NJAS - Wageningen Journal of Life Sciences xxx (2011) xxx–xxx

Contents lists available at ScienceDirect

NJAS - Wageningen Journal of Life Sciences

journal homepage: www.elsevier.com/locate/njas

Review

Organic food and impact on human health: Assessing the *status quo* and prospects of research

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ARTICLE INFO

Article history:
Received 28 November 2009
Accepted 19 January 2011
Available online xxx

Keywords:
Review
Organic food
Health
Humans
Intervention
Observational
In vitro studies

ABSTRACT

The paper gives an overview of recent studies investigating the health value of organic foods and presents a framework for estimating the scientific impact of these studies. Furthermore, the problems connected with the different research approaches are being discussed. A number of comparative studies showed lower nitrate contents and less pesticide residues, but usually higher levels of vitamin C and phenolic compounds in organic plant products, as well as higher levels of omega-3 fatty acids and conjugated linoleic acid in milk from organically raised animals. However, the variation in outcomes of comparative studies is very high, depending on plant fertilization, ripening stage and plant age at harvest, and weather conditions. Moreover, there appeared no simple relationship between nutritional value and health effects. It is difficult therefore to draw conclusions from analytical data about the health effects of organic foods. Some *in vitro* studies comparing health-related properties of organic vs conventional foods showed higher antioxidative and antimutagenic activity as well as better inhibition of cancer cell proliferation of organically produced food. If 'health effects' are defined as effects on defined diseases in humans, evidence for such effects is presently lacking. Animal studies carried out so far have demonstrated positive effects of an organic diet on weight, growth, fertility indices and immune system. Recent human epidemiological studies associated consumption of organic foods with lower risks of allergies, whereas findings of human intervention studies were still ambiguous. The hypothesis might be that organic food increases the capacity of living organisms towards resilience. To confirm this, effect studies on specific markers for health are necessary.

Contents

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doi:10.1016/j.njas.2011.01.004

1. Introduction

Consumer studies continue to show that expectations concerning health effects of organic food are about the strongest motives for consumers to buy organic products, and research results on this topic can count on high societal interest [1–3]. However, until now these expectations lack sound scientific proof [4]. Different kinds of research are being performed to investigate the health value of organic products compared with conventionally produced products. An increasing number of studies are being published, including studies comparing the contents of ingredients of products from conventional and organic production systems, as well as review studies. Apart from this, a much smaller number of studies have been published on effects of organic food consumption. These include animal and human studies on bioavailability and health effects, *in vitro* studies comparing effects of organic and conventional products on different parameters in the laboratory. In this paper an overview of recent studies on the topic is given, with a framework for estimating the scientific value of these studies. In addition, the problems connected with the different approaches are being discussed. A hypothesis is presented about the possible health effects that organic products might have, and suggestions are made for future research.

2. Comparative studies on nutritional value

2.1. Plant products

A number of studies have looked at the contents of primary and secondary metabolites of food from different production systems, e.g., organic and conventional systems. The older studies have been reviewed [5,6]. The main conclusion was that organic products had a higher dry matter and lower nitrate content and contained less pesticide residues. Regarding vitamins they concluded that there were trends towards higher vitamin C contents in organic products, while data on mineral content were inconclusive. Since then, over 200 papers concerning nutrient content of organic vs. conventionally produced foods have been published and it is evident that the interest in this field has increased dramatically over the years. However, conclusions since 1997 have not changed as dramatically. In plants, the focus during the last 10 years has been on the contents of vitamin C, carotenoids and phenolic compounds. Various fruits and vegetables have been investigated under different climatic conditions, with different varieties and on different soil types.

In a review paper, Worthington [6] presented a meta-analysis showing that in most studies the level of vitamin C was significantly higher in organically than in conventionally produced plant foods. Also in more recent studies, higher vitamin C contents were found in many organic products, e.g., peaches [7] and tomatoes [8,9], although other studies reported similar or lower contents of vitamin C in organic tomatoes [10], broccoli [11], bell peppers [9], pears and peaches [7]. A higher carotenoid content was found in organically grown sweet peppers, yellow plums, tomatoes and carrots [9,12,13], whereas others [14,15] found lower or similar contents of carotenoids in organically grown blanched carrots and tomatoes. From a study of Barrett et al. [10] it is known that the content of carotenoids may depend on soil type, genotype, as well as the fertilizers and pesticides used. This might explain the inconsistency of the findings in the above-mentioned studies [10].

An increasing number of studies have measured the content of phenolic compounds that might have a chemopreventive role in humans by modulating the cancer cell cycle, inhibiting proliferation and inducing apoptosis. A number of studies have actually shown that the content of phenolic compounds is higher in organic products [7–9,12,16–18], whereas other studies [9,12] have found similar or lower contents of phenolic compounds in organic products.

In most studies comparing conventionally with organically grown cereals, higher levels of proteins and amino acids were found in the conventionally produced grain (reviews by Heaton [20], Worthington [6] and Benbrook et al. [21], and recent studies [22]). The higher N-fertilization rate in conventional production systems is very likely to explain this difference. Some studies also observed that the quality of the amino acids was higher in the organic products than in the conventional products, meaning that more essential amino acids were available in the organic grains. These latter findings were not confirmed in other studies [22,23]. Apart from the described potentially beneficial components, conclusions can be drawn concerning lower amounts of pesticide residues [24,25], nitrates [26,27] and equal or lower amounts of mycotoxins [25,28] in organic crops.

2.2. Animal products

Also in animal products differences between organic and conventional production systems have been observed. Milk studies from the Netherlands, UK, Denmark and the USA have shown that milk from organically raised animals has higher contents of n-3 linolenic acids and conjugated linoleic acid (CLA) compared with milk from conventional systems [29,30]. Such differences with conventionally raised animals are observed especially in summertime, when the organically raised animals have their outdoor grazing facilities. A recent study from the UK showed that milk from low-input systems, both organic and non-organic, has higher contents of n-3 linolenic acid and CLA, although the highest contents were found in the non-organic low-input system. Outdoor grazing, a high biodiversity in pastures, low levels of concentrates and no silage feeding were found to be predominant factors for beneficial milk fatty acids composition [31].

Most recent are two review papers from the French and the British Food Standard Agencies, both of which published in the summer of 2009, but presenting quite different results [32,33]. The French AFSSA paper [32] mentions the earlier described results of a

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higher dry matter content, more minerals (Fe, Mg) and more antioxidants like phenols and salicylic acid in organic plant products, as well as more polyunsaturated fatty acids in organic animal products, apart from less nitrate in 50% of the products, 94–100% of the products without pesticide residues and equal amounts of mycotoxins. The British FSA paper [33] describes a systematic review of 50 years of publications, with strict inclusion criteria, and mentions more phosphorus and acidity and fewer nitrates in organic products, but no other differences. However, the review did not consider most of the studies presenting data of well-controlled field trials. Contaminant contents were not included in the review paper. The latter paper has given rise to a fierce debate concerning the in- and exclusion criteria, which is still ongoing at the moment the present paper was submitted.

3. Translation of compositional information to impact on human health

Comparative studies on chemical composition of food products from organic and conventional production systems are valuable and may provide indications for possible health effects. However, it should be recognized that hypotheses about effects of compounds are often revised. Considering that plant physiologists estimate the plant world to contain up to 75,000 or even 100,000 different compounds, or 7500–10,000 per plant, that act synergistically in the plant organism, it becomes clear that even advanced methods, like in systems biology that analyse hundreds or even thousands of compounds, only portray the top of the iceberg of plant chemistry. Let alone the interaction between such a complex food product and the likewise complex organism of the consumer. The first clear complicating factor is the way in which compounds are resorbed by an organism, measured as bioavailability. Secondly, it is not predictable how the consuming organism will react biologically to a food product, as this depends on individual constitutional differences, as well as the actual health status. And in real life, products are integrated in a food matrix, with chemical interactions between products. This complicates the question about hypothesized effects even more. So some reticence in speculations about effects based on analytical outcomes is due here. This is why studies that measure factual effects of food products are more informative, although not simple. Some approaches will be described, with a framework for estimating the scientific value of these study designs.

4. Types of studies analysing the effects of organic products

4.1. Intervention studies

Societal interest in health effects of organic products comes from consumers. Seeking for scientific proof to answer the inquiries of this group, studies among humans are most convincing, especially so-called 'intervention studies'. In this study design as many factors as possible need to be controlled for a group of people (as so many factors other than nutrition do affect people's health and well-being) and only the food under study is clearly varied in order to make possible effects become visible. So either a set-up needs to be created where a group of people is brought voluntarily into a controlled situation, or special situations need to be found where groups of people live daily under the same conditions and in the same routine, like children's homes, monasteries or prisons. In such a controlled situation ideally two matched groups should consume parallel either organically or conventionally grown food, blinded. Or a 'cross-over' situation is created where the different test foods are presented, one after the other with sufficient time in between. Health effects will be measured using 'biomarkers', identified as reliable reflection measurements for a person's health status, and that can in such a study design be measured in all study objects at the same moment. The choice of food products and the way in which they are presented are factors to take into consideration. This point will be touched upon later.

4.2. Observational studies

Another way to study health effects in humans are the so-called observational or epidemiological studies, where a large group of people is studied using questionnaires usually supplemented with some measurements in a smaller part of the group. Control is much less as people themselves report. Investigations can look back at eating habits in the past, being 'retrospective', or follow a group from a certain moment into the future, being 'prospective'. Questions need to address many more factors than food, e.g., life-style factors and social status, to be able to rule out confounding. So a large group of people needs to be included in the study.

4.3. Intervention studies in animals

As highly controlled blinded human dietary intervention studies, especially if intended to examine long-term physiological responses, are very expensive and difficult to realize, health effects of foods are usually tested in animal models. Similar to human intervention studies, in such experiments laboratory animals such as rats, mice, chickens and rabbits are fed organically or conventionally grown feeds, and selected physiological parameters reflecting measurements of health status are analysed. By choosing genetically homogenous populations of animals and keeping them under highly controlled conditions it is easier to point out health effects of a diet. Moreover, the short life cycle of animals allows examining effects of diets on more than one generation. Systematic reviews of such animal studies can give indications of possible health effects, though differences between animals and men need to be taken into account. Final confirmations of hypothesized effects need eventually to be verified in humans.

4.4. In vitro studies

The so-called *in vivo* studies, referring to experimentation using a whole, living organism, are often substituted/preceded by low-cost *in vitro* experiments. This type of research aims at describing the effects of experimental variables on the organism's constituent parts (e.g., organs, tissue- or cell cultures, cellular components) in a controlled environment outside the organism (test tubes, Petri dishes). *In vitro* studies are highly focused, enabling to deduce mechanisms of actions and to control many confounding variables. However, weakness of this type of studies is the uncertainty that the effects observed at cell level would occur in the 'real world' of the complex living organism.

The scientific value of different study designs concerning the comparison of organically and conventionally produced food is presented in Table 1.

5. Recent *in vitro* studies

To our knowledge, in recent years, two *in vitro* studies have been published comparing health-related properties of organic vs conventional foods. The first study analysed antioxidative and antimutagenic activity of organically vs conventionally produced green vegetables (qing-gen-cai, Chinese cabbage, spinach, Welsh onion and green pepper) [34]. The authors found antioxidative activity in the organic vegetables to be much higher than that in the conventional ones. Moreover, organic vegetable juices exhibited significantly stronger suppresive effects against mutagens. The second study compared the effects of extracts from organically and

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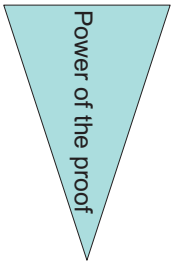
Table 1
Scientific value of different study designs for comparing organically and conventionally produced food, with examples.

Study design	Examples
Intervention studies	Controlled studies in humans
Observational or epidemiological studies	Prospective cohort studies
	Retrospective cohort studies
Intervention studies	Controlled studies in animals
Supportive studies	Bioavailability studies
	In vitro studies



Adapted from GRADE Working Group [60].

conventionally grown strawberries on the proliferation of colon- and breast-cancer cells [35]. The results showed higher antiproliferative activity of extracts from organically grown strawberries on both types of cancer cells, which was probably due to a higher content of secondary metabolites with anticarcinogenic properties in these fruits. These results suggest a possible mechanism by which organic foods could reduce human cancer risks.

6. Recent animal studies

During the last 50 years several animal dietary intervention studies have been carried out investigating the health effects of organic vs conventional feeds [36]. Most of these studies confirmed beneficial effects of organic feeds on development rate and reproductive abilities of laboratory animals [37–39]. Moreover, animal studies published in recent years indicated increased immune parameters in organically fed laboratory animals. In a dietary study with rats, comparing the effects of protein-poor organic and conventional feed Finamore et al. [40] found higher levels of stimulated lymphocyte proliferation in the rats fed organic feed. Lauridsen et al. [41] found higher immune system reactivity in organically fed rats, indicated by the level of IgG in blood serum, as well as a lower amount of fat tissue and more relaxed behaviour. A pilot experiment by Barańska et al. [42] showed higher splenocyte proliferation in male organically fed rats. According to a study performed in the Netherlands [43], chickens fed an organic diet had lower body weights, higher immune reactivity and stronger catch-up growth after a challenge. In this study the concept of 'resilience' was proposed, as to indicate physiological elasticity to come back to homeostasis after a disturbance. Resilience is a well known concept in ecology and psychology [44], and is worth investigating for its value in evaluating physiological effects of organic food products, as these are grown with the aim to be more 'robust' than conventional products.

In summary, animal studies on the health effects of organic vs conventional feeds are sparse. Therefore further, well-planned long-term experiments are necessary to evaluate the overall health status of laboratory animals fed on feeds from different agricultural production systems.

7. Recent studies in humans

7.1. Observational studies

To our knowledge, only a few observational studies investigating the health effects on humans of organic compared with conventional foods have been performed in recent years. According to one of these studies, commonly named the PARSIFAL study (14,000 children, 5 European countries), children representing an anthroposophical lifestyle (including biodynamic and organic food) were found to have less allergies and a (not statistically significant) lower body weight compared with a group consuming conventionally produced foods [45]. At the same time the results of the KOALA Birth Cohort Study in the Netherlands (about 2700 newborns) associated the lower eczema risk in children at the age of 2 years with the consumption of organic dairy products [46]. Moreover, organic dairy consumption resulted in higher CLA levels in breast milk of their mothers [47]. According to a study of Rembiałkowska et al. [48] consumers of organic food assessed their health status significantly better than consumers of non-organic food. However, apart from the organic diet, this might also been related to several aspects of consumers' lifestyle (e.g., nutritional pattern, living conditions, physical activity, ways to manage stress).

As was mentioned above, pesticide residues form part of the dangerous food contaminants known to exert genotoxic, carcinogenic, neuro-destructive, endocrine and allergenic effects, and are usually found in higher contents in conventionally produced plant products. There is scientific evidence that dietary exposure of children to organophosphorus pesticides, measured as the level of pesticide metabolites in urine, is much lower on an organic than on a conventional diet [49]. It can be concluded that consumption of organic foods provides protection against exposure to organophosphorus pesticides commonly used in agricultural practices [50].

7.2. Intervention studies

As several authors have stated previously, interpretation of the results from comparing organic and conventional foods is extremely difficult due to differences in methodologies related to the use of different varieties, growing conditions and sampling procedures. Furthermore, the contents of nutrients and secondary metabolites in the plants cannot be directly related to a potential health effect. First of all, the contents of primary and secondary metabolites in food do not give any indication of how much they are actually absorbed, as the absorption depends on a number of factors, such as the amount of promoters and inhibitors available in the food, as well as the food matrix itself. In order to obtain more information on uptake of valuable compounds, studies on bioavailability and effects on specific markers for health are necessary.

To our knowledge only six human dietary controlled intervention studies comparing organic and conventional foods have been done. Two of these were small single-meal studies comparing the effects of organic and conventional apples or red wine consumption [19,51]. In both studies the postprandial effect on biomarkers for redox-processes was measured. Neither study found any difference in redox markers between the organic and conventional products.

In two other studies, volunteers were given either organically or conventionally produced carrots or tomato purée in addition to an otherwise habitual diet for 2–3 weeks [8,15]. In the first study [15] no effect of the particular diets on basic haematological parameters,

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vitamin C and E in plasma, or LDL oxidation was observed. Carrot consumption had also no effect on the antioxidant status of plasma. However, plasma lutein increased significantly in the group consuming organic carrots. In the second study, in which volunteers were fed organically or conventionally produced tomato purée for three weeks in a parallel design, no differences in bioavailability of lycopene, β-carotene or vitamin C between organic and conventional tomato purée were observed [8]. The reason for the lack of differences between groups consuming organic or conventional carrots and tomato purée could be that the products tested were given in addition to a habitual diet, which could have diluted any effect that there might have been between the production methods. In order to assure that such a dilution does not appear, fully controlled dietary studies are needed. Only two such studies have been done so far [52,53].

A small and very poorly described Italian study intended to compare the effects of an organic vs a conventional Mediterranean diet given to 10 healthy men for 2 weeks. According to the results, the plasma antioxidant status following the organic diet appeared to be higher than following the conventional diet. As no standard deviations were given it is not possible to conclude whether or not the difference was statistically significant. Furthermore, it looked as if the study was not randomized, which means that the observed effect might be due to later harvesting so that more mature products were used in the second period of the study. In the same study, antioxidant activity was measured in a number of fruits and vegetables, and in wine and milk. In the majority of these products the activity was highest in the organic products [52].

The other study was a fully controlled dietary intervention with organic or conventional diets fed to 16 male and female volunteers in a randomized cross over design for 2×3 weeks [53]. The study aimed at a comparison of the intake and excretion of selected flavonoids, and the plasma levels of known oxidative defence markers in both groups of volunteers. The organic diet resulted in higher urinary excretion of quercetin and kaempherol, while no difference was observed between the diets in respect of the excretion of other analysed flavonoids. Most markers of antioxidative defense did not differ between the diets. However, intake of an organic diet resulted in an increased protein oxidation and a decreased total plasma antioxidant capacity compared with the conventional diet. In this study the vegetables were collected by one distributor from established organic and conventional producers within similar geographical locations. However, for some of the products the producers used different crop varieties so that it cannot be concluded whether the observed differences in the human intervention study were due to the differences in varieties as part of the production method or to differences in production method.

8. Discussion

The overall number of studies comparing the nutritional value of organic vs. conventional foods is growing. There also is an increasing interest in investigating the health effects of organic food consumption. Results of comparative studies, as well as *in vitro* analyses, animal intervention trials and human observations are promising. However, the results are still insufficient to formulate explicit conclusions.

One problem is the variation in outcomes of comparative studies, which is very high depending mainly on crop fertilization, ripening stage and plant age at harvest, and weather conditions. First, the amount of fertilizer used differs largely between conventional and organic production [54]. Second, also the type of fertilizer is of influence, being either quickly available nitrate in inorganic fertilizer, or slowly available nitrate in organic fertilizer. Generally, large amounts of fertilizer enhance vegetative growth and the connected formation of primary nutrients, like proteins and carbohydrates, while the generative growth of these plants and connected formation of secondary metabolites, like polyphenols and vitamins, can become inhibited [55]. The ripening stage and the age of a plant at harvest also influences the amount of desired compounds. As the generative stage follows naturally the vegetative stage, a harvest at too an early stage might result in sturdy well transportable products that at the same time have low contents of compounds that are desirable (health promoting, and bringing colour, taste and smell). It is questionable if artificial ripening through ethylene brings about the same quality of ripening as when the ripening takes place on the plant under influence of the sun. Weather is another important factor strongly influencing the composition of plant products. Observed year-to-year variation due to weather conditions is often larger than the differences between production systems [55,56,57].

The lack of a straightforward relationship between nutritional value and health is another reason why it has been difficult so far to draw conclusions from comparative studies on the health effects of organic foods. As the bioavailability of chemicals is limited and can be affected by numerous factors, the contents of nutrients and secondary metabolites in plants cannot give straightforward indications of their health effect.

When intervention studies on health effects are performed several choices concerning the consumed food products need to be made. Least preferable are random market samples, as no indication about production conditions is available [58]. Products from controlled trials have the advantage of the control. However, they lack the embeddedness in a complete farming system, which for organic products might be a disadvantage. Another possibility is the use of products from 'best-practice farm-pairs', a conventional and neighbouring organic farm. Choice for the same or acceptance of different varieties is also a point of discussion. It can be argued that the same crop variety (or animal breeds) should be used in order to avoid an important factor of variability, as it is known that different crop varieties can contain quite different contents of the same nutritive substances. It can, however, also be argued that organically managed soils are so different that adapted varieties are needed with different root systems. That implies that each production method should use its own varieties. A last choice is if analytical differences in feeds observed are accepted as being typical characteristics of these feeds inherent to the production system where they originate from, or that it is necessary to compensate for those differences in order to allow research to identify (possible) differences other than those at macro nutrient content level. A factor of discussion in health effect studies is the choice of health outcomes that are considered relevant for conclusions. Recently the systematic review of the FSA [59] took 'health outcomes' as effects on defined diseases in humans and concluded that evidence for health effects is lacking. It is questionable if foods from different production systems will have such 'strong' effects of influencing existing pathologies, while yet possibly still support health.

On the basis of the experiments done so far a hypothesis might be: 'organic food consumption may increase the capacity of living organisms towards resilience'. However, to confirm this statement it is necessary to perform more effect studies on specific health markers.

9. Towards the future

With the information gathered in the studies thus far, indications have been found of potential health effects of organic food for humans. To further elucidate this relationship, future studies need to be performed in several areas.

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9.1. Comparative studies on nutritional value

Compositional data from studies comparing organically with conventionally produced products are important mainly to obtain more insight into the relation between cultivation practices and nutritional content. This will enable the production of best quality products. As already mentioned above, the relationship between the nutritional value of a product and health is difficult to predict and we therefore suggest putting the focus of future research more on studies in animals and humans. For such studies it will be important to define markers, e.g., fingerprints or other for representative organic food products.

9.2. Intervention studies

To study the effects of a specific food or a diet on health, intervention studies can be done in animals as well as in humans. For such studies only best quality products from the production systems are to be used to ensure good research on the potential impact of the organic food. The hypothesis of the possible increase in the capacity of resilience as a result of organic food consumption should be studied using challenges. For the studies in humans it is important to define specific biomarkers for expected effects from representative food products.

9.3. Observational studies

Big population studies in humans are important to confirm health effects within a large population. Such studies might show unexpected relationships that cannot be investigated with intervention studies because of the time frame and logistics. As long as biomarkers do not give clear answers and the lag time before observable health effects occur is too long, observational studies can fill this gap. It is efficient to attach the organic question to big, already ongoing studies.

9.4. In vitro models

Development of *in vitro* models could be valuable to elaborate mechanisms by which organically produced foods might influence the health status.

Acknowledgement

We gratefully acknowledge funding from the European Community financial participation under the Sixth Framework Programme for Research, Technological Development and Demonstration Activities, for the Integrated Project QUALITYLOWINPUTFOOD, FP6-FOOD-CT-2003-506358.

References

[1] M. Wier, L.M. Anderson, Demand for organic foods—attitudes, values and purchasing behaviors, Newslett. Danish Res. Center Farm. 2 (2003) 1–3.
[2] M.-F. Chen, Consumer attitudes and purchase intentions in relation to organic foods in Taiwan: moderating effects of food-related personality traits, Food Qual. Prefer. 18 (2007) 1008–1021.
[3] S. Zakowska-Biemans, Consumers values and motives regarding organic food products in Poland, in: Proceedings of the 2nd Scientific Conference of the International Society of Organic Agriculture Research ISOFAR, vol. 2, Modena, Italy, June 18–20, 2008, pp. 506–509.
[4] M. Kristensen, L.F. Østergaard, U. Halekoh, H. Jørgensen, Ch. Lauridsen, K. Brandt, S. Bügel, Effect of plant cultivation methods on content of major and trace elements in foodstuffs and retention in rats, J. Sci. Food Agric. 88 (2008) 2161–2172.
[5] K. Woese, D. Lange, C. Boess, K.W. Bogl, A comparison of organically and conventionally grown foods—results of a review of the relevant literature, J. Sci. Food Agric. 74 (1997) 281–293.
[6] V. Worthington, Nutritional quality of organic versus conventional fruits, vegetables, and grains, J. Altern. Complement. Med. 7 (2001) 161–173.
[7] M. Carbonaro, M. Mattera, S. Nicoli, P. Bergamo, M. Cappelloni, Modulation of antioxidant compounds in organic vs. conventional fruit (peach, Prunus persica L., and pear, Pyrus communis L.), J. Agric. Food Chem. 50 (2002) 5458–5462.
[8] C. Caris-Veyrat, M.J. Amiot, V. Tyssandier, D. Grasselly, M. Buret, M. Mikolajczak, Influence of organic versus conventional agricultural practice on the antioxidant microconstituent content of tomatoes and derived purees: consequences on antioxidant plasma status in humans, J. Agric. Food Chem. 52 (2004) 6503–6509.
[9] A.W. Chassy, L. Bui, E.N.C. Renaud, M. Van Horn, A.E. Mitchell, Three-year comparison of the content of antioxidant microconstituents and several quality characteristics in organic and conventionally managed tomatoes and bell peppers, J. Agric. Food Chem. 54 (2006) 8244–8252.
[10] D.M. Barrett, C. Weakley, J.V. Diaz, M. Watnik, Qualitative and nutritional differences in processing tomatoes grown under commercially organic and conventional production systems, J. Food Sci. 72 (2007) 441–450.
[11] S.M. Wunderlich, C. Feldman, S. Kane, T. Hazhin, Nutritional quality of organic, conventional, and seasonally grown broccoli using vitamin C as a marker, Int. J. Food Sci. Nutr. 59 (2008) 34–45.
[12] G. Lombardi-Boccia, M. Lucarini, S. Lanzi, A. Aguzzi, M. Cappelloni, Nutrients and antioxidant molecules in yellow plums (Prunus domestica L.) from conventional and organic productions: a comparative study, J. Agric. Food Chem. 52 (2004) 90–94.
[13] A.J. Pérez-López, J.M. López-Nicolas, E. Núnez-Delicado, F.M. Amor, A.A. Carbonell-Barrachina, Effects of agricultural practices on color, carotenoids composition, and minerals contents of sweet peppers, cv. Almuden, J. Agric. Food Chem. 55 (2007) 8158–8164.
[14] F. Rossi, F. Godani, T. Bertuzzi, M. Trevisan, F. Ferrari, S. Gatti, Health-promoting substances and heavy metal content in tomatoes grown with different farming techniques, Eur. J. Nutr. 47 (2008) 266–272.
[15] B.A. Stracke, C.E. Rüfer, A. Bub, K. Briviba, S. Seifert, C. Kunz, B. Watzl, Bioavailability and nutritional effects of carotenoids from organically and conventionally produced carrots in healthy men, Br. J. Nutr. 20 (2008) 1–9.
[16] J.E. Young, X. Zhao, E.E. Carey, R. Welti, S. Yang, W. Wang, Phytochemical phenolics in organically grown vegetables, Mol. Nutr. Food Res. 49 (2005) 1136–1142.
[17] A.E. Mitchell, Y.J. Hong, E. Koh, D.M. Barrett, D.E. Bryant, R.F. Denison, S. Kaffka, Ten-year comparison of the influence of organic and conventional crop management practices on the content of flavonoids in tomatoes, J. Agric. Food Chem. 55 (2007) 6154–6159.
[18] S.Y. Wang, C.T. Chen, W. Sciarappa, C.Y. Wang, M.J. Camp, Fruit quality, antioxidant capacity, and flavonoid content of organically and conventionally grown blueberries, J. Agric. Food Chem. 56 (2008) 5788–5794.
[19] K. Briviba, B.A. Stracke, C.E. Ruefer, B. Watzl, F.P. Weibel, A. Bub, Effect of consumption of organically and conventionally produced apples on antioxidant activity and DNA damage in humans, J. Agric. Food Chem. 55 (2007) 7716–7721.
[20] S. Heaton, Organic Farming, Food Quality and Human Health. Soil Association Report, Bristol, UK, 2001, p. 87.
[21] Ch. Benbrook, X. Zhao, J. Yanez, N. Davies, P. Andrews, New evidence confirms the nutritional superiority of plant-based organic foods, State Sci. Rev. (2008), www.organic-center.org.
[22] P. Maeder, D. Hahn, D. Dubois, L. Gunst, T. Alföldi, H. Bergmann, M. Oehme, R. Amado, H. Schneider, U. Graf, A. Velimirov, A. Fließbach, U. Niggli, Wheat quality in organic and conventional farming: results of a 21 year field experiment, J. Sci. Food Agric. 87 (2007) 1826–1835.
[23] C. Zörb, G. Langenkämper, T. Betsche, K. Niehaus, A. Barsch, Metabolite profiling of wheat grains (Triticum aestivum L.) from organic and conventional agriculture, J. Agric. Food Chem. 54 (2006) 8301–8306.
[24] L. Pussemier, Y. Larondelle, C. Van Peteghem, A. Huyghebaert, Chemical safety of conventionally and organically produced foodstuffs: a tentative comparison under Belgian conditions, Food Control 17 (2006) 14–21.
[25] L.A.P. Hoogenboom, J.G. Bokhorst, M.D. Northolt, L.P.L. van de Vijver, N.J.G. Broex, D.J. Mevius, J.A.C. Meijs, J. Van der Roest, Contaminants and micro organisms in Dutch organic food products: a comparison with conventional products, Food Addit. Contam. 25 (2008) 1197–1209.
[26] J. Hajslova, V. Schulzova, P. Slanina, K. Janne, K.E. Hellenas, Ch. Andersson, Quality of organically and conventionally grown potatoes: four-year study of micronutrients, metals, secondary metabolites, enzymic browning and organoleptic properties, Food Addit. Contam. 22 (2005) 514–534.
[27] T.R. Abu-Zahra, K. Al-Ismail, F. Shatat, Effect of organic and conventional systems on fruit quality of strawberry (fragaria × ananassa duch) grown under plastic house conditions in the Jordan Valley, Acta Hortic. (ISHS) 741 (2007) 159–171.
[28] I. Schneweis, K. Meyer, M. Ritzmann, P. Hoffmann, P. Dempfle, J. Bauer, Influence of organically or conventionally produced wheat on health, performance and mycotoxin residues in tissues and bile of growing pigs, Arch. Anim. Nutr. 59 (2005) 155–163.
[29] J. Bloksma, R. Adriaansen-Tennekes, M. Huber, L.P.L. van de Vijver, T. Baars, J. de Wit, Comparison of organic and conventional raw milk quality in the Netherlands, Biol. Agric. Hortic. 26 (2008) 69–83.
[30] G. Butler, J.H. Nielsen, T. Slots, C. Seal, M.D. Eyre, R. Sanderson, C. Leifert, Fatty acid and fat-soluble antioxidant concentrations in milk from high- and low-input conventional and organic systems: seasonal variation, J. Sci. Food Agric. 88 (2008) 1431–1441.
[31] D. Kusche, Organic milk and nutritional benefits for the consumer, Org. Food Qual. Health Newslett. (March) (2009), Edition No. 1/2009.

Please cite this article in press as: M. Huber, et al., Organic food and impact on human health: Assessing the *status quo* and prospects of research, NJAS - Wageningen J. Life Sci. (2011), doi:10.1016/j.njas.2011.01.004

[32] D. Lairon, Nutritional quality and safety of organic food. A review, Agron. Sustain. Dev. (2009), Epub. www.agronomy-journal.org.
[33] A. Dangour, S.K. Dodhia, A. Hayter, E. Allen, K. Lock, R. Uauy, Nutritional quality of organic foods: a systematic review, Am. J. Clin. Nutr. 90 (2009) 680–685.
[34] H. Ren, H. Endo, T. Hayashi, Antioxidative and antimutagenic activities and polyphenol content of pesticide-free and organically cultivated green vegetables using water-soluble chitosan as a soil modifier and leaf surface spray, J. Sci. Food Agric. 81 (2001) 1426–1432.
[35] M.E. Olsson, C.S. Andersson, S. Oredsson, R.H. Berglund, K.E. Gustavsson, Antioxidant levels and inhibition of cancer cell proliferation in vitro by extracts from organically and conventionally cultivated strawberries, J. Agric. Food Chem. 54 (2006) 1248–1255.
[36] A. Velimirov, M. Huber, C. Lauridsen, E. Rembialkowska, K. Seidel, S. Bügel, Feeding trials in organic food quality and health research, J. Sci. Food Agric. 90 (2010) 175–182.
[37] D. Staiger, The influence of conventional vs. organic fodder on fertility, health condition and quality of rabbit meat, M.Sc. Thesis, University of Bonn, Germany, 1986, pp. 35–61.
[38] K. Plochberger, Feeding experiments. A criterion for quality estimation of biologically and conventionally produced foods, Agric. Ecosyst. Environ. 17 (1989) 419–428.
[39] A. Velimirov, K. Plochberger, U. Huspeka, W. Schott, The influence of biologically and conventionally cultivated food on the fertility of rats, Biol. Agric. Hortic. 8 (1992) 325–337.
[40] A. Finamore, M.S. Britti, M. Roselli, D. Bellovino, S. Gaetani, E. Mengheri, Novel approach for food safety evaluation. Results of a pilot experiment to evaluate organic and conventional foods, J. Agric. Food Chem. 52 (2004) 7425–7431.
[41] C. Lauridsen, H. Jorgensen, U. Halekon, Ch. Lars-Porskjer, K. Brandt, Organic diet enhanced the health of rats, Newslett. Danish Res. Centre Org. Farm. 1 (2005) 2–11.
[42] A. Barańska, K. Skwarło-Sońta, E. Rembiałkowska, K. Brandt, L. Lueck, C. Leifert, The effect of short term feeding with organic and conventional diets on selected immune parameters in rats, in: Materials of the Congress: "Improving Sustainability in Organic and Low Input Food Production Systems", University of Hohenheim, Germany, 20–23 March, 2007, pp. 59–70.
[43] M. Huber, L.P.L. van de Vijver, H. Parmentier, H. Savelkoul, L. Coulier, S. Wopereis, E. Verheij, J. van der Greef, D. Nierop, R.A.P. Hoogenboom, Effects of organically and conventionally produced feed on biomarkers of health in a chicken model, Br. J. Nutr. 103 (2010) 663–676.
[44] M. Earvolino-Ramirez, Resilience, a concept analysis, Nurs. Forum 42 (2007) 73–82.
[45] T. Alfven, C. Braun-Fahrlander, B. Brunekreef, E. von Mutius, J. Riedler, A. Scheynius, M. van Hage, M. Wickman, M.R. Benz, J. Budde, K.B. Michels, D. Schram, E. Ublagger, M. Waser, G. Pershagen, Allergic diseases and atopic sensitization in children related to farming and anthroposophic lifestyle—the PARSIFAL study, Allergy 61 (2006) 414–421.
[46] I. Kummeling, C. Thijs, M. Huber, L.P. van de Vijver, B.E. Snijders, J. Penders, F. Stelma, R. van Ree, P.A. van den Brandt, P.C. Dagnelie, Consumption of organic foods and risk of atopic disease during the first 2 years of life in the Netherlands, Br. J. Nutr. 99 (2008) 598–605.
[47] L. Rist, A. Mueller, C. Barthel, B. Snijders, M. Jansen, A.P. Simões-Wüst, M. Huber, I. Kummeling, U. von Mandach, H. Steinhart, C. Thijs, Influence of organic diet on the amount of conjugated linoleic acids in breast milk of lactating women in the Netherlands, Br. J. Nutr. 97 (2007) 735–743.
[48] E. Rembiałkowska, R. Kazimierczak, D. Średnicka, K. Bieńko, M. Bielska, Different aspects of organic and conventional food consumers lifestyle, New Med. 1 (2008) 16–19.
[49] C.L. Curl, R.A. Fenske, K. Elgethun, Organophosphorus pesticide exposure of urban and suburban preschool children with organic and conventional diets, Environ. Health Perspect. 111 (2003) 377–382.
[50] Ch. Lu, K. Toepel, R. Irish, R.A. Fenske, D.B. Barr, R. Bravo, Organic diets significantly lower children's dietary exposure to organophosphorus pesticides, Environ. Health Perspect. 114 (2006) 260–263.
[51] Y.D. Akcay, H.K. Yildirim, U. Guvenc, E.Y. Sozmen, The effects of consumption of organic and nonorganic red wine on low-density lipoprotein oxidation and antioxidant capacity in humans, Nutr. Res. 24 (2004) 541–554.
[52] L. Di Renzo, D. Di Pierro, M. Bigioni, V. Sodi, F. Galvano, R. Cianci, Is antioxidant plasma status in humans a consequence of the antioxidant food content influence? Eur. Rev. Med. Pharmacol. Sci. (2007) 185–192.
[53] L. Grinder-Pedersen, S.E. Rasmussen, S. Bugel, L.V. Jorgensen, L.O. Dragsted, V. Gundersen, B. Sandstrom, Effect of diets based on foods from conventional versus organic production on intake and excretion of flavonoids and markers of antioxidative defense in humans, J. Agric. Food Chem. 51 (2003) 5671–5676.
[54] J. Cooper, U. Niggli, C. Leifert, Handbook of Organic Food Quality and Safety, Woodhouse Publishing Ltd., Cambridge, UK, 2007.
[55] K. Brandt, J.P. Moolgaard, Organic agriculture: does it enhance or reduce nutritional value of plant foods, J. Sci. Food Agric. 81 (2001) 924–931.
[56] A.W. Chassy, L. Bui, E.N.C. Renoud, M. Van Horn, A.E. Mitchell, Three-year comparison of the content of antioxidant microconstituents and several quality characteristics in organic and conventionally managed tomatoes and bell peppers, J. Agric. Food Chem. 54 (2006) 8244–8252.
[57] H. Jørgensen, K. Brandt, C. Lauridsen, Year rather than farming system influences protein utilization and energy value of vegetables when measured in a rat model, Nutr. Res. 28 (2008) 866–878.
[58] F.R. Harker, Organic food claims cannot be substantiated through testing of samples intercepted in the marketplace: a horticulturalist's opinion, Food Qual. Prefer. 1 (2004) 91–95.
[59] A. Dangour, K. Lock, A. Hayter, A. Aikenhead, E. Allen, R. Uauy, Nutrition-related health effects of organic foods: a systematic review, Am. J. Clin. Nutr. 92 (2010) 203–210.
[60] Grades of Recommendation Assessment, Development and Evaluation (GRADE) Working Group, corresponding author A.D. Oxman, Education and debate, grading quality of evidence and strength of recommendations, BMJ 328 (2004) 1490.

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