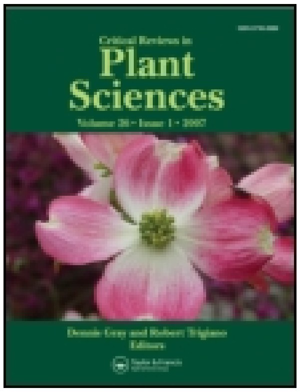

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Agroecosystem Management and Nutritional Quality of Plant Foods: The Case of Organic Fruits and Vegetables

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Agroecosystem Management and Nutritional Quality of Plant Foods: The Case of Organic Fruits and Vegetables

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Organic and conventional crop management systems differ in terms of the fertilisers and plant protection methods used. Ecological and agronomic research on the effect of fertilization on plant composition shows that increasing availability of plant available nitrogen reduces the accumulation of defense-related secondary metabolites and vitamin C, while the contents of secondary metabolites such as carotenes that are not involved in defense against diseases and pests may increase. In relation to human health, increased intake of fruits and vegetables is linked to reduced risk

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of cancer and cardiovascular disease. This benefit may be primarily due to their content of defense-related secondary metabolites, since most other constituents of fruits and vegetables either are not unique to these foods or have been shown to not provide health benefits when the intake is increased. A meta-analysis of the published comparisons of the content of secondary metabolites and vitamins in organically and conventionally produced fruits and vegetables showed that in organic produce the content of secondary metabolites is 12% higher than in corresponding conventional samples ($P < 0.0001$). This overall difference spans a large variation among sub-groups of secondary metabolites, from a 16% higher content for defence-related compounds ($P < 0.0001$) to a nonsignificant 2% lower content for carotenoids, while vitamin C showed a 6% higher content ($P = 0.006$). Based on the assumption that increasing the content of biologically active compounds in fruits and vegetables by 12% would be equivalent to increasing the intake of fruits and vegetables by the same 12%, a model developed to calculate the health outcome of increasing the intake of fruits and vegetables was then used to tentatively estimate the potential increase in life expectancy that would be achieved by switching from conventional to organic produce without changing the amount consumed per day, to 17 days for women and 25 days for men.

Keywords Organic food, secondary metabolites, plant defense compounds, health benefits, meta-analysis

I. INTRODUCTION

Consumers buy organic food for a variety of reasons, one of them being an interest to promote their own health (Schifferstein and Ophuis, 1998; Bourn and Prescott, 2002; Magkos *et al.*, 2003; Ekelund and Tjarnemo, 2004; Yiridoe *et al.*, 2005; Dangour *et al.*, 2009). The present paper reviews and analyses the present state of knowledge regarding how organic farming methods affect the content of secondary metabolites and vitamins in fruits and vegetables compared with the methods used in conventional agriculture, and how this may affect the health of consumers, in particular as regards the risk of cancer and cardiovascular disease.

A. Definition of Organic and Conventional Farming in the Present Context

The basic principles of organic agriculture are 'health, ecology, fairness, and care' (IFOAM, 2005). In many countries the procedures and inputs allowed in agriculture to produce foods labelled as organic are defined by law, including since 1991 the EU (Council Regulation (EC) No. 834/2007 (succeeding Council Regulation (EEC) 2092/91) (European Commission, 2007)), and since 2002 the USA (The National Organic Program (NOP)(USDA, 2009)). Regarding fruits and vegetables, the legal standards ban or limit the use of synthetic pesticides, fertilisers and other nonorganic inputs and define maximum allowed use of organic fertilizer, and if products are offered for sale to the public, the producer must be certified by an approved certifying body. Within organic agriculture each organisztion may then define standards for its members that go further than the legal requirements. For example, some producers adhere to biodynamic principles, which aim to 'revitalise nature, grow nourishing food and advance the physical and spiritual health of humanity' (Biodynamic Agricultural Association, 2009).

For nonorganic agriculture, Integrated Pest Management (IPM), Integrated Crop Management (ICM) and similar regulated systems define their aims as to "coordinate the use of pest biology, environmental information, and available technology to prevent unacceptable levels of pest damage by the most economical means, while posing the least possible risk to people, property, resources, and the environment" (Anonymous, 2004), while, by default, conventional agriculture aims to maximize the return on investment within the conditions set by environment protection legislation and customer specifications. Often these goals are not mutually exclusive, so while the minimum standards for each system are similar across the world, the differences in actual practices between production systems can vary substantially in different regions. In Europe and the United States, most fruits and vegetables are produced using IPM/ICM systems, operated by supermarket chains, producer cooperatives or other organisations [e.g., Assured Produce (2008), EUREPGAP (2004)].

II. EFFECT OF PRODUCTION METHOD ON COMPOSITION OF PLANT PRODUCTS

The composition of a fruit or vegetable is known to depend on a wide range of genetic and environmental factors, many of which, such as climate, ozone pollution and maturity at harvest, are independent of the production system (Gobbo-Neto and Lopes, 2007). Only factors that differ systematically between organic and conventional farming have the potential to cause a systematic difference in product composition. Such factors must depend directly or indirectly on aspects that are universally specified in the rules and regulations defining organic farming. The two groups of basic aspects that differ systematically between organic and conventional farming systems are: 1. restrictions on the use of synthetic pesticides, and 2. restrictions on the type and intensity of fertilization.

Restrictions on pesticides has the direct effect of reducing the content in organic products of residues of pesticides that are allowed in conventional farming (Lairon, 2010). Those same restrictions also indirectly affect variety choices, since organic farmers will put more emphasis on genetic resistance when choosing plant varieties than corresponding conventional farmers. Highly resistant varieties tend to have relatively high contents of defense-related secondary metabolites (Sanford *et al.*, 1992; Leiss *et al.*, 2009), so if they are overrepresented among the organic produce on the market, as indicated by some studies on apples (Veberic *et al.*, 2005), it might affect the overall plant food composition. This hypothesis would be relatively easy to test, however, the authors are not aware of any research surveys or other studies that have addressed it directly.

Restrictions on fertilizers directly result in a lower nitrogen content in organic plant products compared with corresponding conventional ones. In some cases, most commonly in cereals, the nitrogen content is presented as 'protein,' based on the assumption that the protein content is directly proportional to the nitrogen content. This is however not always the case, particularly not in vegetables where a proportion of the nitrogen occurs as nitrate. However, the difference in availability of plant available nitrogen also has a range of indirect effects, due to the effect of nitrogen on plant metabolism and physiology, which systematically affect the contents of some vitamins and plant secondary metabolites, as detailed in the following section.

A. Ecological Background for Differences in Composition

Extensive studies, reviewed e.g., by Koricheva *et al.* (1998) and Stamp (2003), have explored how nutrient availability affects secondary metabolism of plants in the context of ecology, the science of the relationships between organisms and their environments. Increased fertilisation with nitrogen (under nitrogen-limited conditions) causes a reduction in the content of phenolic compounds in the leaves, and this reduction has been shown to match models of trade-off between growth and defence (under conditions where no pesticides are used). Under the conditions prevailing in most natural environments, when plants gain access to an increased supply of nutrients, the optimal improvement in fitness is achieved by using these additional resources for increasing the growth rate, rather than for accumulation of phenolic defense compounds (de Jong, 1995).

B. Effects of Fertiliser Dose on Contents of Secondary Metabolites and Vitamins

Experiments with crops exposed to different intensities of fertilization have shown similar effects as in natural environments (Norbaek *et al*., 2003; Gayler *et al*., 2004; Toor *et al*., 2006; Palit *et al*., 2008; Sousa *et al.*, 2008; Flores *et al*., 2009a). Recently, a different line of research has developed 'a systemic approach monitoring the response of plants to withdrawal and/or re-supply of mineral nutrients at the level of transcripts, metabolites and enzyme activities' (Fritz *et al*., 2006; Amtmann and Armengaud, 2009). The results, that removal of N-fertilizer increases the content of phenylpropanoid defencs compounds, but not carotenes, are broadly in line with the plant-level experiments, confirming that they reflect common or even universal patterns of metabolic regulation, probably evolved to provide optimal responses to natural fluctuations in nutrient availability.

Both approaches indicate that in an agricultural context a decrease in nitrogen availability to the plants will result in increased content of phenolic defense compounds, which then increases the resistance of the plants to pests and diseases, although at the cost of a lower growth rate and therefore in a lower yield (Brandt and Molgaard, 2001).

Some authors have also suggested that the absence of protection from pesticides would result in initially higher rates of attack by pests and pathogens in organic plants compared with corresponding conventional ones, triggering the formation of induced defense compounds, which then subsequently protect the plant against diseases or pests (Bourn and Prescott, 2002; Young *et al*., 2005). However, studies into the protein expression profiles of potatoes grown in a factorial long-term experiment set up as part of the Quality Low Input Food project (FP6-FOOD-CT-2003-506358) showed that differences in the tuber composition were mainly linked to differences in fertilisztion rather than crop protection regimes between organic and conventional systems (Lehesranta *et al*., 2007). Approximately 14% of proteins were differentially expressed when potatoes grown under conventional mineral fertilization were compared with potatoes fertilized with composted manure-based organic fertilization regimes in this study. Also in another study where the hypothesis was tested experimentally, by using factorial combinations of organic and conventional fertilizers and pesticide regimes under greenhouse conditions with low pest load, all the differences in content of secondary metabolites were due to the fertiliser treatments, with no effect of the pesticide treatments (Zhao *et al*., 2009).

In the context of conventional agriculture, studies of fertilization doses have rarely included measurements of the contents of secondary metabolites, since most studies of plant composition have focused on nutrients. However Gayler *et al*. (2004) found similar effects as in the ecological studies performed in natural rather than agricultural environments. In contrast many studies show that increased fertilization tends to reduce the contents of ascorbic acid (vitamin C), as reviewed by Lee and Kader (2000) as well as increase the content of beta-carotene (which can be converted into vitamin A) (Mozafar, 1993). For secondary metabolites that are neither nutrients nor defence related, such as colorants or (some) volatiles, only few data on the effect of fertilisation are available, and no clear pattern is described.

Given that yields in organic systems are usually significantly lower than in conventional production, it appears that the yield reduction and changes in composition caused by the restrictions in fertilizer use are directly linked. If so, future improvements in organic production methods (e.g., improved fertilization regimes), which would allow farmers to achieve higher growth rates (yields), may also result in more similar product compositions between organic and conventional products, as suggested by Brandt and Mølgaard (2001) and Benbrook (2007). However, the temporal nutrient release patterns from mineral fertilizers differ significantly from those of organic fertilizers, mainly because macro- and micro-nutrients in organic fertilizzers only become plant available after mineralization by the soil biota (Lambers *et al*., 2009). Contrasting relative availability pattern throughout the growing season may therefore result in differences in composition even at similar yield levels.

III. PLANT FOODS AND CONSUMER HEALTH

A. Research on Organic Foods in Relation to Consumer Health

The studies comparing nutrient content of organic and conventional foods have been extensively reviewed (e.g, Woese *et al*., 1997; Heaton, 2001; Worthington, 2001; Bourn and

Prescott, 2002; Gennaro and Quaglia, 2002; Williams, 2002; Magkos *et al*., 2003; Winter and Davis, 2006; Rembialkowska, 2007; Benbrook *et al*., 2008; Dangour *et al*., 2009; Lairon, 2010).

While most of these reviews described systematic differences in composition, only very few of them attempted any assessment of the relevance of these differences for population health. Compared with conventional high-input production, in cases where there are differences in composition, organic plant foods tend to show higher levels of vitamin C, less nitrate, less total protein, higher levels of plant secondary metabolites (phytochemicals), lower contamination with mycotoxins and pesticide residues and a higher proportion of essential amino acids in the protein. However, it is also emphasized in most reviews that for any one nutrient most studies show no significant differences, and that these differences are not sufficiently consistent to predict the content in a food, based on knowledge about its production system.

Another general observation emphasised in most of the reviews is that many other factors affect the concentrations of all these nutrients, and often by much more than the production system. For example, for most compounds studied the variation from year to year or from variety to variety has much greater effect on the content than whether the plant is grown in an organic or conventional production system. Depending on the context of the review, and on whether it addresses the interests of the individual consumer ('value for money') or the nutritional status of a population, but seemingly irrespective of whether the review was purely qualitative (Woese *et al*., 1997; Bourn and Prescott, 2002; Gennaro and Quaglia, 2002; Williams, 2002; Magkos *et al*., 2003; Winter and Davis, 2006; Lairon, 2010) or included a more or less systematic quantitative element (Heaton, 2001; Worthington, 2001; Rembialkowska, 2007; Benbrook *et al*., 2008; Dangour *et al*., 2009) the range of interpretations of the limited experimental data is remarkably wide, from 'crops are significantly different' (Heaton, 2001) to 'no evidence for a difference' (Dangour *et al*., 2009). In most cases the authors of the reviews then conclude that more studies are needed before it is possible to make any firm conclusions about the potential consequences of any differences for human health.

B. Effects on Health of Fruits and Vegetables and Their Constituents

In developed countries such as the UK, the majority of the population obtain sufficient or more than sufficient amounts of vitamin C, minerals and protein, and if any widespread deficiencies are identified, fortification programs are established to alleviate them (Hoare *et al*., 2004). Of the few people who are deficient in nutrients that are present in substantial amounts in vegetables and fruit, most eat next to nothing of these foods, so these population segments would not benefit from increased concentrations of these nutrients in the produce. The intake survey data are supported by intervention studies with vitamin C and other vitamins and carotenoids common in plants, which show either no effect or an increase in the risk of diseases such as cancer (Gaziano *et al.*, 2009; Lin *et al*., 2009) or cardiovascular disease (Bjelakovic *et al*., 2008).

Still, many studies show negative associations between the intake of fruits and/or vegetables and the risk of cancer (Linseisen *et al*., 2007; Murthy *et al*., 2009) or cardiovascular disease (Dauchet *et al*., 2009), indicating a preventive role of these foods that cannot be explained merely by the supply of vitamins. Such studies form the basis for methods developed to estimate the effect on public health of factors that change the intake of fruits and vegetables (Veerman *et al*., 2006).

In contrast, in low-income populations, mainly in developing countries, vegetables and fruits are important sources of essential vitamins, minerals, and high-quality proteins in short supply in the population's diet, so for them the content of nutrients in vegetables and fruits are important for health (Ali and Tsou, 1997). Vitamin C and vitamin A deficiency are common in some developing countries, and here an increase in concentrations would be beneficial for health. However, we found no studies that compared the vitamin C or beta-carotene contents in organically produced vegetables with the contents in vegetables from the low-input "subsistence" agriculture, which shows crop yields that are lower than on comparable organic farms (Badgley *et al*., 2007), and provides most of the vegetables and fruits that are available for the poorest populations. Due to this, the present review is only discussed in relation to the nutritional situation in more affluent populations, where most of the fruits and vegetables originate from commercial horticultural production.

C. Choice of Topics for More Detailed Analysis

The present review focuses on secondary metabolites and vitamins in fruits and vegetables including herbs. These two relatively well-defined (although partially overlapping) groups of compounds represent a large proportion of all the available data on compositional differences between organic and conventional foods, while for most other groups of compounds, only a few comparable studies are available for each. The secondary metabolites and vitamins are often considered the main beneficial components of vegetables and fruits (Brandt and Mølgaard, 2001; Brandt *et al*., 2004). To some extent this view is deduced by elimination, since for most other nutrients in plants, such as minerals and proteins, fruits and vegetables are not the main dietary sources and therefore they cannot be responsible for the above-mentioned health benefits of this food category. The two other groups of dietary constituents where fruits and vegetables are the primary dietary sources are pesticide residues and nitrate.

Regarding pesticide residues, despite well known harmful effects at elevated exposure levels (Brandt, 2007; Lairon, 2010) to the best of the authors' knowledge, no published studies have shown any unequivocal health benefits nor detrimental effects of the pesticides currently licensed in Europe at the levels normally found in fruits and vegetables, possibly because the benefits of consumption of these foods tend to outweigh potentially negative effects of the pesticide residues in them (Juhler *et al.*, 1999). So even for a very substantial relative difference in content, it would be difficult to estimate any consequences for consumer health.

Regarding nitrate, as mentioned above, the difference in content between organic and conventional produce can be seen as a direct consequence of the restrictions on fertilizer use in organic farming, and is mentioned in most reviews of the topic (Woese *et al.*, 1997; Bourn and Prescott, 2002; Williams, 2002; Magkos *et al.*, 2003; Winter and Davis, 2006). Several reviews have reported estimates of the difference in nitrate content between organic and conventional products: 16% with $P = 0.19$ (Dangour *et al.*, 2009); difference in 14 of 16 studies (Heaton, 2001); approximately 50% (Lairon, 2010); 49% (Rembialkowska, 2007), and 15.1% with $P < 0.0001$ (Worthington, 2001). However, while an increasing number of studies indicate that and how plant-derived nitrate may provide significant benefits for human health (McKnight *et al.*, 1999; Lundberg *et al.*, 2008), quantitative data on consequences for health of the consumer are scarce and controversial, and some data are being published in support of the view of nitrates as a health hazard, e.g., Winter *et al.* (2007), which forms the basis for the present restrictive standards (Santamaria, 2006). Due to this, while acknowledging that the difference in nitrate content exists and is likely to be important for health, the present review will not attempt to address the magnitude of the difference in nitrate content nor the potential impact on human health.

Regarding primary metabolites, such as sugars, simple organic acids, proteins, and minerals, there is very little if any information in the literature on what effect a (modest) difference in intake might have on health. For these compounds there is also no clearly defined background information that would allow predictions of how the differences between the production systems will affect the content in the plants, so it would not be possible to compare any effects on content with the biological mechanism or at least selection pressures involved. As for nitrate, this is something that it might be relevant to return to, once the relevant background knowledge linking intake and health outcomes has been established.

IV. META-ANALYSIS OF DIFFERENCES IN CONTENTS OF SECONDARY METABOLITES AND VITAMINS IN FRUITS AND VEGETABLES

To assess the (potential) effect on consumer health of differences in composition between organic and conventional plant foods, it is necessary to estimate the magnitude of this difference. This can be done using the method of meta-analysis, where data from different studies are combined to improve the ability to detect and quantify effects of systematic factors, irrespective of randomly occurring factors such as climate, soil type, or variety.

A. Methods

Papers were identified through an initial search of the literature using the search terms '(organic* or ecologic* or biodynamic*) and (conventional* or integrated) and (fruit* or vegetable* or strawberr* or apple* or spinach or carrot* or pea* or lettuce or currant* or cherr* or potato* or cabbage* or banana* or tomato*)' with Web of Science, for the period January 1992 – October 2009. This provided 2,512 references, where titles and (if available) abstracts were checked, to extract 84 studies reporting original data of comparisons of vitamins or secondary metabolites of fruits, herbs, and vegetables grown using organic and conventional methods, as well as eight reviews of the topic. Further hand searches of reference lists of reviews and original papers provided 34 additional references. Of these 118 references, 11 were unavailable and five turned out to contain 'duplicate' data from the same experiment and year(s), leaving 102 separate relevant papers. In two cases sets of papers were partial duplicates, where one paper reported the first year of a trial and another paper the average of two or three years.

Each paper was graded for a range of criteria (Tables 1 and 2) to determine their relevance for the study. As recommended by Englund *et al.* (1999), the criteria for inclusion and exclusion were examined critically to avoid unnecessary loss of statistical power due to unconscious bias.

The retained criteria related to the experimental design rather than to the general scientific quality of the paper, although some papers of low general quality still had to be excluded because the method description was not sufficiently detailed to determine all critical aspects of the design. Specifically, conference proceedings and other non-reviewed publications were included with the same weight as articles in peer-reviewed journals, if the description of the experimental design was sufficiently clear and detailed to assess that the design was appropriate. The criteria for inclusion (Table 2) were as recommended by Harker (2004): appropriate experimental treatments; relevance of the organic/conventional practices used; that the same varieties were used in both systems; and that products from both production systems were grown in (approximately) the same location.

Regarding experimental treatments, the description had to be sufficiently detailed to allow assessment of the other criteria; the plant product should be a food or drink or raw material for such products, and if processed, the processing methods should not differ between organic and conventional samples; the sample size and sample preparation should meet minimum standards comparable to the requirements for publication in a low-impact journal, defined as that a sample should contain material from at least three separate plants or five randomly chosen fruits or vegetables, e.g., as a comparable amount of product by weight, and represent all of the edible part of the product (with or without edible peel/skin/pomace if relating to a product that does not necessarily contain these parts), and that the sample preparation should not include steps appearing to severely degrade the compound in question.

TABLE 1
Papers included in the analysis, which all met criteria for inclusion

Reference	Plant species	Number of replications or harvest dates	Number of varieties	Number of years	Type of study design	Documentation of organic treatment: Inputs listed in method description	Documentation of organic treatment: Certification explicitly stated	Documentation of organic treatment: In legally defined context	Sub-type of conventional system	Notes
(Abreu *et al.*, 2007)	Potato	1	2	1	Un-replicated field trial	Yes	No	Yes	Conventional	Data from 'integrated' treatment not used
(Amodio *et al.*, 2007)	Kiwi	1	1	1	On-farm field trial	Yes	Yes	Yes	Conventional	
(Anttonen and Karjalainen, 2006)	Black currant	3	1	1	On-farm field trial	Yes	Yes	Yes	Conventional	
(Anttonen *et al.*, 2006)	Strawberry	2	6	1	On-farm field trial	Yes	Yes	Yes	Conventional	
(Asami *et al.*, 2003)	Marionberry, Sweet corn	1	2	1	Farm pair	Yes	No	Yes	Conventional	Data from 'sustainable' treatment not used
(Barrett *et al.*, 2007)	Tomato	4	1	1	On-farm field trial	Yes	No	Yes	Conventional	
(Beltran-Gonzalez *et al.*, 2008)	Mandarin orange juice	1	1	1	Un-replicated field trial	Yes	No	Yes	Conventional	
(Camin *et al.*, 2007)	Potato	1	1-2	3	Farm pairs	Yes	No	Yes	Integrated pest management	Four pairs in total
(Carbonaro and Mattera, 2001)	Pear, Peach	1	2	1	Un-replicated field trial	No	No	Yes	Conventional	Probably some overlap of data with Carbonara *et al.* 2002
(Carbonaro *et al.*, 2002)	Pear, Peach	1	2	3	Un-replicated field trial	No	No	Yes	Conventional	Probably some overlap of data with Carbonara and Mattera 2002
(Caris-Veyrat *et al.*, 2004)	Tomato	1	3	1	On-farm field trial	Yes	No	Yes	Integrated pest management	
(Cayuela *et al.*, 1997)	Strawberry	1	1	1	On-farm field trial	Yes	No	Yes	Conventional	
(Chassy *et al.*, 2006)	Bell pepper, Tomato	1	2	3	Un-replicated field trial	Yes	Yes	Yes	Conventional	
(Chinnici *et al.*, 2004)	Apple	1	1	1	Farm pair	Yes	No	Yes	Integrated production	
(Dani *et al.*, 2007)	Grape juice	1	1	1	Farm pair	No	No	Yes	Conventional	
(Fauriel, 2005; J. Fauriel, 2007)	Peach	4	1	2	Farm survey	No	Yes	Yes	Conventional	Data per year calculated from two papers
(Ferreres *et al.*, 2005)	Cabbage	4	1	1	Un-replicated field trial	Yes	Yes	Yes	Conventional	Same plant material as Sousa *et al.* 2005
(Fjelkner-Modig *et al.*, 2001)	Cabbage, Carrot, Onion, Pea, Potato	6	1	6	Replicated field trial	Yes	No	Yes	Integrated crop management	
(Forster *et al.*, 2002)	Banana	11	1	1	Farm survey	No	No	Yes	Conventional	Same plant material as Mendes *et al.* 2003. Years not separated
(Hajslova *et al.*, 2005)	Potato	2	8	4	Farm pairs/field trial	Yes	Yes	?	Good agricultural practice	Some data per year obtained from author

(Continued on next page)

TABLE 1
Papers included in the analysis, which all met criteria for inclusion *(Continued)*

						Documentation of organic treatment				
(Hakkinen and Torronen, 2000)	Strawberry	3	3	1	Farm pairs	No	No	Yes	Conventional	
(Hallmann, 2007)	Tomato	1	5	1	On-farm field trial	Yes	Yes	Yes	Conventional	
(Hamouz, 2005)	Potato	2	7	3	Replicated field trial	Yes	No	Yes	Conventional	
(Juroszek *et al*., 2009)	Tomato	3	2	2	Farm pairs	Yes	Yes	?	Conventional	Years not separated. Some overlap of data with Lumpkin 2005
(Kahu *et al*., 2009)	Black currant	4	3	3	Replicated field trial	Yes	No	Yes	Conventional	
(Keukeleire *et al*., 2007)	Hops	1	3	3	On-farm field trial	Yes	No	Yes	Conventional	
(Lamperi *et al*., 2008)	Apple	1.5	2	1	Farm pairs	No	No	Yes	Integrated crop management	
(Levite *et al*., 2000)	Wine	9	5	1	Farm pairs	No	No	Yes	Conventional	
(Lombardi-Boccia *et al*., 2004)	Plum	1	1	3	Un-replicated field trial	Yes (fertilisers)	No	Yes	Conventional	Years not separated
(Lumpkin, 2005)	Tomato	4	2	1	Farm pairs	Yes	Yes	?	Conventional	Some overlap of data with Juroszek *et al*. 2009
(Malusa *et al*., 2004)	Grape skin	1	1	1	Farm pair	Yes (fertilisers)	No	Yes	Conventional	
(Marin *et al*., 2008)	Sweet pepper	8*3	1	1	Farm pairs	Yes (fertilisers)	No	Yes	Integrated crop management	Data from 'soilless' treatment not used. Years not separated
(Mendez *et al*., 2003)	Banana	11	1	1	Farm survey	No	No	Yes	Conventional	Same plant material as Forster *et al*. 2002. Years not separated
(Mikkonen *et al*., 2001)	Black currant	5	2	1	Farm survey	No	No	Yes	Conventional	
(Mitchell *et al.,* 2007)	Tomato	3	1	10	Replicated field trial	Yes	No	Yes	Best management practice	
(Mogren *et al*., 2008)	Onion	4	1	1	Replicated field trial	Yes	No	Yes	Conventional	
(Moreira *et al*., 2003)	Swiss chard	1	1	1	Farm pair	No	Yes	?	Conventional	
(Mulero *et al*., 2009)	Red wine	9	1	1	Randomised field trial	Yes (pesticides)	No	Yes	Conventional	Experimental design is unclear, may be pseudo replications or farm pairs?
(Nobili *et al*., 2008)	Tomato	1	1	1	Farm pair	No	No	Yes	Conventional	
(Olsson *et al*., 2006)	Strawberry	1	2	1	Un-replicated field trial	Yes	No	Yes	Conventional	
(Ordonez-Santos *et al*., 2009)	Tomato	2	2	1	On-farm field trial	Yes	Yes	Yes	Controlled production	In the sense of complying with UNE 155102: 2005
(de Pascale *et al*., 2006)	Tomato	3	2	2	Replicated field trial	Yes	No	Yes	Conventional	
(Peck *et al*., 2006)	Apple	3	1	2	Replicated field trial	Yes	No	Yes	Conventional	Data from 'integrated' treatment not used
(Perez-Lopez *et al*., 2007b)	Mandarin juice	1	1	1	Un-replicated field trial	Yes	Yes	Yes	Conventional	
(Pieper and Barrett, 2009)	Tomato	3	1	1	On-farm field trial	Yes	Yes	Yes	Conventional	

(Continued on next page)

TABLE 1
Papers included in the analysis, which all met criteria for inclusion *(Continued)*

Reference	Plant species	Number of replications or harvest dates	Number of varieties	Number of years	Type of study design	Documentation of organic treatment: Inputs listed in method description	Certification explicitly stated	In legally defined context	Sub-type of conventional system	Notes
(Rapisarda *et al*., 2005)	Orange (juice)	7	2	3	Farm pair survey	Yes	No	Yes	Integrated pest management	Years not separated
(Rembialkowska *et al*., 2007)	Apple puree	2*2	3	1	Farm pair survey	Yes	Yes	Yes	Conventional	
(Robbins *et al*., 2005)	Broccoli	1	1	1	On-farm field trial	No	Yes	Yes	Conventional	
(Rodriguez *et al*., 2006)	Tomato	1?*4	1	1	Farm pair survey	No	No	Yes	Conventional	
(Sousa *et al*., 2005)	Cabbage	1	1	1	Farm pair survey	Yes	No	Yes	Conventional	Same plant material as Ferreres *et al*. 2005. Order-of-magnitude error for vitamin C?
(Stracke *et al*., 2009b)	Apple	5	1	3	Farm pair trial	No	Yes	Yes	Integrated crop management	
(Tarozzi *et al*., 2004)	Apple	1	1	1	Farm pair survey	No	No	Yes	Integrated crop management	
(Tarozzi *et al*., 2006)	Red orange	4	1	1	Farm survey	No	Yes	Yes	Integrated crop management	Unclear description, maybe shopping basket?
(Valavanidis *et al*., 2009)	Apple	?	5	2	Farm pair survey	No	Yes	Yes	Conventional	Unclear no. of farm pairs. Years not separated
(Vian *et al*., 2006)	Grapes	1	1	1	Farm pair survey	Yes	No	Yes	Conventional	
(Wang *et al*., 2008)	Blueberry	5	1	1	Farm survey	Yes	Yes	Yes	Conventional	
(Warman and Havard, 1997)	Carrot, Cabbage	5	1	3	Replicated field trial	Yes	No	?	Conventional	
(Warman and Havard, 1998)	Potato, Sweet corn kernels	5	1	3	Replicated field trial	Yes	No	?	Conventional	
(Wszelaki *et al*., 2005)	Potato	1	1	1	Un-replicated field trial	Yes	Yes	Yes	Conventional	
(Young *et al*., 2005)	Lettuce, Collard green, Pak choi	?	1	1	Field trial	Yes	Yes	Yes	Conventional	Unclear as regards the number of replications.
(Zafrilla *et al*., 2003)	Wine	1	1	1	Farm pair survey	Yes (pesticides)	No	Yes	Conventional	
(Zhao *et al*., 2007)	Lettuce	6*2	2	1	Replicated field trial	Yes	No	Yes	Conventional	
(Zhao *et al*., 2009)	Pac choi	9*2	2	1	Replicated field trial	Yes	No	Yes	Conventional	

TABLE 2
Papers considered but not included in the analysis.

Reference	Type of study design	Plant species	Experimental design/quality	Organic/conventional	Same variety	Same growing conditions
(Baxter *et al*., 2001)	Shopping basket survey	Various spices etc. in soups	OK	OK	Not controlled	Not controlled
(Briviba *et al*., 2007)	Farm pair trial	Apples	Generally OK, but the data are a subset of the dataset in Stracke *et al*. 2009b, so this paper contains no unique data.	OK	OK	OK
(Chiesa *et al*., 2005)	Field trial	Tomato + 3 lettuce varieties	OK	One of 3 experiments had no organic treatment, and the other 2 had no relevant outcome data	OK	OK
(Daiss *et al*., 2008)	Replicated field trial	Swiss chard	OK	No conventional treatment	OK	OK
(Faller and Fialho, 2009)	Shopping basket survey	Carrot, Onion, Potato, Broccoli, White cabbage	OK	OK	Claimed, but not documented (no variety names)	Not controlled
(Flores *et al*., 2009a; Flores *et al*., 2009b)	Replicated field trial	Sweet pepper	OK	No organic treatment	OK	OK
(Grinder-Pedersen *et al*., 2003)	Shopping basket survey or farm trial depending on species	Several	OK	OK	No, only for some species, and their data not reported separately from the overall averages	Only partially controlled
(Hargreaves *et al*., 2008)	Replicated field trial	Raspberry	OK	No conventional treatment	OK	OK
(Hecke *et al*., 2006)	Farm trial or farm survey?	Apple juice	OK	OK	No	Not controlled
(Heimler *et al*., 2009)	Replicated field trial	Chicory	Single external leaves are not a generally consumed food product	OK	OK	OK
(Ismail and Fun, 2003)	Shopping basket survey	Five green vegetables	OK	OK	Not controlled	Not controlled
(Koh *et al*., 2008)	Shopping basket survey	Marinara sauce	OK	OK	Not controlled	Not controlled
(Kovacevic *et al*., 2008)	Farm survey	Strawberry	OK	Not enough information about organic inputs, certification and/or legal status to be completely certain of the definition	OK	Appears OK, but more detail would have been desirable
(Lima *et al*., 2008)	Farm survey	Peels or leaves of many species	Not generally consumed as foods	OK	Not controlled	Not controlled
(Lima *et al*., 2009)	Farm survey	Maize bran and tassels, Chinese cabbage leaves and stalks	Not generally consumed as foods	OK	OK for maize, not controlled for Chinese cabbage	OK

(Continued on next page)

TABLE 2
Papers considered but not included in the analysis *(Continued)*.

Reference	Type of study design	Plant species	Experimental design/quality	Organic/conventional	Same variety	Same growing conditions
(Masamba and Nguyen, 2008)	Shopping basket survey	Cabbage, carrot, Cos lettuce, Valencia orange	OK	OK	Possibly OK for orange, not controlled for the other species	Not controlled
(Matallana *et al*., 1998)	Shopping basket survey	Lettuce	OK	OK	Not controlled	Not controlled
(Meyer and Adam, 2008)	Shopping basket survey	Broccoli and red cabbage	OK	OK	Not controlled	Not controlled
(Palit *et al*., 2008)	Replicated field trial	Tea leaves	Several details missing, such as the season and developmental stage at sampling, selection of leaves for study	No description of plant protection, so not clear that there was any difference between treatments in this respect.	OK	OK
(Perez-Lopez *et al*., 2007a; Perez-Lopez *et al*., 2007c)	Un-replicated field trial	Sweet pepper	OK	Organic treatment unrealistic (too little fertiliser), despite complying with EC regulation	OK	OK
(Rembialkowska, 1999)	Farm pair survey	Potato	OK	OK	No, only for some samples, and their data not reported separately from the overall averages	OK
(Ren et al., 2001)	Farm trial	Many	Inadequate sample preparation: Vegetable juice polyphenols were allowed to polymerise for 20 minutes and the polymers removed, before polyphenols were measured	OK	OK	OK
(Riu-Aumatell *et al*., 2004)	Shopping basket survey	Pear, abricot and peach juices	OK	OK	Not controlled	Not controlled
(Rossi *et al*., 2008)	Un-replicated field trial	Tomato	Generally OK, but a key detail is missing from the published version of the paper	The organic plot was pre-treated with 100t ha^{-1} of sewage, contravening the EU regulation	OK	OK
(Schulzová and Hajšlová, 2007)	Field trial (not clear whether replicated or not)	Tomato	OK	No description of plant protection, so not clear that there was any difference between treatments in this respect.	OK	OK
(Sousa *et al.,* 2008)	Field trial (not clear whether replicated or not)	Cabbage	OK	No description of plant protection, so not clear that there was any difference between treatments in this respect.	OK	OK

(Continued on next page)

TABLE 2
Papers considered but not included in the analysis *(Continued)*.

Reference	Type of study design	Plant species	Experimental design/quality	Organic/conventional	Same variety	Same growing conditions
(Stracke *et al*., 2009a)	Farm survey	Carrot	Generally OK, but outcome data only available in graphic format on logarithmic scale	OK	OK	OK
(Tinttunen and Lehtonen, 2001) 1	Shopping basket survey	Wine	Generally OK, but not controlled for differences in processing methods	OK	OK	Not controlled
(Toor *et al*., 2006)	Replicate field trial	Tomato	OK	No description of plant protection, so not clear that there was any difference between treatments in this respect. Also not clear which treatments are considered the 'standard' organic and 'standard' conventional, respectively	OK	OK
(Veberic *et al*., 2005)	Farm survey	Apple	OK	OK	No	Not controlled
(Versari *et al.,* 2008)	Shopping basket survey	Abricot juice	OK	OK	Not controlled	Not controlled
(Weibel *et al*., 1998)	Farm trial	Apple	Generally OK, but non-significant comparisons not included	OK	OK	OK
(Wunderlich *et al*., 2008)	Shopping basket survey	Broccoli	OK	OK	Not controlled	Not controlled
(Yanez *et al.,* 2007)	Shopping basket survey	Lemon juices	OK	OK	Not controlled	Not controlled
(Yanez *et al*., 2008)	Shopping basket survey	Fruit juices	OK	OK	Not controlled	Not controlled
(Yildirim *et al*., 2004)	Farm survey + processing trial	Wine	Generally OK, but not controlled for differences in processing methods	OK	OK	Not controlled

Regarding analytical methods, we did not require a detailed description, but we checked whether the values found were of the same order of magnitude as normally seen for the type of compound and species of plant, in particular for papers where methods were not described in detail. However, the only major deviation observed was in a paper with a detailed and appropriate method description (Sousa *et al*., 2005) (Table 1). These data were therefore retained in the analysis, since the out-of-range values were considered most likely to result from a simple scaling error that would affect all data within the study by the same incorrect factor, and therefore have no influence on the ratio of the values within the study.

Regarding relevance of the organic/conventional practices used, relevance of the organic was assessed by requiring at least one of three forms of documentation; 1. that input lists in the method description conformed to the requirements of Regulation (EC) No. 834/2007 or its predecessors; 2. that the growing location was certified; or 3. that the statement that a treatment was organic was made in a place (e.g., EU or USA) and time (>1992 or >2002, respectively) where it would be illegal to designate something as organic if it did not conform to the relevant regulations (Table 1).

Regarding relevance of the conventional treatment: where more than one form was included, only the data from 'conventional' treatments were used at the expense of 'integrated' or 'soilless,' based on the assumption that where these systems are the norm, they would not be contrasted with something else called 'conventional.' Where only one form of nonorganic treatment was used, this was considered the 'conventional,' unless indications were present that this was not the authors' intention. It is recognied that both organic and conventional crop management methods change considerably with time, so data from crops grown before 1992 were not included, to ensure that the results are relevant for the present situation.

For varieties, the variety name was required, since providing only the botanical cultivar classification such as 'white cabbage' or '*Brassica oleracea* cv *capitata,*' which may include any white cabbage varieties, was not considered sufficient to control this variable. Growing conditions were accepted as being the same if the paper included some statement indicating that provision of similar climate and soil type was taken into account in the selection of growing sites.

Among included papers, further quality criteria were defined (Table 1) relating to the number of replications and type of study, however these criteria were not used for weighting, and are presented here mainly to illustrate the wide range of designs among the studies, and the potential for future more detailed studies of the effect of study design on outcome. Generally, replicated field trials are considered the 'gold standard' for plant production experiments, because they allow full control of many of the confounding factors such as soil type and quality, plant genotype and (micro-) climate. However, they are costly and difficult to manage, in particular for treatments that must be established several years before a test can take place, as for comparisons of organic and conventional production systems. Even replicated field trials are susceptible to certain forms of inadvertent bias, for example if the crop does not mature at the same rate in each treatment or the trial's technical manager has less prior practical experience with one system than with the other, in particular if this manager does not have a background in commercial farming operations. Other options are farm trials and surveys, where farmers using already established different production systems grow a crop as part of their normal crop rotation. Here 'farm trials' are defined as studies where the investigator has influence on the crop and its cultivation, e.g., provides the seed and/or defines variables such as sowing dates, while 'farm surveys' rely on the purchase of material resulting from the normal activity of the farm. Farm trials and surveys can be paired (comparing farms or fields located near or even adjacent to each other to minimise differences in soil type and climate) as well as replicated, and well-designed farm-based studies can therefore in some cases provide more accurate estimates of the effects of commercially relevant production systems than field trials, despite less precision due to greater effect of random differences between experimental units. Surveys may also be conducted at the retail stage ('shopping basket surveys'), but while for some crops it would hypothetically be possible to purchase organic and conventional material of the same variety and produced in the same general area, in the present study no publications of shopping basket surveys were identified that met these criteria (Tables 1 and 2).

Based on best practice in meta-analyses of ecological experiments (Osenberg *et al.*, 1999), studies carried out in different years/growing seasons were considered independent, while replications of variety, place/farm pair and harvest time were considered not independent. So for each study, where possible, data were presented as averages of all comparable data within a species, compound and year/growing season. When data were reported as averages of several years, an attempt was made to obtain the data per year/season from the authors. Data from noncomparable samples were excluded from the calculation of averages, for example for a variety found only in one production system but not in the other. For post-harvest treatments, only data from the most freshly harvested treatment was used, partly because the present review focuses on the effect of the production phase, and partly since post-harvest concentration changes often are nonlinear and it therefore would be difficult to devise a consistent method for calculation of a meaningful average value across several durations of post-harvest storage.

Within a study and year/growing season, the data for each reported secondary metabolite or vitamin were recorded on fresh weight basis if reported (or possible to calculate), otherwise on dry matter basis. Regarding the number of different compounds measured within a class, it was observed, as noticed before (Benbrook *et al*., 2008), that this differed substantially among the publications, in particular in terms of detail, in the sense that some studies would report a wide range of different compounds

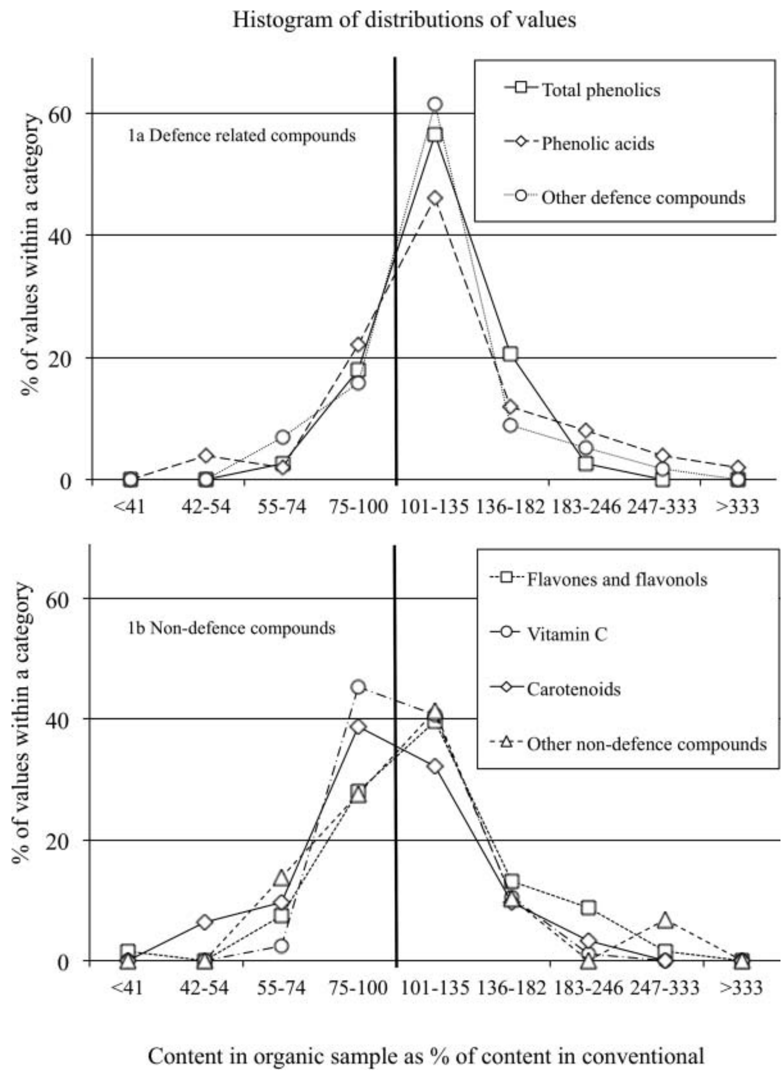

FIG. 1. Graphical representation of the distribution of ratios of content in organic and conventional fruits and vegetables, for different categories of compounds. The vertical line indicates 100% (where the concentrations are equal).

within a class of compounds, while others would report only the total of all compounds measured within a class. This may reflect efforts by authors to analyse as many compounds as possible in order to try to find a significant difference, and therefore poses a potential risk of inflating the effect size. The method chosen to (at least partially) alleviate this issue was that if the paper reported more than six different secondary metabolites, the contents of the members of groups of compounds were added up to fewer figures according to the following criteria (listed in order of priority): 1. Closely related structures such as isomers of the same compound; 2. Glucosides of the same aglycon; 3. Compounds of the same compound class present at similar levels. In this way each study could provide a maximum of six data pairs (organic compared with conventional) per plant species and year/growing season. Where available, data on dry matter content were also collected for each year/growing season and plant species. Data presented only in graphical form were read off the graphs by hand (after appropriate enlargement) using a ruler, except for one dataset (Stracke *et al*., 2009a) where this was not practically feasible because the graph was shown only on a logarithmic scale.

Each pair of values was used to calculate the ratio, as the content in the organic sample in % of the content in the conventional sample. The compounds were grouped into seven groups according to a combination of chemical structure and their function in the plant: 1. Total phenolics (as measured using the Folin-Ciocalteu method); 2. Phenolic acids; 3. Other defense compounds (tannins, alkaloids, chalcones, stilbenes, flavanones and flavanols, hop acids, coumarins and aurones); 4. Carotenoids; 5. Flavones and flavonols; 6. Other non-defense compounds (comprising mainly anthocyanins and volatiles); and 7. Vitamin C. The values used were as reported in the study, or calculated

TABLE 3
Results of meta-analysis of fruit and vegetable constituents.

Functions	Defense secondary metabolites	All defence	Non-defense secondary metabolites			All non-defence	All secondary metabolites	Anti-oxidant		
Types of compounds	Total pheno-lics	Phenolic acids	Other defense com-pounds [a]	Sum or average of 3 groups	Caro-tenes	Flavones and flavonols	Other non-defense compounds [b]	Sum or average of 3 groups	Sum or average of 6 groups	Vitamin C
N[c]	39	50	57	146	32	68	29	129	275	86
Of which on dry matter basis	9	13	15	37	0	20	6	26	63	3
Back-transformed ln(ratio)[d] (%)	114	120	113	116	98	111	108	107	112	106
P from re-sampling test	0.0002	0.0004	0.0007	<0.0001	0.634	0.0076	0.114	0.0104	<0.0001	0.0055
P from *t*-test	0.001	0.002	0.002	0.000	0.731	0.016	0.222	0.021	0.000	0.014
Standard error of the mean	4	6	4	3	6	4	7	3	2	2
Back-transformed ln(ratio)s without dry matter adjustment (%)	113	120	112	115	98	110	107	107	111	106
Normalized difference[e] (%)	17	31	18	22	3	19	16	14	19	9
P from *t*-test	0.001	0.003	0.003	0.000	0.731	0.028	0.261	0.037	0.000	0.016
Standard error of the mean	5	6	4	3	6	4	7	3	2	2

[a]Tannins, alkaloids, chalcones, stilbenes, flavanones and flavanols, hop acids, coumarins, and aurones.
[b]Anthocyanins, tocopherols and volatiles.
[c]N = Number of data pairs of content of a compound in organic material and corresponding conventional material, from the same species, production site and year, as averages over all reported comparable values for varieties and replications within a study.
[d]Ratio in % = 100 times the content in organic material divided by the content in corresponding conventional material = 100*O/C.
[e]Normalized difference = 100 times (content in organic minus content in conventional) divided by content in conventional = 100*(O-C)/C.

arithmetic averages of several reported values from a study. Information on confidence intervals or other statistical data were not used for the meta-analysis, and therefore also not used as a criterion to select studies to include.

Since, as reported by Woese *et al*. (1997) and Heaton (2001), dry matter content tends to be higher in organically grown plants than in comparable conventionally grown ones, Bourn and Prescott (2002) recommended to express measured values on fresh matter basis. Expression of nutrient content on fresh matter basis is common practice in the area of human nutrition (Food Standards Agency, 2002), because it is generally assumed that humans will consume a constant number of portions of a set weight or volume, so the amount of a vegetable or fruit consumed by humans does not depend critically on dry matter content (although the authors have not been able to locate any literature reporting to have tested this assumption experimentally). In contrast, both in animal nutrition research and in ecological research it is customary to express nutrient content on dry matter basis or energy basis, illustrating an interesting barrier to cross-disciplinary research. From the 67 data pairs for which values for dry matter content was available, an average value for the difference in dry matter content was calculated as the ratio of dry matter content in the organic samples divided by dry matter content in the conventional samples. For those sets of data that were reported only on dry matter basis, the ratios were then adjusted by multiplying with the average difference ratio. The table of extracted values is available on the website of the project 'Meta-analysis of data on composition of organic and conventional foods' (MADOC) (http://research.ncl.ac.uk/madoc/).

To calculate significance and magnitude of differences in contents of the compounds, the ratio (in %) was ln-transformed, and the transformed values were used to determine if the arithmetic average of the ln-transformed ratios were significantly different from ln(100), using resampling (Hedges *et al*., 1999). Back-transformation of these average values provided an estimate of the average difference in content between the systems (Table 3). None of the data points differed so much from other points in the same group that there was a need to exclude outliers (see Figure 1). Despite most of the distributions deviating significantly from a normal distribution, for comparison with other meta-analyses significance was also calculated using a t-test, as well as the average and t-test significances for the normalised differences as used by Worthington (2001) and Dangour *et al.* (2009) (Table 3).

B. Results and Discussion

Of the 102 papers initially identified as relevant, 65 papers met the inclusion criteria, while 37 papers were excluded (Tables 1 and 2). The analysis of secondary metabolites resulted in 275 data pairs, of which 212 were reported on fresh weight basis, while 63 data pairs were provided on dry matter basis. (Table 3, and supplementary material online). For vitamin C, 83 of 86 data pairs were on fresh weight basis.

The average dry matter content of the organic material was 103.4% of the corresponding conventional material, with $P = 0.006$ or $P = 0.0017$ for the significance of this difference, using a t-test or re-sampling test, respectively.

The average differences and significances for each group of compounds are given in Table 3, and illustrated graphically in Figure 1. For vitamin C and all groups of secondary metabolites other than carotenes and the other 'non-defense compounds,' anthocyanins, tocopherols and volatiles, the average content in organic plant material were higher than in the corresponding conventional samples. The secondary metabolites appear to group in three categories corresponding to the functional divisions. The first category comprises defense-related compounds, represented by phenolic acids (group 2) and other defense compounds (group 3) as well as the less well-defined 'total phenolics' (group 1), which show substantially higher contents in organically grown plants than in conventional ones. The second category consists of flavones and flavonols (group 5) and other non-defense-related compounds mostly involved in signalling (color, scent) (group 6), where the differences in content between organic and conventional produce is only slightly higher than the difference in dry matter content, although this still results in a significant difference when calculated on fresh weight basis. Vitamin C, while not a secondary metabolite, shows a similar distribution. The last category are the carotenes (group 4), where it appears that organic products tend to have lower content than the conventional, although the difference was not significant in the present dataset, also not if calculated on dry matter basis (data not shown).

In relation to the ecological relevance, the relatively strong effect for defence related secondary metabolites compared with non-defense-related compounds is completely in line with the theoretical considerations (Stamp, 2003), and matches the effects seen in woody plants, which have been extensively studied in this regard (Koricheva *et al*., 1998; Gayler *et al*., 2004). To the best of the authors' knowledge, the difference in dry matter content between plant material from organic and conventional systems has not been described in the context of ecology or plant physiology, so no explanations or even speculations about the physiological relevance are found in the literature. Scattered data indicate that this may also be a general fertilizer-related effect (Kaack *et al.*, 2001; Norbaek *et al*., 2003), however, it appears that most studies in ecology or plant physiology have not included data on dry matter percentage in their reporting, and therefore not allowed assessment of this effect.

Regarding the risk of bias, in particular publication bias and other forms of unbalanced selection of data, the present study did not attempt to quantitatively assess possible relations between study quality and outcome. However, one indication can be found in the distributions of groups of compounds shown in Figure 1. For the defense-related compounds (1a), there is no indication of a dip around 100% (which would have been expected if lack of significant differences reduced the chance of publication), while this cannot as clearly be ruled out for the non-defense compounds. Another more important indication is the substantial differences between the distributions of groups of compounds with different functions in the plants. Many researchers working on food quality and production systems are familiar with the concept of a relatively high water content in conventional/fast-growing plants, and correspondingly lower content of all other compounds. So this effect, which explains approx. a third of the overall average difference found, could be supported or even caused by a bias towards publication of studies showing the expected results. In contrast, comparatively few researchers in this area are aware that the defence compounds (some of which are considered 'toxicants' and therefore undesirable in food) would be expected to be affected differently by differences in growth conditions than non-defense compounds (or even which compounds belong to each of these classes). So the much greater difference between production systems in the content of defense compounds compared with non-defense compounds is unlikely to reflect expectations of researchers or reviewers in the area, indicating that it is much less likely to be caused by bias and thus probably a genuine effect of the growing conditions. Finally, a bias could be caused by researchers more or less intentionally selecting what they considered the best items when they were collecting samples from the system that they believed to be best, and the worst items from the other system. However, since the low content of secondary metabolites are associated with slower growth, a comparison of the largest fruits or vegetables in an organic batch with the smallest from a conventional batch would result in a smaller difference between the compositions than an unbiased selection, while a bias favoring conventional products would increase the difference. In conclusion, it appears to the authors that the most obvious potential forms of bias are unlikely to account for a substantial part of the observed differences, in particular for the defense-related compounds, although this is a question that warrants more detailed analysis in future research.

V. CONSEQUENCES FOR HUMAN HEALTH OF CONSUMING ORGANIC FRUITS AND VEGETABLES

A definitive assessment of the consequences for human health of consuming organic fruits and vegetables would require an intervention study of immense dimensions and cost. One of many steps before embarking on such a challenge is to estimate the likely outcome under as precise as possible assumptions about the mechanisms and magnitudes of effects. The calculations below provide such an estimate, and also point out which assumptions it is based on.

A. Systematic Differences Versus Random Variation

A wide range of external factors influence the composition of plant products, and most of them have much greater effects than the production system effect seen here. Varieties often differ by factors of 2 or 3 in the content of various secondary metabolites (Schindler *et al*., 2005; Kreutzmann *et al*., 2008) and weather/ climate conditions can cause similar variation, as seen when comparing data from different years of the same study (supplementary material online).

Compared with this, the relatively small effect of production system might seem unimportant. However, compared with differences due to climate and soil, which cannot easily be controlled, and differences between varieties, which appear to be random and show no trends across different species, the difference in the content of secondary metabolites between organic and conventional fruits and vegetables is systematic and controllable. The difference in content of secondary metabolites is not sufficiently systematic to be used as a tool for authentication of organic origin, since despite a highly significantly higher average content in the organic samples, in 32% of the data pairs the conventional product had the largest or same value as the organic one (Figure 1). Still, because the production system appears to affect the content of all of the classes of secondary metabolites apart from carotenoids, it is likely that it also affects the largely unknown compounds that are responsible for the health benefits of consumption of fruits and vegetables.

B. Magnitude of Impact on Consumer Health

If a person changes from consuming exclusively conventional fruits and vegetables, to choosing the organic versions of the same products in the same amounts, the intake of all secondary metabolites will increase by approx. 12% (Table 3). From a health perspective, for the reasons provided in section IIIC, it is a reasonable assumption to expect that this would correspond to an increase in the consumption of these foods by 12%. If assuming that the effect is more specifically due to defense-related secondary metabolites, the increase would be even higher, such as 16%. So to set the differences in content in perspective, the question is, how much would such a modest increase in fruit and vegetable intake actually matter for consumer health?

This question has been addressed by Veerman *et al*. (2006), who developed a model to estimate changes in life expectancy caused by changes in fruit and vegetable intake, in relation to assessment of EU policies influencing consumption of vegetables and fruit. The model includes a scenario where an increased intake due to a policy change is proportional to the intake before the change. If there is no change in intake on a g per day basis, and the health impact solely is due to a higher content of the health-beneficial compounds in the food, then the increase in intake of health promoting compounds will be proportional to the habitual intake of fruits and vegetables, so this variant of their model corresponds to a hypothetical situation where consumers change from conventional to organic fruits and vegetables, without changing anything else in their diet or lifestyle. The formula estimated that under these assumptions, in the Dutch population, an increase in the intake of fruit and vegetables of 1.8% would increase life expectancy by 2.6 days for women and 3.8 days for men (Veerman *et al*., 2006). The figures will be slightly different in other populations with different disease patterns and habitual diets. Under the same assumptions, the 12% increase caused by switching to organic fruits and vegetables would correspond to an increase in life expectancy of, on average, 17 days for women and 25 days for men. To put this in perspective, screening for breast cancer has been calculated to provide an average increase in life expectancy of 35 days (Bonneux, 2003), which at the level of the entire population can be considered to be of similar magnitude. Or as another comparison, being overweight by 25 kg will reduce life expectancy by three years (Whitlock *et al.*, 2009), so the 17 days increased life expectancy for women could be described as comparable to the health benefits of a weight loss of 390g, with 570g as the corresponding value for men. This comparison may be particularly relevant, since a likely mechanism for the benefit of increased consumption of vegetables and fruits is the potential ability of defense-related secondary metabolites such as resveratrol to mimic the effect of caloric restriction (Brandt and Mølgaard, 2001), a hypothesis that has subsequently been supported experimentally (Baur and Sinclair, 2006). This effect corresponds with the ecological function of many of these defense compounds to act as antinutrients, making the plant material less attractive to herbivores by reducing their ability to utilize nutrients, thus restricting effective nutrient intake of those who consume foods containing these compounds. It also leads to the interesting possibility that consumers of organic fruits and vegetables may achieve the increased lifespan as a consequence of a corresponding weight loss (or lack of weight gain), which many would consider an added bonus.

The calculations behind these estimates depend on estimates of the relative risks of disease incidences according to fruit and vegetable consumption, most of which are known only with substantial uncertainty (Veerman *et al.*, 2006). It would have been particularly useful to be able to relate the compositional data to more relevant measures of quality of life than simple life expectancy, such as life expectancy after 60 years of age, but such data were not available. Still, by integrating the available data in this way, and identifying the key sources of uncertainty, research can be focused on studies to reduce this uncertainty and thus refine the validity and accuracy of the estimates of benefits.

VI. CONCLUSIONS

The amount of data on compositional differences between organically and conventionally produced fruits and vegetables is now sufficient to not just detect significant differences, but also estimate their magnitude with reasonable precision. The observed differences are that the content of secondary metabolites is approximately 12% higher in organic produce than in corresponding conventional samples, with a larger difference for defense-related compounds and no difference for carotenoids. This corresponds with the predictions from ecology and fertilizer studies, indicating that the differences in content primarily are caused by the differences in fertility management between the systems. If secondary metabolites are responsible for the health promoting effect of consumption of fruits and vegetables, then this means that switching to organic produce will benefit health as much as a 12% increase in intake of fruits and vegetables.

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REFERENCES

Abreu, P., Relva, A., Matthew, S., Gomes, Z., and Morais, Z. 2007. High-performance liquid chromatographic determination of glycoalkaloids in potatoes from conventional, integrated, and organic crop systems. *Food Control* **18:** 40–44.

Ali, M., and Tsou, S. C. S. 1997. Combating micronutrient deficiencies through vegetables—A neglected food frontier in Asia. *Food Policy* **22:** 17–38.

Amodio, M. L., Colelli, G., Hasey, J. K., and Kader, A. A. 2007. A comparative study of composition and postharvest performance of organically and conventionally grown kiwifruits. *J. Sci. Food Agric.* **87:** 1228–1236.

Amtmann, A., and Armengaud, P. 2009. Effects of N, P, K and S on metabolism: new knowledge gained from multi-level analysis. *Curr. Opin. Plant Biol.* **12:** 275–283.

Anonymous. 2004. National road map for Integrated Pest Management. http://www.ipmcenters.org/Docs/IPMRoadMap.pdf (accessed November 2009)

Anttonen, M. J., Hoppula, K. I., Nestby, R., Verheul, M. J., and Karjalainen, R. O. 2006. Influence of fertilization, mulch color, early forcing, fruit order, planting date, shading, growing environment, and genotype on the contents of selected phenolics in strawberry (*Fragaria* x *ananassa* Duch.) fruits. *J. Agric. Food Chem.* **54:** 2614–2620.

Anttonen, M. J., and Karjalainen, R. O. 2006. High-performance liquid chromatography analysis of black currant (*Ribes nigrum* L.) fruit phenolics grown either conventionally or organically. *J. Agric. Food Chem.* **54:** 7530–7538.

Asami, D. K., Hong, Y. J., Barrett, D. M., and Mitchell, A. E. 2003. Comparison of the total phenolic and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry, and corn grown using conventional, organic, and sustainable agricultural practices. *J. Agric. Food Chem.* **51:** 1237–1241.

Assured Produce. 2008. Assured Produce Standards. http://www.assuredproduce.co.uk/ap/scheme/standards.aspx (accessed November 2009)

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M. J., Aviles-Vazquez, K., Samulon, A., and Perfecto, I. 2007. Organic agriculture and the global food supply. *Renew. Agric. Food Syst.* **22:** 86–108.

Barrett, D. M., Weakley, C., Diaz, J. V., and Watnik, M. 2007. Qualitative and nutritional differences in processing tomatoes grown under commercial organic and conventional production systems. *J. Food Sci.* **72:** C441–C451.

Baur, J. A., and Sinclair, D. A. 2006. Therapeutic potential of resveratrol: the in vivo evidence. *Nature Reviews Drug Discovery* **5:** 493–506.

Baxter, G. J., Graham, A. B., Lawrence, J. R., Wiles, D., and Paterson, J. R. 2001. Salicylic acid in soups prepared from organically and non-organically grown vegetables. *Eur. J. Nut.* **40:** 289–292.

Beltran-Gonzalez, F., Perez-Lopez, A. J., Lopez-Nicolas, J. M., and Carbonell-Barrachina, A. A. 2008. Effects of agricultural practices on instrumental colour, mineral content, carotenoid composition, and sensory quality of mandarin orange juice, cv. Hernandina. *J. Sci. Food Agric.* **88:** 1731–1738.

Benbrook, C. 2007. The Impacts of Yield on Nutritional Quality: Lessons from Organic Farming. *Coll. Crop Yield Qual.* **44:** 12–14.

Benbrook, C., Zhao, X., Davies, N., and Andrews, P. 2008. New Evidence Confirms the Nutritional Superiority of Plant-Based Organic Foods. http://www.organic-center.org/science.nutri.php?action= viewandreport_id=126 (accessed November 2009). The Organic Center.

Biodynamic Agricultural Association 2009. Building long-term soil fertility today. http://www.biodynamic.org.uk/ (accessed November 2009)

Bjelakovic, G., Nikolova, D., Gluud L. L., Simonetti, R. G., and Gluud, C. 2008. Antioxidant supplements for prevention of mortality in healthy participants and patients with various diseases (Review). *Cochrane Libr.* **2:** 1–188.

Bonneux, L. 2003. Mortality reduction by breast-cancer screening. *Lancet* **362:** 245–245.

Bourn, D., and Prescott, J. 2002. A comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods. *Crit. Rev. Food Sci. Nutr.* **42:** 1–34.

Brandt, K. 2007. Organic agriculture and food utilization. **In**: *Organic Agriculture and Food Security.* pp. 3–33. Scialabba, N. Ed., Food and Agriculture Organization (FAO), Rome. http://www.fao.org/organicag/ofs/docs_en.htm (accessed March 2010)

Brandt, K., Christensen, L. P., Hansen-Møller, J., Hansen, S. L., Haraldsdottir, J., Jespersen, L., Purup, S., Kharazmi, A., Barkholt, V., Frøkiær, H., and Kobæk-Larsen, M. 2004. Health promoting compounds in vegetables and fruits: A systematic approach for identifying plant components with impact on human health. *Trends Food Sci. Techn.* **15:** 384–393.

Brandt, K., and Mølgaard, J. P. 2001. Organic agriculture: does it enhance or reduce the nutritional value of plant foods? *J. Sci. Food Agric.* **81**: 924–931.

Briviba, K., Stracke, B. A., Rufer, C. E., Watzl, B., Weibel, F. P. and Bub, A. 2007. Effect of consumption of organically and conventionally produced apples on antioxidant activity and DNA damage in humans. *J. Agric. Food Chem.* **55:** 7716–7721.

Camin, F., Moschella, A., Miselli, F., Parisi, B., Versini, G., Ranalli, P., and Bagnaresi, P. 2007. Evaluation of markers for the traceability of potato tubers grown in an organic versus conventional regime. *J. Sci. Food Agric.* **87:** 1330–1336.

Carbonaro, M., and Mattera, M. 2001. Polyphenoloxidase activity and polyphenol levels in organically and conventionally grown peach (*Prunus persica* L., cv. Regina bianca) and pear (*Pyrus communis* L., cv. Williams). *Food Chem.* **72:** 419–424.

Carbonaro, M., Mattera, M., Nicoli, S., Bergamo, P., and Cappelloni, M. 2002. Modulation of antioxidant compounds in organic vs conventional fruit (peach, *Prunus persica* L., and pear, *Pyrus communis* L.). *J. Agric. Food Chem.* **50:** 5458–5462.

Caris-Veyrat, C., Amiot, M. J., Tyssandier, V., Grasselly, D., Buret, M., Mikolajczak, M., Guilland, J. C., Bouteloup-Demange, C., and Borel, P. 2004. 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:** 6503–6509.

Cayuela, J. A., Vidueira, J. M., Albi, M. A., and Gutierrez, F. 1997. Influence of the ecological cultivation of strawberries (*Fragaria x Ananassa* Cv Chandler) on the quality of the fruit and on their capacity for conservation. *J. Agric. Food Chem.* **45:** 1736–1740.

Chassy, A. W., Bui, L., Renaud, E. N. C., van Horn, M., and Mitchell, A. E. 2006. 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:** 8244–8252.

Chiesa, A., Frezza, D., Moccia, S., Oberti, A., Fraschina, A., and Diaz, L. 2005. Vegetable production technology and postharvest quality. *Proc. 5th Int. Postharvest Symp.* **1-3:** 565–572.

Chinnici, F., Bendini, A., Gaiani, A., and Riponi, C. 2004. Radical scavenging activities of peels and pulps from cv. Golden Delicious apples as related to their phenolic composition. *J. Agric. Food Chem.* **52:** 4684–4689.

Daiss, N., Lobo, M. G., and Gonzalez, M. 2008. Changes in postharvest quality of Swiss chard grown using 3 organic preharvest treatments. *J. Food Sci.* **73:** S314–S320.

Dangour, A. D., Dodhia, S. K., Hayter, A., Allen, E., Lock, K., and Uauy, R. 2009. Nutritional quality of organic foods: a systematic review. *Am. J. Clin. Nutr.* **90:** 680–685.

Dani, C., Oliboni, L. S., Vanderlinde, R., Bonatto, D., Salvador, M., and Henriques, J. A. P. 2007. Phenolic content and antioxidant activities of white and purple juices manufactured with organically- or conventionally-produced grapes. *Food Chem. Tox.* **45:** 2574–2580.

Dauchet, L., Amouyel, P., and Dallongeville, J. 2009. Fruits, vegetables and coronary heart disease. *Nature Rev. Cardiol.* **6:** 599–608.

de Jong, T. J. 1995. Why fast-growing plants do not bother about defence. *Oikos* **74:** 545–548.

de Pascale, S., Tamburrino, R., Maggio, A., Barbieri, G., Fogliano, V., and Pernice, R. 2006. Effects of nitrogen fertilization on the nutritional value of organically and conventionally grown tomatoes. *Acta Hort.* **700:** 107–110.

Ekelund, L., and Tjarnemo, H. 2004. Consumer preferences for organic vegetables — The case of Sweden. *Proc. Xvth Int. Symp. Hort. Econ. Man.* 121–128.

Englund, G., Sarnelle, O., and Cooper, S. D. 1999. The importance of data-selection criteria: Meta-analyses of stream predation experiments. *Ecology* **80:** 1132–1141.

EUREPGAP 2004. EUREPGAP Fruit and Vegetables. http://www.eurepgap.org/fruit/documents.html (accessed November 2009)

European Commission 2007. Council Regulation (EC) No. 834/2007. http://ec.europa.eu/agriculture/organic/eu-policy/legislation_en (accessed November 2009)

Faller, A. L. K., and Fialho, E. 2009. The antioxidant capacity and polyphenol content of organic and conventional retail vegetables after domestic cooking. *Food Res. Int.* **42:** 210–215.

Fauriel, J. B., Plénet, D., and Amiot, M.-J. 2005. Can a peach production in organic farming be requalified with polyphenols? A comparative case study in Rhône-Alpes Region (France). http://orgprints.org/6850/ (accessed November 2009)

Fauriel, J. B., Plenet, D., and Amiot, M.-J. 2007. On-farm influence of production patterns on total polyphenol content in peach. **In:** *3rd QLIF Congress*. pp. 122–125. Niggli, U., Leifert, C., Alföldi, T., Lück, L., and Willer, H., Eds., Hohenheim, Germany.

Ferreres, F., Valentao, P., Llorach, R., Pinheiro, C., Cardoso, U., Pereira, J. A., Sousa, C., Seabra, R. M., and Andrade, P. B. 2005. Phenolic compounds in external leaves of tronchuda cabbage (*Brassica oleracea* L. *var. costata* DC). *J. Agric. Food Chem.* **53:** 2901–2907.

Fjelkner-Modig, S., Bengtsson, H., Stegmark, R., and Nystrom, S. 2001. The influence of organic and integrated production on nutritional, sensory and agricultural aspects of vegetable raw materials for food production. *Acta Agric. Scand. Sect. B - Soil Plant Sci.* **50:** 102–113.

Flores, P., Hellin, P., and Fenoll, J., 2009a. Effect of manure and mineral fertilisation on pepper nutritional quality. *J. Sci. Food Agric.* **89:** 1581–1586.

Flores, P., Hellin, P., Lacasa, A., Lopez, A., and Fenoll, J. 2009b. Pepper mineral composition and sensory attributes as affected by agricultural management. *J. Sci. Food Agric.* **89:** 2364–2371.

Food Standards Agency 2002. McCance and Widdowson's The Composition of Foods integrated dataset (CoF IDS). http://www.food.gov.uk/science/dietarysurveys/dietsurveys/#h_2 (accessed November 2009)

Forster, M. P., Rodriguez, E. R., and Romero, C. D. 2002. Differential characteristics in the chemical composition of bananas from Tenerife (Canary Islands) and Ecuador. *J. Agric. Food Chem.* **50:** 7586–7592.

Fritz, C., Palacios-Rojas, N., Feil, R., and Stitt, M. 2006. Regulation of secondary metabolism by the carbon-nitrogen status in tobacco: nitrate inhibits large sectors of phenylpropanoid metabolism. *Plant J.* **46:** 533–548.

Gayler, S., Leser, C., Priesack, E., and Treutter, D. 2004. Modelling the effect of environmental factors on the "trade-off" between growth and defensive compounds in young apple trees. *Trees Struc. Funct.* **18:** 363–371.

Gaziano, J. M., Glynn, R. J., Christen, W. G., Kurth, T., Belanger, C., MacFadyen, J., Bubes, V., Manson, J. E., Sesso, H. D., and Buring, J. E. 2009. Vitamins E and C in the Prevention of Prostate and Total Cancer in Men. The Physicians' Health Study II Randomized Controlled Trial. *JAMA* **301:** 52–62.

Gennaro, L., and Quaglia, G. B. 2002. Food safety and nutritional quality of organic vegetables. **In:** *6th International Symposium on Protected Cultivation in Mild Winter Climate.* pp. 675–680.

Gobbo-Neto, L., and Lopes, N. P. 2007. Medicinal plants: Factors of influence on the content of secondary metabolites. *Quimica Nova* **30:** 374–381.

Grinder-Pedersen, L., Rasmussen, S. E., Bügel, S., Jørgensen, L. V., Dragsted, L. O., Gundersen, V., and Sandström, B. 2003. 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:** 5671–5676.

Hajšlová, J., Schulzová, V., Slanina, P., Janne, K., Hellenäs, K. E., and Andersson, C. 2005. Quality of organically and conventionally grown potatoes: Four-year study of micronutrients, metals, secondary metabolites, enzymic browning and organoleptic properties. *Food Add. Contam.* **22:** 514–534.

Hakkinen, S. H., and Torronen, A. R. 2000. Content of flavonols and selected phenolic acids in strawberries and *Vaccinium* species: influence of cultivar, cultivation site and technique. *Food Res. Int.* **33:** 517–524.

Hallmann, E.R. and Rembialkowska, E. 2007. Comparison of the Nutritive Quality of Tomato Fruits from Organic and Conventional Production in Poland. http://orgprints.org/9944/ (accessed November 2009)

Hamouz, K. Lachman, J., Dvořák, P., and Pivec, V. 2005. The effect of ecological growing on the potatoes yieldand quality. *Plant Soil Environ.* **51:** 6.

Hargreaves, J., Adl, M. S., Warman, P. R., and Rupasinghe, H. P. V. 2008. The effects of organic amendments on mineral element uptake and fruit quality of raspberries. *Plant and Soil* **308:** 213–226.

Harker, F. R. 2004. Organic food claims cannot be substantiated through testing of samples intercepted in the marketplace: a horticulturalist's opinion. *Food Qual. Pref.* **15:** 91–95.

Heaton, S. 2001. Organic farming, food quality and human health. A review of the evidence. http://www.soilassociation.org/Whyorganic/Health/Reports/tabid/388/Default.aspx Accessed November 2009.

Hecke, K., Herbinger, K., Veberic, R., Trobec, M., Toplak, H., Stampar, F., Keppel, H., and Grill, D. 2006. Sugar-, acid- and phenol contents in apple cultivars from organic and integrated fruit cultivation. *Eur. J. Clin. Nutr.* **60:** 1136–1140.

Hedges, L. V., Gurevitch, J., and Curtis, P. S. 1999. The meta-analysis of response ratios in experimental ecology. *Ecology* **80:** 1150–1156.

Heimler, D., Isolani, L., Vignolini, P., and Romani, A. 2009. Polyphenol content and antiradical activity of *Cichorium intybus* L. from biodynamic and conventional farming. *Food Chem.* **114:** 765–770.

Hoare, J., Henderson, L., Bates, C. J., Prentice, A., Birch, M., Swan, G., and Farron, M. 2004. National Diet and Nutrition Survey: Adults Aged 19 to 64 Years. vol. 5: Summary report. http://www.food.gov.uk/science/dietarysurveys/ndnsdocuments/ndnsvol52004 Accessed November 2009.

IFOAM 2005. The Principles of Organic Agriculture. http://www.ifoam.org/about_ifoam/principles/index.html Accessed November 2009.

Ismail, A., and Fun, C. S. 2003. Determination of vitamin C, β-carotene and riboflavin contents in five green vegetables organically and conventionally grown. *Malays. J. Nutr.* **9:** 31–39.

Juhler, R. K., Larsen, S. B., Meyer, O., Jensen, N. D., Spano, M., Giwercman, A., and Bonde, J. P., 1999. Human semen quality in relation to dietary pesticide exposure and organic diet. *Arch. Env. Cont. Tox.* **37:** 415–423.

Juroszek, P., Lumkin, H. M., Yang, R. Y., Ledesma, D. R., and Ma, C. H. 2009. Fruit quality and bioactive compounds with antioxidant activity of tomatoes grown on-farm: Comparison of organic and conventional management systems. *J. Agric. Food Chem.* **57:** 1188–1194.

Kaack, K., Nielsen, M., Christensen, L. P., and Thorup-Kristensen, K. 2001. Nutritionally important chemical constituents and yield of carrot (*Daucus carota* L.) roots grown organically using ten levels of green manure. *Acta Agric. Scand. Sect. B - Soil Plant Sci.***51:** 125–136.

Kahu, K., Janes, H., Luik, A., and Klaas, L. 2009. Yield and fruit quality of organically cultivated blackcurrant cultivars. *Acta Agric. Scand.Sect. B - Soil Plant Sci.***59:** 63–69.

de Keukeleire, J., Janssens, I., Heyerick, A., Ghekiere, G., Cambie, J., Roldan-Ruiz, I., van Bockstaele, E., and de Keukeleire, D. 2007. Relevance of organic farming and effect of climatological conditions on the formation of alpha-acids, beta-acids, desmethylxanthohumol, and xanthohumol in hop (*Humulus lupulus* L.). *J. Agric. Food Chem.* **55:** 61–66.

Koh, E., Wimalasiri, K. M. S., Renaud, E. N. C., and Mitchell, A. E. 2008. A comparison of flavonoids, carotenoids and vitamin C in commercial organic and conventional marinara pasta sauce. *J. Sci. Food Agric.* **88:** 344–354.

Koricheva, J., Larsson, S., Haukioja, E., and Keinanen, M. 1998. Regulation of woody plant secondary metabolism by resource availability: hypothesis testing by means of meta-analysis. *Oikos* **83:** 212–226.

Kovacevic, D. B., Vahcic, N., Levaj, B., and Uzelac, V. D. 2008. The effect of cultivar and cultivation on sensory profiles of fresh strawberries and their purees. *Flav. Fragr. J.* **23:** 323–332.

Kreutzmann, S., Christensen, L. P., and Edelenbos, M. 2008. Investigation of bitterness in carrots (*Daucus carota* L.) based on quantitative chemical and sensory analyses. *Food Sci. Techn.* **41:** 193–205.

Lairon, D. 2010. Nutritional quality and safety of organic food. A review. In *Agron. Sust. Dev.* **30:** 33–41.

Lambers, H., Mougel, C., Jaillard, B., and Hinsinger, P. 2009. Plant-microbe-soil interactions in the rhizosphere: an evolutionary perspective. *Plant Soil* **321:** 83–115.

Lamperi, L., Chiuminatto, U., Cincinelli, A., Galvan, P., Giordani, E., Lepri, L., and del Bubba, M. 2008. Polyphenol levels and free radical scavenging activities of four apple cultivars from integrated and organic farming in different Italian areas. *J. Agric. Food Chem.* **56:** 6536–6546.

Lee, S. K., and Kader, A. A. 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Posth Biol. Techn.* **20:** 207–220.

Lehesranta, S. J., Koistinen, K. M., Massat, N., Davies, H. V., Shepherd, L. V. T., McNicol, J. W., Cakmak, I., Cooper, J., Luck, L., Karenlampi, S. O., and Leifert, C. 2007. Effects of agricultural production systems and their components on protein profiles of potato tubers. *Proteomics* **7:** 597–604.

Leiss, K. A., Maltese, F., Choi, Y. H., Verpoorte, R., and Klinkhamer, P. G. L. 2009. identification of chlorogenic acid as a resistance factor for thrips in *chrysanthemum*. *Plant Physiol.* **150:** 1567–1575.

Lester, G. E., Manthey, J. A., and Buslig. B. S. 2007. Organic vs conventionally grown Rio Red whole grapefruit and juice: Comparison of production inputs, market quality, consumer acceptance, and human health-bioactive compounds. *J. Agric. Food Chem.* **55:** 4474–4480.

Levite, D., Adrian, M., and Tamm, L. 2000. Preliminary Results on Contents of Resveratrol in Wine of Organic and Conventional Vineyards. http://orgprints.org/9107/ Accessed November 2009.

Lima, G. P. P., da Rocha, S. A., Takaki, M., Ramos, P. R. R., and Ono, E. O. 2008. Comparison of polyamine, phenol and flavonoid contents in plants grown under conventional and organic methods. *Int. J. Food Sci. Techn.* **43:** 1838–1843.

Lima, G. P. P., Lopes, T. D. C., Rossetto, M. R. M., and Vianello, F. 2009. Nutritional composition, phenolic compounds, nitrate content in eatable vegetables obtained by conventional and certified organic grown culture subject to thermal treatment. *Int. J. Food Sci. Techn.* **44:** 1118–1124.

Lin, J., Cook, N. R., Albert, C., Zaharris, E., Gaziano, J. M., van Denburgh, M., Buring, J. E., and Manson, J. E. 2009. Vitamins C and E and beta carotene supplementation and cancer risk: A randomized controlled trial. *J. Nat. Cancer Inst.* **101:** 14–23.

Linseisen, J., Rohrmann, S., Miller, A. B., Bueno-de-Mesquita, H. B., Buchner, F. L., and Riboli, E. 2007. Fruit and vegetable consumption and lung cancer risk: Updated information from the European Prospective Investigation into Cancer and Nutrition (EPIC). *Int. J. Cancer* **121:** 1103–1114.

Lombardi-Boccia, G., Lucarini, M., Lanzi, S., Aguzzi, A., and Cappelloni, M. 2004. Nutrients and antioxidant molecules in yellow plums (*Prunus domestica* L.) from conventional and organic productions: A comparative study. *J. Agric. Food Chem.* **52:** 90–94.

Lumpkin, H. 2005. A comparison of lycopene and other phytochemicals in tomatoes grown under conventional and organic management systems. *AVRDC Tech. Bull*. **34:** 1–60.

Lundberg, J. O., Weitzberg, E., and Gladwin, M. T. 2008. The nitrate-nitrite-nitric oxide pathway in physiology and therapeutics. *Nature Rev. Drug Disc.* **7:** 156–167.

Magkos, F., Arvaniti, F., and Zampelas, A. 2003. Organic food: nutritious food or food for thought? A review of the evidence. *Int. J. Food Sci. Nutr.* **54:** 357–371.

Malusa, E., Laurenti, E., Ghibaudi, E., and Rolle, L. 2004. Influence of organic and conventional management on yield and composition of grape cv. 'Grignolino'. *Acta Hort.* **640:** 135–141.

Marin, A., Gil, M. I., Flores, P., Hellin, P., and Selma, M. V. 2008. Microbial Quality and Bioactive Constituents of Sweet Peppers from Sustainable Production Systems. *J. Agric. Food Chem.* **56:** 11334–11341.

Masamba, K. G., and Nguyen, M. 2008. Determination and comparison of vitamin C, calcium and potassium in four selected conventionally and organically grown fruits and vegetables. *Afr. J. Biotech.* **7:** 2915–2919.

Matallana, G. C., Hurtado, C., and Martínez, T. J. 1998. Study of water-soluble vitamins (thiamin, riboflavin, pyridoxine and ascorbic acid) in ecologically-grown lettuce (*Lactuca sativa* L.). *Alimentaria* **35:** 39–43.

McKnight, G. M., Duncan, C. W., Leifert, C., and Golden, M. H. 1999. Dietary nitrate in man: friend or foe? *Brit. J. Nutr.* **81:** 349–358.

Mendez, C. D. V., Forster, M. P., Rodriguez-Delgado, M. A., Rodriguez-Rodriguez, E. M., and Romero, C. D. 2003. Content of free phenolic compounds in bananas from Tenerife (Canary Islands) and Ecuador. *Eur. Food Res. Techn.* **217:** 287–290.

Meyer, M., and Adam, S. T. 2008. Comparison of glucosinolate levels in commercial broccoli and red cabbage from conventional and ecological farming. *Eur. Food Res. Techn.* **226:** 1429–1437.

Mikkonen, T. P., Maatta, K. R., Hukkanen, A. T., Kokko, H. I., Torronen, A. R., Karenlampi, S. O., and Karjalainen, R. O. 2001. Flavonol content varies among black currant cultivars. *J. Agric. Food Chem.* **49:** 3274–3277.

Mitchell, A. E., Hong, Y. J., Koh, E., Barrett, D. M., Bryant, D. E., Denison, R. F., and Kaffka, S. 2007. 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:** 6154–6159.

Mogren, L. M., Caspersen, S., Olsson, M. E., and Gertsson, U. 2008. Organically fertilized onions (*Allium cepa* L.): Effects of the fertilizer placement method on quercetin content and soil nitrogen dynamics. *J. Agric. Food Chem.* **56:** 361–367.

Moreira, M.D., Roura, S.I., and del Valle, C. E. 2003. Quality of Swiss chard produced by conventional and organic methods. *Food Sci. Techn.* **36:** 135–141.

Mozafar, A. 1993. Nitrogen fertilizers and the amount of vitamins in plants - a review. *J. Plant Nutr.* **16:** 2479–2506.

Mulero, J., Pardo, F., and Zafrilla, P. 2009. Effect of principal polyphenolic components in relation to antioxidant activity in conventional and organic red wines during storage. *Eur. Food Res. Techn.* **229:** 807–812.

Murthy, N. S., Mukherjee, S., Ray, G., and Ray, A. 2009. Dietary factors and cancer chemoprevention: An overview of obesity-related malignancies. *J. Postgrad. Med.* **55:** 45–54.

Nobili, F., Finotti, E., Foddai, M. S., Azzini, E., Garaguso, I., Raguzzini, A., Tisselli, V., Piazza, C., Durazzo, A., and Maiani, G. 2008. Bioactive compounds in tomatoes: effect of organic vs. conventional management in Parma in 2006. http://orgprints.org/11902 (accessed November 2009)

Norbæk, R., Aaboer, D. B. F., Bleeg, I. S., Christensen, B. T., Kondo, T., and Brandt, K. 2003. Flavone C-glycoside, phenolic acid, and nitrogen contents in leaves of barley subject to organic fertilization treatments. *J. Agric. Food Chem.* **51:** 809–813.

Olsson, M. E., Andersson, C. S., Oredsson, S., Berglund, R. H., and Gustavsson, K. E. 2006. Antioxidant levels and inhibition of cancer cell proliferation in vitro by extracts from organically and conventionally cultivated strawberries. *J. Agric. Food Chem.* **54:** 1248–1255.

Ordonez-Santos, L. E., Arbones-Macineira, E., Fernandez-Perejon, J., Lombardero-Fernandez, M., Vazquez-Oderiz, L., and Romero-Rodriguez, A. 2009. Comparison of physicochemical, microscopic and sensory characteristics of ecologically and conventionally grown crops of two cultivars of tomato (*Lycopersicon esculentum* Mill.). *J. Sci. Food Agric.* **89:** 743–749.

Osenberg, C. W., Sarnelle, O., Cooper, S. D., and Holt, R. D. 1999. Resolving ecological questions through meta-analysis: Goals, metrics, and models. *Ecology* **80:** 1105–1117.

Palit, S., Ghosh, B. C., Gupta, S. D., and Swain, D. K. 2008. Studies on tea quality grown through conventional and organic management practices: Its impact on antioxidant and antidiarrhoeal activity. *Trans. Asabe* **51:** 2227–2238.

Peck, G. M., Andrews, P. K., Reganold, J. P., and Fellman, J. K. 2006. Apple orchard productivity and fruit quality under organic, conventional, and integrated management. *Hortsci.* **41:** 99–107.

Perez-Lopez, A. J., del Amor, F. M., Serrano-Martinez, A., Fortea, M. I., and Nunez-Delicado, E. 2007a. Influence of agricultural practices on the quality of sweet pepper fruits as affected by the maturity stage. *J. Sci. Food Agric.* **87:** 2075–2080.

Perez-Lopez, A. J., Lopez-Nicolas, J. M., and Carbonell-Barrachina, A. A. 2007b. Effects of organic farming on minerals contents and aroma composition of Clemenules mandarin juice. *Eur. Food Res. Techn.* **225:** 255–260.

Perez-Lopez, A. J., Lopez-Nicolas, J. M., Nunez-Delicado, E., del Amor, F. M., and Carbonell-Barrachina, A. A. 2007c. Effects of agricultural practices on color, carotenoids composition, and minerals contents of sweet peppers, cv. Almuden. *J. Agric. Food Chem.* **55:** 8158–8164.

Pieper, J. R., and Barrett, D. M. 2009. Effects of organic and conventional production systems on quality and nutritional parameters of processing tomatoes. *J. Sci. Food Agric.* **89:** 177–194.

Rapisarda, P., Calabretta, M. L., Romano, G., and Intrigliolo, F. 2005. Nitrogen metabolism components as a tool to discriminate between organic and conventional citrus fruits. *J. Agric. Food Chem.* **53:** 2664–2669.

Rembialkowska, E. 1999. Comparison of the contents of nitrates, nitrites, lead, cadmium and vitamin C in potatoes from conventional and ecological farms. *Pol. J. Food Nutr. Sci.* **8:** 17–26.

Rembialkowska, E. 2007. Quality of plant products from organic agriculture. *J. Sci. Food Agric.* **87:** 2757–2762.

Rembialkowska, E., Hallmann, E., and Rusakzonek, A. 2007. Influence of processing on bio-active substances content and anti-oxidant properties of apple puree from organic and conventional production in Poland. **In:** *3rd QLIF Congress*. pp. 139–143. Niggli, U., Leifert, C., Alföldi, T., Lück, L., and Willer, H., Eds., Hohenheim, Germany.

Ren, H. F., Endo, H., and Hayashi, T. 2001. 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:** 1426–1432.

Riu-Aumatell, M., Castellari, M., Lopez-Tamames, E., Galassi, S., and Buxaderas, S. 2004. Characterisation of volatile compounds of fruit juices and nectars by HS/SPME and GUMS. *Food Chem.* **87:** 627–637.

Robbins, R.J., Keck, A.S., Banuelos, G., and Finley, J. W. 2005. Cultivation conditions and selenium fertilization alter the phenolic profile, glucosinolate, and sulforaphane content of broccoli. *J. Med. Food* **8:** 204–214.

Rodriguez, J., Rios, D., Rodriguez, D., and Diaz, C. 2006. Physico-chemical changes during ripening of conventionally, ecologically and hydroponically cultivated Tyrlain (TY 10016) tomatoes. *Int. J. Agric. Res.* **1:** 452–461.

Rossi, F., Godani, F., Bertuzzi, T., Trevisan, M., Ferrari, F., and Gatti, S. 2008. Health-promoting substances and heavy metal content in tomatoes grown with different farming techniques. *Eur. J. Nut.* **47:** 266–272.

Sanford, L. L., Deahl, K. L., Sinden, S. L., and Ladd, T. L. 1992. Glycoalkaloid contents in tubers from *Solanum tuberosum* populations selected for potato leafhopper resistance. *Am. Potato J.* **69:** 693–703.

Santamaria, P. 2006. Nitrate in vegetables: toxicity, content, intake and EC regulation. *J. Sci. Food Agric.* **86:** 10–17.

Schifferstein, H. N. J., and Ophuis, P. A. M. O. 1998. Health-related determinants of organic food consumption in the Netherlands. *Food Qual. Pref.* **9:** 119–133.

Schindler, M., Solar, S., and Sontag, G. 2005. Phenolic compounds in tomatoes. Natural variations and effect of gamma-irradiation. *Eur. Food Res. Techn.* **221:** 439–445.

Schulzová, V. and Hajšlová, J. 2007. Biologically active compounds in tomatoes from various fertilisation systems. **In:** *3rd QLIF Congress*. pp. 144–147. Niggli, U., Leifert, C., Alföldi, T., Lück, L., and Willer, H., Eds., Hohenheim, Germany.

Sousa, C., Pereira, D. M., Pereira, J. A., Bento, A., Rodrigues, M. A., Dopico-Garcia, S., Valentao, P., Lopes, G., Ferreres, F., Seabra, R. M., and Andrade, P. B. 2008. Multivariate analysis of tronchuda cabbage (*Brassica oleracea* L. *var. costata* DC) phenolics: Influence of fertilizers. *J. Agric. Food Chem.* **56:** 2231–2239.

Sousa, C., Valentao, P., Rangel, J., Lopes, G., Pereira, J. A., Ferreres, F., Seabra, R. A., and Andrade, P. B. 2005. Influence of two fertilization regimens on the amounts of organic acids and phenolic compounds of tronchuda cabbage (*Brassica oleracea* L. *var. costata* DC). *J. Agric. Food Chem.* **53:** 9128–9132.

Stamp, N. 2003. Out of the quagmire of plant defense hypotheses. *Quart. Rev. Biol.* **78:** 23–55.

Stracke, B. A., Rufer, C. E., Bub, A., Briviba, K., Seifert, S., Kunz, C., and Watzl, B., 2009a. Bioavailability and nutritional effects of carotenoids from organically and conventionally produced carrots in healthy men. *Brit. J. Nutr.* **101:** 1664–1672.

Stracke, B. A., Rufer, C. E., Weibel, F. P., Bub, A., and Watzl, B. 2009b. Three-year comparison of the polyphenol contents and antioxidant capacities in organically and conventionally produced apples (*Malus domestica* Bork. cultivar 'Golden Delicious'). *J. Agric. Food Chem.* **57:** 4598–4605.

Tarozzi, A., Hrelia, S., Angeloni, C., Morroni, F., Biagi, P., Guardigli, M., Cantelli-Forti, G., and Hrelia, P. 2006. Antioxidant effectiveness of organically and non-organically grown red oranges in cell culture systems. *Eur. J. Nut.* **45:** 152–158.

Tarozzi, A., Marchesi, A., Cantelli-Forti, G., and Hrelia, P. 2004. Cold-storage affects antioxidant properties of apples in caco-2 cells. *J. Nutr.* **134:** 1105–1109.

Tinttunen, S., and Lehtonen, P. 2001. Distinguishing organic wines from normal wines on the basis of concentrations of phenolic compounds and spectral data. *Eur. Food Res. Techn.* **212:** 390–394.

Toor, R. K., Savage, G. P., and Heeb, A. 2006. Influence of different types of fertilisers on the major antioxidant components of tomatoes. *J. Food Comp. Anal.* **19:** 20–27.

USDA 2009. National Organic Program (NOP) http://www.ams.usda.gov/AMSv1.0/NOP Accessed November 2009.

Valavanidis, A., Vlachogianni, T., Psomas, A., Zovoili, A., and Siatis, V. 2009. Polyphenolic profile and antioxidant activity of five apple cultivars grown under organic and conventional agricultural practices. *Int. J. Food Sci. Techn.* **44:** 1167–1175.

Veberic, R., Trobec, M., Herbinger, K., Hofer, M., Grill, D., and Stampar, F. 2005. Phenolic compounds in some apple (*Malus domestica* Borkh) cultivars of organic and integrated production. *J. Sci. Food Agric.* **85:** 1687–t1694.

Veerman, J. L., Barendregt, J. J., and Mackenbach, J. P. 2006. The European Common Agricultural Policy on fruits and vegetables: exploring potential health gain from reform. *Eur. J. Pub. Health* **16:** 31–35.

Versari, A., Parpinello, G. P., Mattioli, A. U., and Galassi, S. 2008. Characterisation of Italian commercial apricot juices by high-performance liquid chromatography analysis and multivariate analysis. *Food Chem.* **108:** 334–340.

Vian, M. A., Tomao, V., Coulomb, P. O., Lacombe, J. M., and Dangles, O. 2006. Comparison of the anthocyanin composition during ripening of Syrah grapes grown using organic or conventional agricultural practices. *J. Agric. Food Chem.* **54:** 5230–5235.

Wang, S. Y., Chen, C. T., Sciarappa, W., Wang, C. Y., and Camp, M. J. 2008. Fruit quality, antioxidant capacity, and flavonoid content of organically and conventionally grown blueberries. *J. Agric. Food Chem.* **56:** 5788–5794.

Warman, P. R., and Havard, K. A. 1997. Yield, vitamin and mineral contents of organically and conventionally grown carrots and cabbage. *Agric. Ecosys. Env.* **61:** 155–162.

Warman, P. R., and Havard, K. A. 1998. Yield, vitamin and mineral contents of organically and conventionally grown potatoes and sweet corn. *Agric. Ecosys. Env.* **68:** 207–216.

Weibel, F. P., Bickel, R., Leuthold, S., Alfoldi, T., and Niggli, U. 1998. Are organically grown apples tastier and healthier? A comparative field study using conventional and alternative methods to measure fruit quality. **In:** *12th International IFOAM Scientific Conference*. pp. 147–153.

Whitlock, G., Lewington, S., Sherliker, P., Clarke, R., Emberson, J., Halsey, J., and Aric, P. C. 2009. Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies. *Lancet* **373:** 1083–1096.

Williams, C. M. 2002. Nutritional quality of organic food: shades of grey or shades of green? *Proc. Nutr. Soc.* **61:** 19–24.

Winter, C. K., and Davis, S. F. 2006. Organic foods. *J. Food Sci.* **71:** R117-R124.

Winter, J. W., Paterson, S., Scobie, G., Wirz, A., Preston, T., and McColl, K. E. L. 2007. N-nitrosamine generation from ingested nitrate via nitric oxide in subjects with and without gastroesophageal reflux. *Gastroent.* **133:** 164–174.

Woese, K., Lange, D., Boess, C., and Bogl, K. W. 1997. A comparison of organically and conventionally grown foods - Results of a review of the relevant literature. *J. Sci. Food Agric.* **74:** 281–293.

Worthington, V. 2001. Nutritional quality of organic versus conventional fruits, vegetables, and grains. *J. Alt. Compl. Med.* **7:** 161–173.

Wszelaki, A. L., Delwiche, J. F., Walker, S. D., Liggett, R. E., Scheerens, J. C., and Kleinhenz, M. D. 2005. Sensory quality and mineral and glycoalkaloid concentrations in organically and conventionally grown redskin potatoes (*Solanum tuberosum*). *J. Sci. Food Agric.* **85:** 720–726.

Wunderlich, S. M., Feldman, C., Kane, S., and Hazhin, T. 2008. Nutritional quality of organic, conventional, and seasonally grown broccoli using vitamin C as a marker. *Int. J. Food Sci. Nutr.* **59:** 34–45.

Yanez, J. A., Miranda, N. D., Remsberg, C. A., Ohgami, Y., and Davies, N. M. 2007. Stereospecific high-performance liquid chromatographic analysis of eriodictyol in urine. *J. Pharm. Biomed. Anal.* **43:** 255–262.

Yanez, J. A., Remsberg, C. M., Miranda, N. D., Vega-Villa, K. R., Andrews, P. K., and Davies, N. M. 2008. Pharmacokinetics of selected chiral flavonoids: Hesperetin, naringenin and eriodictyol in rats and their content in fruit juices. *Biopharm. Drug Disp.* **29:** 63–82.

Yildirim, H.K., Akcay, Y.D., Guvenc, U., and Sozmen, E.Y. 2004. Protection capacity against low-density lipoprotein oxidation and antioxidant potential of some organic and non-organic wines. *Int. J. Food Sci. Nutr.* **55:** 351–362.

Yiridoe, E. K., Bonti-Ankomah, S., and Martin, R. C. 2005. Comparison of consumer perceptions and preference toward organic versus conventionally produced foods: A review and update of the literature. *Renew. Agric. Food Syst.* **20:** 193–205.

Young, J. E., Zhao, X., Carey, E. E., Welti, R., Yang, S. S., and Wang, W. Q. 2005. Phytochemical phenolics in organically grown vegetables. *Mol. Nutr. Food Res.* **49:** 1136–1142.

Zafrilla, P., Morillas, J., Mulero, J., Cayuela, J.M., Martinez-Cacha, A., Pardo, F., and Nicolas, J. M. L. 2003. Changes during storage in conventional and ecological wine: Phenolic content and antioxidant activity. *J. Agric. Food Chem.* **51:** 4694–4700.

Zhao, X., Carey, E. E., Young, J.E., Wang, W. Q., and Iwamoto, T. 2007. Influences of organic fertilization, high tunnel environment, and postharvest storage on phenolic compounds in lettuce. *Hortsci.* **42:** 71–76.

Zhao, X., Nechols, J. R., Williams, K. A., Wang, W. Q., and Carey, E. E. 2009. Comparison of phenolic acids in organically and conventionally grown pac choi (*Brassica rapa* L. *chinensis*). *J. Sci. Food Agric.* **89:** 940–946.