

Organic food: nutritious food or food for thought? A review of the evidence

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Apparently, one of the primary reasons for purchasing organic food is the perception that it is more nutritious than conventional food. Given the increasing interest towards organic food products, it is imperative to review the existing literature concerning the nutritional value of the produce, and to determine to what extent are consumer expectations met. There are only few well-controlled studies that are capable of making a valid comparison and, therefore, compilation of the results is difficult and generalisation of the conclusions should be made with caution. In spite of these limitations, however, some differences can be identified. Although there is little evidence that organic and conventional foods differ in respect to the concentrations of the various micronutrients (vitamins, minerals and trace elements), there seems to be a slight trend towards higher ascorbic acid content in organically grown leafy vegetables and potatoes. There is also a trend towards lower protein concentration but of higher quality in some organic vegetables and cereal crops. With respect to the rest of the nutrients and the other food groups, existing evidence is inadequate to allow for valid conclusions. Finally, animal feeding experiments indicate that animal health and reproductive performance are slightly improved when they are organically fed. A similar finding has not yet been identified in humans. Several important directions can be highlighted for future research; it seems, however, that despite any differences, a well-balanced diet can equally improve health regardless of its organic or conventional origin.

Introduction

Organic farming is not a recent evolution in agriculture; man has been practicing many of the techniques that are used today for thousands of years (Korcak, 1992). The current regeneration, however, can be traced back to several facts that took place in Europe during the first half of the 20th century (Sansavini & Wollesen, 1992). Since

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ISSN 0963-7486 printed/ISSN 1465-3478 online
03/010005-10 © 2003 Taylor & Francis Ltd
DOI: 10.1080/09637480120092071

that time, many claims concerning the properties of organic food products have arisen (Table 1), but no hard evidence has ever been provided and scientific basis for such anecdotal reports is lacking.

Probably the greatest historical assertion of the organic movement is the ability of organic foods to cure cancer. In one of his studies, Dr D. Collins reported that five patients, who had metastasised cancers during their lifetimes, and who subsequently begun to eat organically grown food showed no evidence of previous malignancy at autopsy after their deaths, many years later and from unrelated causes (Finesilver *et al.*, 1989). In another case, J. I. Rodale has reported the complete cure of four cancer patients after the adoption of a 100% organic food diet (Jukes, 1974). As expected, the medical community has criticised the validity and truthfulness of such assertions (Jukes, 1974, 1975).

In spite of these paradoxes, and although only a small market sector until recently, organic farming became one of the fastest growing segments of US (Greene, 2000) and European (FAO, 1999) agriculture during the 1990s, and is rapidly gaining ground in many other parts of the world as well (Willer & Yussefi, 2001). Many surveys of consumer attitudes have been conducted to identify the reasons for this increased trend. More speci-

fically, the preference for organic food has been associated with multiple factors that reflect an increased consumer interest towards both their personal health as well as that of the environment (Tregear *et al.*, 1994; Wilkins & Hillers, 1994; Schifferstein & Oude Ophuis, 1998; Harris *et al.*, 2000; Magnusson *et al.*, 2001; Makatouni, 2002). Health-related issues seem to assume a greater importance than environmental concerns and, among the former, notions about superior nutritional value are fundamental for purchasing organics (Lohr, 2001). It is generally accepted that the continuously growing demand for organic foods is driven primarily by consumer perceptions of their quality (Shukla, 2001).

In the face of such consumer expectations, it is important to carefully consider the question of nutritional value of organic and conventional food, in order to support or refute such perceptions. The present paper does not make a value judgment about the best approach to agricultural development; the objective is to present a critical and transparent overview of issues that relate to the nutritional value of the produce. The main focus is targeted towards fruits and vegetables, since the organic market for these food products has been growing the fastest (FAO/ITC/CTA, 2001). Available data, however, are presented for other food groups as well, although their limited number does not allow for generalised conclusions. Their inclusion is made for reasons of completeness of the present review. Furthermore, the validity and limitations of the existing scientific literature will be discussed, and several directions for future research will be identified. Finally, a more general discussion of the factors that determine the quality of food will be attempted.

Difficulties in compiling the results

Direct, comparative studies of organic and conventional produce are difficult to construct, because of extraneous variables such as climate and soil conditions (Adam, 2001). Nevertheless, the determination of differences in the chemical composition of organic and conventional food products has been the

Table 1. Historical claims for the properties of organic food

Researcher (Year)	Claim
Sir B. Greenwell (1939)	Poultry, pigs, horses, and dairy cows, all did better and became more resistant to disease when fed on organic grain than on a similar market-purchased grain, while requiring 15% less food
F. Sykes (1944)	Livestock was healthier and crops were more disease resistant, as outcomes of organic fertilisation on his farm
Sir A. Howard (1947)	Crops grown on organically manured soil were more resistant to disease, and animals and humans eating this food were similarly resistant
Lady E. Balfour (1959)	Organic crops demonstrated increased disease resistance; livestock and humans (adults and children) were healthier and less susceptible to disease when fed organically grown food

Source: Finesilver *et al.* (1989).

objective of scientific research since the first decades of the 20th century (McCarrison, 1926). Improvements in analytical methodology over time and differences in the statistical manipulation of the data have resulted in vast differences in the study design. Most comparative studies, however, fall into one of three basic categories, depending on the origin of the foods that have been tested (Table 2). Food products have been purchased either from retail markets (retail market studies) or directly from organic and conventional production units (farm studies). Alternatively, the scientists themselves grew the food samples in special land pots, using different kinds of fertiliser corresponding to the two cultivation types (cultivation studies).

Another approach in the attempt to compare the nutritional quality of organic and conventional foods is animal feeding experiments, in which several animal species are fed on organically and/or conventionally produced feedstuffs. This kind of comparison is rather indirect, since it rests on the biological effect that each type of food has on animal organism. In the feeding experiments evaluated, the preferred test criteria include sever-

al reproduction characteristics, possible changes in body and organ weights, general health condition, disease resistance, and the feeding behaviour of the animals (Scott *et al.*, 1960; Aehnelt & Hahn, 1978; Plochberger & Velimirov, 1992). The results of such experiments reflect several other factors beyond the nutritional value of the food and, as a consequence, they allow for a more generalised evaluation of food quality (Plochberger, 1989). It is not possible, however, to distinguish whether the existing differences in animal behaviour, if any, are due to the cultivation system, *per se*, or due to other factors like the genetic background of the animal, or the bioavailability of the nutrient. Last but not least, the results from such studies can by no means be extrapolated to humans.

Results from comparative studies

Vegetable group

Protein. Most of the studies comparing the protein content of organically and conventionally grown vegetables refer to the crude protein content, as well as to the concentrations of specific free amino acids. Only a few

Table 2. Some characteristics of the three different approaches used in the literature for the comparison of organic and conventional food products

Retail market studies

- They are relatively small in number
- They refer to the product as it reaches the consumer
- The method is simple and fast
- The certification of the production method is impossible
- Pseudo-organic products may also be included
- They can identify differences in the chemical composition of the product
- They cannot conclude whether the differences are due to the production method

Farm studies

- They record the exact conditions under which the food is produced
- Sample size can be large enough
- Environmental conditions (climate, soil fertility, etc.) can be partly controlled by the selection of neighboring farms
- The information regarding the production method comes directly from the farmers
- The selection of farms that accurately and realistically reflect the two production systems is often difficult

Cultivation studies

- They are considered as the most accurate and valid method of comparison
- They can definitively identify if there are any differences in the nutrient composition of the food products
- They can also identify the factors that are responsible for these differences
- Sample size is often limited
- The results cannot be generalised as reflective of the production system

have simultaneously evaluated the quality of the protein, that is, its composition in essential amino acids. The general conclusion that arises, although not uniformly supported (Dlouhy, 1977; Pettersson, 1977; Lairon *et al.*, 1984; Millard, 1986; Reinken, 1986), is that vegetables from organic cultivation, such as spinach, beetroots, carrots, tomatoes and potatoes, have a slightly lower crude protein and free amino acid content than conventionally grown vegetables; yet, they have higher concentrations of several essential amino acids (Schuphan, 1974; Clarke & Merrow, 1979; Eppendorfer *et al.*, 1979; Bourn, 1994; Lecerf, 1995; Wawrzyniak *et al.*, 1997; Woese *et al.*, 1997; Kumpulainen, 2001; Bourn & Prescott, 2002). The higher crude protein content of conventional vegetables probably reflects the greater nitrogen availability from conventional than from organic fertilisers. These results are in accordance with, and probably a direct reflection of, the commonly held view that a high nitrogen application to plant crops may increase their crude protein concentration, but, at the same time, decrease the nutritional value of that protein (Eppendorfer & Eggum, 1996).

Nevertheless, any differences with respect to the amount, type, and quality of protein in vegetable crops have a rather doubtful practical significance, should one bare in mind their negligible (vegetables) or small (potatoes) contribution as protein sources, in the context of a well-balanced diet. Only in the case of vegetarian diets may such a difference assume some importance.

Dry matter. The results of a small number of studies evaluating the dry matter content of several vegetables suggest that organically cultivated crops have higher dry matter content than those grown conventionally. This finding, however, was evident only for the plants that grow above the ground (leafy vegetables), such as spinach, lettuce, chard, Savoy cabbage, and white cabbage (Schuphan, 1974; Vogtmann *et al.*, 1984; Bourn, 1994; Lecerf, 1995; Fjellkner-Modig *et al.*, 2000), whereas no clear picture emerged for those plants that grow below the ground (root and tuber vegetables), such as potatoes,

leeks, turnips, and carrots (Schuphan, 1974; Reinken, 1986; Termine *et al.*, 1987; Rembialkowska, 1998).

Knowledge of the dry matter content of vegetable crops allows for correct use and interpretation of the results. Nutrient concentrations in plants are often expressed on a dry matter basis. Nevertheless, non-significant differences between organically and conventionally grown foods on a dry matter basis may translate into significant differences on a fresh weight basis, if there are large enough differences in the percent dry matter between the two types of products. This was exactly the case in a study testing a number of organically and conventionally grown vegetables as purchased by retail markets (Lairon *et al.*, 1983). Thus, it is important that nutrient levels are reported and compared on a fresh weight basis. Gathering and comparing results expressed on a dry weight basis with those expressed on a fresh weight basis is impossible and will unequivocally lead to erroneous conclusions, especially since conventional vegetables have been reported to contain higher levels of moisture (Bourn, 1994; Worthington, 1998).

Vitamins. Although several studies have examined the vitamin content of organically and conventionally grown vegetables, only vitamin A (mainly β -carotene), vitamins B₁ and B₂, and ascorbic acid (vitamin C), have been investigated. There is no information relevant to other vitamins. With respect to vitamins A, B₁ and B₂, no clear or significant differences have been documented among the vegetables cultivated in the organic or conventional manner (Clarke & Merrow, 1979; Bourn, 1994; Lecerf, 1995; Warman & Havard, 1996; Woese *et al.*, 1997; Warman & Havard, 1998; Kumpulainen, 2001; Bourn & Prescott, 2002). Moreover, some studies have reported both higher (Leclerc *et al.*, 1991) and lower (Clarke & Merrow, 1979) concentrations of β -carotene in organic carrots. It has been proposed, however, that β -carotene content in carrots displays a greater increase after the application of a certain amount of conventional fertiliser, than after the application of an equivalent amount of organic fertiliser (Bourn, 1994).

The concentration of ascorbic acid is a rather ambiguous issue, since several studies have reported higher content in organically grown vegetables (Schuphan, 1974; Vogtmann, 1988; Leclerc *et al.*, 1991; Kumaran *et al.*, 1998; Worthington, 1998; Xu *et al.*, 2000; Premuzic *et al.*, 2001), while others found either no difference (Lairon *et al.*, 1986; Termine *et al.*, 1987; Warman & Havard, 1996; Rembalkowska, 1998; Warman & Havard, 1998; Fjelkner-Modig *et al.*, 2000), or lower concentrations (Auclair *et al.*, 1995). Therefore, although there seems to be a trend for higher vitamin C concentrations in some organic vegetables, no general statement can be made. What is noticeable, however, is that the differences were mainly observed in green leafy vegetables, such as spinach, lettuce, Savoy cabbage, and chard, while the results for root and tuber vegetables were not as clear. Interestingly, vitamin C content in spinach and other vegetables is negatively correlated with nitrogen availability (Mozafar, 1996). As far as potatoes are concerned, and taking into account their significant contribution as a nutritional source of ascorbic acid, the results are again mixed, with a slight trend towards higher concentrations in the organically grown crops (Bourn, 1994; Lecerf, 1995; Warman & Havard, 1996; Woese *et al.*, 1997; Warman & Havard, 1998).

Minerals and trace elements. The minerals and trace elements that have received the greatest attention by the researchers are calcium (Ca), iron (Fe), phosphorus (P), manganese (Mn), magnesium (Mg), zinc (Zn), copper (Cu), and potassium (K). Although a small number of studies have reported slightly higher contents in organic vegetables (Schuphan, 1974; Auclair *et al.*, 1995), the majority of evidence has revealed no significant differences (Peavy & Greig, 1972; Clarke & Merrow, 1979; Lairon *et al.*, 1984, 1986; Termine *et al.*, 1987; Perez-Llamas *et al.*, 1996; Warman & Havard, 1996; Tan *et al.*, 1998; Fjelkner-Modig *et al.*, 2000). On the whole, the results of the studies comparing the vitamin and mineral contents of vegetable crops from the two cultivation systems vary greatly, according to the specific

micronutrient and the type of vegetable tested. This precludes making generalised statements at the present, and reduces the reliability and validity of the aforementioned conclusions. Moreover, it clearly dictates the necessity for further research under more controlled conditions.

Fruit group

Protein and dry matter. In spite of the great importance of fruits as nutritional sources of vitamins, minerals, and trace elements, a rather small number of comparative studies have evaluated the possible qualitative and quantitative differences between crops from the organic and conventional production systems. The spectrum of species examined is also very limited: apples, strawberries, oranges, lemons, and pineapples. With respect to the dry matter content of fruits, and although few relevant studies are available, significant differences between organic and conventional produce are not to be expected, due to the low ability of fruits to absorb and assimilate nitrogen (Bordeleau *et al.*, 2002). Moreover, the concentrations of crude protein and free amino acids are also the same (Reinken, 1986; Woese *et al.*, 1997), a finding that assumes no practical significance, taken into account the negligible contribution of fruits as protein sources in the diet.

Vitamins, minerals and trace elements. As far as the content of organic and conventional fruits in vitamins (vitamins B₁, B₂, ascorbic acid) is concerned, existing evidence does not reveal any significant difference, while the same applies for the concentrations of most minerals and trace elements (Ca, Mg, Cu, Fe, Mn, P, and Zn) that have been examined (Jukes, 1977; Alvarez *et al.*, 1993; DeEll & Prange, 1993; Bourn, 1994; Woese *et al.*, 1997; Alvarez *et al.*, 2001; Bourn & Prescott, 2002). Only one study has reported significantly higher micronutrient concentrations in apples, pears, and pineapples cultivated organically (Smith, 1993). The general conclusion, however, remains that the fruits of organic agriculture do not appear, as yet, to differ in their nutritional value from those of conventional farming. It may be that the

effect of the specific variety on the nutrient content of the fruits is of much greater importance than the cultivation system, *per se*. This hypothesis is in accordance with the finding that each individual organic fertiliser has an independent and totally different effect on the nutrients (sugars, organic acids) of apples of each variety (DeEll & Prange, 1992).

Carbohydrate group (cereals and legumes)

Protein. Cereals and legumes have been examined in only a small number of comparative studies, and the nutrients that have been tested to date are quite limited. The most well studied parameters include the quantity and quality of the protein content, and the changes that occur depending on the cultivation system or the fertiliser applied. The general picture is not different from that formulated for vegetables: organic cereal crops, such as wheat, rye, and corn, tend to contain a lower amount of crude protein and free amino acids, but at the same time a higher proportion of essential amino acids (Dlouhy, 1977; Pettersson, 1977, Chakhovskii, 1981; Starling & Richards, 1990; Campbell *et al.*, 1991; Starling & Richards, 1993; Bourn, 1994; Ragasits & Kismanyoky, 2000). In other words, organically grown cereal crops and legumes seem to have a lower protein content, but of higher quality, when compared with their conventionally grown alternatives. Other studies, however, failed to reach such a conclusion (Shier *et al.*, 1984).

Nevertheless, and despite the differences recorded among individual crops, it has long been known that a high availability of nitrogen in plant crops results in increased protein synthesis and accretion (Locascio *et al.*, 1984). Accordingly, the proportions of the essential amino acids decrease, resulting in a lowering of the protein's quality. Of interest, however, are the results reported for corn. Increasing application of nitrogenous fertiliser has resulted in higher crude protein content in conventional than in organic corn, but no clear picture for the proportion of essential amino acids emerged: the protein from organically grown corn was higher in lysine, methionine, histidine, and threonine,

but lower in isoleucine, leucine, and phenylalanine (Lockeretz *et al.*, 1981; Wolfson & Shearer, 1981). These results most probably imply that each individual amino acid responds in a unique way to the application of nitrogen, probably owing to the plant's genetic make-up, and, therefore, any conclusions remain uncertain.

Vitamins, minerals, and trace elements. With respect to the micronutrient content of cereals and legumes, only selected vitamins of the B complex, vitamin C, β -carotene, Ca, P, Cu, Fe, Mn, and Zn have been examined to date. The crops that have been compared include corn, beans, wheat, rye, barley, soybeans, and maize. The available studies in the literature, however, are small in number and provide conflicting results: some have reported higher micronutrient concentrations in organically grown crops; others found no differences; and finally, others observed higher micronutrient concentrations in conventional crops (Finesilver *et al.*, 1989; Smith, 1993; Bourn, 1994; Warman & Havard, 1996; Woese *et al.*, 1997; Warman & Havard, 1998; Bourn & Prescott, 2002). In addition, the findings of most studies differentiate depending on the season, crop, micronutrient tested, and so on, therefore making it difficult to draw a general conclusion concerning the effect of the cultivation system. Interestingly, the results also varied for different morphological parts of the plants, a fact that emphasises the importance of testing different morphological types depending on which organ of the plant is commonly eaten (Muller & Hippe, 1987).

Milk and meat group

Organic livestock farming is a relatively new development, compared with the expansion of organic production in the fruit and vegetable market. As a result, the number of studies that compared or evaluated organic and conventional animal products (milk, dairy products, eggs, meat, etc.) is limited. Consequently, it is inappropriate to make any kind of generalised statements. In this case, the main difference between the two production systems, organic and conven-

tional, rests on the type of feedstuff upon which animals are fed. In general, however, and contrary to the commonly held view, there is no evidence for a system-related effect on product quality due to the production method (Sundrum, 2001).

For example, a number of studies evaluating the content of organic and conventional milk in specific nutrients (proteins, lipids, vitamins, minerals, and trace elements), as well as several other of its properties (pH, acidity, microbiological condition, and suitability for cheesemaking), failed to reveal any kind of significant or consistent difference (Pabst, 1994; Woese *et al.*, 1997; Zangerl *et al.*, 2000; Pirisi *et al.*, 2002). At this point, it should be noted that the discovery of significant differences between dairy products from organic and conventional farming should be dealt with extreme care, due to the effect of animal species and genetic variation between animals of the same species in product quality. The results of an older study cited in Finesilver *et al.*, (1989) clearly demonstrate this argument: there was little difference in the composition of the milk in four generations of cows fed on organic or conventional feedstuff, and the concentrations of most vitamins (niacin, pantothenic acid, vitamin A, β -carotene) were not different. Riboflavin content, however, was higher in conventional 60-day milk, and in organic terminal milk. Useful conclusions regarding the quality of meat and its products from animals from different livestock farming and feed forms cannot be drawn, on the basis of the extremely limited data available (Woese *et al.*, 1997).

Animal feeding experiments

In most animal feeding experiments with mice and rats, fertility parameters and body growth were similar, regardless of the organic or conventional origin of the feedstuff (McSheehy, 1977; Plochberger & Velimirov, 1992; Velimirov *et al.*, 1992; Bourn, 1994). When animals were fed on organically produced feedstuff, however, several individual positive effects have been documented. For example, weight gain was greater (10–17%) for organically fed rats (McCarrison, 1926),

mortality rate at 9 weeks of age for three generations of mice fed organic grain was 9% compared with 17% for those on conventional grain (Linder, 1973), and the incidence of degenerative diseases was lower (Scott *et al.*, 1960). Interestingly, when the animals were fed a mixed diet (a mixture of organic and conventional feedstuff), the effects on fertility and weaning weight were different than those produced by each feedstuff alone: mice fed a mixed wheat diet exhibited consistently poorer fertility (number of live births, number of offspring surviving at 21 days) than the other two groups ('organic' and 'conventional') (Scott *et al.*, 1960).

The limited available studies with rabbits reveals small differences in most fertility parameters (number of ovulations, number of egg cells found, percent fertilised egg cells, number of uterine glands) (Aehnelt & Hahn, 1978) that, on the whole, suggest a slightly improved reproductive performance when the animals are fed on organically grown feedstuff. A lower mortality rate has also been reported for organically fed rabbits, while organ weights (ovaries, uteri, suprarenal glands) did not differ in general (Woese *et al.*, 1997). Milk production, based on weights of 21-day-old rabbits, was higher in rabbits on organic leys, but growth rate of litters did not favour either group (McSheehy, 1975).

Of interest are the results of a well-designed and controlled study, which compared diets based on raw materials grown under either organic or conventional standards, and equivalently supplemented with vitamins and minerals (Staiger, 1988). The birth rate for the first generation of rabbits in the two groups was not different, despite the fact that the organic group was eating 25% less. The birth rate rose in the second generation in the organic group only, thereby becoming statistically significantly higher. The number of embryos in sacrificed females of the first generation was equal, but was significantly higher in the organically fed rabbits of the second and third generations. Conventionally fed second-generation animals suffered infectious illnesses significantly more often than those in the organic group. This study emphasises the importance of

conducting long-term intergenerational feeding studies to show differences in nutritional value. Another study stresses the importance of genetic factors: the overall reproductive performance, based on the total number of animals weaned, was superior for Dutch rabbits maintained on organic diet, compared with those fed conventional feedstuff, while the reverse was true for New Zealand white rabbits (McSheehy, 1975). These results suggest that carefully carried out studies might show real differences in the nutritional quality of the produce.

Hens that were fed on organically fertilised wheat showed a better laying performance than the animals who had been given conventionally fertilised wheat; no clear differences, however, could be identified in respect of the weight development of chicks (Fine-silver *et al.*, 1989; Woese *et al.*, 1997). In another study, significant differences with respect to egg weight and the distribution of the egg components were observed: higher egg and yolk weights but lower albumen weight were recorded when chicks were fed with organic feedstuff (Plochberger, 1989). Another study reported that hens given organic grain began laying at an earlier age (166 days versus 181 days) and produced more eggs over 9 months (192/hen versus 150/hen) with a better keeping quality (27% versus 60% spoilage after 6 months at room temperature) than conventionally fed hens (Linder, 1973). Interestingly, the growth rate of hens after 4 and 8 weeks (first generation) was higher in the animals that were fed conventional feedstuff, while after 32 weeks (second generation) it was higher in hens fed organic feedstuff (Bourn, 1994).

The results of the studies evaluating the feeding behaviour of the animals (hens, rabbits, mice, rats) in feed selection tests are also interesting. It was clearly shown that most test animals preferred organically over conventionally produced food (Linder, 1973; Woese *et al.*, 1997). Moreover, when three types of feedstuff were used (organic, conventional, and mixed), rats showed a significantly higher preference for organically produced feed; the animals did not, however, differentiate between conventional and mixed feed (Mader *et al.*, 1993). A preference

towards organically rather than conventionally grown food was also demonstrated when, according to chemical analysis, both types of feedstuff met the physiological needs of the test animals (Plochberger & Velimirov, 1992). Therefore, the reason for this preference most probably does not rest on nutritional superiority of organic food, but on other parameters that were not examined (e.g. taste).

Discussion

Whether a difference indeed exists in the nutritional value of organic and conventional food products is a crucial question but with no definitive answer (Brandt & Molgaard, 2001). Comparing studies of different design could be misleading, and unequivocally reduces the validity of the conclusions. Furthermore, most studies have compared the effect of organic and conventional fertilisers on the nutrient content of the produce, and not the effect of the production system as a whole. Simply measuring the concentrations of the various nutrients in a food product, however, by no means reflects the quality of the food, *per se*. Even if a production method does not alter the nutrient content of the produce, this does not mean that other important parameters, such as bioavailability, remain the same as well (Knorr & Vogtmann, 1983). Most available studies to date have neglected to take into account this important parameter of food quality (Bourn & Prescott, 2002). In a recent study, however, no significant differences were observed in the bioavailability of β -carotene from carrots and sorrel grown by conventional and organic methods (Gronowska-Senger *et al.*, 1997).

Other factors that make it difficult to compile the existing results and come to a valid conclusion rest on the intrinsic differences between the items of the same food group. For example, iron and manganese contents in green leafy vegetables increase, whereas zinc and copper contents decrease as the plant matures; varietal differences are also evident at different stages of maturity (Khader & Rama, 1998). Furthermore, in fresh asparagus, the concentrations of calcium, magnesium, and phosphorus increases

with the ripening process, while the content of sodium decreases, and that of potassium remains the same (Lopez *et al.*, 1996). The influence of production, handling, and storage on the nutrient content of plant foods may also differ according to the plant species tested (Goldman *et al.*, 1999). On the whole, the factors that may potentially influence the study results concerning the nutritional value of organic and conventional food products are summarised in Table 3. Valid nutritional quality comparisons between organic and conventional foods require that the plants be cultivated in similar soils, under similar climatic conditions, be sampled at the same time and pre-treated similarly, and analysed by validated methods (Kumpulainen, 2001). In terms of food products of animal origin, animals would have to be fed on plants meeting the aforementioned production criteria.

At this point, it is interesting to refer to three recently published review papers.

Table 3. Factors that may influence the results of the comparative studies regarding the nutritional value of organic and conventional food

Study variables	Production methods		Farm location
Duration	Cultivar	Geographical location	
Replication	Soil type	Climate	
Statistical design	Organic matter	Seasonal variations	
Sampling of plant	Planting date	Storage conditions	
Sample size	Harvest date	Post-harvest processing	
Nutritional analyses	Trace elements	Plant disease	

Source: Hornick (1992) and Goldman *et al.*, (1999).

Worthington (1998) evaluated 34 publications of the last 50 years that had compared the effects of organic and conventional cultivation on the nutrient content of crops. The results are summarised in Table 4, where it can be seen that data are rather mixed. A trend is apparent, however, for organic produce to be more likely to contain increased levels of ascorbic acid and some other micronutrients. Overall, out of some 210 comparisons regarding the content of various micronutrients, organic crops were found to have higher nutrient levels in 40.9% of the cases, while the reverse was true in only 13.0% of cases; no difference was observed in 46.1% of the comparisons (Worthington, 1998). In a follow-up review of 41 published studies regarding the nutrient content of organically and conventionally grown fruits, vegetables, and grains (Worthington, 2001), it was again concluded that organic crops contain considerably more vitamin C and various micronutrients (range 9–42%) than conventional ones (Figure 1). In addition, the author noted the increased proportion of comparisons (about 56%) showing better nutritional quality in organic than in conventional crops (Worthington, 2001).

The third publication is an 87-page report prepared for the Soil Association of the United Kingdom (Heaton, 2001). The author considered some 400 previous papers comparing organic and conventional foods, and concluded that organic crops appear to be higher in vitamin C, some essential minerals (calcium, magnesium, iron and chromium),

Table 4. Comparison of protein quality and selected micronutrient contents of organic and conventional crops

Nutrient	% of comparisons			Number of comparisons
	Org > Conv	Org = Conv	Org < Conv	
Protein quality	100.0	0.0	0.0	3
Ascorbic acid	58.3	33.3	8.3	36
β-Carotene	38.5	38.5	23.1	13
Vitamins B	12.5	75.0	12.5	16
Calcium	44.7	42.6	12.8	47
Magnesium	37.8	53.3	8.9	45
Iron	42.9	40.0	17.1	35
Zinc	25.0	56.3	18.8	16

Abbreviations: Org, organic food; Conv, conventional food. Data derived from Worthington (1998).

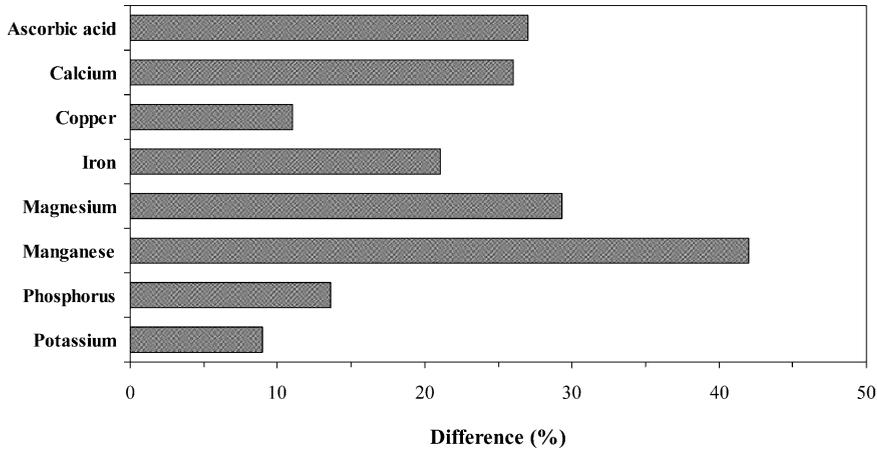


Figure 1. Comparison of organic and conventional fruit, vegetables and grains with respect to their micronutrient content. Differences between the micronutrient content of organic (Org) and conventional (Conv) crops have been calculated by using the following formula: % Difference = $100 \times (\text{Org} - \text{Conv}) / \text{Conv}$. Drawn with data provided in Worthington (2001).

and phytonutrients (lycopene in tomatoes, polyphenols in potatoes, flavonols in apples, and resveratrol in red wine) (Heaton, 2001). It is important to note that the study excluded many trials that, according to the author's criteria, failed to compare the two types of produce properly. For instance, of 99 studies comparing the nutrient content of organic and conventional foods, only 29 were considered valid, since the rest looked at food that had not been grown according to the organic standards. The results of these studies clearly point towards improved nutritional quality in organic compared to

conventional produce (Figure 2). Finally, the report emphasised the urgent need for further studies under more controlled conditions. It is true that many researchers have tried to document nutritional differences between organic and conventional foods. Where differences have shown up, they do not consistently give the nutritional edge to either type of food, probably because the variability within a given crop is greater than the variability between one cropping system and another.

Nevertheless, in spite of the difficulties encountered in the gathering, interpretation,

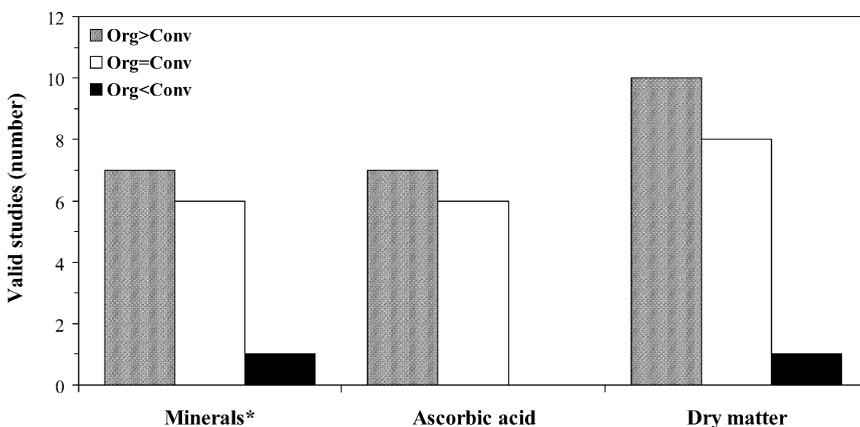


Figure 2. Studies into the nutritional content of organic and conventional foods. Abbreviations: Org, organic food; Conv, conventional food. * K, Ca, Mg, P, Fe, Cu, Mn, Zn, S, B, Cr, Co, Mo, Ni, Se, Si, St, and Va (in descending order of number of comparisons). Drawn with data provided in Heaton (2001).

and generalisation of the results, some differences can be identified. With respect to protein content, there is a slight trend towards lower protein concentrations but of higher biological value in organic vegetables, cereal crops and legumes, as compared with conventionally grown crops. These differences, however, seem to arise due to the amount of nitrogen available to the plant, and not due to the cultivation system, *per se*: should nitrogen availability from organic and conventional fertilisers be the same, these differences would probably not be evident. Organically grown leafy vegetables contain a higher amount of dry matter and lower proportions of moisture. At the present, however, this conclusion cannot be generalised for the rest of the produce (root and tuber vegetables).

With respect to vitamin content, there is little or no hard evidence of differentiation between organic and conventional fruits and vegetables. Only perhaps in the case of ascorbic acid in leafy vegetables and in potatoes could it be stated that organically grown crops have slightly higher concentrations than conventional ones. This may well be the result of the latter maturation state of organic crops at the time of harvest. In general, however, nitrogen fertilisation at high rates tends to decrease the vitamin C content in several fruits and vegetables (Lee & Kader, 2000), but differences in ascorbic acid content in other types of organic and conventional produce have not been consistent to date. Furthermore, vitamin C concentrations in fruits and vegetables are influenced by various factors such as genotypic differences, pre-harvest climatic conditions and cultural practices, maturity and harvesting methods, and post-harvest handling procedures (Lee & Kader, 2000). With respect to minerals and trace elements, no significant differences can be identified. As far as the rest of the nutrients and the other food groups are concerned, available data are either conflicting or extremely limited to support a generalised statement.

The results from animal feeding experiments suggest that several indices of the animals' biological function and performance improve slightly when they are fed

on organically produced feedstuff. Those fed on organic diets exhibit some, but not unanimous, improvements in other health-related indicators. Finally, when given the opportunity, most animal species will probably show a clear preference towards organically grown food. The interpretation of this conclusion, however, should be made with prudence, and any extrapolation to humans should take into account the profound metabolic and physiological differences between animals and humans.

The ultimate test of the nutritional value of food depends on its ability to support health, growth, and reproduction over successive generations of humans. Food products from organic and conventional systems have not been compared so far in nutritional interventions in man. Some pre-war studies that have compared the effects of organic and conventional food products on human health manifest serious limitations, e.g., lack of dietary data, heterogeneity in the study populations, absence of information on growing conditions of the foods, etc., and thus cannot be scrutinised according to current scientific criteria (Woese *et al.*, 1997; Williams, 2002). Tests of that kind are very difficult to carry out and evaluate, since all the factors that influence human health must be kept constant for the study subjects, in order to be able to identify the effects of food from different production systems. Although there is a clear need for research in humans, it is generally believed that epidemiological studies of people who consume organic and conventional produce would be expensive and prone to influence by factors, such as genetic variability and lifestyle differences between the two population groups, that would be difficult if not impossible to control (Adam, 2001).

The nutritional value of food, as the absolute content of individual nutrients, is only one aspect of food quality. Quality of the produce is not a single, well-defined attribute but comprises many properties or characteristics; it encompasses sensory attributes (appearance, texture, taste and aroma), nutritive values, safety determinants, chemical constituents, mechanical properties, functional properties and defects (Abbott, 1999).

Food quality may be defined in several different ways, either from a product orientation or a consumer orientation. From all the different definitions different measurement methods arise, as well as different theories about how quality actually relates to consumer satisfaction (Shewfelt, 1999). Consumers measure food quality using visible features, such as the “pleasure” attributes of the product, and their awareness of invisible qualities, such as microbial and toxicological safety and nutritional value (Taeymans, 2000). In order to make useful comparisons between organic and conventional produce, therefore, food quality should be considered in a wider sense. Very often, in conventional food production systems, food quality is determined by properties that are easy to measure, quantify, or weigh, for example nutrient content, microbiological safety, color, texture, shape, size, and price. Unfortunately, yield and profit are sometimes of greater importance than food quality (Thiermann, 2000). By contrast, the quality of organic food is believed to include social, environmental, and political dimensions, besides appearance, technological, and biological value (Browne *et al.*, 2000). The organic movement claims that an agricultural system is more than the sum of its parts, and therefore, the quality of a food product

should be considered as the result of the general quality of its production system (Morkeberg & Porter, 2001). Focusing on one aspect of food quality only, like the nutritional value, underscores the importance of other factors. The complexity of the production system, however, forces scientists to examine only a few characteristics of food.

As an overall conclusion, the main health-promoting properties of food lie in its ability to provide human organism with carbohydrates, proteins, fats, vitamins, minerals, fiber and protective factors needed for growth, repair, reproduction, energy, and good health. Plants produce these complex nutrients from water, air, soil and sunlight. How well they do so is under the influence of many environmental and genetic factors, and the type of agriculture is only one variable. Individual metabolism, as it relates to health and predisposes to disease or other health outcomes, should guide agriculture toward foods for improved health and nutrition (Watkins *et al.*, 2001). At present, a balanced diet, rich in fruits and vegetables, and adequate in foods from the other groups, is unequivocally able to maintain and improve health, regardless of its organic or conventional origin.

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