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Review

Quality of plant products from organic agriculture

Ewa Rembiałkowska*

Organic Foodstuffs Division, Faculty of Human Nutrition and Consumer Sciences, Warsaw Agricultural University, Nowoursynowska 159 C, PL-02 776 Warszawa, Poland

Abstract: During the last decade, consumers' trust in food quality has decreased drastically, mainly because of growing ecological awareness and several food scandals (e.g. BSE, dioxins, bacterial contamination). It has been found that intensive conventional agriculture can introduce contaminants into the food chain. Consumers have started to look for safer and better controlled foods produced in more environmentally friendly, authentic and local systems. Organically produced foods are widely believed to satisfy the above demands, leading to lower environmental impacts and higher nutritive values. So far, studies have partly confirmed this opinion. Organic crops contain fewer nitrates, nitrites and pesticide residues but, as a rule, more dry matter, vitamin C, phenolic compounds, essential amino acids and total sugars than conventional crops. Organic crops also contain statistically more mineral compounds and usually have better sensory and long-term storage qualities. However, there are also some negatives: plants cultivated in organic systems generally have 20% lower yields than conventionally produced crops. Several important problems need to be addressed in the coming years: environmental, bacterial and fungal contamination of organic crops and, the most essential issue, the impact of organic food consumption on animal and human health.

Keywords: organic plant crops; quality; yield; composition; nutrition; vitamins; phenolics; sugars; nitrates; nitrites; pesticides; dry matter; health; sensory qualities

FACTORS INFLUENCING THE QUALITY OF ORGANIC PLANT FOOD PRODUCTS

There are several important factors influencing the quality of food products that also are relevant to organically produced plant products. As illustrated in Fig. 1, the basic factors are the quality of the environment (abiotic factors) and the levels of pest and pathogen damage (biotic factors) to which plants are subjected. The main components of the environment (air, water, soil) have to be unpolluted if the crops obtained are expected to be of high nutritive quality. Many environmental contaminants enter the food production chain (soil–plant–animal–human organism), causing significant problems in human health.[1] These contaminants include heavy metals, pesticide residues, nitrogen compounds, mycotoxins, chlorinated biphenyls (PCBs), aromatic hydrocarbons (e.g. benzo[*a*]pyrene), plant growth stimulators (e.g. choline chloride), antibiotics, hormones, radioactive isotopes and plastic substances (monomers).

Climate and weather are also important factors, as well as soil type and pH, soil cultivation, fertilisation and conditions of crop storage after harvest.

Biotic factors can have also a significant impact on crop quality. The main biotic factors are cultivar choice, bacterial and fungal contamination (disease) and pest damage. Cultivars of the same crop species can differ significantly in nutritive quality. For example, the content of β-carotene in carrots (*Daucus carota* L.) can vary between 7.19 and 13.84 mg g^{-1} depending on the cultivar.[2]

The main potential source of bacterial contamination in plant crops is animal manure used in organic farming. Contamination can take place via the roots or by water splashing onto the leaf surfaces. The most important organisms are several species of facultative anaerobic bacteria (*Salmonella enterica, Escherichia coli* O157:H7, *Campylobacter* spp., *Listeria monocytogenes, Clostridium botulinum, Mycobacterium paratuberculosis*), protozoa (*Toxoplasma gondii*), tapeworms, viruses and prions. The results obtained so far are contradictory. Some studies indicate higher bacterial contamination in organic crops, while others show the opposite.[3]

Mycotoxins (produced by fungi) originate mostly in the field but can also develop during storage. Owing to the fact that fungicides are not used

* Correspondence to: Ewa Rembiałkowska, Organic Foodstuffs Division, Faculty of Human Nutrition and Consumer Sciences, Warsaw Agricultural University, Nowoursynowska 159 C, PL-02-776 Warszawa, Poland
E-mail: ewa_rembialkowska@sggw.pl
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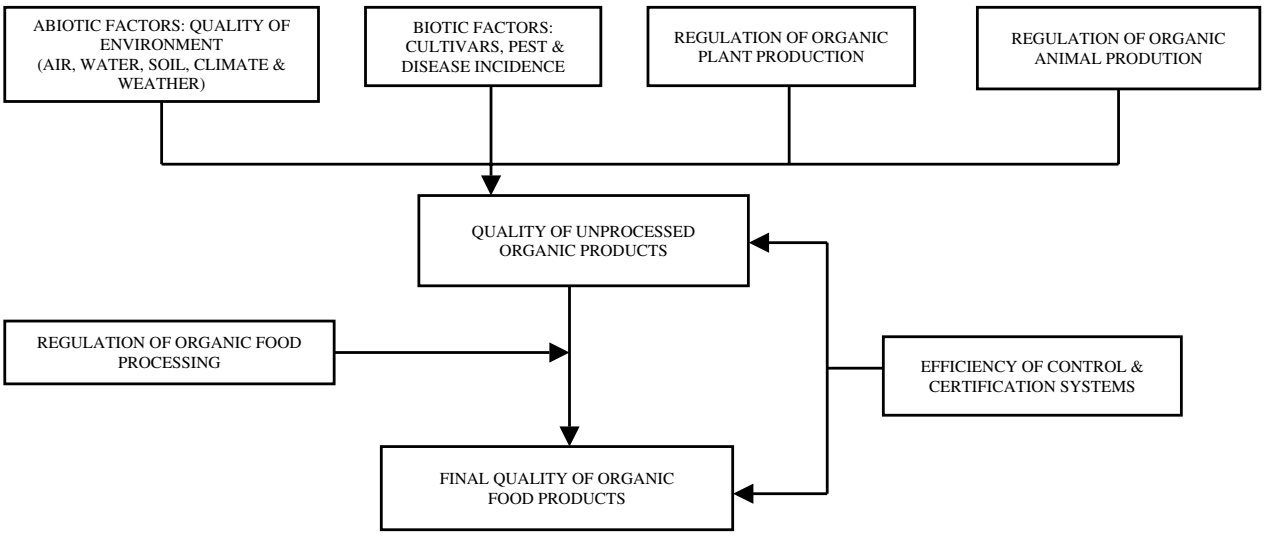

Figure 1. Factors influencing the quality of organic food products.

in organic agriculture, some authors believe that organically produced foods will contain higher concentrations of mycotoxins. However, literature reviews show that mycotoxin concentrations are usually similar or reduced in organic compared with conventional products.[4] The most notorious mycotoxins are those produced by *Fusarium* species on cereal crops and maize. One of the reasons for lower *Fusarium* infections in organic grains could be the lower nitrogen concentrations in the tissues.[5]

Insect pests also exert an influence on crop quality. Because of the ban on synthetic pesticides in organic agriculture, insects often damage fruits and vegetables, thereby diminishing their yield and harming their appearance. However, it is not clear whether they also reduce their nutritive quality. In contrast, there is evidence that organically grown plants contain more phytochemicals (which are natural insecticides) and are therefore more resistant to insect damage.[6] They can also play a positive role in human health, because several phytochemicals, being plant defence compounds, are connected with possible health benefits (Brandt K, oral presentation at QLIF Congress, Newcastle, 2005).

Regulations on organic plant production allow actions that avoid many negative features of crop quality if they are consistently performed by producers. In order to fulfil these demands and to offer high-quality products to consumers, an efficient and airtight certification and control system must be implemented. In most countries such systems are quite efficient, though a rapid increase in the number of organic farms could lead to problems with a subsequent loosening of regulatory control. Therefore the main rule should be 'trust is good, but control is better'.

Moreover, the final quality of organic food products is influenced by the effective implementation of the regulations on animal production and organic food processing. Only precise fulfilment of all these regulations can guarantee the best organic food quality (Fig. 1).

IMPACT OF REGULATION ON ORGANIC PLANT PRODUCTION

The regulations for organic plant production are clear and detailed.[7] The European Union (EU) regulation published in 1991[8] contains parts that relate directly to the composition of organic plant products. The most important aspects of this regulation include:[7]

- a ban on genetic engineering and genetically modified organisms (GMOs);
- lower nitrogen levels – a maximum limit for manure application of 170 kg N ha^{-1} $year^{-1}$;
- a ban on synthetic pesticides;
- a ban on synthetic mineral fertilisers;
- a ban on growth promoters.

Organic farmers must follow the above regulations if they want to pass the inspection procedure every year and receive a certification document. If all requirements are complied with, several qualitative results can be expected. The most important conclusions from scientific comparisons are given below.

CONTAMINANTS

Nitrates and nitrites

A large amount of data shows that the content of nitrates and nitrites is distinctly higher in conventionally cultivated than in organic crops. This is important, because nitrates can easily be converted into nitrites, which can cause a dangerous illness called methaemoglobinaemia in babies, infants and elderly people.[9]

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Moreover, nitrites can react with amines to create nitrosamines, which are carcinogenic and mutagenic substances causing cancer of the digestive tract and leukaemia.[10] This process is dangerous not only for young children but also for adults of any age.

Based on a large amount of data, the nitrate content of organic and conventional crops has been compared. On average, the nitrate content of organic crops was 49% that of conventional crops.[11]

These and other data provide a basis for stating that organic methods lead to an approximately 50% reduction in the intake of nitrates and nitrites by humans.

Pesticides

Governments place legal limits, known as the Maximum Residue Level (MRL), on the level of pesticides that can be present in food. The MRL is usually estimated by testing individual pesticides on rats. Governments maintain that consumption of pesticides below the MRL is not a health risk. However, at lower levels, pesticides are known or suspected to cause many diseases and health problems, including cancer.[12]

The main problem is that the MRL for pesticides is usually estimated by testing individual pesticides on rats for a relatively short period. Virtually nothing is known about the effects of consuming combinations of potentially hundreds of different pesticides over the course of a lifetime. We do not and cannot know explicitly what is causing what, so precaution is the main tool available to us (Howard V, oral presentation at QLIF Congress, Newcastle, 2005).

The levels of pesticide residues found in organic crops are definitely lower than those present in conventional crops (Howard V, oral presentation at QLIF Congress, Newcastle, 2005).

It can be expected that eating organic foods will result in lower pesticide levels in human milk and body tissues. There is some evidence confirming this hypothesis. Researchers in France found that the level of pesticide residues in the milk of breast-feeding women decreased significantly with an increase in the proportion of organic food in the daily diet (from 25 to 80%).[13]

All available results show that the content of pesticide residues is significantly lower in organic crops, which creates safer health conditions for consumers eating organically.

Heavy metals

Heavy metals such as cadmium, lead, arsenic, mercury and zinc are introduced into the food chain from various sources, including industry, transportation, communal wastes and agriculture. For example, mineral phosphoric fertilisers used in conventional agriculture can introduce cadmium into crops, but the metal industry and transportation also cause cadmium contamination of soils and crops. Therefore there are no clear results in studies comparing the levels of heavy metals in organic and conventional crops. Some data point to higher levels in conventional crops, while others show the opposite.[11] A problem to be solved is whether organic farming (composting, increasing the organic matter in soil, pH, etc.) can diminish the intake of heavy metals by cultivated plants.

DESIRABLE COMPOUNDS IN PLANTS

Vitamins, phenolic compounds and mineral compounds

The nutritive value of foods depends mainly on them having the appropriate content of compounds indispensable for proper functioning of the human organism.

The content of phyto-compounds in plant foods is a topic of great interest in food science nowadays. A growing body of evidence indicates that secondary plant metabolites (phytochemicals) play a critical role in human health and may be nutritionally important.[14]

There are two main theories explaining the factors influencing the levels of compounds in plants.[15] The carbon/nitrogen (C/N) balance theory states that, when nitrogen is easily available, the plant will first make compounds with high nitrogen content, e.g. proteins for growth and nitrogen-containing secondary metabolites such as alkaloids, glucosinolates and non-protein amino acids such as the *Allium* flavour precursors. When nitrogen availability is limiting for growth, the metabolism changes more towards carbon-containing compounds, e.g. starch, cellulose and non-nitrogen-containing secondary metabolites such as phenolics and terpenoids.

The second, newer theory is the growth/differentiation balance hypothesis (GDBH).[15] It states that the plant will always assess the resources available to it and optimise its investment in processes directed towards growth or differentiation. The term 'differentiation' encompasseses increased formation of defence compounds as well as accelerated maturation and seed development.

The C/N balance theory is a special and typical case of the GBDH theory, since low nitrogen availability is the most common growth-limiting condition in natural ecosystems.[15] To verify the above theories, several authors investigated the content of some vitamins and phyto-compounds in organically and conventionally produced crops.

In order to summarise different data, for each organic–conventional comparison a % difference was calculated:

$$[(\text{organic} - \text{conventional})/\text{conventional}] \times 100$$

The collected data for several desirable components are presented in Table 1.

The role of vitamin C (ascorbic acid) in the human organism is basic for several metabolic functions, mainly because it is one of the major cellular direct antioxidants (along with glutathione) and is a

Table 1. Contents of desirable components in organic crops relative to those in conventional crops

Component	Mean % difference	Range (%)	Number of studies
Vitamin C	+28.7	−38 to +135.5	21
Phenolic compounds	+119.3	−56.6 to +734.2	15
Iron	+21.1	−73 to +240	16
Magnesium	+29.3	−35 to +1206	17
Phosphorus	+13.6	−44 to +240	18

Source: Ref. 17 and author's own calculations.

cofactor for certain enzymes. Vitamin C also supports detoxication and resistance of the human organism. The higher content of vitamin C in organic crops is beneficial to health, because vitamin C inhibits the *in situ* formation of carcinogenic nitrosamines, thus diminishing the negative impact of nitrates on the human organism.[10] Therefore organic vegetables can play an important anticarcinogenic role.

Plant-based phenolic metabolites are particularly interesting because of their potential antioxidant activity and medical properties, including anticarcinogenic activity.[15] According to Benbrook,[16] organic farming has elevated antioxidant levels in about 85% of the cases studied to date and, on average, levels are about 30% higher compared with foods grown conventionally.

Mineral compounds containing iron, magnesium and phosphorus are fundamental for human health. According to Worthington,[17] the higher mineral content in organic crops may be connected with the higher abundance of micro-organisms in organically managed soil. These micro-organisms produce many compounds that help plants to combine with soil minerals and make them more available to plant roots.

Unfortunately, there have been only a few studies on other vitamins such as β-carotene, B_1 and B_2 and the results are contradictory. Therefore no general conclusions can be drawn about these compounds.

Total sugars

A higher total sugar content in plant crops not only improves their taste but is also an important component of their technological quality, e.g. in the case of sugar beet. Studies clearly indicate a higher content of total sugars, mainly sucrose, in organically produced vegetables and fruits such as carrots, sugar beet, red beetroot, potatoes, spinach, Savoy cabbage, cherries, redcurrants and apples.[11,18]

Proteins

Several studies analysed in review papers[11] show that the quantity of crude protein is lower in organic than in conventional crops but that the quality is better as measured by essential amino acid content.

According to Worthington,[17] nitrogen from any kind of fertiliser affects the quantity and quality of protein produced by plants. Provision of a large amount of nitrogen to a plant increases protein production and reduces carbohydrate production. Moreover, the increased protein produced in response to high nitrogen levels contains lower amounts of certain essential amino acids such as lysine and therefore has a lower quality with respect to human nutrition.

SENSORY QUALITY OF ORGANIC FOODS

Many studies have proved quite unequivocally that vegetables and fruits from organic farms have a better taste and smell. This was found for carrots and potatoes, celery and red beetroot, head cabbage and tomatoes as well as for apples, cherries and redcurrants.[11] Organic fruits contained more total sugars, which probably influenced the better taste perception by consumers.

Better taste and smell have also been found for bread made from organic grain, which also had better crumb elasticity.[6] Interesting studies have been conducted on animal food preference in which animals were given organic or conventional fodder. Most studies have proved a clear animal preference for foods produced organically; such studies have been conducted on rats, mice, hens and rabbits.[19]

Preference for organic fodder was also observed in cases where, according to chemical analyses, both organic and conventional fodder fulfilled all physiological needs of the animals tested.[20] The reason for this was probably the difference in taste between organic and conventional fodder.

STORAGE QUALITY OF ORGANIC PLANT CROPS

Transpiration losses and decay processes, as well as changes in nutritive value, normally take place during the storage period of potatoes and other vegetables. However, these changes can proceed at different rates and to differing degrees.

Most of the available data indicate that the decay process is slower in organic crops, which therefore show better storage quality after the winter period.

A review study based on many sources[21] concluded that the storage quality of vegetables and fruits was better in the case of plants grown on organic farms (Table 2). The better storage quality of organic crops

Table 2. Storage losses of carrots, potatoes and various fruits and vegetables from organic (ORG) and conventional (CONV) farms[a]

	Carrots		Potatoes		Fruits and vegetables	
	ORG	CONV	ORG	CONV	ORG	CONV
Number of quoted studies	15	15	22	22	53	53
Storage loss (% of initial mass)	33	40	22	30	28	38

[a] Average data based on literature review.[21]

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Table 3. Positive nutritive attributes of organic plant products

No.	Attribute
1	Organic crops contain fewer nitrates, nitrites and pesticide residues than conventional crops. There is no clear difference in the content of heavy metals between organic and conventional crops
2	Organic plant products contain, as a rule, more dry matter, vitamin C, phenolic compounds, essential amino acids and total sugars. However, the level of β-carotene is often higher in conventional plant products
3	Organic plant products contain statistically more iron, magnesium and phosphorus. They also tend to contain more chromium, iodine, molybdenum, selenium, calcium, boron, manganese, copper, potassium, sodium, vanadium and zinc
4	Organic plant products usually have better sensory quality. They have a clearer smell and taste and are sweeter and more compact because of their higher dry matter content
5	Preference for organic products is typical not only for humans but also for animals such as rats, rabbits and hens. This preference was also observed in cases where, according to chemical analyses, both organic and conventional fodder fulfilled all physiological needs of the animals tested
6	Vegetables and fruits from organic production maintain better quality during winter storage, showing lower mass losses due to transpiration, decay and decomposition processes. A possible reason for this is their higher content of dry matter, minerals, sugars and other bioactive compounds

Table 4. Negative and unclear aspects of organic plant products

No.	Negative aspect	Unclear aspect
1	Plants cultivated in organic systems have, as a rule, significantly (on average 20%) lower yields than conventionally produced crops. This increases their price and creates for many consumers a barrier to buying organic foods	Environmental contamination (heavy metals, PCBs, dioxins, aromatic hydrocarbons) can be similar in organic and conventional crops, because the impact of industrial, transport and communal sources is similar on organic and conventional farms located in the same area
2		Bacterial (mainly *Salmonella* and *Campylobacter*) contamination can sometimes be higher in organic produce, but scientific evidence of this is still not clear
3		Mycotoxins can contaminate both organic and conventional foods, but scientific data are contradictory
4		The impact of organic food consumption on human health and wellbeing remains essentially unknown in spite of some positive indications, so the subject needs further study

was probably associated with a higher content of dry matter in their flesh, resulting in less extensive decay and decomposition.

Lower losses in organic production have not only nutritive but also economic benefits. In conventional systems, high yields are produced but significant losses during storage reduce the economic benefits.

CONCLUSIONS

Recent food crises (BSE, foot and mouth disease, food contamination by dioxins, toxic fungi, *Salmonella* and *Campylobacter* bacteria) have caused consumers to look for more authentic and safer foods. Organic food production is widely recognised as being more friendly to the environment, more controlled and better for animal welfare.

On the other hand, many data indicate that a lot of food contaminants have their source in conventional methods of agriculture, animal production and food processing. The negative effect of the continuing enthusiastic use of chemical fertilisers and pesticides in agriculture is potentially huge. Therefore safer methods of agricultural production, mostly organic methods, are very important.

Studies conducted in various countries have indicated several positive attributes of organic plant products (Table 3) but also a few negative and unclear aspects (Table 4).

To summarise the positives, organic food should be recommended for all, but especially for young babies, pregnant and breast-feeding women, elderly and chronically ill people and vegetarians. The last group obviously consumes a lot of vegetables, which can contain too high levels of carcinogenic substances when produced conventionally.

The lower content of nitrates and higher content of phenolic compounds and vitamin C in organic crops are especially important for health. Nitrates are easily converted in the digestive tract into poisonous nitrites, which are the precursors of carcinogenic nitrosamines. This process is hampered by vitamin C, and carcinogenesis is retarded by phenolic compounds and other dietary phytochemicals present at higher levels in organically produced crops. Therefore organic vegetables can play an important anticarcinogenic role.

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