A literature-based comparison of nutrient and contaminant contents between organic and conventional vegetables and potatoes

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Abstract

Purpose – The increasing demand for organic foods is explained mainly by consumers' concerns about the quality and safety of foods and their perception that organically produced foods are healthier and safer than conventional foods. Based on internationally available concentration data of organic and conventional vegetables (carrots, tomatoes, lettuce and spinach) and potatoes, the paper aims to investigate the scientific validity of nutrition claims as "no vegetable/potato has higher amounts of nutrient X than organic vegetables/potatoes" and "no vegetable/potato has lower amounts of contaminant Y than organic vegetables/potatoes".

Design/methodology/approach – Detailed nutrient and contaminant databases were developed for organic and conventional vegetables separately. Non-parametric (Mann-Whitney test) methods were used to detect significant differences between both types of vegetables. A chi-square test was used to compare the incidence of pesticide residues in organic and conventional vegetables.

Findings – From a nutritional and toxicological point of view, organic vegetables and potato in general are not significantly better than conventional vegetables and potatoes. For some nutrients and contaminants organic vegetables and potatoes score significantly better but for others they score significantly worse. Therefore, it becomes difficult to justify general claims indicating a surplus value of organic over conventional vegetables and potatoes. More data from controlled paired studies are needed to reconsider the use of claims for these organic plant foods in the future.

Research limitations/implications – Only a limited number of studies comparing the nutrient and/or contaminant concentration of organic and conventional vegetables are available ("paired studies"). Additionally, the majority of the studies are of moderate or poor quality. The implication is that more of those paired studies are heavily needed. Another limitation of the study is the fact that most pesticide residue data originated from the USA, the EU and Australia.

Originality/value – So far only few studies compared both nutrient and contaminant contents between organic and conventional plant foods. This paper covers therefore an important, not well-explored research sub area.

Keywords Organic foods, Vegetables, Agricultural products, Contamination, Nutrition, Consumer psychology

Paper type Research paper

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Introduction

Organic products in the EU are understood to be those products produced under controlled cultivation conditions in line with the provisions of the European Regulation on organic farming (for agricultural products (EU Regulation 2092/91)) (Woese *et al.*, 1997). The sales of organic products in Belgium have increased from about 62 million euro in 1997 till 315 million euro in 2004 (National Institute of Statistics (NIS), 2008) showing the increased consumer demand for organic products. Market share of organic vegetables in the total Belgian vegetable market is 3.1 per cent. The European market of organic products showed a considerable growth in recent years and represented about 11 billion euro in 2004 (European Commission (EC), 2005).

Vegetables are an important source of bioactive components like dietary fibre, minerals, trace elements, (pro)vitamins and a broad range of secondary plant metabolites. Due to the presence of these nutrients the consumption of vegetables is associated with a reduced risk of age related diseases like cardiovascular diseases and certain forms of cancer (Riboli and Norat, 2003, Hung *et al.*, 2004). Vegetables also contain less favourable components like pesticide residues, natural toxins, mycotoxins, environmental contaminants (heavy metals, PCB's), nitrate and pathogenic micro-organisms (Dedaza and Diaz, 1994; Malmauret *et al.*, 2002). As such, the consumption of vegetables is subjected to a potential nutritional-toxicological conflict between nutritional recommendations and toxicological safety aspects, both from a scientific perspective as well as from the more subjective consumer perspective.

Perceived food safety risks and pesticide-related concerns are significant contributors to an increased consumer demand for organically grown food (Williams and Hammitt, 2001). From a scientific point of view, studies comparing the different aspects of quality (nutrient content, sensory attributes, safety) of organic and non-organic vegetables are rather scarce (Woese *et al.*, 1997; Worthington, 1998; Bourn and Prescott, 2002; Magkos *et al.*, 2006). Although it is difficult to make a valid comparison between both vegetable groups due to the limited availability of well-controlled or paired studies, some trends have been observed (Worthington, 1998). Organic vegetables generally contain lower levels of synthetic pesticide residues than conventional vegetables. Furthermore, no major differences exist in the presence of environmental contaminants in organic and conventional vegetables (Woese *et al.*, 1997). Except for vitamin C for which literature suggests higher contents in organic vegetables compared with the conventional alternative, no strong evidence exists that the nutrient content of conventional and organic vegetables differ (Bourn and Prescott, 2002).

The aim of this research is to perform a meta-analysis of the relevant literature published after the establishment of the EU organic regulation in 1991 (EU Regulation 2092/91). After the collection, evaluation and selection of the secondary data, a statistical comparison will be made between the content of selected nutrients and contaminants between organic and conventional vegetables and potato. Special attention will be given to communication strategies for organic products with regard to the nutritional and toxicological value.

Methodology

Electronic literature searches were performed on the Web of Science, PubMed and Google to retrieve international research studies on the nutritional and toxicological value of organic and conventional vegetables and potato in order to compare products originating from both cultivation methods. The following keywords were used: organic, conventional, vegetables, [vegetable] (e.g. carrot), potato, nutrient [nutrient] (e.g. vitamin), contaminant [contaminant] (e.g. nitrate), agriculture, comparison. Additionally, a manual search of the reference lists of relevant articles was conducted. Government organisations and research institutes who published only abstracts and incomplete data were contacted and asked to contribute full datasets or completed research reports and papers. In total, 74 relevant publications were identified and included in the meta-analysis – 39 for nutrients and 35 for contaminants.

The data collected from literature were assembled in databases. The criteria for studies and data points to be included, are the following: study period after the establishment of the organic regulation (EC Regulation 2092/91), food originating from EU or continent with similar organic regulation (e.g. the USA and Australia), food descriptives (edible part, cooking method, etc.), component identity and fresh weight as unit. It is recognised that the comparability of the organic and conventional data may be hampered by other factors, as for example the growing conditions and soil type. Due to missing and inconsistent documentation of the data, all confounding factors could not be considered in the evaluation procedure. To compensate for this shortcoming, data obtained from paired or comparative studies (confounding factors are controlled) received a higher weight or appreciation ($W_{i,pair} = 5$) than data from semi-paired ($W_{i,pair} = 3$) or non-paired studies ($W_{i,pair} = 1$). An additional weighing of the data was applied in function of the representativeness of the sampling procedures according to Sioen *et al.* (2007a, b). Eventually, for each data point x_i in the compiled database, $W_{i,pair}$ was multiplied with a second weighing factor $W_{i,meas}$ (expressing the number of measurements) and with a third weighing factor $W_{i,unit}$ (expressing the number of individual sample units), in order to have an overall weighing factor ($W_{i,final} = W_{i,pair} * W_{i,meas} * W_{i,unit}$).

As a result, separate databases for nutrient and contaminant concentrations in selected organic and conventional vegetables (carrot, tomato, lettuce, spinach) and potato were established (Hoefkens *et al.*, 2008). The following classes of nutrients and contaminants were included in the present study: vitamins and pro-vitamins (vitamin C, carotenoids: β-carotene, lycopene, lutein), minerals (K, Ca), secondary plant metabolites other than carotenoids (chlorogenic acid, glycoalkaloids), nitrate, heavy metals (Cd, Pb) and pesticides (see Table I) The selection of components (nutrients and contaminants) for this study was the result of a compromise between the relevance of a specific component for the considered plant foods and the availability and accessibility of the according component content data in literature and other secondary data sources.

A meta-analysis of the collected literature was performed, which means that the results of the independent studies with the same research question were analysed and synthesised. Such a meta-analysis is especially useful for examining the general evidence pro or contra a specific hypothesis, which for the present study is: Organic vegetables contain more beneficial nutrients and less harmful contaminants compared to conventional vegetables. The general patterns found in the meta-analysis are useful to suggest further more explicit research and communication strategies for both organic and conventional vegetables.

Table I. Summary of contaminant concentrations (µg or mg/g fresh weight (FW)) in organic (O) and conventional (C) vegetables and potato (number of data points (n), number of data points above the limit of detection (n_D), mean, standard deviation (SD))

		Carrot O	Carrot C	Tomato O	Tomato C	Lettuce O	Lettuce C	Spinach O	Spinach C	Potato O	Potato C
Nitrate (mg/g FW)	n	39	50	–	–	73	1,384	16	313	74	322
	Mean	0.197*	0.153**			1.236*	1.973**	1.421**	1.429*	0.133*	0.168**
	± SD	0.171	0.045			0.927	0.835	0.534	0.710	0.093	0.094
Heavy metals (µg/g FW)											
Cd	n	40	220	12	43	35	169	7	81	43	251
	Mean	0.026**	0.022*	0.013	0.011	0.019*	0.023**	0.079**	0.040*	0.022*	0.029**
	± SD	0.023	0.018	0.007	0.006	0.013	0.013	0.023	0.022	0.010	0.020
Pb	n	35	167	–	–	34	105	7	75	44	133
	Mean	0.263**	0.105*			0.039	0.051	0.055*	0.056**	0.062*	0.136**
Pesticides (µg/g FW)											
Azoxystrobin	$n(n_D)$	46 (0)	225 (3)	–	–	–	–	–	–	–	–
	Mean	0.000*	0.012**								
	± SD	0.000	0.014								
Bifenthrin	$n(n_D)$	–	–	20 (0)	318 (8)	30 (0)	1,322 (4)	–	–	–	–
	Mean			0.000*	0.025**	0.000*	0.005**				
	± SD			0.000	0.013	0.000	0.008				
Chloropropham	$n(n_D)$	–	–	–	–	–	–	–	–	43 (11)	1,767 (1,265)
	Mean									0.087*	1.380**
	±									0.231	2.397
Chlorothalonil	$n(n_D)$	–	–	31 (1)	1,632 (187)	–	–	–	–	38 (16)	1,304 (2)
	Mean			0.003*	0.012**					0.002*	0.005**
Cyfluthrin	$n(n_D)$					28 (0)	1,485 (9)	–	–	–	–
	Mean					0.00*	0.032**				
	± SD					0.000	0.086				
Deltamethrin	$n(n_D)$	70 (0)	1,501 (0)	–	–	–	–	12 (0)	327 (18)	42 (0)	445 (1)
	Mean	0.000*	0.012**					0.000*	0.021**	0.000*	0.015**
	± SD	0.000	0.010					0.000	0.044	0.000	0.012
Dichlorovos	$n(n_D)$	–	–	38 (0)	1594 (0)	–	–	–	–	–	–
	Mean			0.000*	0.04**						
	± SD			0.000	0.004						
Dimethoate	$n(n_D)$	39 (0)	1,849 (6)	–	–	–	–	–	–	–	–
	Mean	0.000*	0.002**								
	± SD	0.000	0.004								
Esfenvalerate	$n(n_D)$	–	–	–	–	–	–	–	–	18 (0)	1,278 (0)
	Mean									0.000*	0.013**
	+ SD									0.000	0.004

(*continued*)

Table I.

		Carrot		Tomato		Lettuce		Spinach		Potato	
		O	C	O	C	O	C	O	C	O	C
Ethoprophos	$n(n_D)$	–	–	–	–	–	–	–	–	36 (0)	1,340 (0)
	Mean									0.000*	0.007**
	± SD									0.000	0.003
Iprodion	$n(n_D)$	85 (2)	1,833 (543)	30 (1)	444 (86)	34 (0)	2,611 (378)	–	–	–	–
	Mean	0.001*	0.015**	0.010*	0.025**	0.000*	0.229**				
	± SD	0.006	0.047	0.024	0.057	0.000	1.269				
Lambda-cyhalothrin	$n(n_D)$	68 (0)	1,188 (0)	–	–	–	–	6 (0)	137 (13)	–	–
	Mean	0.000*	0.006**					0.000*	0.008**		
	± SD	0.000	0.009					0.000	0.032		
Myclobutanil	$n(n_D)$	66 (0)	1,773 (2)	29 (0)	1,533 (0)	–	–	–	–	–	–
	Mean	0.000*	0.005**	0.000*	0.023**						
Pirimicar**	$n(n_D)$	58 (0)	950 (0)	19 (0)	302 (0)	–	–	6 (0)	135 (2)	24 (0)	418 (0)
	Mean	0.000*	0.008**	0.000*	0.010**	–	–	0.000*	00.12**	0.000*	0.010**
	± SD	0.000	0.003	0.000	0.002			0.000	0.07	0.000	0.001
Tebuconazole	$n(n_D)$	48 (0)	1,610 (0)	–	–	–	–	–	–	–	–
	Mean	0.000*	0.010**								
	± SD	0.000	0.000								
Thaibendazole	$n(n_D)$	–	–	–	–	–	–	–	–	34 (0)	1,749 (88)
	Mean									0.000*	0.025**
	± SD									0.000	0.106

Notes: *, **Indicate significantly different means for specific nutrient-matrix combination using Mann Whitney test ($\alpha = 0.05$); – indicates no result

Data were analysed using SPSS software version 15.0 (SPSS Inc., Chicago, IL, USA). Specifically, the non-parametric Mann-Whitney test was used to assess whether the mean concentrations of two groups, organic and conventional vegetables, were statistically different from each other. A chi-square test was applied to compare the frequencies in which pesticide residues occurred between both farming systems. Significance was assessed at $\alpha = 0.05$.

The results are presented in two ways. A first visualisation of the findings is made by means of box plots, which show the central tendency and the variability (dispersion) of a (weighed) data set. The second way to present the results are tables including numerical statistics.

Results of the meta-analysis

Nutrients

For the nutrients, vitamin C, β-carotene (provitamin A), potassium (K), calcium (Ca), lycopene, lutein, chlorogenic acid and glycoalkaloids (α-chaconine $+\alpha$-solanine) have been taken into consideration. The concentrations of each nutrient have been described in one to five food matrices: carrots, tomatoes, lettuce, spinach and potatoes. The nutrient-matrix combinations being studied, are summarised in Table II.

The literature search identified 39 relevant sources of nutrient data for the selected vegetable groups: 24 peer-reviewed papers (of which 11 paired or comparative studies), seven food composition databases (Souci *et al.*, 2000; Beemster *et al.*, 2001; Danish Institute for Food and Veterinary Research, 2006; Health Canada, 2006; National Public Health Institute of Finland, 2006; US Department of Agriculture, Agricultural Research Service, 2006; VZW NUBEL, 2006), three reports or databases (of research or consumer organisations), three personal communications and two proceedings of symposia. The result of the data collection is summarised in box plots, visualising the central tendency and observed variability within the organic and conventional food (see Figure 1). The number of data points (n) (without weighing) is mentioned in Table II. In total, 802 nutrient concentration data points were included in the meta-analytic comparison of which 198 data points were obtained from paired studies.

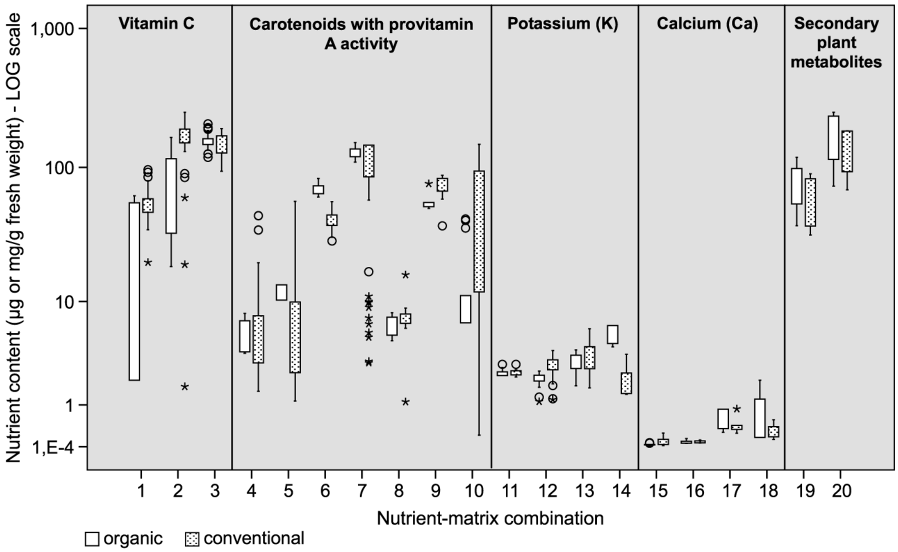
For each plant food and nutrient, the mean concentrations with standard deviations are tabulated for both farming systems (organic versus conventional) (see Table II). Statistical analysis revealed that the vitamin C concentration was significantly higher in organic tomato (154 mg/g FW) than in conventional tomato (142 mg/g FW) ($p < 0.05$, Mann-Whitney test). However, for carrots and potatoes significantly higher concentrations of vitamin C were found in the plant food coming from a conventional farming system (carrot: 57 mg/g FW, potato: 162 mg/g FW) than from an organic farm (carrot: 35 mg/g FW, potato: 80 mg/g FW) ($p < 0.05$, Mann-Whitney test).

When comparing the mean concentrations of β-carotene between organic and conventional vegetables, the organic vegetable consistently contained significantly higher concentrations of β-carotene compared to the conventional variant ($p < 0.05$, Mann-Whitney test), with the exception of lettuce where the difference was not significant, despite a similar tendency as observed for the other vegetable groups ($p = 0.056$, Mann-Whitney test). Opposite results were obtained for some other carotenoids with provitamin A activity, namely lycopene in tomato and lutein in lettuce and spinach (see Table II). The results, although not to be generalised for other compounds and vegetables, indicate that the organic vegetables contain significantly

Table II. Summary of nutrient concentrations (μg or mg/g fresh weight (FW)) in organic (O) and conventional (C) vegetables and potato (number of data points (n), mean, standard deviation (SD))

		Carrot		Tomato		Lettuce		Spinach		Potato	
		O	C	O	C	O	C	O	C	O	C
Vitamins											
Vitamin C (μg/g FW)	n	21	24	21	25	–	–	–	–	4	17
	Mean	34.97*	57.34**	153.71**	141.66*					80.48*	161.66**
	± SD	± 25.03	± 15.56	± 18.74	± 24.4					± 53.58	± 57.49
Carotenoids with provitamin A activity											
β-carotene (μg/g FW)	n	21	24	3	44	6	21	6	13	–	–
	Mean	130.42**	95.08*	12.30**	10.91*	5.79	7.92	70.55**	40.22*		
	± SD	± 10.90	± 46.61	± 1.45	± 13.91	± 1.61	± 9.01	± 7.40	± 5.91		
Lycopene (μg/g FW)	n	–	–	5	174	–	–	–	–	–	–
	Mean			13.80*	51.62**						
	± SD			± 11.46	± 43.50						
Lutein (μg/g FW)	n	–	–	–	–	6	8	6	12	–	–
	Mean					6.36*	7.53**	57.03*	76.59**		
	± SD					± 1.20	± 2.76	± 9.07	± 10.07		
Minerals											
Potassium (mg/g FW)	n	7	15	8	15	12	20	–	–	37	48
	Mean	2.07*	2.73**	2.41**	2.35*	5.24**	1.81*			3.08*	3.64**
	± SD	± 0.38	± 0.59	± 0.19	± 0.12	± 0.83	± 0.61			± 0.63	± 1.07
Calcium (mg/g FW)	n	8	16	10	17	14	22	–	–	0.04*	0.09**
	± SD	± 0.26	± 0.23	± 0.03	± 0.02	± 0.60	± 0.12			± 0.02	± 0.06
Secondary plant metaboplities (other than carotenoids)											
Chlorogebuc acid (μg/g FW)	n	–	–	–	–	–	–	–	–	7	8
	Mean									196.96**	139.09*
	± SD									± 60.50	± 44.16
Glycoalkaloids (μg/g KW)	n	–	–	–	–	–	–	–	–	9	11
	Mean									77.00**	58.07*
	± SD									± 28.34	± 23.11

Notes: *, ** indicate significantly different means for specific nutrient-matrix combination using Mann Whitney test ($\alpha = 0.05$); – indicates no result



Notes: 1: vitamin C in carrot; 2: vitamin C in potato; 3: vitamin C in tomato; 4: β-carotene in lettuce; 5: β-carotene in tomato; 6: β-carotene in spinach; 7: β-carotene in carrot; 8: lutein in lettuce; 9: lutein in spinach; 10: lycopene in tomato; 11: K in tomato; 12: K in carrot; 13: K in potato; 14: K in lettuce; 15: Ca in potato; 16: Ca in tomato; 17: Ca in carrot; 18: Ca in lettuce; 19: glycoalkaloids in potato; 20: chlorogenic acid in potato

Figure 1. Nutrient concentrations in different vegetables and potato, box plots

lower concentrations of the carotenoids than the conventional vegetable ($p < 0.05$, Mann-Whitney test).

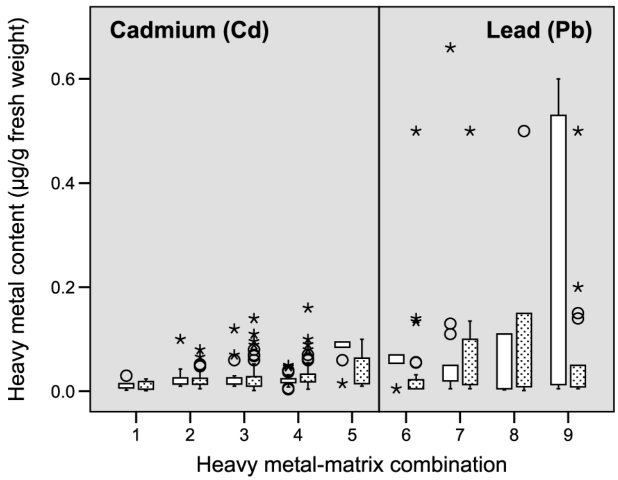
For the minerals K and Ca, significantly higher concentrations are observed in organic lettuce on one hand and in conventional tomato, potato and carrot (only for K) on the other hand ($p < 0.05$, Mann-Whitney test).

Finally, the content of some secondary plant metabolites (other than carotenoids) has been compared between organic and conventional potato (see Table II). Significantly higher concentrations of chlorogenic acid and glycoalkaloids were retrieved in the organic variant ($p < 0.05$, Mann-Whitney test). This observation is in line with the results of beta-carotene in carrot, tomato and spinach, but in contrast with those of beta-carotene in lettuce, lycopene in tomato, and lutein in lettuce and spinach. No specific reason could be identified.

Contaminants

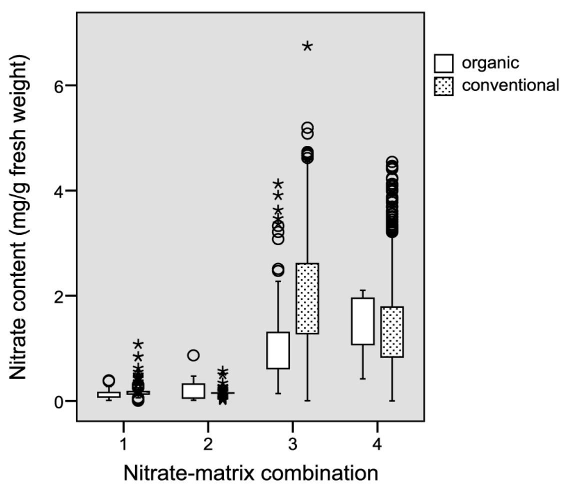
A second database was developed containing concentrations of nitrate, heavy metals (cadmium (Cd) and lead (Pb)) and synthetic pesticides in the same food matrices as for nutrients. Table I shows the different combinations that have been studied. In total, the contaminant database contains about 35,840 data points coming from 35 different data sources: ten peer-reviewed papers (including four paired studies), 23 reports and/or databases of governments and research institutes and two personal communications. The number of paired data points is about 123. For nitrate and the heavy metals Cd and Pb, the variability and some statistics (cfr. Methodology) are illustrated as box plots (see Figures 2 and 3).

Table I gives an overview of the number of pesticide concentration data (without weighing) above and below the limit of detection (LOD) and the mean concentration for organic and conventional vegetables and potatoes. Most of the collected data for synthetic pesticide residues were present at undetected levels (< LOD). In the case of organically grown foods, these *non-detects* (NDs) have been systematically replaced by zero, following the recommendation of the Office of Pesticide Programs (OPP) (US Environmental Protection Agency (US EPA), 2000). By law, organic foods are not to be



Notes: 1: tomato; 2,7: lettuce; 3,9: carrot; 4,8: potato; 5,6: spinach

Figure 2.
Heavy metal concentrations in different vegetables and potato, box plots



Notes: 1: potato; 2: carrot; 3: lettuce; 4: spinach

Figure 3.
Nitrate concentration in different vegetables and potato, box plots

treated with synthetic pesticides (European Communities (EC), 1991). For the pesticide-treated foods like conventionally grown vegetables and potatoes, OPP's preferred approach is to use a residue value of half LOD (or half LOQ (limit of quantification) if an LOD has not been determined) (US Environmental Protection Agency (US EPA), 2000).

Given the prohibition of using synthetic pesticides and synthetic fertilizers (containing nitrogen) in organic farming systems, it is reasonable to assume that organically grown foods will contain lower concentrations of synthetic pesticide residues and nitrates compared to conventionally grown foods. This assumption was supported in general by statistical analysis, with the exception of nitrate in spinach where the organic alternative contained significantly higher amounts of the contaminant (see Table I). The incidence of detectable residue levels of chloropropham in conventional potato is significantly higher than that of the organic variant ($p < 0.05, \chi^2$ test). More surprising is the significantly higher incidence of chlorothalonil in organic versus conventional potato ($p < 0.05, \chi^2$ test) although the concentration is significantly lower. The incidence of iprodione was significantly higher in conventional carrot, tomato and lettuce compared to the organic vegetable ($p < 0.05, \chi^2$ test). Nevertheless, when residues of pesticides are found in conventional vegetables and potatoes, they are well below the statutory maximum amount or maximum residue limit (MRL). For cadmium and lead, significantly higher or lower concentrations and even insignificant differences in concentrations were found depending on the food matrix (see Table I).

The nutritional-toxicological conflict

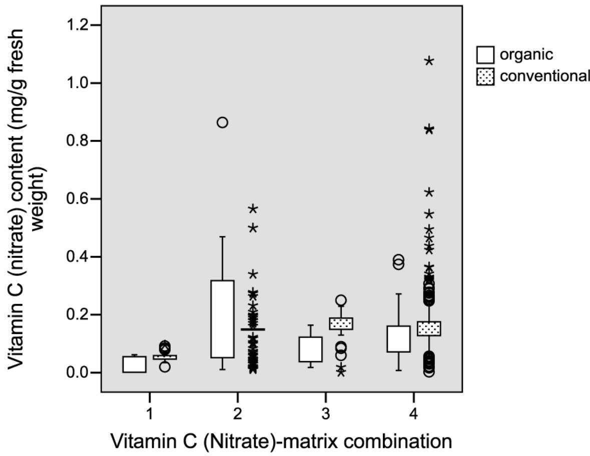
Vegetables and potatoes containing both beneficial nutrients and harmful contaminants can be considered as a conflict model between dietary recommendations and toxicological safety assurance. The nutritive and toxicological value of plant foods depends on numerous factors like the quality of the environment (air, water, soil and climate), cultivars, pest and disease incidence, and post-harvest practices (Holden, 2002; Zhao *et al.*, 2006; Rembialkowska, 2007). Extensive efforts have been made to understand the interactions between plants and their environment in order to explain the factors that influence plant composition. These efforts have resulted in two main theories, the carbon/nitrogen (C/N) balance theory and the growth/differentiation balance hypothesis (GDBH), which are applied to explain potential differences in the nutrient and contaminant content between organic and conventional foods (Brandt and Molgaard, 2001; Rembialkowska, 2007). The C/N balance theory states that plants will first synthesise components with a high nitrogen content (e.g. proteins for growth and N-containing secondary plant metabolites) when nitrogen is readily available. When nitrogen is limiting for growth, plants will rather make carbon-containing components (e.g. starch and non-N-containing secondary metabolites). The more general GDBH claims that plants, depending on the available resources, will optimise their investment in processes directed to growth or differentiation (e.g. increased formation of defence compounds).

From the previous theory it is expected that organic plant foods contain less nitrate and as such more non-N-containing secondary plant metabolites and vitamin C because of the replacement of synthetic fertilisers (N immediately available) by animal manure (N slowly released) in organic farming systems. Two conflict models have been worked out:

(1) Vitamin C versus nitrate in carrots and potatoes.

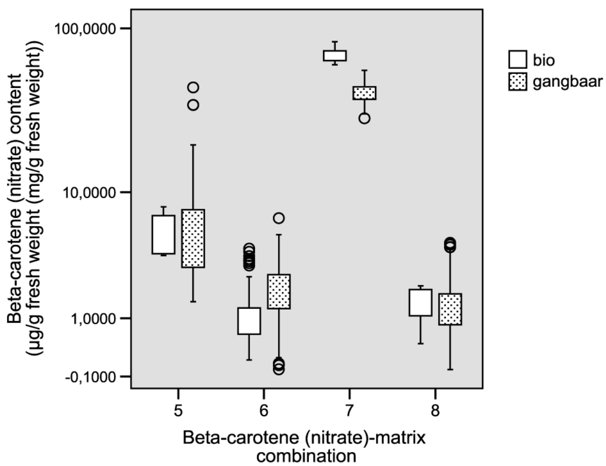
(2) β-carotene versus nitrate in lettuce and spinach (Figures 4 and 5).

When excluding outliers, the box plots of vitamin C and nitrate in organic carrots show respectively a downward and upward variation. This observation is in line with the previous theories. However, these theories are less strong in explaining the small,



Notes: 1: vitamin C in carrot; 2: nitrate in carrot; 3: vitamin C in potato; 4: nitrate in potato

Figure 4.
Vitamin C versus nitrate concentrations in different organic and conventional vegetables and potato, box plots



Notes: 1: β-carotene in lettuce; 2: nitrate in lettuce; 3: β-carotene in spinach; 4: nitrate in spinach

Figure 5.
β-carotene versus nitrate concentrations in different organic and conventional vegetables and potato, box plot

although significant ($p < 0.05$) differences in vitamin C and nitrate concentrations between the organic and conventional carrot. For potatoes a larger difference in nitrate content is observed, which is translated in a larger difference in vitamin C content. Following the theories, the higher nitrate content in conventional potatoes compared to organic potatoes should lead to a lower vitamin C content in the conventional versus organic potato, which is not the case. The second conflict model, illustrated in Figure 5, indicates a large within-product variation of β-carotene and nitrate in conventional lettuce with a significantly higher nitrate content but similar β-carotene content ($p > 0.05$) in conventional compared to organic lettuce. The results for spinach show significantly higher amounts of β-carotene and nitrate in the organically grown vegetable compared to the conventional variant. Both examples indicate a certain mismatch between theory and evidence.

Discussion

During the compilation of the nutrient and contaminant databases, several problems were encountered influencing the comparability of the concentration data within and between organic and conventional vegetables and potato. Potential solutions for the problems as a result of intra-variability of nutrient and contaminant concentrations (i.e. within a plant food) were proposed by Sioen *et al.* (2007a, b). In this paper a first attempt was made to filter out the intervariability in vegetable composition due to (interacting) confounding factors in order to have a good evaluation of the effect of farming system. The limited number of paired studies currently available necessitated inclusion of non (fully) paired data sources. Therefore, a weighing factor was introduced to enable distinction between data obtained from paired, semi-paired (not giving appropriate details) and non-paired studies. An additional problem was the selection of the value of the weighing factors. Here the weighing factors were arbitrary chosen as no validation method could be found in literature. The choice of allocating a higher weight to paired data compared to non (fully) paired data was trivial. In order to define standardised weighing factors and to create more uniformity and traceability in the evaluation of the data quality, it may be interesting for future research to adopt EuroFIR's (European Food Information Resource Network) system for quality index attribution to data from scientific literature or reports (Oseredczuk *et al.*, unpublished). The system is a quality evaluation system based on four categories:

(1) Food description.

(2) Component identification.

(3) Sample plan.

(4) Sample analysis.

Within each category a set of criteria is proposed and the scores for each criterion (5 for high quality, 3 for intermediate quality, and 1 for low quality) are summed to form the quality index belonging to a specific data point.

A final problem is related to the statistical treatment of concentrations below the limit of detection or quantification. In the present study the undetected data obtained from organic foods have been systematically replaced by zero and the data from conventional foods by half of the LOD (or one quarter of the LOQ). OPP generally recommends the use of a residue value of zero for the proportion of the data set corresponding to the percentage of the commodities known not to be treated with pesticides (US Environmental Protection Agency (US EPA), 2000). This proportion is clearly defined in the case of organic foods, but rarely known for conventional foods. Moreover, when the proportion of non-detects in a data set exceeds 50 per cent – as it is the case here – the handling of NDs should be considered on a cases-by-case basis (US Environmental Protection Agency (US EPA), 2000). As no general rule of thumb exists, it is useful to consider the potential effect of the substituted values by performing a sensitivity analysis. When comparing the results between different approaches, for example NDs = 0 versus NDs = half LOD for conventional samples, the number of significantly higher pesticide residue levels in conventional vegetables compared to organic vegetables decreases from 27 to three (of a total of 27). Whatever the approach, it should be recommended to inform the reader about the approach used in order to avoid wrong interpretations.

The primary aim of the meta-analysis was to map the potential differences in nutritional and toxicological value between organic and conventional vegetables and potatoes. The meta-analysis found that:

(1) Vitamin C concentrations were significantly higher in conventional carrots and potatoes, but significantly lower in conventional tomato compared to the organic product.

(2) The concentration of β-carotene in three of the four vegetables was significantly higher in the organically grown vegetable.

(3) The organic vegetables in contrast with organic potatoes had a significantly lower content of some secondary plant metabolites (except for β-carotene) compared to the conventionally grown food.

(4) For both minerals (K and Ca) various results were obtained.

(5) No trend was observed for the heavy metals Cd and Pb.

(6) Nitrate was present in significantly higher amounts in three of the four conventional foods (no data for tomato).

(7) Concentrations of synthetic pesticide residues were significantly higher in the conventional product but still lower than the statutory maximum amount.

Meta-analyses are performed on the basis of available scientific evidence, which is usually identified and compiled in a first phase by systematic reviews. Inconclusive findings observed in reviews concern especially the nutritional value (except vitamin C) of organic foods compared with conventional foods (Woese *et al.*, 1997; Brandt and Molgaard, 2001; Worthington, 2001; Bourn and Prescott, 2002; Magkos *et al.*, 2003; Rembialkowska, 2003).

Evidence-based communication is important in order not to mislead the consumer. Based on existing consumer science literature, it appears that consumers in general perceive organic foods as being healthier and safer (Bonti-Ankomah and Yiridoe, 2006). Present large-scale meta-analysis indicates, however, that scientific evidence is currently lacking to unconditionally recommend organically grown vegetables over conventional vegetables, especially in relation to the nutritional value. As a result, nutrition claims on organic vegetables and potatoes are considered not to be possible at the moment. The Food and Agriculture Organisation (FAO) (1999)) suggests that "organic" should be seen as a process claim, indicating to the consumer that a product was produced according to the organic regulation, rather than a product claim (including nutrition and health claims). More well controlled paired studies and a standardisation of the format for reporting are needed to determine which claims could possibly be made in the future. The question remains whether farmers will be able to control for all previously mentioned confounding factors.

Conclusion

In this literature comparison, evidence is provided that organically grown vegetables and potatoes in general contain significantly lower concentrations of synthetic pesticide residues and nitrates. On the other hand not enough evidence is available yet to conclude that organic farming usually enhances the nutritional value compared to conventional farming systems. Although conflicting messages are found between single research studies, our conclusions are in accordance with earlier made reviews. When looking at the effect of the farming system on the balance between nutrients and contaminants, no systematic trend is found as proposed in the C/N balance theory and the GDBH. Further research is recommended to understand better:

- the relative nutritional value; and
- the nutritional and toxicological conflict related to organic and conventional vegetables (and potatoes) and, as such, to come to evidence-based communication strategies for both farming systems.

In order to achieve this aim, more paired studies of high quality will be needed. Based on current findings, nutrient and/or contaminant comparative claims for organic vegetables cannot be scientifically proven.

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