INFLUENCE OF ORGANIC AND CONVENTIONAL FARMING SYSTEMS ON NUTRITIONAL QUALITY OF FOOD

U. Kopke
Institute of Organic Agriculture, University of Bonn, Germany

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Summary

Nutritional quality is defined as the value of the food for the individual consumer's physical health, growth, development, reproduction and psychological or emotional well-being. Organic farming systems avoid the severe negative effects on human health that can be caused by conventional animal husbandry. Together with the problem of residues from veterinary drugs (e.g. antibiotics) used in conventional agriculture, direct relationships of agricultural production methods to human health can be shown. In organic farming systems, a farm is organized as an almost completely closed system, i.e. like an organism. The BSE/vCJD complex and its risks for human health make the advantages of this system most convincing. Regarding plant products, clearer differences between farming systems were shown for undesirable ingredients when compared with desirable ingredients; organically produced or fertilized products showed lower contents of undesirable ingredients. Differences between farming systems were more significant for vegetable crops than for seed crops. Differences in desirable ingredients of plant products were comparatively small. In most cases, organic produce showed a higher product quality. Nevertheless, it is difficult to estimate the value of nutritional quality in its narrow definition of sustaining basic physical needs. However, this problem is not confined to the comparison of organic and conventional food.

Although results from long-term human nutrition tests are not available and results from animal feeding experiments are inconsistent, most studies showed that organically produced food had a favorable influence on animal fertility and health. Despite consistent differences in food ingredients, the contribution to overall health is difficult to measure because of the extensive access to food and diversified diets in Europe and North America. Nutritional quality as defined in this contribution covers a broad spectrum of parameters and aspects that includes psychological or emotional effects in addition to the effects of nutritional chemistry. These conclusions can be substantiated by additional knowledge gained, for example, from life-cycle assessments, which indicate that organic farming systems are the more sustainable, environmentally sound forms of agriculture, able to substantially reduce negative impacts on wild flora and fauna, water, soil, air, and climate. The environmental benefits, along with positive social implications and implications for animal welfare, may ultimately be more important than the measurable (if at all measurable) contribution of balanced Western diets to individual nutritional health.

1. Introduction

In addition to grading and technical suitability (utility value), food quality is determined by its nutritional quality. Nutritional quality describes the inherent biological or health value of a product including the ratio of beneficial to harmful substances, and taste, fragrance, freshness and shelf-life as important quality characteristics governing consumer behavior. Customers regularly ask whether organic products have health or taste quality advantages. Organic Farming claims to produce higher quality than conventional agriculture. The production processes are an important part of food quality identified as 'process quality'. In these terms, the organic label is not a health claim but primarily a process claim, encompassing environmental impacts and ethical aspects. It is scientifically challenging to adequately assess the nutritional quality of food grown using different cultivation methods, because the final measure of nutritional quality lies in the organism that consumes the food. However, human beings are individuals with individual reaction patterns, also governed by the culinary value that a product promises. In the end, nutritional quality is determined by the value of the product for the consumer's physical health, growth, development, reproduction and general well-being. Thus, this extended definition of nutritional quality may be divided into two terms. The first term covers the effects of food determined by its substance, i.e. the sum of all ingredients, beneficial and harmful compounds, and their nutritional (or biological) aspects. The other term covers the psychological effects of well-being based on the knowledge related to the organic label indicating the process quality, and the ethical, environmental, social and political values. To assess the 'substance' effects, animal studies or so-called holistic methods (see section 4) can be used, but 'label' aspects can be investigated by human studies only.

In contrast to feeding experiments with animals, long-term nutritional tests in humans comparing results of organic and conventional production have so far not been satisfactorily performed due to many methodological difficulties and ethical reservations. The few comprehensive reviews published between 1995 and 2001 covering more than 400 publications, and some newer unpublished or not well distributed investigations, are dominated by chemical and physiological investigations of concentrations of desirable and undesirable ingredients regarded as being directly related to nutritional quality.

Generalization derived from extrapolation of results gained by the different approaches to comparing the quality of organic and non-organic foods is often inadequate due to methodological insufficiencies. Market-oriented supply studies, used to monitor the situation of the consumer, often do not identify the origin of the samples. Considerable differences among organic growers, their farm organization, cultivation practices, choice of cultivars, and specific site conditions that cannot be influenced by the producers can overshadow the effects of the farming systems. With market-oriented supply studies, no *ceteris paribus* approach is possible. Significant results require very broad sample sizes.

Effects of farming systems on product quality would be best investigated by comparing produce of selected neighboring farms. With this approach, environmental factors related to climate are the same, but a high number of farm pairs would be required to truly represent the cultivation forms, and to avoid effects not directly related to the cultivation systems. Nevertheless, using this approach it should be possible to identify which farming system was able to optimize product quality under the given site conditions.

From the scientific point of view, long-term factorial field trials are the most accurate form of comparative studies, indicating for each field experiment which cultivation method results in highest product quality under specific site conditions. With this approach, however, some problems remain unsolved. For example, which cultivars should be chosen? One (for each crop) that is adapted more or less equally to both organic and non-organic growing conditions, or two cultivars each with specific adaptation to one farming system only? Again, with this approach, results can only be generalized when there are a sufficient number of field trials comparing the cultivation systems under different site conditions and years. On the other hand, these trials may not be representative for long due to the limited useful life of cultivars (especially in conventional agriculture), and the increasing influx of farmers with different background knowledge converting to Organic Agriculture. This could force a rapid development of Organic Agriculture, which might result in products quite different from that produced by the pioneer organic farmers. But the same might hold true for the conventional group, who may show a similar dynamic when entering so-called integrated farming systems.

Because long-term experiments with farming systems are rare, this summary evaluation is based on individual valid results derived from the different approaches mentioned above. It determines whether quality differences between products from conventional and organic farming systems or food produced using different fertilization systems are either significant, convincing or show a clear trend. Special attention was given to assessing the validity of the comparative studies in terms of defined agricultural practice and scientific analysis to allow a ranking of the available literature. A similar approach was performed in a recent review of about 100 studies focussing on primary nutrients (dry matter, vitamins, minerals, protein content and protein quality), which rejected about 2/3 of the studies due to the strict criteria set to ensure study validity. Finally, the current status of knowledge was evaluated against a product quality model, which was synthesized and suggested by biodynamic researchers three decades ago.

2. Undesirable Ingredients – Food Safety

2.1. Plant Products

Organic Agriculture differs from conventional agriculture because it does not use synthetic agricultural inputs such as synthetic pesticides, herbicides, fungicides, highly soluble mineral fertilizers, growth regulators, synthetic supplements and preservatives, components derived from genetically modified organisms (GMO), or irradiation. It thus fulfils at least the psychological aspects of the food safety aims of the consumer.

2.1.1. Pesticide Residues

Potential hazards from synthetic input residues are prevented in Organic Agriculture to the greatest extent possible, reinforcing consumer expectations that organic food is healthier. On the other hand, health risks associated with chemical residues in conventionally grown products can be avoided by establishing maximum residue limits, below which no significant health risks are to be expected. National food control programs, such as those in Switzerland and Germany, insuring adherence to the maximum residue limits, have kept calculated intakes below about 1% of the acceptable daily intake. On the other hand, the 2000 annual report on pesticide residues in the U.K. shows that in 1999 about half of the tested fresh fruit and vegetable samples contained pesticide residues. Similar results were found by the German food-monitoring scheme that also indicated higher residue levels in goods of non-EU origin. From less developed countries, no comparable data sets are available, but residue levels were frequently reported to be higher in products imported from developing countries compared with products of European origin (see *Nutritional Consequences of using Organic Agricultural Methods in Developing Countries*).

Many of the pesticides used in conventional agriculture, with more than 600 active ingredients, are linked to potential toxicological effects on humans, including mutagenic and carcinogenic risks and those affecting reproductive properties. There may also be links to several neurotoxic and immunotoxic effects. Furthermore, some pesticides with a significant mutagenic and carcinogenic potential (e.g. phenoxyacetic acids, dichlorvos, isoproturon) are either not classified or not yet identified as including harmful compounds. Designations used for pesticides with respect to specific toxic effects are often inadequate for demonstrating possible health effects. Long-term effects of pesticide residues and possible interactions of ‘cocktail effects’ on human health are difficult to determine. Only very few of biological control agents are permitted on crops grown according to the rules of Organic Agriculture. By definition there are no residues of synthetic pesticides on organic products and also lower amounts of contaminants. However, several studies have confirmed the reduced presence of pesticide contaminants in organic food although organic food is generally not pesticide-free. Low levels of pesticides and other contaminants are sometimes found in certified organic food as a function of previous land use and/or by drift of chemical sprays from conventionally managed neighboring fields, where only a part of the active ingredients finds its target.

In Germany, conventional produce has been monitored since 1988. Under the 1999 food monitoring scheme, 4918 samples of conventional agricultural products of domestic and foreign origin were analyzed for undesirable contents. Depending on the food, examinations included residues of pesticides, which were confirmed to be low and not requiring specific action with regard to preventive health protection of consumers. Modern analysis enables detection of trace contamination of food, often regarded as not necessarily affecting human health, but nevertheless regarded as able to describe nutritional quality when at least the consumer concerns are taken into account (see section 6). In a survey, Californian consumers cite food safety as the main reason for consuming organic foods, thereby confirming many other polls of similar nature performed in other industrial countries. Levels of concern were highest for residues and irradiation; the latter is not allowed in processing organic food.

In the 1997 food monitoring scheme, analyses for 55 different biocides in lettuce grown in Germany showed that 70 to 85% of the samples had residue levels below the maximum residue limits. Depending on variety, the share of residue levels above the maximum limits ranged between 2.5% (Batavia lettuce), 10% (head garden lettuce), and 20.5% (oak-leaf-lettuce). Residues in conventionally grown lettuce can be described as high because 8.7% of the samples had residue levels higher than the maximum limits. The degree of contamination is generally higher in winter (greenhouse) lettuce compared to summer production. Compared to previous investigations, in the German food monitoring schemes analyzing conventional agricultural products in the late 1990s, no change of the situation concerning residue impacts was observed.

As the above-mentioned monitoring program did not include the minimum sample size per food type and year for organic products, no data on pesticide contamination of organic products are available. However, other direct comparisons of fruits and vegetables performed in Germany and Switzerland have clearly shown higher levels of residues in conventional products compared with contaminants in organic products. Consumer Report studies in the USA, investigating more than 300 synthetic pesticides in tomatoes, peaches, green bell peppers and apples, which were unlabeled, labeled ‘green’ (not organic, but grown with ‘environmentally friendly’ methods), or 'organic', substantiate these results. Organic foods, in fact, showed significantly lower levels of pesticide contaminants than foods in the other two categories. A clear trend toward lower contents of pesticides in organic fruits corresponded with the findings for vegetables.

Compared with fruits and vegetables, grains of non-organic wheat and rye were found to be practically free of residues. Residues above the maximum limits were not found in any of the samples of these food items in the above-mentioned German monitoring program. In wheat, 4.4% and in rye 6.5% of the grains analyzed showed residue levels below the statutory maximum residue level. The movement of pesticides into organic fields via air, rain, surface waters and groundwater is always possible. Determination of different origins based on the identification of biocide residues is therefore unlikely, because organohalogens such as lindane, DDT, and environmental contaminants of the PCB group are ubiquitous. In contrast to pesticides, undesirable residues of growth regulators such as CCC can indicate the type of production measure used. However, because only 60% of the conventional samples showed CCC residues (mean: 0.1 mg/kg, maximum level: 3.0 mg/kg wheat), samples free of CCC residues can provide no clear evidence of organic origin.

Given the above-mentioned shortcomings, there is still a clear trend toward lower levels of pesticide contaminants in vegetables and vegetable products from organic production compared to those from conventional production. In conventional products, levels were mostly below the statutory maximum. Residue levels in the range between detection limit and maximum limit were determined more frequently in conventionally produced vegetables than in organic products. The results underline the effect of banning the use of chemical-synthetic pesticides in certified Organic Farming, where residue levels as a rule did not exceed the maximum limits or where traces of persistent active ingredients pointed to existing contamination. It is difficult to prove that dietary exposure to pesticide residues at levels found in and on foods is harmful. For ethical reasons, controlled tests with humans are not possible. But effects on the reproductive system and neurotoxicity of chronic exposures to pesticides have been demonstrated in animal trials. Nevertheless, there are concerns about pesticide residues in conventional agriculture. For example:

- Conventional growers learn to use sophisticated spray schemes that alternate different active ingredients of pesticides thus holding single pesticides below maximum residue limits.
- Maximum residue levels and acceptable daily intakes were set as legal limits and safety levels for individual pesticides only. Interactions, which have been demonstrated as able to multiply the toxicity of the single pesticides (so-called ‘cocktail effects’), are not taken into account.
- Mean residue levels can be much lower compared with the fruit that is ingested, e.g. apples near the center of a tree are unlikely to receive as much pesticide spray as the apples growing on the outside of the tree.
- Risks for children may be much higher than for adults, because their intake of fruits per unit of bodyweight is higher. Children’s ability to enzymatically detoxify these substances may be limited and their immature organ system might show a more sensitive reaction.
- Results of residue analyses might be questionable because not all pesticides used were investigated or pesticide compounds may be unstable and degrade during the analysis procedures.
- Verification of chronic toxicity on vital organs (e.g. kidneys, liver or nervous system) is difficult.

Without any doubt, harmful effects of pesticides on human health are more related to environmental and occupational exposure than to diets. By purchasing food of organic origin, exposure to contaminants/residues on foods and potential risk can be minimized. In addition, support for farming systems that contaminate the environment with these toxins will be decreased.

2.1.2. Nitrate

The inherent toxicity of nitrate is low. The food safety implication of a high nitrate content in food is related to (i) the reduced ability of the hemoglobin in blood to carry oxygen where excess nitrite converted from nitrate may pose a serious risk of methemoglobinemia (cyanosis), especially for very young babies, and (ii) nitrosation with amines to nitrosamines that may behave as carcinogen precursors. Thus, the World Health Organization (WHO) has set the maximum acceptable daily nitrate uptake to 3.65 mg per kg bodyweight (see *Agricultural Practices to Minimise Nitrate Accumulation in Arable Parts of Crop Plants*). The risk of exceeding the daily acceptable nitrate intake is documented by a person of 50 kg bodyweight, who would exceed the acceptable daily nitrate intake (182.5 mg) with a single portion of lettuce, which contains 4000 mg nitrate per kg fresh matter, a content typical for conventional winter produce. The maximum tolerated nitrate concentration for lettuce in Germany is 3500 ppm nitrate/fresh matter. Health concerns of consumers are, therefore, reasonable in that nitrate intake is further increased by ingestion of drinking water, and some meat, sausages and fish products. The permitted level for baby food is 250 mg nitrate/kg fresh matter. For this reason, the German market for baby food is dominated by certified organic produce.

There are several reasons why the nitrate contents in vegetables from organic cultivation or vegetables grown with organic manure are clearly lower compared to conventional produce or products grown with the use of highly soluble mineral N-fertilizers. Cheap mineral N-fertilizers drive conventional farmers to apply higher amounts than necessary. Excessive supply of N-fertilizer accumulates nitrate and free amino acids and also results in a higher probability of aphid infestation and consequently application of insecticides. Readily soluble nitrogen fertilizers tend to lead to (sometimes only temporarily) higher nitrate concentrations in the plant petioles and tissue compared with organic manure (farmyard manure or compost), which releases nitrate more slowly and steadily, and where mineralization and nitrification are a function of soil temperature, i.e. solar irradiation. Since nitrate reduction in plants directly depends on light intensity, surplus of nitrogen applied to plants can lead to imbalances in nitrate and carbon provided by photosynthesis and necessary for nitrate reduction, resulting in nitrate accumulation.

Higher nitrate levels in conventionally cultivated crops or those treated with mineral N-fertilizers are predominantly found in leaf vegetables with either a short vegetation period or known as nitrophilic, e.g. lettuce and spinach. In experiments with root and tuber vegetables, nitrate contents of carrots, beetroots and potatoes were also lower with manure compared with mineral N-fertilization. In a long-term experiment where amounts of fertilizers and composted farmyard manure were applied in order to gain comparable yields, an aim that in most cases could be fulfilled, nitrate contents were clearly lower, although total nitrogen applied with manure was considerably higher compared with mineral fertilizer. Over three years of measurements, the manured carrots had around 160 ppm fresh matter (f.m.) nitrate (range: 115-200 ppm). With mineral N fertilization, carrots had an average of 227 and 325 ppm at the medium and high fertilizer level, respectively. The highest value measured in all experimental years was 369 ppm with mineral and 200 ppm with manure fertilization. In the case of beetroots with all three levels and in all years, mineral fertilization also resulted in higher nitrate contents. For the medium level mineral fertilization, 1708 and 1903 ppm f.m. were determined in 1983 and 1984, i.e. 117 and 131%, respectively, of the contents of the corresponding manure treatments. In beetroots, the highest nitrate contents were found using the highest mineral fertilizer level leading to 2186 and 2200 ppm nitrate.

Potato tubers also showed a trend toward lower levels of nitrate when organically produced, although potatoes are not regarded as nitrophilic or nitrate accumulating plants. Results of controlled field experiments are confirmed by German market-oriented supply studies, where 92 ppm nitrate were determined for carrots of organic origin compared with 357 ppm nitrate in conventional carrots.

Even considering interactions of site conditions and farming methods, vegetables of organic origin clearly have a lower probability of high nitrate content. Since about 70% of nitrate ingestion originates from vegetables, organic produce has received special attention in nutritional ecology, in children's feeding programs and by vegetarians. Reproductive parts of plants (grains and oil seeds) are generally low in nitrate content (see *Influence of Mineral Fertilizers on Nutritional Quality of Staple Food Crops*), and no marked differences in nitrate contents between conventional and organic products have been observed.

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Biographical Sketch

Prof. Dr. Ulrich Kopke is director of the Institute of Organic Agriculture (IOL) at the University of Bonn, Germany. He started his professional career as an agronomist at the University of Göttingen, Germany (Dr. sc. agr. 1979). After his habilitation in 1987 he was appointed as a Professor in Organic Agriculture at the University of Bonn, where he is actively involved in all aspects of environmentally, socially and economically sustainable agricultural research and development. His thematic interests, meanwhile documented in about 230 publications, have covered agricultural and environmental concerns, natural resources management as well as farm level concerns and macro policy issues. His main research activities include: Optimizing methods and techniques of agronomy in Organic Agriculture including nutrient management strategies especially in cereals, pulses, potatoes and field vegetables, oriented especially towards product quality, designing site-specific whole-farm concepts, and development and application of life-cycle assessment (LCA) in agriculture. In addition to several national and international joint research projects, Prof. Köpke was coordinator and leader of the multidisciplinary researcher group "Optimizing strategies in Organic Farming", OSIOL, funded by the German Research Foundation DFG (Deutsche Forschungsgemeinschaft, 1994-2000). EU-research activities include the research project Organic Livestock Farming (PN 06156, AIR3-CT92-0776) and the membership of the concerted action "Fertilization Systems in Organic Farming", FERSY (AIR3-CT94-1940). He was sub-coordinator for “Crop Production and Weed Control” of “The European Network for Scientific Research Co-ordination in Organic Farming”, ENOF, (AIR3-CT94-2143). Currently he is coordinator of an EU-research project "Strategies of Weed Control in Organic Farming", WECOF (QLRT-1999-31418).