at one location only; carbohydrates more influenced by yr and location than tmt; no difference in carotene levels bet. tmts; carotene increased with increasing fertilizer application; no effect of tmt on dry matter, decreased dry matter with increasing mineral fertilizers

Table 2 (continued)

Maga et al.[106]	spinach	field trial, randomized complete block, 6 tmts (control, mineral fertilizer (2 levels), org. fertilizer (2 levels), late application of mineral fertilizer	nitrate	non-sig. lower levels of nitrate in org. fertilized plants
Meier-Ploeger et al.[107]	cabbage	randomized block with 4 replicates per treatment; 4 tmts at various levels (NPK, manure compost. biogenic compost, commercial org. fertilizer)	vit C, dry matter, brix, nitrate	lower dry matter and brix for NPK treatment cf some compost tmts for cabbage; nitrate - NPK at highest level caused highest nitrate for cabbage; no trends for vit C
Mozafar[108]	soybean, barley, spinach	pot trial, 5 replicates, 3 tmts (control, B_{12} added to soil, cow manure)	vit B_{12}	no effect of tmts on soybeans; cow dung increased vit B_{12} level by 3X in barley and 2X in spinach; direct B_{12} increased vit B_{12} level by 4X in barley and 34X in spinach.
Muller and Hippe[109]	cauliflower, lettuce, potato, spinach tomato	pot trial, 10 tmts 2 supplying org. N, 4-10 replicates per treatment, expts repeated 2-5 times depending on crop; no statistics	vit C, dry matter, protein, amino acids, nitrate, sugars	dry matter: tendency for increasing N to increase dry matter in all crops except tomato; org. N not increase dry matter as much as inorganic N; protein: tendency to increase with increasing N application; nitrate: higher levels from org. N for lettuce, cauliflower, potato; for tomato - lower nitrate levels from org. N
Nilsson[110]	carrots, cabbage, leeks	field trial, 3 tmts (NPK, manure plus org. fertilizers, PK plus org. N), 2 levels, 3 replications, 2 yrs; sample size - carrots (n=20), cabbage (n=6), leeks (n=10)	dry matter, vit C, carotene, sugars, N, nitrate, K, Ca, Mg, Na, P	dry matter: highest from manure cf PK plus org. N in carrot, lowest in manure for cabbage, lowest in PK plus org.; vit C, carotene, sugars: no effect; nitrate: higher from org. N tmts cf NPK for cabbage and leek, lowest for carrot from manure plus org. fertilizers; P, Ca higher from org. tmts and K, Mg not affected (no figures given) for all 3 crops
Peavy and Greig[111]	spinach	field plots, randomized complete block, 2 yrs, 3 crops of spinach; 3 tmts (org. (manure); conv. (mineral fertilizer and mineral fertilizer with split N application); 4 levels of application	N, P, K, Ca, Mg, Fe, Zn, Mn, Na	N, Ca - lower from org. fertilizer cf conv. in 2 of 3 crops; P, Na - higher from org. fertilizer cf conv. in all crops; Fe - higher from org. fertilizer cf conv. in 2 of 3 crops; little effect on K, Mg, Zn, Mn

Perez et al.[112]	rice	field plots, randomized complete block, 4 replicates, 12 tmts plus control	protein, lysine	protein: urea super-granules and fresh rice straw - higher protein cf control; no effect on lysine
Pettersson[113]	potatoes, spring wheat, barley	field plots (2 crop rotations over 3 yrs; conv. and biodyn. tmts; 3 replicates)	protein, vit C	potatoes: higher protein and lower vit C in conv. cf biodyn.; wheat and barley: higher protein in conv. cf biodyn.
Pfiffner at al.[114]	beetroot	randomized block design with 4 replicates; 5 tmts - control, biodyn., org., conv., mineral fertilizer only; crop rotation - same for all tmts, 3 yr study	dry matter, P, K, Ca, Mg, nitrate, vit C	variable results over yrs; for 1 yr lower dry matter from mineral treatment but overall org., biodyn. and conv. tmts had similar dry matter over all yrs; P similar for org., biodyn. and conv. tmts - mineral treatment lower; Ca and Mg similar in all yrs, K higher from conv. cf other tmts; no difference in nitrate amongst tmts for 2 of 3 yrs; vit C similar for all tmts
Raupp[115]	carrots, potatoes, beetroot	field trial, 4 yrs, 3 tmts (composted cattle manure, composted cattle manure plus biodyn. preparations, mineral fertilizer)	nitrate	similar lower nitrate from both composts cf mineral application in all three crops on average over 4 yrs
Schuphan[116]	potatoes, spinach, lettuce, cabbage, celeriac, carrots, sugar beet (grown in rotation); potatoes, spinach, cabbage and carrots analysed	12 yr field trial; 4 tmts (NPK, NPK plus manure, manure, biodyn. compost); 4 replicates except for compost treatment, repeated on 2 soil types; no statistics	nitrate, vitamin C, carotene, K, Na, Ca, Mg, P, Fe	nitrate: lower from compost cf NPK in spinach only for both soil types; vit C: higher from compost cf NPK for spinach, cabbage both soil types; carotene: levels similar for all tmts; effects on minerals variable depending on crop and soil types
Stopes et al.[117]	lettuce	3 lettuce varieties, 5 tmts (unfertilised control, 2 levels of N application from either inorganic fertilizer or composted farm yard manure); randomized block design, 4 replicates	nitrate, dry matter	no effect of fertilizer tmt on dry matter though both inorganic fertilizer and compost decreased dry matter cf unfertilized control, 20% increase in N levels from inorganic fertilizer cf compost
Svec et al.[118]	tomatoes, potatoes, peppers, lettuce, onions, peas	field plots; 5 tmts (org. - dairy manure, cottonseed meal, blood meal, rock phosphate; conv. - mineral fertilizer); 2 yr trial	vit C (tomatoes, potatoes, peppers), N, K, P, Ca, Mg (peppers, tomatoes)	no difference in vit C for any crops, lettuce - K sig. lower in org. cf conv.; tomatoes - K sig. higher in org. cf conv.; no other differences

Table 2 (continued)

Termine et al.[119]	leeks, turnips	5 randomized replicates of 5 tmts (control, NPK, blood meal, sheep manure compost, woodchip compost)	dry matter, nitrate, Ca, Mg, Fe, Cu, Mn, Na, K, vit C	leeks: dry matter higher for NPK and both composts cf control and blood meal; highest nitrates from NPK and blood meal, other tmts similar; vit C higher in manure cf woodchip compost; turnips: dry matter higher in control and woodchip compost cf other tmts; highest nitrates from NPK and blood meal, other tmts similar; no effect on vit C; no consistent trends for minerals in either vegetable
Vogtmann et al.[120]	tomatoes, carrots, cabbage, potatoes	container trial in glasshouse - tomatoes: 4 varieties, biogenic waste compost cf commercial potting soil; field trial - carrots, cabbage, potatoes - 8 tmts (control, mineral fertilizer (2 levels), biogenic waste compost with and without org. mineral fertilizer, manure compost with and without org. commercial fertilizer, org. commercial fertilizer)	tomatoes: brix, total acid; carrots, cabbage: brix, nitrate, N, free amino acids (carrots), vit C (cabbage); potatoes: starch, free amino acids, nitrate, N	tomatoes: higher acid in biogenic waste compost; carrots: no sig. difference in nitrate amongst tmts; cabbage: highest mineral treatment lowest vit C but not sig. different from other tmts; highest nitrate from highest mineral N tmt; potatoes: no effect on vit C; highest nitrate for highest mineral and compost/mineral tmts; increasing N application increased total N in all 3 crops
Vogtmann et al.[121]	leafy green vegetables	container and field plots; 5 tmts (control, NPK and nitrate of ammonia (2 levels), dairy manure compost (2 levels)), 4 replicates; 3 yrs for field trials; farm survey - 12 varieties of lettuce tested for dry matter, nitrate; paired farms - lettuce from conv. and org	dry matter, nitrate, vit C	pot trials: - dry matter decreased for highest NPK tmt, lowest nitrate level in compost tmt, effect on vit C varies with spinach variety; field trials: - nitrate lower, vit C higher in compost cf NPK tmt; farm survey - variation in nitrate levels amongst cultivars under same growing conditions; paired farms - nitrate levels lower from org. farms except in winter
Warman and Havard[122]	carrots, cabbage	field trial, 5 replicates, alternate plots each yr over 3 yrs; 2 tmts (conv. - lime, NPK fertilizers, pesticides; org. - lime, compost, rotenone and bacillus thuringiensis (Bt) for insect control	carrots - N, P, K, Na, Ca, Mg, S, B, Fe, Mn, Cu, Zn, vit C, carotene, vit E; cabbage - as for carrots, no carotene	carrots: no effect of tmt on vit content, org. higher in S, B; conv. higher in N, Mn, Cu; cabbage: no effect of tmt on vit. content, some differences in minerals but not consistent over 3 yrs
Warman and Havard[123]	potatoes, sweetcorn	as in Warman and Havard 1997; 2 tmts (org. - compost plus rotenone and Bt; conv. - NPK plus a range of pesticides for weed/insect control)	potatoes N, P, K, Na, Ca, Mg, S, B, Fe, Mn, Cu, Zn, vit C; sweetcorn as for potatoes plus vit E	potatoes: P, Mg, K higher in org. in some yrs; vit C not affected by tmt; sweetcorn: inconsistent sig. differences in P and K; no effect on vit E or C

Abbreviations: org. – organic; conv. - conventional; biodyn. – biodynamic; tmt(s). – treatment(s); bet. – between; sig. – significant; yr(s) - year(s)

fertilizers may be justified, some may not because the author only reports the percentage increases for some nutrients rather than reporting any proper statistical tests for significance. It is also interesting to note that in this particular study, results varied depending on the soil type.[116] There have been numerous other reports by Schuphan that review a number of studies.[124,125] One of the topics discussed is the effect of nitrogen on crop composition,[124] and it is claimed that increasing nitrogen application may decrease dry matter, total sugar, vitamin C, essential oils, methionine, and a number of minerals. In addition, nitrate levels in plants may increase in response to increasing nitrogen applications. A number of studies are referenced in support of these claims, although the details are often difficult to verify.

The studies by Vogtmann and colleagues[120,121] are also often quoted in support of nutritional benefits of organic fertilizers. Certainly some of the container, field trials, and farm comparison studies support the claimed lower nitrate levels in produce grown using organic fertilizers compared with mineral fertilizers. However, there is some variation among the findings, with cultivar type and season being identified as two variables that may also influence crop composition.

The study by Lieblein[38] is one of the better designed, analyzed, and reported studies investigating the effects of fertilizer treatments on the quality of carrots. Three factors were investigated: fertilization (four levels of organic and mineral fertilizer each plus control), location (2), and year (2). The field experiment was conducted on farms that had been managed biodynamically for the previous 5 years. Rainfall and air temperature were recorded at the two locations (which had different soil types). It was found that carrot nitrogen levels increased with increasing application of nitrogen from mineral fertilizers only, but that this trend was not consistent over the 2 years and at both locations. At one location only, organic fertilizers resulted in a lower nitrate content in the carrots compared with the carrots grown using mineral fertilizer. There was no effect of fertilizer type on the carotene content of the carrots. Multivariate analysis revealed that location was a particularly important variable affecting any differences between organic and mineral fertilizer treatments on carrot quality. In other words, the effects of specific fertilizer types and dosage strongly depends on local conditions, and so results from one location cannot necessarily be expected to be repeated in another.

Overall, the fertilizer comparison studies suggest that at least in some situations the use of organic fertilizers may result in lower nitrate levels of some crops and some cultivars than when using the more soluble mineral fertilizers. Whether this trend would continue consistently under long-term management is not clear. Certainly different climatic conditions could well influence nitrogen and nitrate content as well as fertilizer treatments. With regard to the effect of fertilizer type on mineral and vitamin content of crops, the study designs and results are too variable to make any definite conclusions.

D. Whole Farm Comparisons

Table 3 presents a summary of studies that have compared the nutritional value of food produced from conventional and organic farming systems. Some researchers have attempted to control variables such as farm location, soil type, cultivar, and maturity at harvest, in an effort to reduce the number of potential factors affecting nutritional value.[126,127,130,132,136,138] Farm comparison studies have the advantage that effects of whole farming systems are compared, although they commonly preclude the relative importance of individual factors on nutritional value from being clarified because few researchers have used appropriate experimental designs and statistical methods. The studies vary in duration with only a small number of studies being carried out for more than 3 years.[58,139] However, some of the studies were carried out on farms that had been managed organically or conventionally for a considerable period of time.

As with the fertilizer treatment studies, the results from the farm comparison studies are also highly variable. It appears that the farm comparison studies have generally shown fewer significant differences in the nutritional value of organically and conventionally grown food than the fertilizer treatment studies. This could be because

Table 3
Summary of Studies Comparing the Nutritional Value of Food Produced from Organic and Conventional Farms

Study	Products Tested	Study Design	Nutrients Analysed	Key Results
Cayuela et al.[126]	strawberries	1 pair of org. and conv. farms; same cultivar, soil conditions, planting system; 11 samples randomly taken at weekly intervals over 3 months	acidity, sugar (brix), dry matter, ash, vit C, Ca, Mg, Fe, Mn, Zn, Cu	overall no difference in acidity, vit C, ash, minerals; higher brix and dry matter in org. cf conv.
Clarke and Merrow[127]	tomatoes	3 conv. growers and 3 org. growers grew 6 plants each of 2 cultivars on their properties for 2 seasons; rainfall, irrigation recorded; tomatoes harvested at same stage of maturity (firm ripe),	vit C, carotene, P, Ca, Fe, Zn, Mg, Na, protein	climate similar over 2 growing seasons but different rainfall among plots; no difference bet. cultivars for all 9 nutrients except for 1 yr when vit C higher in org. tomatoes cf conv. - other yr trend reversed; no sig difference in Ca, P, Mg bet. org. and conv. in either yr, carotene, protein, Na, Fe, Zn, dry matter higher in conv. cf org. in 1 yr only
Dlouhy[58]	potatoes, wheat	biodyn. and conv. systems compared, two crop rotations used in each farming system; 5 yr trial	dry matter, protein, nitrate, vit C	potatoes: conv. higher cf biodyn. for protein, nitrate while biodyn. higher cf conv. for dry matter, vit C; wheat: conv. higher cf biodyn. for protein
Fischer and Richter[128]	potatoes	samples taken from 9 conv. farms and 11 org. farms; 10 varieties; on average more available nitrogen from conv. farms cf org.	nitrate, vit C	nitrate sig. lower in org. potatoes cf conv., vit C sig. higher in org. potatoes cf conv.
Guinot-Thomas et al.[129]	milk	milk from 3 farms compared – conv., transitional, org.; all in same location	nitrate, dry matter, Ca, K, Na, Mg, P, Fe, Zn, Cu, N, protein	no difference in dry matter, fat, Ca, K, Fe, Cu, bet. 3 systems; org. lower Zn, N, protein cf transitional and conv.; org. higher nitrate cf conv., transitional
Hansen[130]	potatoes, carrots, beetroot, curly kale	4 biodyn. growers and 4 neighbouring conv. growers in 4 different regions; soil type and climate similar	N, ash, nitrate, P, K, Na, Ca, Mg	nitrate lower in biodyn. beetroot cf conv. in 3 of the 4 regions, otherwise no major differences

Jorhem and Slanina [131]	potatoes, carrots	potatoes from 10 pairs of org. and conv. farms located close together; carrots from 6 pairs of org. and conv. farms located close together	Zn	no difference in Zn levels bet. org. and conv. farms for either crop
Leclerc at al. [132]	carrots, celeriac	2 yr study; 6 pairs of org. and conv. farms per yr per crop, pairs matched for location, soil type, variety, growing period, sowing date (where possible)	dry matter, vit C, beta-carotene, B vits (thiamin, vit B_6, pantothenic acid, niacin), nitrate, minerals	carrots: org. higher in beta-carotene and thiamin cf conv. - no other differences; celeriac: org. lower nitrate and Zn, but higher dry matter, P, vit C cf conv.
Lund [133]	milk	milk samples collected from 9 org. and 6 conv. farms over 12 month period	total solids, fat, protein, non-casein N, non-protein N, lactose, vit C, ash, P, Na, K, Ca, Mg, fatty acids	generally small differences in composition bet. farming systems
Mercadante and Rodriguez-Amaya [134]	kale	1 org. farm and neighbouring conv. farm; 2 cultivars of kale harvested in summer and winter from both farms;	beta carotene, total vit A (differences bet. org. and conv. only analysed for 1 variety and 1 season (summer))	sig. differences bet. cultivars in summer but not winter in beta-carotene and total vit A; beta-carotene and total vit A higher in org. cf conv.
Pfeilsticker [135]	cauliflower, lettuce, carrots, celery, red radish	experimental farms; 3 farming systems (biodyn. 1 and 2 (different fertilizer practices); conv.)	sugars, nitrate, K, Mg, Fe, Mn, Cd, Zn	complete results not provided – cauliflower: nitrate no different bet. conv. and biodyn.; overall higher mineral levels in biodyn. cf conv.
Shier et al. [136]	wheat	9 pairs org. and conv. farms matched for location, size, time, yr of harvest	protein, moisture, ash	no difference in protein, moisture, ash bet. org. and conv.
Starling and Richards [137]	wheat, barley	wheat: 40 org. samples from various regions 1 yr and 39 samples the next yr, data cf conv. farms; barley: samples from 3 org. and conv. farms over 2 yrs	N, protein	barley: higher % N in org. cf conv. (possibly from presence of mildew); wheat: lower N and protein in org. cf conv.
Weibel et al. [138]	apples	10 farms (5 org. and conv. located within 1km of each other); 1 cultivar	N, P, K, Ca, Mg, vit C, vit E, fibre, Se, phenolic compounds	org. fruit higher in P, fibre, phenolic compounds cf conv.
Wolfson and Shearer [139]	maize	14 pairs of org. and conv. farms; farms matched for location, variety, planting date, soil type; sampled over 4 yrs	N, protein, amino acids	protein lower in org. cf conv.; all amino acids except methionine, lysine, histidine, arginine lower in org. maize cf conv. (% total grain weight)

Abbreviations: org. – organic; conv. - conventional; biodyn. – biodynamic; tmt(s). – treatment(s); bet. – between; sig. – significant; yr(s) - year(s)

of the interaction of a larger number of variables affecting nutritional value when comparing whole farming systems than when comparing fertilizer treatments only (particularly when in fertilizer experiments efforts have been made to control some variables).

A relatively consistent finding appears to be that organic products tend to have lower nitrate levels.[58,128,130,132] A finding of a higher nitrate level in organic milk was subsequently thought to have arisen from contamination from equipment cleaning agents.[129] It is extremely difficult to identify any other trends from the results of these farm comparison studies, although of the four studies that analyzed protein in wheat/maize, the protein level in conventional wheat was either higher or the same as in organic wheat.[58,136,137,139] It has been suggested that lower protein levels in organic wheat may be caused by lower nitrogen availability under an organic farming system, although this could readily be modified with various organic production techniques.[137] Storey et al.[140] have also reported a low protein content of organically grown wheat from a study investigating the suitability of wheat cultivars for an organic production system. In contrast, as discussed earlier, McCarrison and Viswanath[94] claimed organic wheat to be nutritionally and metabolically superior.

The carotenoid content of crops has been analyzed frequently in both fertilizer treatment and farm comparison studies. There is some evidence that higher applications of nitrogen may decrease beta-carotene levels[132] and also that the use of some pesticides in conventional production systems may cause lower beta-carotene levels in some crops,[134] although other studies are not in agreement. For example, Giannopolitis et al.[141] reported that an application of two herbicides to lettuce resulted in no change in carotene content in 1 year of the trial but decreased carotene levels in a subsequent year. However, it was noted that the rainfall was higher in the second year, which may have facilitated root absorption of the herbicides.

Demonstration of differences in the vitamin C content of organic and conventional foods have not been consistent, with some studies reporting higher levels in organic crops[58,127,128,132,133] and others reporting no significant differences or lower levels in organic crops.[126,127,130,138] Because vitamin C content is readily affected by maturity at harvest, storage conditions (e.g. temperature), surface bruises, and presence of oxygen, irrespective of farming system,[142] it is not surprising that there is considerable variation in results both within and among studies.

The study by Bear et al.[143] is frequently cited in support of higher nutrient levels of organically grown food. Although this study demonstrated that the mineral content of crops from commercial farms can vary considerably with location and soil type, it did not compare the effect of organic and conventional farming systems on nutritional value.[144]

E. Animal Feeding and Human Health Studies

Most of the studies that have compared the consumption of organically and conventionally grown feed on animal health were carried out some time ago and, frequently, detailed reports of studies are lacking. Hodges and Scofield[145] cite studies that claim that the intensive use of mineral fertilizers may lead to increased infertility in cattle. In addition, Gottschewski (1975) and Staiger (1986) (see Vogtmann[146]) report improved reproductive health from the consumption of organically grown feed. Rabbits given biodynamic feed had more embryos, had a higher number of offspring born, and were less susceptible to infection than those rabbits given conventionally grown feed. Because both the biodynamic and conventional feeds had a similar composition, the study suggested that factors other than feed composition may be causing differences in biological performance. What these factors may be is not clear. Another study (see Vogtmann[146]) reported lower mortality of newborn rabbits for those fed organically grown feed compared with those given conventional or commercial feed but no differences in fertility. In contrast, however, a number of studies report no benefits on health from the consumption of organically grown feed.[92,93,147-149] However, some of these studies[121] have been criticized over the use of unbalanced diets given to the test animals.[145]

As with the other types of studies investigating the nutritional value of organically and conventionally grown food, the overall findings of the animal experiments are variable. The long-term Haughley experiments[150] suggest that organically grown feed may have some benefit for animal health and performance (for example, increased milk production from organically fed cows), although it has been suggested that animals were placed in "artificial conditions" in the experiments and so the findings may not be generalizable to other situations.[150,151] These experiments and others[94,152-155] could also be criticized over the use of feeds obtained from various fertilizer treatment studies rather than from organically and conventionally managed farms.[156]

One of the better controlled studies is that by Velimirov et al.,[157] in which organic and conventionally produced feed (from neighboring farms) were compared for their effects on rat fertility over three generations. All the test feeds were chemically analyzed and based on these results the vitamin and mineral composition of the feed mixture was adjusted so as to avoid both excessive levels and deficiencies of any nutrient. Twenty pairs of rats were fed organic feed and 20 pairs the conventional feed. There was no significant difference in the pregnancy rate, birth weight, or weekly weight gain of the offspring between the conventionally and organically fed rats. There were significantly fewer offspring born dead in the "organic" fed group than in the "conventional" fed group in the first litter but not in the second litter. Generally, the "organic" fed group had significantly fewer perinatal deaths than the "conventional" fed group, but a change in feed (with respect to year of harvest and growing site) between the first and second litters of the second generation was thought to have a favorable effect on the rearing performance of the "conventional" fed group for the second litter of the second generation. However, it was found that the number of perinatal deaths was again lower for the "organic" fed group than the "conventional" fed group for both litters of the third generation. Overall, this study indicated that some aspects of rat fertility may be improved from "organic" feed and that results can often be inconsistent even over generations within a study.

One of the few studies attempting to evaluate the effect of organically grown food on human health was that reported by Schuphan.[124] Although some benefit of organically grown food on infant weight and blood measures was reported, the details of this work are not readily available. More recently there has been some interest in semen quality of men involved in the organic food industry (farmers, consumers) compared with that of men in other industries or workplaces.[158-161] These studies have either attempted to correlate organic food consumption/dietary pesticide residue levels with semen quality or compare semen quality of organic farmers/consumers with nonorganic consumers. Abell et al.[158] found that organic farmers had a higher sperm density than three groups of blue-collar workers, but offered no particular explanation for this finding. In contrast, Jensen et al.[159] found no clear relationship between eating habits and semen quality, although sperm concentration was higher in members of organic food associations than controls. Because a number of demographic variables were not controlled in this study, it was suggested that factors other than eating habits could have confounded the result.

No significant differences in sperm quality of organic and conventional farmers were identified in the study by Larsen et al.[160] In this study semen quality was also correlated with organic food consumption/dietary pesticide exposure.[161] The farmers were divided into three groups according to the amount of organic food consumed and dietary pesticide intakes (of 40 compounds) were estimated. Although the pesticide intake was found to be lower in "high organic food consumption" group, the pesticide intake of all groups was estimated to be very low. The group of men who consumed no organic food was found to have a significantly lower proportion of morphologically normal semen but for the other 14 semen parameters measured, no significant differences were found. In conclusion, these studies do not provide strong evidence of any effect of organic food consumption or pesticide exposure on semen quality, although sperm concentration could be further investigated.

F. Relevance to Overall Diet and Research Limitations

The majority of studies investigating nutritional differences between organically and conventionally grown food have limited their analyses to a small range of food components such as protein, sugars, vitamins, and minerals. This is a very limited approach because nutrient concentrations do not give any indication of how these nutrients may be metabolized and hence their bioavailability. Whether there are any differences in the bioavailability of nutrients from food grown using the two production systems has not yet been studied.

Another factor that may confound the interpretation of the nutritional value of organically and conventionally grown food is whether the nutrient concentrations are expressed on a dry weight or fresh weight basis. Although the results are variable (see Tables 1, 2, 3), there has been some suggestion that organically grown crops may have a higher dry matter content than conventionally grown crops.[46-48,54] Hence nutrient concentrations might be more meaningful if expressed on a fresh weight basis. Clearly, the dry matter content is another factor that requires further research along with investigations on possible mechanisms that might explain any differences in the dry matter content of organic and conventional foods.

The significance of any possible differences in the nutritional value of individual organic and conventional food products on the overall nutritional quality of a person's diet also needs to be considered. Currently, few people are able to consume totally organic food because of difficulties in supply. Also, even if a person's diet predominately consists of organic foods, if the diet is unbalanced (high in fat or high in sugar, for example), any presumed benefits of consuming organic food may be negated by the overall dietary habits of that person. On the other hand, tentative evidence that the nutritional value of our "conventional" food supply may be declining could mean that organically grown food may offer extra benefits yet to be documented.[162]

Only recently has there been any research investigating the concentrations of nonnutritional compounds, for example, phenolic compounds, in organically grown foods.[163] In contrast, there is currently an enormous amount of research investigating the role of such compounds (present in conventionally produced food) in common diseases such as heart disease and cancer.[164-166] Studies have shown that increasing nitrogen application may decrease the level of phenolic compounds in crops, thus making them more susceptible to pest and disease problems.[163] As well as influencing the growing of these crops, the decrease in phenolic compounds may also have health implications. Given that organic farming systems can result in lower nitrate levels in some crops in some situations, it is possible that organically grown food may offer health benefits that cannot be measured only in terms of nutrient concentrations.[163,167]

Some researchers have attempted to develop different methods to compare the quality of organic and conventional food. Schulz et al.[168] have developed a quality index in which 10 parameters (including such factors as dry matter, nitrate, free amino acids, protein) were combined in order to make a more valid comparison between fertilizer treatments. Although an approach such as this might have some merit it appears to have not been pursued in subsequent studies. Other very different approaches that have been used include copper chloride crystallization and paper chromatographic methods. In the copper chloride crystallization method, the plant extract is mixed with a copper chloride solution and then crystallized under standard conditions. The interpretation of the crystal patterns focuses on the number of centers, the structure and distribution of the needles, the number and kind of branches, and the formation of hollow structures. The patterns in which salts crystallize from solutions have been shown to be affected by the presence of impurities,[37] and this technique has been used in organic/conventional food comparison studies. For example, it has been reported that protein concentration and protein composition have a significant influence on the crystallization pattern of copper chloride.[37] The key difficulty with this approach is the interpretation of the pictures generated,[163] although currently work is progressing using computer-generated images to help standardize interpretation. Lieblein[38] used the copper chloride crytallization method for evaluating carrots grown under different fertilizer treatments.

He reported that mineral fertilization resulted in less well-formed crystal pictures than organic fertilization when no significant differences were found in the chemical composition. This could indicate that mineral fertilization affects the structure of the carrot tissue; however, the significance of this is unclear. Pfiffner et al.[114] have also reported differences in the structure of beetroot tissue grown under different cultivation systems when using the copper chloride crystallization technique. Knorr[169] has reported the use of a circular chromatographic method for distinguishing between plants grown under different fertilizing conditions. Using a "blind" evaluation procedure with 50 panelists, differences in chromatograms were seen when the level of nitrogenous fertilizer was changed, indicating that nitrate concentrations could be an important factor when attempting to interpret such chromatograms. Clearly, much more work is required using such techniques if they are to be useful in attempting to distinguish between organically and conventionally produced food.

As discussed earlier, comparing the effect of organic and conventional farming systems on nutritional value of crops is inherently difficult due to the wide range of factors that can potentially affect crop composition. While some of these factors can be controlled, others cannot and so it is unlikely that clear answers will be obtained in using traditional analytical approaches such as measuring nutrient concentrations.

III. THE SENSORY QUALITIES OF ORGANICALLY AND CONVENTIONALLY GROWN FOOD

A. Introduction

Among the claims made about organic growing methods is that they produce more flavourful ("better tasting") fruits and vegetables. This is certainly the stated rationale for undertaking a number of studies in recent years,[106,170-172] which have set out to determine the validity of this claim. However, even if organic produce is not superior in sensory terms, there may be other reasons for implementing organic farming systems, including safety and environmental considerations. Given this, it is equally important to assess if organic growing methods adversely affect sensory properties, because this would certainly discourage consumers from selecting organic over conventional produce.

A number of studies comparing organic and conventional production methods have included sensory tests of one form or another along with chemical, agricultural, or nutritional analyses. These studies suffer, of course, from the same limitations as other studies in this area, namely, utilizing a variety of meanings (sometimes unspecified) of "organic" as well as study designs that differ in their suitability to make the appropriate comparisons. Of particular relevance is the specification of the source of the organic produce and the extent to which factors such as climate, soil, harvest time, and other growing conditions were controlled in the comparison. In the studies examined, this ranged from sourcing produce from "organic producers" (e.g., Porretta[173]) or "organic farms"[138] to highly controlled studies in which specific details of growing conditions and approaches, for example, fertilizer types, are provided and the organic and conventional foods are grown under close to identical conditions (e.g., Svec et al.[118]). Such variability clearly militates against finding consistent effects because, even if there are sensory differences due to fertilizer type, they may be less apparent than differences due to climate, soil, or other factors.

There is a view, however, that although there may be multiple factors that differ between conventional and organic growing methods, and this makes controlled experiments difficult, this may not matter if we simply want to know about any consistent differences between conventional and organic produce that is currently available to the consumer. In this sense, it might be considered worthwhile to evaluate studies comparing organic and conventional produce irrespective of differing methodologies and definitions of organic produce. The limitation of this is, of course, that purchased products labeled "organic" may not necessarily reflect any of the accepted meanings of the term, and hence neither positive nor negative findings can be interpreted with any certainty.

Another factor that impedes drawing definitive conclusions at times is the incomplete specification of both the sensory techniques used (which tests, definition of terms, etc.) or the results obtained, evident in many studies.[120,138,173,174] As one example, reporting only that organic tomatoes had a higher "taste quality" as measured by a trained panel[120] provides little useful information.

All sensory evaluation techniques can be broadly classified into three categories:

1. Discrimination tests, which allow a determination of the presence of differences;
2. Descriptive analysis techniques, which use trained panels to describe the nature of, and quantify, any differences that may be present; and
3. Preference/acceptability measures that reflect relative degrees of liking.

In the studies examined here, all of these approaches are present, and classification along these lines provides a convenient means of summarizing the study outcomes.

B. Discrimination Studies

Valid discrimination techniques such as the triangle test allow straightforward and sensitive determinations of the presence of sensory differences, irrespective of the quality of that difference. Ideally, such studies would be the first step in establishing whether consumers can tell organic from conventional foods, because until differences of any sort can be reliably shown, preference and descriptive studies might be considered premature.

A small number of studies have opted to use discrimination methods, although their findings are mixed. Using similarity judgements (which can be considered a form of discrimination testing), a group of 18 consumers[174] failed to discriminate between organic and conventional carrots. Using a trained panel, which performed a series of triangle tests, Maga et al.[106] also failed to show a difference between organic and conventional spinach. In contrast, Basker[171] did find differences for spinach and grapes, but not for grapefruit and sweet corn. A study of several vegetables found a similar mixed pattern of results with organic/conventional differences evident for beetroot and carrots, but not for curly kale.[130]

There are two important considerations, relating to whether differences are present or not, which have an impact on interpretations of the failure to find a pattern of results in such studies. Moreover, these two issues apply not just to discrimination tests, but to all of the sensory tests considered in this review. First, failure to find differences with one fruit or vegetable type or variety does not necessarily imply that such differences will not be found in studies of other types or varieties. This, of course, will make definitive generic conclusions regarding organic vs. conventional produce difficult to make until large numbers of studies have been undertaken. Second, interpretations of one, or a few differences in the context of large numbers of comparisons, such as those reported by Hansen,[130] need to be made with consideration of the possibility that the positive findings are spurious. This is due to Type 1 errors, occurring as a result of inflated alpha levels when multiple nonindependent comparisons are undertaken within the same data set.

C. Descriptive Analysis Studies

As with discrimination tests, those studies that have measured responses to specific sensory qualities have failed to produce consistent results, and in some cases produced results that are difficult to interpret. For example, although Weibel et al.[138] found that organic apples had a "higher sensory score" than apples from an "integrated farm", it is difficult to know what this means. Another study, of Macintosh and Cortland apple varieties, had more clearly interpretable results, finding no differences for *juiciness*, *sweetness*, *tartness,* and *off flavor*, but concluding that "organically grown" Macintosh apples were more *firm*.[175]

Three studies have compared the sensory properties of organic and conventional tomatoes. Porretta[173] showed that a cluster analysis of "all parameters" (including results of chemical analysis) discriminated between organic and conventional tomatoes. Although the contribution of sensory characteristics to this process was not specified, it was noted that conventional products had better sensory characteristics, particularly with respect to *color* and *natural taste*. By contrast, Vogtmann et al.[120] found that organic versions of two out of three tomato varieties had higher "taste quality", again, a conclusion that is difficult to interpret. A clearer result was obtained by Johansson et al.'s study[176] in which trained panels assessed organic and conventional tomatoes for a variety of different attributes. They found no differences in *acidity*, *sweetness*, and *bitterness*, but did find that organic tomatoes were less *firm*, less *juicy* and *redder*. This same group[172] also compared organic and conventional carrots from two growing seasons. The results show little in the way of a consistent pattern. In the first year, organic carrots had less *sweetness*, *crunchiness,* and *flavour*, but were *harder*. There were no differences in *aftertaste* and *bitterness*. In the second year, they were again *harder* and had less *flavor*, but more *aftertaste*. There were no differences for *sweetness*, *crunchiness* or *bitterness*.

D. Preference Studies

Is organic produce preferred to conventional produce? As with other types of sensory studies, the research on this issue does not provide an unambiguous answer. Using a consumer group, Schutz and Lorenz[170] found no differences in ratings of liking between organic and conventional lettuce and green beans. On the other hand, organic broccoli was preferred, as were conventional carrots. Basker[171] undertook preference tests with groups of consumers, finding that organic bananas were preferred, as were conventionally grown mangoes and juice from conventionally grown oranges. There were no differences in preference for grapefruit, grapes, corn, spinach, carrots, or tomatoes from the two sources despite, in the case of spinach and grapes, there being perceived differences. Svec et al.'s[118] small panel (12) preferred the *color* and *texture* of conventional potatoes, but there were no differences in liking for *appearance* or *flavor*. With tomatoes, the panel showed a preference for the organic product on all of these sensory attributes. Using a much larger group of consumers, Johansson et al.[176] reported a preference for one organically grown tomato variety but the conventional version of another variety.

Given a general failure to report consistent ability to discriminate the sensory properties of organic and conventional produce, it is not very surprising that studies of preference also fail to show a consistent pattern of results. Why then does there seem to be a conviction, presumably primarily among regular consumers, that organic produce is better tasting? Two of the sensory studies reviewed may give insight into this. It has been demonstrated that labeling associated with a food can create expectations regarding its sensory properties, and ultimately its acceptability.[177,178] Both Schutz and Lorenz[170] and Johansson et al.[176] examined the impact of information about growing method on consumer preferences for organic and conventional vegetables. In both studies, this information influenced acceptability, in that relative to these same foods unlabeled, products labeled as organic generally showed increases in measures of preference. Thus, both studies suggest that consumers have expectations regarding the superior taste of organic produce. It may be that this derives either from a rationalization of the higher cost of organic produce or a belief that chemical fertilizers are more likely to impart unacceptable sensory qualities. Important also in the effects of labels on food acceptability is the fact that consumers can bring their actual perceptions and preferences into line with such expectations.[177] Hence, such beliefs may be reinforced by repeated consumption of organic produce.

One other reason for the popular belief in the flavor superiority of organic produce that should be considered here though is the possibility that organic produce might be consumed in a more optimal state of freshness. This could be due to any of the following reasons:

1. Some organic producers may be distributing primarily locally, rather than using more elaborate distribution systems;
2. There may be a greater emphasis on more natural forms of ripening, prior to harvest;
3. Organic farming may use different varieties of the same food than conventional farming.

At least in the case of the first two factors, even those systematic studies making well-controlled comparisons, may fail to take into account commonly used distribution and ripening practices.

E. Conclusion

Overall, then, what can be concluded from these studies? The simplest statement would be that there is yet to be convincing evidence that organic produce differs in sensory terms from conventional produce, let alone that there is some taste advantage. However, as noted earlier, without considerably more well-controlled research, it cannot be proposed that such differences may not be apparent for some foods under some growing conditions. Moreover, as noted above, the impact of distribution practices needs to be considered.

This conclusion is supported by a previous overview of literature published primarily in German up to 1995. Woese et al.[46] reviewed a large number of studies covering a variety of agricultural products, as well as foods made from organically grown produce (e.g., bread). In reviewing those studies that dealt with the sensory aspects of organically grown foods, the authors note that there was no clear evidence for sensory differences between organic and conventional versions of potatoes, vegetable or vegetable products, or apples. They did note "greater fluctuations.... in quality characteristics" (p. 256) for bread produced with organically grown grain, although they suggested that this might be due to different baking methods or recipes. The review also examined studies that compared produce from animals that had been fed organically grown feed to those conventionally fed. These products included milk and dairy products, meats, eggs, and honey. In none of the studies reviewed was there evidence for differences in the sensory properties of products associated with organic and conventional growing methods.

IV. FOOD SAFETY ISSUES

A. Chemical Residues in Organic and Conventional Foods

As discussed earlier, consumers frequently cite health concerns, and specifically low or no pesticide residues, as a key reason for consuming organically grown food. Given the prohibition of chemical pesticides in an organic farming system, it is a reasonable assumption that organically grown food will in general contain lower levels of pesticide residues than conventionally grown food. However, there have been very few studies carried out considering this question.

1. Residues in Organically Grown Foods

In a review of the risks of consuming organically grown food,[179] reference is made to a Swedish study in which there were no detectable residues in organically grown carrots, iceberg lettuce, tomatoes, and strawberries. In comparison, 17% of conventionally grown carrots and 50% of strawberries had detectable residues, while conventionally grown iceberg lettuce and tomatoes had no detectable residues. The concentrations of residues in the conventionally grown carrots and strawberries were well within the allowable limits.

Internationally there is little accessible data on pesticide residues in organic foods. In New Zealand, the main potential source of data on residues (if any) present in organically grown food is Bio-Gro New Zealand, the main organic certification agency. Typically, however, residue testing of food products may only be required by Bio-Gro New Zealand when a grower first becomes certified and thereafter only when auditors make special requests. It is considered that if the property is being managed according to the standards, end-point routine pesticide residue testing is not required. It is important to note that like most certifying agencies, Bio-Gro New Zealand recognizes that some pesticide residues can be widely present in the environment, particularly the more persistent organophosphates and organochlorines, and so Bio-Gro New Zealand does not guarantee certified organic produce to be totally free of residues.

Some producers and larger companies, however, do a certain amount of residue testing of organic food products, often in order to satisfy overseas markets or be able to verify the low or no residue content of their products. For example, from 1998 to 2000 Zespri International tested kiwifruit from every certified organic orchard in New Zealand and no residues were detected. No residues have been detected in the fruit over the last 2 years. Since the 1996/97 season, all New Zealand kiwifruit have been produced using either organic or *kiwigreen* production systems. *Kiwigreen* is an Integrated Pest Management (IPM) based system in which there is more monitoring of pest and disease burdens than in a conventional system so that pesticides are only applied when required.[180] *Kiwigreen* grown fruit are also tested for residues and over the last 2 seasons, 80% of the fruit tested has had no detectable residues while 20% has contained residues, at less than 5% of the Codex Maximum Residue Limits (MRLs) (Richardson, D., Zespri International, personal communication, February 2000). These data therefore suggest that the majority of both organic and *kiwigreen* kiwifruit (i.e., all kiwifruit) contain no detectable residues, although certified organic produced is slightly more likely to be free of residues than *kiwigreen* kiwifruit.

The food company Heinz-Wattie Ltd also carries out a significant amount of residue testing of their New Zealand organically grown crops. All crops on all farms are tested for residues when the farm is converting to organic production systems. Once the grower has achieved full Bio-Gro certification, 10% of all organic crops are randomly tested annually. Throughout the 1998/2000 seasons, there were no detectable residues in any organic crops. In contrast, less residue testing is carried out on their conventional frozen process vegetable crops. Heinz-Wattie operates management systems that ensure that the chances of inappropriate chemical usage is minimized. Typically, a selection of crops is tested from each of the main production areas in New Zealand each year. No detectable residues have been found in conventional peas, carrots, sweetcorn, and potatoes in recent years. Occasionally, green beans may be found to contain residues often due to a withholding period violation, however the bean samples with residues account for less than 5% of all samples tested. In the growing of peas, carrots, sweetcorn and potatoes, pesticide use is not heavy and few are applied close to harvest, hence the very low level of residue detection. The limits of detection vary from chemical to chemical but typically are 0.01 to 0.05 ppm (Mackintosh, B.L., Heinz Wattie Ltd personal communication, March 2000).

2. Residues in Conventionally Grown Foods Available in New Zealand

Recently, the New Zealand Ministry of Agriculture and Forestry (MAF) has reviewed pesticide use in New Zealand,[181] and their findings suggest that total pesticide use has declined between 1994 and 1998 from 3700 tonnes to 3300 tonnes of active ingredient. Herbicides are most widely used (68% of active ingredient) followed by fungicides (24%) and insecticides (8%). Overall, pesticide use in pastoral agriculture appears to be static or declining, while orchard crops still make use of relatively high amounts of pesticides (possibly with the exception of kiwifruit and more recently pipfruit).[182] The amount of pesticides used in vegetable production appears to vary considerably from crop to crop with usage for process vegetables being low, while intensive spray programs are commonly used for crops such as lettuce, brassicas, potatoes, and onions. Unfortunately, no comment is made on the connection between pesticide usage and pesticide residues in food in the MAF report.[181] Clearly, a number of factors will affect the residues present in foods, including the stage at which pesticides are applied during the growing of the crop and their persistence, post-harvest pesticide use and general background levels of pesticides in the environment.[183]

The only regular assessment of pesticide levels in the New Zealand diet is made via the Total Diet Surveys currently carried out by the Ministry of Health and the Institute of Science and Research Ltd (ESR). The first survey was carried out in 1974[184,185] and since then there have been four more surveys completed (1982, 1987/88, 1990/91, 1997/98). The primary aim of these surveys is to assess the pesticide and contaminant element intakes from foods consumed by "the average New Zealander". Aspects of the methodology, including the range of foods and pesticides analyzed, have been modified over the years.[186] The main change in study design occurred in the 1987/

88 survey in which a larger range of foods was analyzed, and this approach has been used in subsequent surveys. In addition, the range of pesticides tested for has increased with each survey.

The Total Diet Surveys have received much criticism over the years in terms of design and the limited number of foods and pesticides tested.[187] In the 1997/98 survey, food samples were collected on two occasions in four locations. Two samples of each of 48 foods were collected. These foods were known as "Regional Foods" and there was a minimum of eight samples of each food type analyzed — some separately for each region and some composited. In addition, 66 foods were sampled on two occasions from one location — known as "National Foods". In this regime, different brands of the same food type were collected resulting in a minimum of 10 samples for each food type. Again for some food types, some brands were analyzed separately, while for other foods the brands were composited and analyzed as one sample. Therefore, in the total survey 114 foods were analyzed for 90 pesticides (including the class of dithiocarbamates that includes 8 fungicides but does not distinguish among them).

Of the 90 residues measured, 20 (22%) were found in at least one food type on at least one sampling occasion.[188] Of the 114 foods analyzed for the 90 residues, 70 (61%) different foods contained at least one residue. According to the raw data reports,[186,189-191] there were only a very small number of samples that contained residues in quantities exceeding those permitted according to the New Zealand Food Regulations.[192] The foods concerned were bran cereal, pears, and muesli. Although it is difficult to make comparisons with organically grown foods, it does appear that conventionally produced cereal products and products containing cereals (biscuits, breads, etc.), meat, dairy products, and some fruits and vegetables may contain a number of residues, and that given the prohibition of chemicals in organic production systems many of these residues are not likely to be present in certified organic foods. The possible key exceptions to this are DDT residues and its breakdown products (DDE), because these are highly persistent in the environment.[193]

Given the move in New Zealand conventional food production systems to decrease the use of pesticides, at least for some crops, it could be that in the future the amount and number of residues in conventionally produced food will decline, thus narrowing the difference between organic and conventional foods with respect to residues. While the most recent Total Diet Survey does indicate reduced concentrations of pesticide residues compared with those reported in the 1990/91 survey, it does not indicate that the number of different pesticides being used is reducing.[188] Because of these trends it is likely that consumers of organically produced food would at the very least consume fewer types of residues. Whether this results in a health benefit for consumers remains controversial.[187,193,194]

B. Microbiological Safety of Organic Foods

Irrespective of food production system, all foods need to be produced in such a manner to ensure that they are safe to eat. The need for organic producers to adopt safe food production and processing practices is just as important as it is for conventional food producers. The question of whether the consumption of organically grown food confers any greater microbiological risk to consumers than conventional food has not yet been addressed in a scientific manner.

Some commentators (e.g., Stephenson[195]) have suggested organic production practices such as the use of animal manures and the prohibition of some food additives and food processing techniques by organic certifiers may increase the risk of microbiological contamination and thus food poisoning. Schmidt[196](p149), however, suggests that "microbial contamination could occur just as easily on an organic farm as on a conventional farm" and that the important issue is that proper production practices are used within both organic and conventional systems. To this end, organic certifiers around the world stipulate that raw animal manure can never be applied to crops in such a manner that could allow it to come into contact with food destined for human consumption. The exact composting requirements vary from certifier to certifier, and it has been argued that some standards may not require a sufficiently long composting period or high enough temperature treatment in order to destroy *E. coli* (0157:H7). Wang et al.[197] have reported that *E. coli* (0157:H7) can survive in animal manures for up to 56 days at 37°C; however, survival times at higher temperatures were not investigated in this study. Other research has suggested that soil-borne pathogens are normally destroyed after 30 min at 55°C[198] and more specifically human pathogens destroyed after 5 to 7 days at 55 to 60°C, depending on frequency of turning the compost and other variables.[199] Internationally, certified organic producers are typically audited annually to specified standards as a requirement of certification procedures, whereas the majority of conventional producers (who also frequently use animal manures) are not subject to such procedures.

Much of the discussion about possible increased risks of microbiological contamination of organically grown foods compared with conventional foods has arisen from a non-peer-reviewed article by Avery.[200] Avery[200] claimed that "people who eat organic and "natural" foods are eight times as likely as the rest of the population to be attacked by a deadly new strain of *E. coli* bacterium (0157:H7)" (p19). His conclusions were based on 1996 data from the US Centers for Disease Control that indicated that 2 of 10 outbreaks of *E. coli* (0157:H7) infection from food sources were from organic/natural foods. However, currently there is no peer-reviewed literature suggesting certified organic produce to be at a greater risk of *E. coli* contamination than conventional produce.

Documented cases of lettuce consumption being associated with *E. coli* (0157:H7) contamination have been incorrectly associated with certified organic production systems.[201,202] In Montana, USA in 1995, an *E coli* outbreak caused illness in 61 people who consumed lettuce originating from producers in Washington State and Montana.[201] While the cause of the contamination was not established, four possibilities were suggested: (1) fertilization of lettuce with manure from a dairy farm; (2) contamination of irrigation water (flood irrigation) with cattle feces or contaminated surface water run-off; (3) direct contamination of pond water with cattle feces and subsequent use of the water for irrigating lettuce; (4) feces of sheep or deer contaminating irrigation water or lettuce directly. The contaminated lettuce was not identified as being certified organic. In another outbreak of an *E. coli* (0157:H7) infection that occurred in Connecticut and Illinois in 1996, mesclun lettuce was found to be contaminated.[202] The contamination was most likely to have been caused by wash water used for the lettuce. The lettuce was claimed to be grown using organic production methods; however, the product was not certified organic. Hence, there is no basis to any claimed association of these particular outbreaks of *E. coli* infection with certified organic production systems. In fact, the majority of outbreaks of *E. coli* (0157:H7) infections have been associated with meat products, particularly undercooked ground beef.[203]

Avery[200] also suggested that because organic farmers refuse to use artificial pesticides they "allow their crop fields to suffer more damage from insects and rodents, which creates openings through which fungi can enter the fruits and seeds" (p.19). Aflatoxins (toxic compounds produced by *Aspergillus* spp.) have been found to be present in high levels in nut products stocked by health food shops in the UK, although those products were not labeled as organic.[204] To date, there does not appear to be any documented evidence of increased risk of aflatoxin contamination from organic foods compared with conventional foods, although clearly the issue itself should be of concern to all food producers. Slanina[179] has also concluded that growing system does not have a significant effect on mold or mycotoxin contamination.

There has also been some confusion over the microbiological hazards of so-called "natural" foods and organic foods. For example, Unger[205] equated "natural" unpasteurized Odwalla apple juice that was found to be contaminated with *E. coli* 0157:H7 in 1993[206] with organic foods, as did Avery.[200] Pasteurization is permitted in certified organic production systems. It was believed that the apple juice had been contaminated from cow or deer feces that had come into contact with windfall apples. Clearly, management procedures had been inadequate; however, the apples had not been grown or juiced as a certified organic product.

Tauxe et al.[207] have reviewed foodborne disease and microbial pathogens associated with fresh produce in order to identify potential hazards and control strategies. Although the US Centers for Disease Control keep a national database on food poisoning outbreaks and their epidemiology, they have not yet specifically compared the microbiological risk of organically and conventionally grown foods. Tauxe et al.[207] acknowledge that the increased use of manure rather than chemical fertilizers (by many farmers) may play a role in the increased incidence of poisoning from pathogens such as *Salmonella* spp. and *E. coli* 0157:H7, along with many other changes in food production and food consumption patterns. These authors also suggest that traditional composting practices (perhaps without a defined heat treatment) may now not be sufficient to render animal manure safe for use on vegetables with the advent of new pathogens such as *E. coli* 0157:H7. Hussein[208] has recently reviewed the sources of *E. coli* 0157:H7 contamination on beef and dairy farms and also discussed management practices (for example, involving animal, manure, water- and diet-related factors) that may help to reduce the risk of contamination. Gagliardi and Karns[209] reported that tillage practice, soil type, and method of pathogen delivery (e.g., from manure or from run-off) affect the movement of *E. coli* 0157:H7, and that soluble nitrogen may also increase the movement of this pathogen. Clearly, organic certifying agencies need to constantly review their standards for composting in light of the developing knowledge in this area of food safety.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The wide range of factors that can affect plant composition (e.g., genetics, agronomic practices, climate, and post-harvest conditions) makes investigations of the nutritional value of organically and conventionally grown food difficult to carry out and interpret. Nonetheless, because of the significant interest in this topic internationally, both in the past and perhaps even more so currently with the increasing production and consumption of organic foods, many studies have been conducted. Overall, any differences in nutrient concentrations of organic and conventional foods have varied from study to study along with the considerable variation in study designs and study duration. Perhaps the exception to this is nitrate content that tends to be lower in organically grown crops than in conventionally grown. This is likely to be due to the use of lower amounts and less available sources of nitrogen in an organic farming system (e.g., composts), although as some studies indicate the use of high levels of nitrogen even in an organic system can cause correspondingly higher nitrate levels to be present in the organic crop. The majority of studies have tended to focus on a narrow range of nutrients, which only give a very limited indication of nutritional value. Studies are yet to be carried out investigating nutrient bioavailability and only recently has work begun considering nonnutrient components. These two areas of research may prove to be of greater interest in the future than simply investigating nutrient concentrations. Studies investigating the effect of organic and conventional feed on animal health have so far been inconclusive. However, there has been some indication from this work that organic and conventional feed of similar composition may have differing effects on aspects of animal fertility. In addition, sperm concentration has been found to be higher in organic farmers and members of an organic association than control subjects with no connection with the organic food industry, another finding that may warrant further investigation.

Although the results from the sensory studies reviewed do not give much hope for drawing definitive conclusions, it should be pointed out that the number of such studies carried out to date has not been large. When one considers only those studies using appropriate comparison methods, suitable panellists, and exercising reasonable control over confounding factors, the number is considerably lower. Therefore, it might be considered worthwhile to undertake further well-controlled studies comparing organic and conventional produce in terms of sensory properties. In addition, it might be productive, as suggested earlier, to compare foods from certified organic growers with similar conventionally grown foods available at supermarkets, with a view to assessing if factors such as distribution methods or types and duration of storage influence the freshness of the different types of produce.

On a somewhat different issue, more formal expectation studies that manipulated product labeling (organic vs. conventional) and examined the impact of this on consumers' perceptions and preferences for a variety of foods may contribute to our understanding of motivations underlying the choice of organic vs. conventional foods.

The lack of data on the pesticide residue content of organically grown food prevents definitive conclusions from being made about any differences in the residue levels of organic and conventional food. However, given the non-use of chemical pesticides in a certified organic production system and the documented use of pesticides in conventional food production systems (along with the documented residue concentrations in conventional foods), it is highly likely that certified organic food contains lower residue levels. A possible exception to this in New Zealand is DDT/DDE residues because these chemicals are highly persistent and are widespread in the environment. Because many consumers choose to purchase organically grown foods because of the assumed lower residue level, it would be of interest to carry out some analytical studies to confirm this. In the future, with the general decline in the use of chemical pesticides in the growing of at least some conventional crops, it could be that residue levels become less important over other issues in the decision of consumers to purchase organic foods.

Recently, the contamination of food with *Escherichia coli* (0157:H7) resulting in severe illness and in some cases death has stimulated a debate on whether the use of animal manures in certified organic food production systems might confer any extra health risk for consumers. To date, this question has not been studied in a scientific manner and so is clearly an area for future research. Organic certifying agencies generally require animal manures to be composted before use, which is likely to decrease the risk of pathogens from contaminating foods. However, studies investigating time/temperature treatments required to minimize the levels of emerging pathogens such as *Escherichia coli* (0157:H7) in the production of compost are required. General farm management practices are also important in reducing the risk of contaminating food with pathogens, an area that needs to be of constant concern to all food producers, not just those working within an organic food production system.

This review has focussed on differences in the nutritional value, sensory qualities, and food safety issues of organically and conventionally grown foods. To fully evaluate the two food production systems, many other aspects such as environmental, social, political, and economic factors must also be considered.

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