



## Review article

# Nutritional quality and safety of organic food. A review

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**Abstract** – Food security, nutritional quality and safety vary widely around the world. Reaching these three goals is one of the major challenges for the near future. Up to now, industrialized production methods have clearly shown severe limitations such as a worldwide contamination of the food chain and water by persistent pesticide residues, and reduced nutrient and flavor contents through low-cost intensive food production and/or processing. In line with several published literature reviews, the French Agency for Food Safety (AFSSA) performed under my coordination an up-to-date exhaustive and critical evaluation of the nutritional and sanitary quality of organic food. This review is based on the AFSSA report issued and recently published studies. The major points are: 1/ organic plant products contain more dry matter and minerals (Fe, Mg); and contain more anti-oxidant micronutrients such as phenols and salicylic acid, 2/ organic animal products contain more polyunsaturated fatty acids, 3/ data on carbohydrate, protein and vitamin levels are insufficiently documented, 4/ 94–100% of organic food does not contain any pesticide residues, 5/ organic vegetables contain far less nitrates, about 50% less; and 6/ organic cereals contain overall similar levels of mycotoxins as conventional ones. Thus, organic agricultural systems have already proved able to produce food with high quality standards. I propose also improvements of organic production to achieve sustainable food production for humans in the near future.

**sustainable agriculture / organic agriculture / human food / nutrition / food safety / contaminants / health**

## 1. INTRODUCTION

While mass foodstuff production was achieved in industrialized countries during the twentieth century, the limitations of such an intensive production system have been highlighted for decades by ecologists and numerous agronomists, nutritionists and medical doctors. Briefly, great concern has been caused by high energy and chemical inputs, worldwide contamination of the food chain and water by persistent pesticide residues and nitrates, and the reduced nutrient and flavor contents through low-cost and intensive food production and extensive milling or processing. Only recently has the combined awareness for environment protection, food safety and security and well-being markedly raised public concern and demand for ecologically grown staple foods (El-Hage Scialabba, 2007; Niggli et al., 2007). For developing countries, concern is also focused on the appropriate way to ensure present and future food security, the number of malnourished and undernourished people approaching one billion worldwide, with no decreasing trend for the coming decade (FAO, <http://www.fao.org>). Worldwide, emphasis is increasingly being put on the relationship between food, nutrition and health (WHO, 2004; WCRF, 2007).

In fact, the nutritional and toxicological value of food produced under methods of ecological agriculture has long been a matter of interest and debate. Despite the potential importance of this topic for human well-being, only a limited number of studies have been specifically carried out due to the past general lack of consideration of alternative and sustainable methods of food production. During the last few decades, several literature reviews have already been performed and published in this field (Schuphan, 1974; Finesilver et al., 1989; Lairon et al., 1984a; Woëse et al., 1997; Worthington, 1998; Food Standards Agency, 2000; Soil Association, 2001; Brandt and Mølgaard, 2001; Bourn and Prescott, 2002). Our AFSSA report was issued in 2003 (AFSSA, 2003) and some new reviews have recently been published (Magkos et al., 2006; Winter and Davis, 2006; Rembialkowska, 2007). In most cases, these reviews have used data from original studies or previous reviews without true consideration of the quality of the data. The conclusions derived can somewhat differ but they generally highlight some benefits from organic agriculture.

In 2001, the French Agency for Food Safety (Agence française de sécurité sanitaire des aliments (AFSSA), <http://www.afssa.fr>) aimed to perform an exhaustive and critical evaluation of the nutritional and sanitary quality of organic food. To this aim, an expert working group was set up under

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my coordination. We aimed to reach the highest quality standard during our evaluation. We thus defined inclusion as well as exclusion criteria for use of original publications. Briefly, selected papers should refer to well-defined and certified organic agricultural practices, and have necessary information on design and follow-up, valid measured parameters and appropriate sampling and statistical analyses. After more than two years of work involving about 50 experts from all specific areas including organic agriculture, a final consensus report was issued in the French language in 2003 (AFSSA, 2003). The present review paper is a summary of this report including some updating and some more personal suggestions.

In all circumstances, organic agriculture is first defined as by the European Union regulation (CCE/2092/91 and CE/1804/99) and secondly by the French regulation for animal productions. To summarize, the main characteristics of the organic agriculture production system are respect for the environment and animals, promotion of sustainable cropping methods, use of non-chemical fertilizers and pest/disease/weed control means, production of high-quality foodstuffs and no use of genetically modified (GM) crops.

The limit of such an evaluation is the insufficient number of studies published in this area. For some aspects, the available studies allow one to reveal some trend or conclusion. In some others, too limited information of sufficient quality hinders any sound assessment.

In the first part of this review, the nutritional value of organic food will be described comparatively with that of conventional food. This includes the dry matter contents of fruit and vegetables, macronutrients, minerals and vitamins in various staple foods, and phyto-microconstituants, especially antioxidants. In the second part, sanitary properties of organic foodstuffs will be reported. Contaminations by pathogenic microorganisms, phytochemical contaminants or mycotoxins, and nitrate levels are reported. In the Conclusion, the main data obtained are discussed in the context of sustainable agriculture development, with some specific suggestions for further improving food quality.

## 2. NUTRITIONAL QUALITY OF ORGANIC FOODSTUFFS

### 2.1. Dry matter content

The available data mostly refer to vegetables and fruit. For leafy vegetables as well as root vegetables and tubers, a trend for higher dry matter contents in organic foodstuffs has been found while no significant difference has been identified for fruit vegetables and fruit (Woëse et al., 1997; Bourn and Prescott, 2002; AFSSA, 2003).

### 2.2. Macronutrient contents

Data regarding the levels of starch and carbohydrates in organic food are too limited to allow any conclusion.

For protein levels, it has been reported that organically-grown cereals, especially wheat, can have comparable protein levels with conventional ones (Shier et al., 1984) but generally have somewhat lower levels of protein than the conventional ones (Woëse et al., 1997). Nonetheless, it is noteworthy that the cultivars selected by organic farmers are mostly high-protein ones (e.g. for bread-making) and that optimized fertilization practices can maintain reasonably high protein levels. Moreover, a 25–30% increase in lysine has been reported in organic wheat (Wolfson and Shearer, 1981; Brandt et al., 2000). Comparative studies performed on hen eggs (Kouba, 2002) and raw cow's milk (Toledo et al., 2002) did not show any noticeable difference in protein levels.

For lipids, few studies have compared the total lipid content of beef, pork or chicken meat (Pastshenko et al., 2000; Hansson et al., 2000; Hönikel, 1998; Fischer, 2001; Castellini et al., 2002). It is acknowledged that meat from cows and sheep contains less fat when animals are fed with grass rather than concentrate. In that line, a study conducted in Sweden showed that organically-bred cows have more lean meat than their conventional counterparts (Hansson et al., 2000). This was not found in pigs (Sundrum et al., 2000). More qualitatively, feeding cows with grass compared with concentrate led to a four-fold higher muscle content of linolenic acid, a recommended essential fatty acid of the n-3 series, with a concomitant decrease in oleic and linoleic acids (Nuernberg et al., 2002). Meat from organically-grown cows has more polyunsaturated fatty acids (Pastshenko et al., 2000). Castellini et al. (2002) showed that chickens of the same strain raised under an organic husbandry system have meat containing two- to three-fold less abdominal fat with 2–3 times less fat in the filet and 1.8 times less fat in the leg. Moreover, the n-3 fatty acid content in the filet was significantly higher with no difference for saturated fatty acids.

The total milk fat was not overall different, while some studies highlighted the higher levels of polyunsaturated fatty acids (Lund, 1991). Clearly, cow diet is a determinant of tissue and milk fatty acid levels, grazing or ingesting silages modulating the levels of polyunsaturated fatty acids as well as trans-fatty acids and conjugated linoleic acid (Ferlay et al., 2006).

A single study has shown that organic virgin olive oil has a higher oleic acid level (Gutierrez et al., 1999).

### 2.3. Mineral contents

The most important mineral elements are calcium (Ca), magnesium (Mg), potassium (K), iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), selenium (Se) and iodine (I). Phosphorus (P) and sodium (Na) are generally found in sufficient quantity.

Fruit and vegetables. 22 scientific publications were considered in the AFSSA report (2003). Regarding fruit, and especially apples, it is noteworthy that the mineral composition is generally not noticeably altered by the production system. Regarding vegetables (potato, carrot, beetroot, lettuce, kale, leek, turnip, onion, celeriac and tomato), a trend has been observed for higher levels of iron and magnesium expressed on a

fresh matter basis in organic foodstuffs, with no other marked change.

Cereals. From two long-term fertilization trials, it appears that the mineral composition (P, K, Ca, Mg, Mn, Zn, Fe, Cu and Cr) of cereals is not markedly affected by the cropping regime (Miller and Dema, 1958; Morel et al., 1984). Another study did not show any marked difference but a trend for higher levels of Ca, Cu and Zn in organic barley (Alföldi et al., 1996).

In a recent review (Rembalkowska, 2007), it was estimated that organic crops overall contain 21% more iron and 29% more magnesium than their conventional counterparts.

Animal products. Very limited information is available. For milk, an evaluation of three different studies did not allow the identification of a difference due to the husbandry system. The same conclusion was reached by Woëse et al. (1997) from four comparative studies performed on meat. Nevertheless, it has been clearly shown that chickens grown in open fields compared with housing have somewhat higher iron levels (Castellini et al., 2002).

## 2.4. Vitamin contents

The number of studies dedicated to vitamin contents is limited to some fruits and vegetables and eggs. Regarding water-soluble vitamins, the most studied one has been Vitamin C (ascorbic acid), a key vitamin for which higher daily intakes are recommended. Studies performed on potato (Fischer and Richter, 1986; Kolbe et al., 1995), tomato (Pither and Hall, 1990; Caris-Veyrat et al., 2004), celeriac (Leclerc et al., 1991) and kale showed higher vitamin C levels in organically-grown products. In contrast, no difference was found during studies in leek, carrot or beetroot. A study on apple did not show any difference either (Weibel et al., 2000). Very sparse and inconclusive data have been published on vitamin B1 and B2 levels.

Fat-soluble vitamin and carotenoid contents have been the subjects of some studies. A higher vitamin E level in organic olive oil has been found in one study (Gutierrez et al., 1999). A review by Woëse et al. (1997) related 27 studies reporting on  $\beta$ -carotene levels in vegetables and no noticeable differences were found overall between organic and conventional foodstuffs. Brandt and Mølgaard (2001) reported a positive relationship between N-fertilization and  $\beta$ -carotene levels in carrots, while a recent study on organic vs. conventional tomatoes showed higher contents of  $\beta$ -carotene (Caris-Veyrat et al., 2004). Another report (Martin et al., 2002) has shown that a grass-rich regimen compared with a maize silage or concentrate generates milk with a higher vitamin E and  $\beta$ -carotene content.

## 2.5. Other phytonutrients

Fruit and vegetables contain a large variety of microcompounds which are secondary metabolites in plants such as polyphenols, resveratrol and some non-pro-vitaminic carotenoids. These compounds have increasingly been shown

to have drastic regulatory effects at cellular level and are thus involved in prevention of certain diseases such as cancers, chronic inflammation and other pathologies. Some of them are phytoalexins which are produced in plants as a response to external stress such as fungal disease. While several factors can modulate their plant level such as cultivar, maturity, light or temperature, some studies have compared the levels of some of these phyto-microcompounds in fruit or vegetables depending on the cropping system. For phenols and polyphenols, a majority of studies showed higher levels in organic foodstuffs such as apple (Lucarini et al., 1999), peach (Carbonaro et al., 2002), pear (Carbonaro et al., 2002), potatoes (Hamouz et al., 1999), onion (Ren et al., 2001), tomato (Mitchell et al., 2007), pepper (Pérez-López et al., 2007), orange (Tarozzi et al., 2006) and olive oil (Gutierrez et al., 1999), while some others did not show any difference. It has been estimated in a recent review (Rembalkowska, 2007) that organic plant foods overall contain double the amount of phenolic compounds. One study reported higher levels of resveratrol in organic wines (Levite et al., 2000).

The median contents of salicylic acid in organic vegetable soups were significantly higher (117 vs. 20) than in the compared non-organic ones (Baxter et al., 2001). Organically-grown tomatoes also have a higher salicylic acid content than conventional ones (Rossi et al., 2008). It is noteworthy that salicylic acid is the active anti-inflammatory compound of aspirin.

While some better anti-oxidant and anti-proliferative positive effects on cancer cells have been observed with organic vs. conventional extracts (Tarozzi et al., 2006; Olsson et al., 2006) the effects of chronic diets in humans have yet to be fully investigated (Grinder-Pedersen et al., 2003).

Table I highlights the key items of nutritional and sanitary value of organic compared with conventional food.

## 3. SANITARY ASSESSMENT OF ORGANIC FOODSTUFFS

Risk assessment is a scientific approach aiming at identifying known hazards and related risks. Contaminations by bacteria, viruses, worms, mycotoxins and agro-chemicals are mainly involved. Not all aspects have yet been comparatively studied such as hazards due to viruses or worms. We will therefore take some relevant examples on other aspects based on more reliable information.

### 3.1. Pathogenic microorganisms

Plant products. Concern has been raised by the EU Scientific Committee on Food on the possible contamination of fruit and vegetables by sewage sludges, animal manures or irrigation waters (SCF, 2002). Indeed, they can provide pathogenic microorganisms such as bacteria pathogenic to humans (Strauch, 1991), *Listeria monocytogenes* (Van Renterghem et al., 1991) or *Salmonella sp.* (Warnick et al., 2001). In fact, sewage sludges are not allowed for use in organic agriculture and fresh manures are not used as such for fertilization

**Table I.** Key items of nutritional and sanitary value of organic compared with conventional food.

Increased contents	Reduced contents	Comparable contents
Dry matter in vegetables	Pesticide residues in all food (mostly absent)	Mycotoxins in cereals & milk
Some minerals (iron, magnesium) in vegetables	Nitrates in vegetables	Most minerals in fruit, vegetables & cereals
Anti-oxidants in crops: Vitamin C (potatoes) Polyphenols in fruit & vegetables, Salicylic acid in vegetables		Beta-carotene in fruit & vegetables
Polyunsaturated fatty acids in meat and milk	Saturated fatty acids in meat	
Most nutrients in wholegrain organic cereals and derivatives	Protein content in grains	

but composted for variable periods of time. It has been shown that the aerobic composting process, including a high temperature phase, has the capability of markedly reducing or fully eliminating the pathogenic microorganisms initially present such as *Salmonella Enteritidis* or *E. coli* (Lung et al., 2001; Droffner and Brinton, 1995; Vuorinen and Saharinen, 1997; Tiquia et al., 1998). This could be less efficient in eliminating *Clostridium botulinum* (Bohnel and Lube, 2000). In addition, when added to the soil, the exogenous bacteria are quickly eliminated due to unfavorable conditions (Van Renterghem et al., 1991; Dowe et al., 1997). In conclusion, it appears that the systematic use of aerobic composting is a suitable way to maximize the hygienic properties of organic fertilizers, and thus to avoid significant contamination of organic foodstuffs by pathogenic microorganisms.

**Animal products.** A survey conducted in Austria (Zangerl et al., 2000) evaluated the degree of bacterial contamination of dairy products using two indicators (*E. coli* and *S. aureus*) and did not find different levels in organic or conventional foodstuffs. Another survey conducted in France (Echevarria, 2001) in 1997–99 in four different regions also found comparable levels for total bacteria count or butyric microorganisms in milks produced with the two husbandry systems. In fact, the limited use of silage in organic husbandry could be beneficial for reducing the possible contamination of ruminant feed by *Listeria monocytogene E. coli* O157s (Herriott et al., 1998). In contrast, a Danish study reported that about 100% of poultry samples were contaminated by *Campylobacter* sp in organic farms, whereas 36–49% of samples in conventional farms were (Heuer et al., 2001).

To summarize, there is no convincing information indicating that organic foodstuffs can be differently contaminated than conventional ones. This is likely the result of efficient preventive measures. Enteric viruses from five families (*Picornaviridae*, *Caliciviridae*, *Astroviridae*, *Reoviridae* and *Adenoviridae*) are known to be harmful to humans but there is a lack of comparative studies on this aspect.

### 3.2. Phytochemical contaminants

The banned use of toxic chemical pesticides, fungicides and herbicides in organic agriculture systems is clearly a gold standard in terms of protection of land workers' health and

environment biodiversity and well-being. Anyway, the question has repeatedly been raised of the level of contamination of organic foodstuffs by environmental pollution. Several surveys have been dedicated to this matter. The SETRABIO survey (SETRABIO, 2000) was conducted in France in 1993–99 on 15,772 samples of raw or processed foodstuffs, mostly cereals. 94% of organic samples were devoid of any contaminant residue while 3.3% only contained levels clearly above the detection level but far less than legal maximum levels. During the years, a trend has been observed for diminishing contamination levels (i.e. 1.7% in 1998–99 vs. 4.4% in 1993–97). The French DGAL/COOPAGRI/ESMISAB survey (2001) was then conducted in 1999–2001 on 1500 samples. No residue of 78 potential phytochemical contaminants was detected.

Another study performed on vegetables and strawberries in Sweden did not show any contamination of organic ones, while 17–50% of conventional ones contained residues (Bourn and Prescott, 2002). Results from the monitoring of pesticide residues in fruit and vegetables on the Danish market in 2000–01 found that only 2.8% of organic samples were contaminated by pesticide residues, all being below the MRL (Poulsen and Andersen, 2003). A recent survey conducted in Italy in the 2002–2005 period on 3500 samples of food of plant origin concluded that the vast majority (97.4%) of organic farming products do not contain detectable pesticide residues (Tasiopoulou et al., 2007).

In contrast, it is known that a large proportion of usual foodstuffs are contaminated by phytochemical residues. This has clearly been shown by the recent reports by the EU DG SANCO for 2001 and 2005. The 2005 report (DG SANCO, 2007) was based on 62 500 samples collected in EU member states and analyzed for 706 chemicals. 41% of samples were shown to be contaminated, with 4.7% of samples with levels above the legal maximum levels (MRL).

In fact, all these phytochemicals have been fully or permanently authorized for use and residue levels considered harmless have been set up on the basis of available toxicity data. Because these molecules have a high toxic capacity (including mutagenesis and carcinogenesis) and the long-term effects of chronic low-dose ingestion are not known in humans, the consumer and scientific concern about possible health damage is real. The EU REACH project is aimed at better evaluating

their toxicity and deleting the most risky ones. In that context, organic products clearly show a real advantage.

It is worthwhile mentioning that some natural extracts are used in organic agriculture for pest and disease control such as pyrethrins, rotenone, copper salts and sulfur. The first two are quickly degraded in the fields and no contaminations of foodstuffs have been observed (Moore et al. 2000). Regarding copper and sulfur, their use is limited to surface spraying and copper amounts have been progressively reduced. Contamination levels have not been investigated.

### 3.3. Mycotoxins

Mycotoxins are a large family of toxic molecules synthesized by molds developing on plants such as *Aspergillus*, *Penicillium* and *Fusarium*. Most are highly toxic and heat-resistant and can be transferred along the alimentary chain from plants to animals then human food. The most recognized in terms of public health hazard are aflatoxins, Ochratoxin A (OTA), Fumonisin, Deoxynivalenol (DON), Patulin and Zearalenone. Overall, they display strong harmful effects such as immunotoxicity, teratogenesis, embryotoxicity, nephrotoxicity and liver cancerogenesis. They all have very low legal maximum levels in food (0.1–2 ppb/kg body weight).

Given the lack of use of chemicals (including chemical fungicides) in organic production, the question has been raised of a possible high level of contamination of organic productions. Several surveys have been conducted to test this hypothesis. A study in Germany was conducted on cereals in 1997–98 (Birzele et al., 2000), indicating that most organic samples were contaminated by DON and a minority by OTA, but that conventional samples were comparably contaminated. A French study searched for contamination of cereals by several mycotoxins and observed that conventional ones were frequently contaminated at low levels while organic ones were less frequently contaminated but at high levels in a few cases (Malmauret et al., 2002). Wheat contamination has also been tested in a controlled DOC trial in Switzerland with mean DON levels of 74 ppb in organic and 109 ppb in conventional wheat (Kuhn, 1999). A study in Denmark (Jorgensen et al., 1996) showed a trend for higher mean OTA levels in organic cereals but with the highest levels recorded in conventional ones. A recent study showed that organic wheat was less contaminated by *Fusarium* and contained less ZEN and DON than conventional wheat: when fed to pigs, the bile samples from organically-fed pigs contained lower concentrations of ZEN (Schneweis et al., 2005).

Some other studies have been conducted on wheat flour, providing comparable or lower levels of mycotoxin contamination for organic flour. Finally, processed cereal products such as bread, muesli and biscuits have been tested (Parent-Massin et al., 2002). Overall, almost half of the organic products were found to be contaminated to variable degrees but no comparison was made with conventional ones. When a comparison was made, lower levels of contamination were found in organic ones (Usleber et al., 2000). No marked differences in OTA levels were found in cereal derivatives in

Italy (Biffi et al., 2004) or in cereal-based baby food (Beretta et al., 2002). Two studies have observed lower levels of aflatoxin in organic milks compared with conventional ones (Gravert et al., 1989; Frank Hansen, 1990), whereas another one found some high levels in organic milk (Ghidini et al., 2005). Organic beers collected in Belgium during 2003–2004 were more frequently OTA-contaminated than their conventional counterparts but this difference was not found in 2005 (Anselme et al., 2006). Contamination of beers by DON was marginal.

In conclusion, contamination of foodstuffs, especially cereals, is widespread but at a low level and an organic or conventional mode of production do not lead to overall noticeable differences. In fact, the preventive measures used in organic systems, despite the non-use of fungicides, appears generally able to maintain contamination at a low level.

### 3.4. Nitrates

Nitrates are a matter of concern for public health due to their easy transformation into nitrites. Nitrites are highly reactive molecules capable of i/ competing with oxygen in blood circulation for binding to hemoglobin, thus leading to methemoglobinemia and possible anoxia and, ii/ binding to secondary amines to generate nitrosamines which are among the most powerful natural cancer-promoting moieties. For that reason, maximum daily intakes for nitrates (3.7 mg/kg body weight) and nitrites (0.07 mg/kg body weight) have been set up by the FAO/OMS JECFA, along with a maximum nitrate level in drinking water (50 mg/L).

In the human diet, about 80% of nitrates are provided by vegetables, while nitrate levels in fruits, cereals and legumes are very low (French Inventaire National de la Qualité Alimentaire, 1982; Stopes et al., 1988; Cornée et al., 1992). Animal products contain very low levels of nitrates while processed meat can contain added nitrites as a preservative.

Nitrates are naturally present in plants; they are absorbed through the roots and further used for amino-acid synthesis. They can accumulate in plant tissues, especially in vegetables. Several comparative studies have been performed on nitrate levels in vegetables.

At the level of a retail shop, we performed a study on five vegetables in spring and observed significantly lower nitrate contents (–28 to –85%) in organic potato, leek, turnip and salad but not in organic kale (Lairon et al., 1982). A comparable study performed in Austria on 17 vegetables found lower nitrate contents (–40% to –86%) in organic ones except in spinach (Rauter and Wolkerstorfer, 1982). In Germany, a comparison on carrots showed 61% less nitrates in organic ones (Pommer and Lepshy, 1985).

At farm level, by comparing designated crops on matched farms, three studies provided interesting data. We performed one in Provence (Lairon et al., 1985) and found in the organically-grown samples –39% nitrates in lettuce, –46% in potato, –22% in carrot and a higher content in one sample for leek. In Switzerland, organic lettuces grown over two years contained 2.5 times less nitrates than their conventional counterparts in May–June, 1.2 times less in October

**Table II.** Key aspects of a sustainable organic food chain.

Agricultural management	Food production	Food access and security	Food quality	Consumer attitude
Soil fertility management	Reliable certification	Fair trade	High sensory value	Confidence
Preventive crop protection	Sustained optimal yields	Local food access	High nutrient content	Appropriate awareness and demand
Animal welfare			Controlled pathogens	
Environment and biodiversity protection	Low inputs	Optimized supply chain	No pesticide residues	Health protection
Farmer well-being	Sufficient income	Affordable retail price		Sustained well-being

and comparable high levels in November (Temperli et al., 1982; Vogtmann et al., 1984). In contrast, two other studies performed on tomato in Israel (Basker, 1992) and carrot in Norway (Hogstad et al., 1997) did not show noticeable differences.

Fertilization trials have also been designed to compare the effects of fertilization regimes on nitrate contents in vegetables. Overall, composts compared with chemical fertilizers lead to lower nitrate accumulations in most vegetables such as lettuce, potato, carrot, turnip, leek, beetroot and spinach (Lairon et al., 1984a, 1984b; Mäder et al., 1993) while an absence of difference can also be found on a few occasions (Vogtmann et al., 1984). Nitrogen-rich organic fertilizers can also generate lower nitrate contents, but when mineralization conditions are very favorable they can also lead to high nitrate accumulations (Lairon et al., 1985; Termine et al., 1987). Finally, it is noteworthy that some natural nitrogen-rich fertilizers such as Chili sodium nitrate can stimulate nitrate accumulation in sensitive vegetables (Lairon et al., 1984b). Indeed, it is clear that the level of nitrate in vegetables results from nitrogen availability for roots, temperature, light exposure, and cultivars and species. The use of organic fertilization with slowly or moderately available nitrogen (especially composts) is key to explaining the generally observed lower nitrate accumulation in organic vegetables.

From the above data, it appears that depending on seasons, organic vegetables can overall contain at least 30–50% less nitrates than conventional ones. Because the habitual average level of nitrate intake is in the range 120–280 mg/d (French Inventaire National de la Qualité Alimentaire, 1982; Cornée et al., 1992; Stopes et al., 1988) and close to the maximum daily dose defined by the FAO/OMS JECFA (i.e. 220 mg/60 kg person), and a marked increase in vegetable and fruit consumption is widely recommended (WHO, 2004; PNNS, 2001), organic vegetables can make this recommended increase safer regarding the nitrate issue.

#### 4. CONCLUSION

The present review based on available scientific literature highlights that organic plant products tend to have more dry

matter, some minerals (Fe, Mg) and anti-oxidant micronutrients (phenols, resveratrol) while animal organic products have more polyunsaturated fatty acids. Regarding safety issues, the vast majority (94–100%) of organic food does not contain any pesticide residues, organic vegetables contain markedly less nitrates (about half) and organic cereals contain overall comparable levels of mycotoxins with conventional ones. The conclusions of this new review are in line with those of most reviews published on this matter.

This critical literature review indicates that organic agriculture, as developed until now, has the potential to produce high-quality products with some relevant improvements in terms of contents of anti-oxidant phytomicronutrients, nitrate accumulation in vegetables and toxic phytochemical residue levels.

After decades of smooth increase in organic production, a sharp rise in consumer demand and producer awareness is occurring now. The nutritional and toxicological data I reported here should encourage such a new trend. Indeed, I think that organic agricultural systems, recently recognized as highly efficient and sustainable ones (El-Hage Scialabba, 2007), are now facing the challenge of turning from a “niche” into a potential long-term worldwide impact. This implies a global development strategy for a sustainable organic food chain as summarized in Table II. To successfully achieve this goal new and significant support for the development of these sustainable systems should be raised. For instance, raising new cultivars and crops suited to low-input systems and more resistant to diseases, along with optimized nutrition value, is one of the biggest challenges for future sustainable agriculture worldwide. This may be performed in the context of sustained biodiversity rather than GM productions, which are not allowed in organic/ecological farming systems. Regarding nutritional aspects, I suggest that several research lines are developed in the near future to improve sustainable food production systems such as increasing the levels of dry matter in foodstuffs to optimize nutrient density and intakes, increasing the levels of recommended n–3 fatty acids and lower saturated ones, increasing levels of limiting minerals, vitamins and anti-oxidants, improving the taste and flavor of fruit and vegetables to stimulate awareness, developing the use of wholemeal/partly-refined cereal flours rich in fibers and

nutrients and the sourdough fermentation process for optimized nutritional efficiency, further limiting accumulation of nitrates in vegetables and mycotoxins in cereal products, and improving producers', consumers' and stakeholders' knowledge in the food production-diet-health chain.

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