Organic vs conventional plant-based foods: A review

Organic *vs* conventional plant-based foods: a review

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Abstract

Organic farming is characterized by the prohibition of the use of chemical synthetic fertilizers, pesticides, feed additives and genetically modified organisms and by the application of sustainable agricultural technologies based on ecological principles and natural rules. Organic products are believed to be more nutritious and safer foods compared to the conventional alternatives by consumers, with the consequent increase of demand and price of these foodstuffs. However, in academic circles there is much debate on these issues, since there is not a clear scientific evidence of the difference on the environmental impact and on the nutritional quality, safety and health effects between conventional and organic foods. Therefore, this work aims to describe and update the most relevant data on organic foods, by describing the impact of this practice on environment, producers, consumers and society, as well as by comparing the physicochemical, nutritional and phytochemical quality of conventional and organic plant foods.

Keywords: environmental impact; nutritional quality; residues; safety; sustainability.

1. Introduction

Food security, nutritional quality and safety are three of the main goal to reach for the next near future worldwide. Plants-derived foods are important ingredients of the human diet, and are consumed either as direct source of nutrients, or indirect when used to feed comestible animals. Global agriculture is facing the pressure to produce at higher and higher rates to feed over 7 billion people, and during the last past years its goal has been to increase the yield of the plants to fulfill the food needs of the growing world population; however, this is also a leading cause of environmental degradation and considerably contributes to greenhouse gasses emission (Clark & Tilman, 2017). To face this increasing demand pressure, intensive production methods have been set, but they clearly showed severe limitations, such as the contamination of the water and food chain by impacting soil fertility, increasing pesticide residues, and decreasing crop productivity and quality, through intensive low-cost food production and processing which reduce flavor and nutrients contents (Lairon, 2010). In response to this over-exploiting of the environmental resources by agricultural intensification, the concept of sustainable agriculture has become of primary importance in policy, research, and practice. The main aims of sustainable agriculture are to balance the environmental, social, and economic aspects of farming, and to create a farming system that could be resilient in the long term . Its key challenge is to increase the production of foods and feeds with minimal environmental impacts, in terms of nutrient leaching, biodiversity loss, greenhouse gasses emissions, and resources exhaustion (Schrama et al., 2018). The understanding of how alternative sustainable agricultural systems, food choice, and agricultural input efficiency could positively affect environmental degradation is a key point for reducing the environmental impacts of agriculture (Clark & Tilman, 2017). Furthermore, new consumer awareness of environment- friendly production techniques is also shifting agriculture towards more sustainable practices, creating a virtuous cycle between producers and consumers enabled by eco-labelling. Eco-labelling gives information to the consumers on specific characteristics of products and is being used to market eco-friendly products. In particular, in the food industry, eco-labelling has been mostly focused on the promotion of organic farming, which limits the scope to the impact of the agricultural stage of the supply chain. These labelling strategies increase the value of the products , at the expense of other sustainable systems which are trying to achieve the same sustainability goals, but are not associated with a product label. Suffice it to say that Integrated Pest Management (IPM), an ecosystem approach to producing healthy crops and protecting them while minimizing the use of pesticides, is promoted by FAO as a preferred approach to crop protection and is considered a pillar both for the sustainable intensification of agricultural production and for the reduction of pesticide risk (http://www.fao.org/agriculture/crops/core-themes/theme/pests/ipm/en/), but it is not associated with a product label.

Organic farming is commonly thought to consist of few sustainable agricultural practices, which reduce the environmental impact of agriculture and preserve the naturalness of the food products (Pacifico & Paris, 2016). There are different interpretations of what "organic" means by different players in the sector (Seufert et al., 2017). Primarily, organic farming has been proposed as a holistic and alternative production system that does not allow the use of artificial synthetic pesticides, fertilizers, growth hormones, livestock feed additives and genetic engineering products (Yu, Guo, Jiang, Song, & Muminov, 2018).

There is currently a large body of published research on the technical, economic, political, and social aspects of organic production, supporting the evidence that organic farming is one of the fastest growing sectors of world agriculture. It has been adopted in approximately 186 countries, covering a total area of 71.5 Mha worldwide (Ramakrishnan et al., 2021). Although it represents only 1% of the world's agricultural area (Figure 1), organic label is one of the most recognized in food-products, being sustained by a strong marketing policy , having as a result that the current demand of organic food in developed countries involves more and more people (Seufert et al., 2017).

In addition, over the past 20 years, a dramatic increase in published research on organic farming reflects the existence of political support and also the availability of government funding for organic farming in some countries. This has led to an expansion of organic research from privately funded research organizations to traditional universities and research institutes. In parallel, the publication of research results on organic farming has increasingly appeared in the most available literature sources for farmers and consultants as well as in the referenced literature (Watson et al., 2008).

Finally, in recent years consumers have become more and more aware of the importance of adopting a healthy diet to maintain a good well-being and prevent the onset of the most common diseases, including cancer and cardiovascular disorders. Consequently, they have started looking for safer and healthier products, shifting their attention also to organic grown foods . O rganic vegetables and fruits are expected to possess lower agrochemical contaminants and higher macro-, micronutrients and bioactive compounds than conventionally grown substitutes. However, the scientific evidence provided to support this assumption is still inconclusive and in most cases contradictory, due to the lack of adequate, well-planned comparative data (Magkos, Arvaniti, & Zampelas, 2003).

Lastly, from the point of view of health advantages, until now, there are no well-designed studies demonstrating the health or the disease-preventive properties of organic diet compared to conventional diet, as well as there are no studies reporting any disease-promoting or detrimental effects exerted by organic products (Forman & Silverstein, 2012). While, on the contrary, because of the communication strategies based on the assumption of the high benefits for the consumers, organic products can cost up to 40% more than traditional foodstuff (Forman & Silverstein, 2012).

This review aims to summarize and update relevant data on organic farming, by describing the impact of this practice on environment, producers, consumers, and society, as well as by comparing the physicochemical, nutritional and phytochemical quality of conventional and organic plant foods.

2. Material and methods

A comprehensive search was done, using electronic databases, including Medline, Scopus, Google Scholar, Web of Science. The list of the keywords used for the manuscript search is shown in supplementary material. Hundreds of studies were found according to the literature search. The references were selected according to their relevance in the literature (journal's impact factor, number of citations, year of publication), and their representativeness of as much plant-based foods as possible. All the manuscripts included have been published in English from 2001–2021. This time frame was selected because it represents the most active period of trials in organic farming. It could be useful to remember that organic farming was officially regulated by the EU in 1991, while organic livestock productions were regulated in 1999. Consequently, many relevant studies on organic farming were conducted at the beginning of the 2000s, and for this reason are included in this study.

3. Organic and conventional farming: main issues and characteristics

3.1 A brief introduction to organic farming

Organic farming is based on the 4 principles defined by IFOAM: the Principles of Health, Ecology, Fairness, and Care (IFOAM, 2017). The organic agricultural practices, regulated by national and international institutional bodies, which certify the production, handling and transformation of organic products (Codex Alimentarius, 2007; EC, 2016; USDA, 2016), are consequences of these main principles. Organic farming is characterized by an ecological approach and by the absolute ban on the use of synthetic pesticides and fertilizers. The defense against parasites and pests is based on the use of biological control agents (e.g. predators, parasitoids, pathogens and competitors) and soil management practices (e.g. crop rotation, inter-associations, soil management, which are also useful for fertilization management and organic matter increase). Similarly, weed control is applied through mulching, manual and mechanical weeding, crop cover and crop rotation. However, the use of some natural products with low toxicity and high degradation rate is allowed, and traditional products such as lime. As far as the so-called natural products are regarded , organic farming is using different toxic pesticides of natural origin such as copper sulfate or pyrethrin-based products. Furthermore, for years very toxic natural products have been largely used, like rotenone which, finally, has been recently banned. The use of Genetically Modified Organisms (GMOs) is also prohibited (Gomiero, 2018). Regarding the treatment of animals, organic farming tends to minimize the impact on the soil (pollution, erosion and poaching) by animals. The organic regulation also prohibits the use of hormones and antibiotics as growth promoters, limiting the use of antibiotics only to exceptional cases. The disciplinary of organic production therefore concerns many aspects linked to the production chain, with regulatory aspects that may vary among continents, but also within them (among the states of the European Union, for example) (Gomiero, 2018).

3.2 A brief introduction on conventional farming

In terms of input levels, different non-organic management strategies can be distinguished for the cultivation of crops. Intensive high-input or high-yield farming is characterized by a massive use of chemical pesticides and fertilizers. Integrated Pest Management (IPM) aims to reduce pesticide use to economically and ecologically justified levels. It emphasizes the growth of a healthy crop with the least possible disturbance to agro-ecosystems and encourages natural pest control mechanisms (European Parliament 2009), with the use of pesticides as a last resort.

The concepts of low input and extensive farming systems are sometimes used interchangeably (Nemecek et al. 2011). In low-input management, weeds are controlled by herbicides and mechanical weeding, and the use of fungicides and regulators of growth is forbidden. Fertilization with nitrogen is also reduced (Le Campion et al., 2014; Loyce et al., 2008, 2012). Extensive farming is considered here as a very low-input management system that uses very small amounts of fertilizers and pesticides compared to the low-yield potential of the area. Furthermore, this latter management can be followed to respond to specific environmental constraints (plans for the recovery of water quality in the catchment area) (Le Campion, Oury, Heumez, & Rolland, 2020).

3.3 Environmental impacts of organic and conventional farming

3.3.1 Plant yield

There are numerous meta-analyses and reviews in the literature regarding the environmental impact and productivity of organic systems compared to conventional ones. On average, the yields of crops managed through organic farming are about 20-30% lower than those obtained through conventional farming (Seufert et al., 2012). The differences in yield between conventional and organic crops are certainly influenced by climatic factors (sunlight and temperatures), but also by pedological factors, such as the availability of water and nutrients, the composition of the soil, the presence of parasites and diseases in the soil. Organic practices prohibit the use of synthetic chemicals, so fertilization is certainly more difficult in these conditions, even if all nutrients can be supplied through organic fertilizers (Niggli, 2015). The main limits of organic cultivation are represented by nitrogen and phosphorus: the release of these elements from organic sources, in fact, is often too slow and insufficient to integrate the real needs of the plant (Seufert et al., 2012).

As far as the capacity of water use is concerned, the lands cultivated according to organic practices show greater resilience and greater resistance in drought conditions, thanks to the better capacity of water retention and infiltration compared to land managed in a conventional manner (Niggli, 2015). Organic systems are more susceptible to yield losses due to weeds, insects and diseases (Seufert & Rarankutty, 2017). The ban on the use of synthetic chemicals for the defense of organic plants from these agents severely limits the possibility of effectively fighting them, and where environmental pressure is greater, the yield gap between organic and conventional products is even more biased in favor of the latter (Meemken & Qaim, 2018).

3.3.2 Land use efficiency

About 40% of the land not occupied by ice is currently dedicated to agricultural production (Foley et al., 2011). Increasing this quota to meet the growing demands of the world population has negative effects on the ecosystem, causing a decrease in biodiversity and the release of carbon into the atmosphere. To reduce negative impacts, the agricultural sector is stimulated to apply management practices that optimize land use efficiency. Organic production systems do not represent a sustainable material from the point of view of the efficiency of land use: the production yields are in fact lower than the same crops grown in a conventional way, the organic crop rotations traditionally include species not suitable for human nutrition; finally, t he production of meat according to organic methods requires longer production cycles and lower growth rates of the animals, with a consequent greater need for fodder and surface area to produce the same quantity of meat compared to the conventional method (Treu et al., 2017). The data on the lower yield of organic crops derive from 1% of the world's agricultural area: it is therefore reasonable to believe that the production gap could even be greater if small farms in developing countries are taken into consideration, where the cultivation conditions are more difficult and the preparation of the farmers is lacking. In these cases, yield differences of 30-40% correspond to the need for 40-65% more land to produce the same amount of conventional products, resulting in a change in land use and loss of natural habitats (Meemken & Qaim, 2018).

E xpressing the environmental impact per unit of product rather than per unit of surface, could underestimate the negative effects that a greater conversion of land to organic farming could have, which would cause other environmental "costs" (for example the loss of natural habitats for cultivation) not fully accounted when simply considering the impact on the production unit (Gabriel et al., 2013; Leifeld, 2016; Meemken & Qaim, 2018).

3.3.3 Biodiversity

In recent years, the homogenization of landscapes and the intensification of agriculture have led to a significant loss of biodiversity (Halberg, 2012). It has been widely recognized in the literature that the application of organic practices favors landscape biodiversity (Smith et al., 2020).

Practices such as the use of semi-natural landscape elements (hedges), large crop rotations, and the reduction in the use of pesticides favor the richness of the number of species and the relative abundance of different species compared to environments subjected to conventional cultivation. Biodiversity gains increased in a direct way as average organic crop field size increased (Smith et al., 2020). However, from a global perspective, the benefits of organic farming on biodiversity diminish as cultivated areas increase. As already mentioned, the lower yield of organic farming would require the conversion of natural land to cultivated land, and the biodiversity benefits brought about by organic farming would not compensate for the biodiversity loss associated with this conversion of land use (Mondelaers et al., 2009).

3.3.4 Soil quality

The mismanagement of millions of hectares of land around the world has led to degradation phenomena, such as erosion, that have transformed previously fertile soils into unsuitable land for cultivation (Halberg, 2012). Some agricultural practices applied in organic farming, such as longer and diversified crop rotations and the application of organic matter (such as green manure), are useful for reducing erosion and maintaining soil fertility (Niggli, 2015). In literature, both field trials and meta-analyzes have shown that the quality of land managed with organic farming is superior, both in terms of organic matter and activity and presence of microbial communities in the soil, compared to conventional land (Meemken & Qaim, 2018).

3.3.5 W ater quality

Agriculture poses a major threat to water quality, affecting both biodiversity of fresh and marine waters, and human water security (Vörösmarty et al., 2010; Halberg, 2012). In areas subjected to intensive agriculture, agricultural management affects water quality through nitrogen (N) and phosphorus (P) losses (leading to eutrophication and hypoxia), as well as pesticide leaching and soil erosion leading to loading of sediments. The lack of use of synthetic fertilizers has been associated with the reduction of the eutrophication potential in organic farming (Niggli, 2015); however, the eutrophication potential was often greater than in conventional agriculture, due to the difficulty of managing the plant's real needs for nutrients and their administration, potentially leading to greater losses (Halberg, 2012). The leaching of nitrates appears to be lower in organic systems if considered per unit of soil, but becomes greater if the unit of product is considered (Mondelaers et al., 2009).

Another delicate issue concerns the supply of organic matter to organic crops: organic farming currently uses inputs from the conventional livestock sector (Nowak et al., 2013). To avoid the use of synthetic nitrogen fertilizers, prohibited in organic farming, a solution would be to significantly increase the number of animals raised to obtain the necessary manure, increasing the areas used for forage. This would have a very strong impact on the ecosystem, both in terms of natural habitat loss and of greenhouse gas emissions linked to the livestock sector. Another solution could be to use nitrogen from crop residues, growing more cover crops, such as legumes. However, in order to supply sufficient nitrogen, it would be necessary to increase the areas of cultivation, reducing the area useful for food production (Connor, 2008). Finally, if enough nitrogen is not supplied to organic crops, the risk would be that of a further decline in production yield, with the consequent need for additional land to increase production. In conclusion, the complete conversion to organic agriculture could potentially cause an increase in greenhouse gas emissions and a loss of biodiversity linked to the reconversion of natural land (Meemken & Qaim, 2018).

The limited number of studies and the wide variation in the results do not allow reliable conclusions on the loss of P from organic systems compared to conventional ones. Organic horticultural systems, which often apply, as already mentioned, large amounts of external organic matter to avoid N limitation, typically have high P surplus; on the contrary, organic crops systems mostly rely on biological fixation of the N, and they often present a deficit of P. However, excess or lacking of P in agricultural fields does not necessarily lead to P losses or deficiency due to the high P buffering capacity of many soils (Seufert & Ramankutty, 2017).

Pesticide's reduction is one of the main sustainability aims of the EU Farm to Fork strategy, which envisages the use of sustainable practices (such as IPM, precision agriculture and Artificial Intelligence) to promote less pesticide use (Taning et al., 2020). To a certain extent, organic farming contributes to that aim, since synthetic pesticides are prohibited in organic farming; also, the risk of pollution of water bodies is low (Reganold & Wachter, 2016), but critics argue that some organic pesticides are more dangerous than synthetic pesticides (Trewavas, 2001). Some organic pesticides, such as sulfur and rotenone, can have a greater total impact due to the higher dosages and the increased frequency of application required, despite lower toxicity ratios (Edwards-Jones & Howells, 2001). Attention should be paid also to some non-synthetic pesticides (such as copper-based solutions), commonly used in organic farming, as they are potentially harmful to aquatic life (Niggli, 2015), and could increase the risk of large accumulation in soil and soil water of not degradable heavy metal.

3.3.6 Life cycle assessment

The environmental impacts of agriculture are significant (Foley et al., 2005, 2011). In order to develop more sustainable agricultural systems, policy makers and researchers need data on the weaknesses and strengths of different agricultural systems with respect to environmental impacts and productivity within the carrying capacity of ecosystems. Therefore, assessment tools are needed that enable comprehensive environmental impact assessments of different agricultural systems to enable informed conclusions (Meier et al., 2015). Life Cycle Assessment (LCA) is increasingly used to evaluate the ecological sustainability of food products and is seen as a useful tool for assessing the environmental impacts of production systems and food products (Roy et al., 2009), because it analyzes potential environmental impacts during the life cycle of a product (ISO, 2006) including the supply chain and downstream processes (Finnveden et al., 2009). The impact of organic farming on biodiversity varies from much better to equal than conventional agriculture. In particular, organic farming clearly performs better for the diversity of fauna and flora species, but genetic diversity could be affected both negatively and positively compared to conventional farming (Bengtsson et al., 2005; Schader, Stolze, & Gattinger, 2012). With respect to landscape and habitat diversity, organic farming can perform better than conventional farming because it provides higher implementation rates of structural elements such as hedges and fruit trees (Schader, Stolze, & Gattinger, 2012) and more diverse crop rotations (Norton et al. 2009). However, the effects on the landscape are very farm and site specific, so no general trend can be determined (Schader, Stolze, & Gattinger, 2012). .As far as energy consumption is concerned, organic farming has been shown to require less energy per unit of land and, above all, per unit of product than conventional agriculture (Meemken & Qaim, 2018). This result was possible above all thanks to the ban on the use of synthetic fertilizers and pesticides. As far as fuel consumption is concerned, it is similar for the different systems adopted, although for some particular situations, organic farming requires a higher consumption (e.g. more mechanical or thermal interventions are required for the treatment of weeds) (Smith et al., 2015). As far as greenhouse gas emissions are concerned, organic farming has a lower impact if we consider the unit of land, but it has greater impacts if we consider the unit of production, in respect to conventional farming (Tricase et al., 2018). Usually, the greatest advantage of organic farming is the lower nitrogen input into the soil, with less loss of N2O. However, it is difficult to balance the demand and supply of nutrients in an organic crop, and even an excess of organic nitrogen fertilizers can lead to significant N2O emissions, with a decrease in production yields (Clark & Tilman, 2017). In organic farming, the less intense system leads to a higher production of manure per unit of meat, with a consequent increase in methane and N2O emissions (Treu et al., 2017).

The eutrophication of surface and ground waters depends a lot on what exactly is the subject of comparison. The impact of nitrate leaching from organic farming compared to conventional agriculture can range from worst to best. When it comes to pesticide emissions into surface and ground water, organic farming works much better thanks to the ban on artificial pesticides. Ammonia emissions to air are lower in organic systems, however, depending on the hypothesis, some studies show an equal yield of both systems (Schader, Stolze, & Gattinger, 2012). Organic agriculture performs much better in terms of biological soil activity than conventional agriculture. Although the soil structure remains unaltered, organic matter content and soil erosion are positively affected by organic practices (Schader, Stolze, & Gattinger, 2012).

In both conventional and organic farming, exists the potential to improve environmental performance. None of the systems currently satisfy the principles of sustainability. The betterments suggested for conventional agriculture are optimizing energy and fuel use, reducing the use of toxic pesticides, increasing its self-sustaining capacity, and improving the farms nutrient flows in order to reduce nutrient surplus. Since the yields obtained from organic farming are lower than conventional agriculture, the overall environmental benefits are greatly reduced or even disappear after correcting for these smaller quantities produced per hectare. Therefore, more research should be done on how to substantially increase yields in organic agriculture without increasing the environmental burden (de Backer, Aertsens, Vergucht, & Steurbaut, 2009).

These results imply that there is no "right" choice open to objectification. When the focus is on the impact per area of land, organic farming is clearly preferable to conventional farming. When the emphasis is on efficiency, conventional agriculture performs better. Improving the yields in organic farming can make the choice substantially in its favor. However, it might be interesting to broaden the point of view and consider the fact that organic farming may not be the only solution for sustainable farming. Evolve towards a more integrated agricultural approach achieving yields that lie midway between the lower yields in organic systems and the high yields of conventional agriculture, still relying on the use of inorganic inputs, albeit at lower levels than conventional systems, by supporting sufficient agricultural production and the protection of the environment, they can give a just answer to the problem of sustainability (de Backer, Aertsens, Vergucht, & Steurbaut, 2009).

4. Impact of organic and conventional farming on pollutants and contaminants residues

4.1 Pollutants residues in food

About 2.5 million tons of pesticides are used in agriculture every year, and many of these degrade very slowly in the environment, accumulating in living organisms, water and soil (Fenner et al., 2013). The negative effects of pesticides can primarily affect the operators of the agricultural system directly. In addition to farmers, consumers can also be exposed to these compounds: in this regard, several studies have reported that in organic products it is possible to find a much lower quantity of residues than that found in conventional foods, with consequent lower toxicity (Barański et al., 2014; EFSA, 2016; Lairon, 2010). The most comprehensive comparative study on pesticide residues in food was carried out by the European Food Safety Authority (EFSA, 2016), comparing the residue content for 191 pesticides in 82,649 conventional and organic food samples obtained within the EU. Overall, 53.6% of the total samples were free of quantifiable residues (residues below the LOQ). Of the samples containing measurable residues (46.3%), 43.4% contained residues not exceeding the permitted residue concentrations, while 2.9% exceeded the maximum residue levels (MRLs) allowed by EU legislation. In conclusion, this study stated that the general level of pesticide residues in both conventional and organic foods is well below potentially harmful levels for health. However, the cocktail effect of adding several toxic compounds (each with a low level) should be considered as a potential risk for the consumer's health.

Other studies show that some pesticides prohibited in organic farming (eg. Bendiocarb; chlorpyrifos; amitraz) have been detected in organic products (Chiarello & Moura, 2018). Two recent studies have evaluated the presence of different environmental pollutants (mycotoxins, PCBs, PAHs, Furans and trace elements) and the nutritional quality of organic and conventional foods, concluding that in both situations there were no significant differences such as to indicate one type of food as healthier than the other (Suciu et al., 2019). These results show that the consumption of organic products does not necessarily reduce the ingestion of carcinogenic products, and that there can be a flow of environmental pollutants, often involuntary, deriving from the application of natural substrates (green and domestic waste, compost, sludge, manure and forage grass) rich in heavy metals, microplastics, pharmaceuticals, pesticides and their derivatives, which can contaminate organic products (Ramakrishnan et al., 2021). Also, some tuber leafy, and root vegetables from organic farming showed lower nitrate amounts than conventional ones, but it is still not clear if dietary nitrate constitutes a threat to human health or not (Magkos et al., 2006).

Regarding heavy metals, several studies have been conducted, but no significant differences in the content of these toxic compounds have been demonstrated between organic and conventional products (Magkos et al., 2006). The only difference was in cadmium levels, which were found to be lower in organic products (Barański et al., 2014). However, it should be emphasized that the levels of cadmium in food of agricultural origin also depend on the endowment of the cultivation land and are likely to be present in foods from both origins (Gomiero, 2018).

4.2 Mycotoxins and bacterial contamination

In addition to pollutants, mycotoxins and bacteria can also contaminate food during cultivation and harvesting (Gomiero, 2018). It is therefore important to know if there are differences between conventional and organic foods in relation to the presence of these substances.

As regards mycotoxins, numerous studies have been carried out to evaluate their presence in organic and non-organic foods. Specifically, mycotoxins are toxic by-products of some molds that can colonize both products in the field and in storage, and are able to persist in the food chain, reaching dairy products and meats (Rossi et al., 2020). Since the use of synthetic fungicides is not allowed in the organic production regime, this production system would seem potentially more at risk due to the presence of these mycotoxins. Few studies underlined a significant difference between the presence of mycotoxins in products of conventional and organic origin, such as the high incidence and mean concentration of Ochratoxin A in organic cereals cultivated in Spain (Juan et al., 2008). Some other studies reported no significant differences in the concentration of mycotoxins in conventional and organic products (Lairon, 2010; Magkos et al., 2006). Finally, with regard to bacterial contamination of conventional and organic products, numerous reports have been carried out, but in none of these any significant difference was found (Lairon, 2010; Magkos et al., 2006), even if recent findings regarding the presence of aflatoxins in organic corn and *E. coli* in organic bean sprouts and *alpha alpha*, are raising concerns about the management of dangerous mycotoxins and bacteria in organic farming.

5. Physicochemical quality of conventional and organic plant foods

5.1 Dry matter content

Dry matter is an important parameter related to the accumulation of organic and nutritive compounds, such as fats, proteins, celluloses and starch. It is formed during the plant photosynthesis and is obtained as the rest of the full and constant drying of the food matrix at temperature around 60-90 °C (Yu, Guo, Jiang, Song, & Muminov, 2018).

The results on the contents of dry matter in conventional and organic plant foods are inconsistent. Indeed, a number of studies have found that organic vegetables and fruits had a higher content of dry matter compared to the conventional ones, , while other reports showed that organic seem to have similar or lower dry matter contents compared to the conventionally cultured foods (Table 1) . The higher content of dry matter in organic foods can be correlated to fertilizers typically used in conventional system that implies plants to absorb more water, even if these contradictory results may be due also to the different soil types and even to the different cultivars analyzed for each plant (Maggio, De Pascale, Paradiso, & Barbieri, 2013).

Table 1: Effect of organic and conventional production system on dry matter contents of fruits and vegetables

Food	Species	Production system	References
Cabbage	*Brassica oleracea*	↑ Organic	Rembiałkowska, 2007

	L.		
Celeries	*Apium graveolens* L.	↑ Organic	Yu, Guo, Jiang, Song, & Muminov, 2018
Spinach	*Spinacia oleracea*	↑ Organic	Rembiałkowska, 2007
Tomato	*Lycopersicon esculentum*, var. AB2	↑ Organic	Pieper & Barrett, 2009
Strawberry	*Fragaria x ananassa* Duch., cv. Diamante, San Juan, Lanai	↑ Organic	Reganold et al., 2010
	Fragaria x ananassa, cv. Honeoye, Cavendish	No effects	Olsson, Andersson, Oredsson, Berglund, & Gustavsson, 2006; Drobek, Frąc, Zdunek, & Cybulska, 2020
Black currants	*Ribes nigrum* L.	↑ Organic	Yu, Guo, Jiang, Song, & Muminov, 2018
Pears	*Pyrus communis*	↑ Organic	Yu, Guo, Jiang, Song, & Muminov, 2018
Pepper	*Capsicum annuum*, cv. Roberta, Berceo	↑ Organic	Hallmann et al., 2019
Carrots	*Daucus carota* subsp. *sativus*	↑ Organic	Hallmann et al., 2019
Potatoes	*Solanum tuberosum* L.	↑ Conventional	Yu, Guo, Jiang, Song, & Muminov, 2018
Apples	*Malus domestica* Borkh.	↑ Conventional	Yu, Guo, Jiang, Song, & Muminov, 2018
Zucchini	*Cucurbita pepo* L.	No effects	Maggio, De Pascale, Paradiso, & Barbieri, 2013
Eggplants	*Solanum melongena*	No effects	Raigón, Rodríguez-Burruezo, & Prohens, 2010
Endive bunches	*Cichorium endivia* L. var. *Latifolium*	No effects	Maggio, De Pascale, Paradiso, & Barbieri, 2013

4.2 Soluble solids content and total acidity

Soluble solids contents (SSC) and total acidity (TA) determine the organoleptic properties of fruits and a balance ratio (SSC:TA) between these two parameters should be guaranteed to ensure a good taste of the fruits (Mditshwa, Magwaza, Tesfaya, & Mbilic, 2017). Some studies have compared the content of SSC and TA in fruits grown under conventional and organic systems, failing to reveal any consistent or significant difference. For example, many reports found that conventional plant foods had the same or higher contents of SSC and/or TA compared to the organic ones, others reported opposite results, with higher TSS and lower or similar TA compared to the conventional fruits (Table 2).

It should be taken in mind that the fruit content of TSS and TA is affected by several parameters, including the type of cultivar, the degree of fruit maturation, the sunlight exposure, the farming practices and the used fertilizers, all aspects that may explain the differences between the opposite results obtained in these reports (Dangour et al., 2009; Mditshwa, Magwaza, Tesfaya, & Mbilic, 2017).

Table 2: Effect of organic and conventional production system on soluble solids content and total acidity of fruits and vegetables.

Food	Species	Compounds	Production system	References
Orange	*Citrus sinensis* L., cv. Washington navel	Soluble solids Acidity	No effects ↑ Conventional	Khalil & Hassan, 2015
Strawberry	*Fragaria vesca*, var. Festival	Soluble solids Acidity	No effects ↑ Conventional	Khalil & Hassan, 2015
	Fragaria x ananassa Duch., cv. Honeoye	Soluble solids Acidity	↑ Organic ↑ Conventional	Drobek, Frąc, Zdunek, & Cybulska, 2020
Apples	*Malus domestica* Borkh., cv. Galaxy Gala	Soluble solids Acidity	No effects No effects	Peck, Andrews, Reganold, & Fellman, 2006
	Malus domestica, cv. Royal Gala, Fuji	Soluble solids Acidity	↑ Organic ↑ Conventional	Do Amarante, Steffens, Mafra, & Albuquerque, 2008
Cauliflower	*Brassica oleracea* L. var. *botrytis*	Soluble solids	No effects	Maggio, De Pascale, Paradiso, & Barbieri, 2013
Black currants	*Ribes nigrum* L., cv. Öjebyn	Soluble solids Acidity	No effects No effects	Anttonen, & Karjalainen, 2006
Kiwifruits	*Actinidia deliciosa*, cv. Hayward	Soluble solids	↑ Organic	D'Evoli et al., 2013
Passion fruits	*Passiflora edulis* Sims f. *flavicarpa* Deg.	Soluble solids Acidity	↑ Organic ↑ Conventional	Oliveira et al., 2017
Black berries	*Rubus fruticosus*, cv. Loch Ness, Chester Thornless	Soluble solids Acidity	↑ Organic No effects	Pinto et al., 2018

4.3 Color and firmness

The color of fruits is a fundamental aspect for the food market, since it is closely associated with the acceptance by consumers, who usually discard plant products insufficiently colored, thus leading to the decrease of prices. Some studies have compared the color of foods grown under conventional and organic systems (Table 3). Some authors reported that the use of nitrogen fertilization may deeply affect the color of plant products, due to the higher nitrogenous substances and reduced carbohydrate accumulation in fruits, as found for apples and grape (Do Amarante et al., 2008), or due to the decrease of the activity of enzymes that modulate the pigment synthesis, as occurred with grapevine and mango (Brunetto et al., 2015). Further studies are strongly encouraged to understand the potential factors that may affect the color and pigment contents of fruits and vegetables.

Firmness, one of the most useful parameter related to fruit quality, strictly depends on water content and metabolic changes; it usually decreases during postharvest storage and supply chain, so that it is very important for farmers and industries that fruits maintain a certain level of firmness (Mditshwa, Magwaza, Tesfaya, & Mbilic, 2017).

Some studies have evaluated the difference in fruit firmness between conventional and organic system production, obtaining contradictory results.

Also firmness is influenced by several factors, including fertilizers and sunlight exposure (Mditshwa, Magwaza, Tesfaya, & Mbilic, 2017). For instance, high content of Ca is associated with a higher firmness of the fruits, while N and K seem to negatively affect this parameter, as reported for apple (Peck, Andrews, Reganold, & Fellman, 2006; Do Amarante et al., 2008), making the comparison even more difficult to do.

Table 3: Effect of organic and conventional production system on color and firmness of fruits and vegetables.

Food	Species	Compounds	Production system	References
Kiwifruits	*Actinidia deliciosa*, cv. Hayward	Color Firmness	↑ Organic ↑ Conventional	Amodio et al., 2007
	Actinidia deliciosa, cv. Hayward	Firmness	↑ Organic	D'Evoli et al., 2013
Apple	*Malus domestica*, cv. Royal Gala, Fuji	Color	↑ Organic	Do Amarante Steffens, Mafra, & Albuquerque, 2008
	Malus domestica Borkh., cv. Galaxy Gala	Firmness	↑ Organic	Peck, Andrews, Reganold, & Fellman, 2006
Black berries	*Rubus fruticosus*, cv. Loch Ness, Chester Thornless	Color	↑ Organic	Pinto et al., 2017
Strawberry	*Fragaria x ananassa* Duch., cv. Diamante, San Juan, Lanai	Color Firmness	↑ Organic No effects	Reganold et al., 2010
	Fragaria x ananassa Duch., cv. Honeoye	Firmness	↑ Organic	Drobek, Frąc, Zdunek, & Cybulska, 2020
Blueberries	*Vaccinium corymbosum* L., cv. Brigitta Blue	Color	No effects	Ochmian, Błaszak, Lachowicz, & Piwowarczyk, 2020

5. Nutritional quality of conventional and organic plant foods

5.1 Proteins and amino acids

Proteins are the main biological macromolecule that form the cellular structure of all living organisms and are constituted by 20 different amino acids, that represents the organic units with both amino (–NH_2) and carboxyl (–COOH) functional groups; 8 out of 20 amino acids (i.e., histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine) are essential, meaning that humans are not able to synthetize and must obtain by foods. Therefore, it is important to evaluate not only the total quantity of proteins present in certain foods, but also the quality of the proteins, in terms of essential amino acids contents.

Some studies have compared the content of proteins and free amino acids of foods cultivated under conventional and organic systems . Generally, conventional foods present higher levels of proteins or free amino acids, since in an organic system the use of nitrogen fertilizer is lower (Yu, Guo, Jiang, Song, & Muminov, 2018). Conversely, two studies have found that organic potatoes have higher levels of essential amino acids (Table 4) .

These results can be explained with the theory of C/N balance, affirming that a plant increases the production of proteins and nitrogen-containing secondary metabolites, including glucosinolates and alkaloids, and reduces the synthesis of carbohydrates, vitamins and phenolics, when it has high levels of nitrogen, but the increased protein production may be associated with a decreased amounts of certain amino acids, such as certain essential ones, thus reducing the protein quality (Rembiałkowska, 2007). For these reasons, organic plants, that usually grow with lower amounts of nitrogen, may present less protein content but of a higher quality, but further studies are strongly needed in this field.

Table 4: Effect of organic and conventional production system on proteins and amino acids of fruits and vegetables.

Food	Species	Compounds	Production system	References
Rye	*Secale cereale*	Proteins	↑ Conventional	Magkos, Arvaniti, & Zampelas, 2003
Wheat	*Triticum aestivum* L.	Proteins	↑ Conventional	Magkos, Arvaniti, & Zampelas, 2003; Vrček et al., 2014
	Triticum aestivum L.	Proteins, amino acids content	No effects	Mader et al., 2007
Corn	*Zea mays* L.	Proteins	↑ Conventional	Magkos, Arvaniti, & Zampelas, 2003
	Zea mays L.	Proteins, amino acids content	No effects	Röhlig, & Engel, 2010
Carrots	*Daucus carota* subsp. *sativus*	Proteins, free amino acids	↑ Conventional	Magkos, Arvaniti, & Zampelas, 2003
Beetroots	*Beta vulgaris*	Proteins, free amino acids	↑ Conventional	Magkos, Arvaniti, & Zampelas, 2003

Spinach	*Spinacia oleracea*	Proteins, free amino acids	↑ Conventional	Magkos, Arvaniti, & Zampelas, 2003
Potatoes	*Solanum tuberosum* L.	Proteins, free amino acids	↑ Conventional	Magkos, Arvaniti, & Zampelas, 2003
	Solanum tuberosum L., cv. Agria, Merit	Essential amino acids, threonine	↑ Organic	Maggio et al., 2008
	Solanum tuberosum L., cv. Agria	Essential amino acids, leucine, phenylalanine, tryptophan and valine	↑ Organic	Carillo, Cacace, De Pascale, Rapacciuolo, & Fuggi, 2012
	Ipomoea batatas (L.) Lam.	Proteins, amino acids content	No effects	Dos Santos et al., 2019
Tomatoes	*Solanum lycopersicum* L.	Proteins, free amino acids	↑ Conventional	Magkos, Arvaniti, & Zampelas, 2003
	Lycopersicon esculentum, var. AB2	Proteins, amino acids content	No effects	Pieper, & Barrett, 2009
Kiwifruit	*Actinidia deliciosa*, cv. Hayward	Proteins, amino acids content	No effects	D'Evoli et al., 2013
Yellow plums	*Prunus domestica* L., cv. Shiro	Proteins, amino acids content	No effects	Lombardi-Boccia, Lucarini, Lanzi, Aguzzi, & Cappelloni, 2004
Eggplants	*Solanum melongena*	Proteins, amino acids content	No effects	Raigón, Rodríguez-Burruezo, & Prohens, 2010
Zucchini	*Cucurbita pepo* L.	Proteins, amino acids content	No effects	Maggio, De Pascale, Paradiso, & Barbieri, 2013

5.2 Sugars

The content of sugars in plant foods is strictly correlated to the taste and to the processing quality of the different food matrices. A number of studies have evaluated and compared the content of total and simple soluble sugars in fruits cultivated under conventional and organic systems . For example, D'evoli and colleagues (2013) found higher levels of total carbohydrates and total glucose, fructose and sucrose in organic kiwifruit compared to the conventional one, while no significant difference was found between the two different cultivation system for sweet potato (dos Santos et al., 2019), corn (Röhlig, & Engel, 2010), kiwifruit (Amodio et al., 2007), and yellow plums (Lombardi-Boccia, Lucarini, Lanzi, Aguzzi, & Cappelloni, 2004).

Theoretically, the content of total sugars should be higher in organic fruits, because an inverse relationship exists between this parameter and the concentration of nitrogen in the soil, as explained for the protein (Rembiałkowska, 2007); in addition, until now, the evaluation of sugars content has received little attention from scientists, so that other studies are strongly needed to identify the difference between the conventional and organic food sugar content that mostly contributes to the fruit taste.

5.3 Organic acids

Citric, malic, fumaric and oxalic acids are the most common organic acids present in plant based foods; they exert important role in organoleptic properties and fruit quality, being important indicator of freshness and contributing to fruits acidic taste (Mditshwa, Magwaza, Tesfaya, & Mbilic, 2017). Some efforts have been made to investigate the effect of the production system on the levels of organic acids (Table 5).

Table 5: Effect of organic and conventional production system on organic acid contents of fruits and vegetables.

Fruits	Species	Compounds	Production system	References
Lemons	*Citrus meyeri* Tan.	Citric acid	↑ Conventional	Uckoo, Jayaprakasha, & Patil, 2015
Plums	*Prunus salicina* Lindl.	Malic acid Succinic acid Shikimic acid Tartaric acid	↑ Organic	Cuevas et al., 2015
	Prunus domestica L., cv. Shiro	Citric acid Fumaric acid	No effects	Lombardi-Boccia, Lucarini, Lanzi, Aguzzi, & Cappelloni, 2004; Cuevas et al., 2015
Blueberry	*Vaccinium corymbosum* L.	Malic citric Citric acid	↑ Organic No effects	Wang, Chen, Sciarappa, Wang, & Camp, 2008
Peaches	*Prunus persica* L., cv. Regina bianca	Citric acid	↑ Organic	Carbonaro, Mattera, Nicoli, Bergamo, & Cappelloni, 2002
Kiwifruits	*Actinidia deliciosa*, cv. Hayward	Citric acid Malic acid	↑ Organic	D'Evoli et al., 2013
	Actinidia deliciosa, cv. Hayward	Citric acid	No effects	Amodio et al., 2007
Pears	*Pyrus communis* L., cv. Williams	Citric acid	No effects	Carbonaro, Mattera, Nicoli, Bergamo, & Cappelloni, 2002
Pepper	*Capsicum annuum* L.	Citric acid	No effects	López, Fenoll, Hellín, & Flores, 2014
Tomato	*Solanum lycopersicum* L.	Citric acid Malic acid	No effects	Ordonez-Santos, Vazquez-Oderiz, & Romero-Rodrıguez, 2011

The low levels of organic acids in conventional fruits could be explained with the higher amounts of nitrogen fertilization that may decrease the concentration of these compounds or with the use of some pesticides that may inhibit the shikimate pathway negatively affecting the accumulation of organic acids in fruits (Asami, Hong, Barrett, & Mitchell, 2003; Amodio et al., 2007).

5.4 Polyunsaturated fatty acids

Polyunsaturated fatty acids (PUFAs) are typical compounds of plant oils and seeds, with important effects on the human body, including the regulation of the immune system, lipid metabolism, neurotransmission and coagulation.

To the best of our knowledge, only few studies have assessed the content of PUFAs in plant oils and seeds cultured with conventional or organic system: most of them did not find any differences between organic and conventional vegetable oils, as occurred for different Spanish olive oil cultivars (García-González et al., 2014), for coconut, canola, mustard seed and sesame oils (Samman et al. 2008) and for *Perilla* seeds (Rouphael et al. 2015). To the best of our knowledge only one study reported a higher PUFA content in organic olive oils compared to the traditional one, even if these differences might have depended on different factors, including the degree of sample maturation, seasons and geographical origins (Anastasopoulos et al., 2011).

5.5 Vitamins

Vitamins exert an essential role in maintaining a healthy well-being and in preventing the onset of many common diseases, including cardiovascular diseases, diabetes and some types of cancers. For these reasons, in the last years food technologists and food researchers have focused their attention on the evaluation and the improvement of vitamin contents in plant foods, especially fruits.

Regarding water-soluble vitamins, vitamin C is the most studied one, indispensable for human health but also for food industry since it is usually used in processed foods as an additive. However, no unequivocal difference can be highlighted between traditional and organic farm systems (Dangour et al., 2009) (Table 6).

Table 6: Effect of organic and conventional production system on vitamin C contents of fruits and vegetables.

Food	Species	Production system	References
Acerola	*Malpighia punicifolia* L., var. Olivier	↑ Organic	Cardoso, Tomazini, Stringheta, Ribeiro, & Pinheiro-Sant'Ana, 2011
Red oranges	*Citrus sinensis*, cv. Tarocco	↑ Organic	Tarozzi et al., 2006
Passion fruit	*P. edulis* Sims f. *flavicarpa,* Degener	↑ Organic	Pertuzatti, Sganzerla, Jacques, Barcia, & Zambiazi, 2015; Oliveira et al., 2017
Kiwifruits	*Actinidia deliciosa*, cv. Hayward	↑ Organic	D'Evoli et al., 2013
Strawberry	*Fragaria x ananassa*, cv. Honeoye, Cavendish	↑ Organic	Olsson, Andersson, Oredsson, Berglund, & Gustavsson, 2006
	Fragaria x ananassa Duch., cv. Diamante, San Juan, Lanai, Honeoye	No effects	Reganold et al., 2010; Drobek, Frąc, Zdunek, & Cybulska, 2020
	Fragaria vesca L., var. Oso Grande	↑ Conventional	Cardoso, Tomazini, Stringheta, Ribeiro, & Pinheiro-Sant'Ana, 2011
Grapefruits	*Citrus paradisi* Macf	↑ Organic	Chebrolu, Jayaprakasha, Jifon, & Patil, 2012
Tomato	*Lycopersicon esculentum*, cv. Félicia, Izabella, Paola	↑ Organic	Caris-Veyrat et al., 2004
	Solanum lycopersicum L.	No effects	Juroszek, Lumpkin, Yang, Ledesma, & Ma, 2009
Corn	*Zea mays*, cv. Supersweet Golden Jubilee	↑ Organic	Asami, Hong, Barrett, & Mitchell, 2003
Swamp cabbage	*Ipomoea aquatica*	↑ Organic	Ismail, & Cheah, 2003
Citrus juice	*Citrus sinensis* (L.) Osbeck, cv. Maltaise	No effects	Letaief, Zemni, Mliki, & Chebil, 2016
Persimmon	*Diospyros kaki* L., var. Rama Forte	No effects	Cardoso, Tomazini, Stringheta, Ribeiro, & Pinheiro-Sant'Ana, 2011
Broccoli	*Brassica oleracea* var. italica	No effects	Wunderlich, Feldman, Kane, & Hazhin, 2008
Chinese mustard	*Brassica juncea*	No effects	Ismail, & Cheah, 2003

Chinese kale	*Brassica alboglabra*	No effects	Ismail, & Cheah, 2003
Lettuce	*Lactuca sativa*	No effects	Ismail, & Cheah, 2003
Spinach	*Amaranthus viridis*	No effects	Ismail, & Cheah, 2003
Yellow plums	*Prunus domestica* L., cv. Shiro	No effects	Lombardi-Boccia, Lucarini, Lanzi, Aguzzi, & Cappelloni, 2004
Apples	*Malus domestica*, cv. Golden Delicious	No effects	Weibel, Bickel, Leuthold, & Alföldi, 2000
Pears	*Pyrus communis* L., cv. Williams	No effects	Carbonaro, Mattera, Nicoli, Bergamo, & Cappelloni, 2002
Peppers	*Capsicum annuum* L.	No effects	López, Fenoll, Hellín, & Flores, 2014
Blueberry	*Vaccinium corymbosum* L., cv. Brigitta Blue	↑ Conventional	Ochmian, Błaszak, Lachowicz, & Piwowarczyk, 2020

Regarding liposoluble vitamins, vitamin A and its main precursors, carotenoids, are the most studied compounds, with an essential role on human nutrition, well-being and health. As for vitamin C, it is not possible to identify clear differences between conventional and organic products, since the data reported in literature are contradictory (Table 7).

Table 7: Effect of organic and conventional production system on carotenoid contents of fruits and vegetables

Plant foods	Species	Compounds	Production system	References
Passion fruits	*P. edulis* Sims f. *flavicarpa*, Degener	Total carotenoids β-carotene Lycopene β-Criptoxantin	↑ Conventional	Pertuzatti, Sganzerla, Jacques, Barcia, & Zambiazi, 2015
Grapefruits	*Citrus paradisi* Macf	β-carotene Lycopene	↑ Conventional	Chebrolu, Jayaprakasha, Jifon, & Patil, 2012; Lester, Manthey, & Buslig, 2007
Acerola	*Malpighia punicifolia* L., var. Olivier	β-carotene	↑ Conventional	Cardoso, Tomazini, Stringheta, Ribeiro, & Pinheiro-Sant'Ana, 2011
Olive oil	Gemilik and Memecik	Total carotenoids	↑ Conventional	Dolgun, Ozcan, & Erbay, 2010
Plums	*Prunus domestica* L., cv. Shiro	β-carotene α-carotene γ-carotene	↑ Conventional ↑ Organic	Lombardi-Boccia, Lucarini, Lanzi, Aguzzi, & Cappelloni, 2004
Chinese mustard	*Brassica juncea*	β-carotene	↑ Organic	Ismail, & Cheah, 2003
Swamp cabbage	*Ipomoea aquatica*	β-carotene	↑ Organic	Ismail, & Cheah, 2003
Kiwifruits	*Actinidia deliciosa*, cv. Hayward	β-carotene	↑ Organic	D'Evoli et al., 2013
Pepper	*Capsicum annuum* L.	Total carotenoids β-carotene α-carotene	↑ Organic	López, Fenoll, Hellín, & Flores, 2014; Hallmann et al., 2019
Tomato	*Solanum lycopersicum* L.	β-carotene Lycopene	No effects	Juroszek, Lumpkin, Yang, Ledesma, & Ma, 2009; Ordonez-Santos, Vazquez-Oderiz, & Romero-Rodrıguez, 2011
Carrots	*Daucus carota cv. bolero*	β-carotene α-carotene Lutein	No effects	Søltoft, et al., 2011
Wheat	*Triticum aestivum* L.	Total carotenoids Lutein	No effects	Stracke, Eitel, Watzl, Mader, & Rufer, 2009

		Zeaxanthin		
Cauliflower	*Brassica oleracea,* L., *subsp. Botrytis*	Total carotenoids	No effects	Picchi et al., 2012
Chinese kale	*Brassica alboglabra*	β-carotene	No effects	Ismail, & Cheah, 2003
Lettuce	*Lactuca sativa*	β-carotene	No effects	Ismail, & Cheah, 2003
Spinach	*Amaranthus viridis*	β-carotene	No effects	Ismail, & Cheah, 2003
Pepper	*Capsicum annuum* L.	Lutein Zeaxanthin	No effects	Hallmann et al., 2019
Persimmon	*Diospyros kaki* L., var. Rama Forte	β-carotene Lycopene	No effects	Cardoso, Tomazini, Stringheta, Ribeiro, & Pinheiro-Sant'Ana, 2011
Strawberry	*Fragaria vesca* L., var. Oso Grande	β-carotene	No effect	Cardoso, Tomazini, Stringheta, Ribeiro, & Pinheiro-Sant'Ana, 2011

Vitamin E, including tocopherols and tocotrienols, are liposoluble compounds mainly found in vegetable oils and nuts; they exert multiple biological functions, comprising antioxidant, anti-inflammatory, pro-apoptotic, anti-angiogenic, antiproliferative and immunomodulatory effects (Szewczyk, Chojnacka, & Górnicka, 2021). To the best of our knowledge, few studies have assessed the content of tocopherols and tocotrienols in conventional and organic plant products (Table 8) .

Table 8: Effect of organic and conventional production system on tocopherol contents of fruits and vegetables.

Food	Species	Compounds	Production system	References
Peaches	*Prunus persica* L., cv. Regina bianca	α-tocopherol γ-tocopherol	↑ Conventional	Carbonaro, Mattera, Nicoli, Bergamo, & Cappelloni, 2002
Sunflower seed oil		α-tocopherol	↑ Conventional	Perretti, Finotti, Adamuccio, Della Sera, & Montanari, 2004
Plums	*Prunus domestica* L., cv. Shiro	α-tocopherol γ -tocopherol	↑ Conventional ↑ Organic	Lombardi-Boccia, Lucarini, Lanzi, Aguzzi, & Cappelloni, 2004
Pears	*Pyrus communis* L., cv. Williams	α-tocopherol	↑ Organic	Carbonaro, Mattera, Nicoli, Bergamo, & Cappelloni, 2002
Passion fruits	*P. edulis* Sims f. *flavicarpa*, Degener	Total Tocopherols (β+γ)-Tocopherols δ-Tocopherol	↑ Organic	Pertuzatti, Sganzerla, Jacques, Barcia, & Zambiazi, 2015
Kiwifruits	*Actinidia deliciosa*, cv. Hayward	α-tocopherol γ-tocopherol γ-tocotrienol	No effects	D'Evoli et al., 2013

It is of utmost importance to underline that besides the farming methods, there are other important factors that contribute to the vitamin content of plant foods, including the soil quality, the fertilizer program, the number of sunny days, the cultivars, the degree of maturity (Asami, Hong, Barrett, & Mitchell, 2003; Reganold et al., 2010; Picchi et al., 2012) that may explain the great variability found in published studies.

5.6 Minerals

Together with vitamins, minerals, including calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), nitrogen (N), phosphorus (P), potassium (K), sodium (Na) and zinc (Zn), are micronutrients that exert a key role in human health. In addition, the content of minerals is directly associated with fruit firmness and texture and with the post-harvest quality (Mditshwa, Magwaza, Tesfaya, & Mbilic, 2017). In the last years, several researches have been performed to highlight potential differences in mineral contents between conventional and organic systems. A number of studies showed that organic foods have higher contents of these micronutrients, while others underlined small or even non-existent differences (Dangour et al., 2009) (Table 9). Therefore, also in the case of minerals, it is very difficult to delineate a clear trend between conventionally and organically fruits and vegetables, because their content is affected by other factors, including for example the fertilization programs, the activity of microorganisms in soil, the genetic background of plants, the seasonal influences and the anthropogenic contamination (Rembiałkowska, 2007); all these factors make the production system an irrelevant parameter for the micronutrient contents of plant-based foods.

Table 9: Effect of organic and conventional production system on mineral contents of fruits and vegetables

Food	Species	Compounds	Production system	References
Apple	*Malus x domestica*, cv. Starking Delicious	Ca, K, Na, Mn	↑ Organic	Roussos, & Gasparatos, 2009
	Malus x domestica, cv. Royal Gala and Fuji	K, Mg, N	↑ Conventional	Do Amarante, Steffens, Mafra, & Albuquerque, 2008
	Malus domestica Borkh., cv. Gala	P, Ca, Mg, Zn	No effects	Peck, Andrews, Reganold, & Fellman, 2006
Kiwifruits	*Actinidia deliciosa*, cv. Hayward	Ca, K, Mg	↑ Organic	Amodio et al., 2007
Yellow plums	*Prunus domestica* L., cv. Shiro	K, Mg, Zn	↑ Organic	Lombardi-Boccia, Lucarini, Lanzi, Aguzzi, & Cappelloni, 2004
Wheat	*Triticum* spp	Ca, Cu, Fe, K, Zn	↑ Organic	Hussain, Larsson, Kuktaite, & Johansson, 2010
	Triticum aestivum L., cv. Tommi	C, K, Mg, P, S, Ca, Fe, Mn, Zn, Cu, Ba, Sr, Na	No effects	Laursen et al., 2011
	Triticum aestivum L.	Ca, Fe, Mn	↑ Conventional	Vrček et al., 2014
Corn	*Zea mays*	P, Mg, K Mn	↑ Organic	Yu, Guo, Jiang, Song, & Muminov, 2018
Potato	*Ipomoea batatas* (L.) Lam.	Ca, Cu, K, P, Mn, Zn Mg, Na	↑ Organic ↑ Conventional	Dos Santos et al., 2019
	Solanum tuberosum L., cv. Sava	C, N, K, Mg, P, S, Ca, Fe, Mn, B, Zn, Cu, Mo, Ba, Sr, Na	No effects	Laursen et al., 2011
Lettuce	*Lactuca sativa* L.	Cu, Fe, K, Mg Mn, Zn	↑ Organic ↑ Conventional	de Souza et al., 2014
Pepper	*Capsicum annuum* L.	K, Mg, Na, Zn	↑ Organic	de Souza et al., 2014
Yellow plums	*Prunus domestica* L., cv. Shiro	Na, Cu	↑ Conventional	Lombardi-Boccia, Lucarini, Lanzi, Aguzzi, & Cappelloni, 2004
Strawberry	*Fragaria x ananassa*, cv. Diamante, San Juan and Lanai	K, P	↑ Conventional	Reganold et al., 2010

Lemons	*Citrus meyeri* Tan.	Zn, Cu, Fe, Mn	No effects	Uckoo, Jayaprakasha, & Patil, 2015
Grapefruit juice	*Citrus paradisi* Macf., cv. Rio Red	B, Cl, Cu, Fe, Na, P, Zn	No effects	Lester, Manthey, & Buslig, 2007
Tomato	*Solanum lycopersicum* L., cv. Lladò, Antillas	K, Ca, Na, Mg	No effects	Ordonez-Santos, Vazquez-Oderiz, & Romero-Rodriguez, 2011
	Solanum lycopersicum L.	Cd, Pb, Ni, Cr, Cu, Fe, Zn	No effects	de Souza et al., 2014
Zucchini	*Cucurbita pepo* L.	P, N	No effects	Maggio, De Pascale, Paradiso, & Barbieri, 2013
Barley	*Hordeum vulgare* L., cv. Simba, Smilla, Power	C, N, Mg, P, S, Ca, Fe, Zn, Cu, Ba, Sr, Na	No effects	Laursen et al., 2011
Faba bean	*Vicia faba* L., cv. Columbo	N, K, Mg, P, Sb, Ca, Fe, Mn, B, Zn, Cu, Mo, Ba, Sr, Na	No effects	Laursen et al., 2011

5.7 Total polyphenols

Polyphenols are secondary metabolites produced by plants to protect against environmental insults, such as insect wounds, fungal infections or mechanical damage. In the last decade, these compounds have attracted the attention of researchers worldwide for their multiple biological functions, including the antioxidant, anti-inflammatory, anti-cancer and anti-atherosclerotic effects, contributing to maintain a healthy well-being and prevent the onset of most common human diseases (Cianciosi et al., 2020; Battino et al., 2021; Hininger-Favier, et al., 2021). Many factors affect the accumulation of the secondary metabolites in plants, comprising the use of synthetic pesticides or herbicides that may decrease plant carbon fixation, reducing the carbon available for phenolics synthesis or may block the shikimate pathway, diminishing the synthesis of aromatic compounds (Lombardi-Boccia et al., 2004); therefore, it could be deduced that organic crops may have a higher phenolic contents than conventional ones due to the lack of highly soluble fertilizers and synthetic pesticides, as a mechanism to increase plant resistance. However, when organic *versus* conventional production systems have been compared, it was not possible to delineate a clear conclusion (Dangour et al., 2009). From the data presented in Table 10, it emerges that accumulation of polyphenols in fruits and vegetables depends not only on cultivation system practices, but also on other factors (Di Vittori et al., 2018; Mazzoni et al., 2016, 2020; Mezzetti et al., 2014), including the genotypic characteristics, the fertilization management, the soil biology and the environmental pressure, so that the extent to which the abiotic and biotic stresses may contribute to the possible differences between conventionally and organically system remains to be still explored. **Table 10: Effect of organic and conventional production system on polyphenols contents of fruits and vegetables**

Food	Species	Compounds	Production system	References

Blueberry	*Vaccinium corymbosum*, cv. Bluecrop	total anthocyanins, total phenols, chlorogenic acid, myricetin 3-arabinoside, quercetin 3-glucoside, delphinidin 3-galactoside, delphinidin 3-glucoside, cyanidin 3-galactoside, delphinidin 3-arabinoside, petunidin 3-galactoside, petunidin 3-glucoside, malvidin 3-glucoside, malvidin 3-arabinoside	↑ Organic	Wang et al., 2008
	Vaccinium corymbosum L., cv. Brigitta Blue	Total flavonols, Total anthocyanins, Total polyphenols	↑ Conventional	Ochmian, Błaszak, Lachowicz, & Piwowarczyk, 2020
	Vaccinium virgatum	Total anthocyanins, Total quercetin	No effects	You et al., 2011
Grapes	*Vitis vinifera*	Total polyphenols content	↑ Organic	Bunea et al., 2012
	Vitis vinifera, cv. Monastrell	Total anthocyanins, hydroxycinnamic acids, flavonols, Total phenolic compounds, all in full ripe grapes	No effects	Mulero, Pardo, & Zafrilla, 2010
Kiwifruits	*Actinidia deliciosa*, cv. Hayward	Total phenolics	↑ Organic	Amodio et al., 2007
Corn	*Zea mays*, cv. Supersweet Golden Jubilee	Total phenolics	↑ Organic	Asami, Homg, Barrett, & Mitchell, 2003
Blackberries	*Rubus "Marion"*	Total phenolics	↑ Organic	Asami, Homg, Barrett, & Mitchell, 2003
	Rubus fruticosus, cv. Loch Ness, Chester Thornless	Total phenolic compounds	No effects	Pinto et al., 2018
Strawberry	*Fragaria vesca* L., cv. Festival	Total phenolics	↑ Organic	Khalil & Hassan, 2015
			No effects	Reganold et al., 2010

	Fragaria x ananassa Duch., cv. Diamante, San Juan, Lanai	Total anthocyanins, quercetin, kaempferol glycoside, total kaempferol, ellagic acid glycoside, ellagic acid, total ellagic acid, phloridzin glycoside, phloretin, total phloretin, R-naringin glycoside, S-naringin glycoside, R-naringenin, S-naringenin, total R-naringenin, total S-naringenin		
Lemons	*Citrus meyeri* Tan.	Hesperidin, didymin	↑ Organic	Uckoo, Jayaprakasha, & Patil, 2015
Peaches	*Prunus persica* L., cv. Regina bianca	Chlorogenic acid, Total polyphenols	↑ Organic	Carbonaro, Mattera, Nicoli, Bergamo, & Cappelloni, 2002
Pears	*Pyrus communis* L., cv. Williams	Caffeic acid, chlorogenic acid, Total polyphenols	↑ Organic	Carbonaro, Mattera, Nicoli, Bergamo, & Cappelloni, 2002
Plums	*Prunus salicina* Lindl.	Total anthocyanins, Total phenolics	↑ Organic	Cuevas et al., 2015
	Prunus domestica L., cv. Shiro	Total polyphenols	↑ Conventional	Lombardi-Boccia, Lucarini, Lanzi, Aguzzi, & Cappelloni, 2004
Oranges	*Citrus sinensis*, cv. Tarocco	Total phenolics, Total anthocyanins	↑ Organic	Tarozzi et al., 2006
	Citrus sinensis L., cv. Washington navel	Total phenols	↑ Conventional	Khalil & Hassan, 2015
Red currants	*Rubus rubrum* L., cv. Rondom	Total polyphenols, Total phenolic acids, quercetin-3-O-glucoside, Total flavonols, oligomeric procyanidins	↑ Organic	Wojdyło, Oszmiański, Milczarek, & Wietrzyk, 2013
Black currants	*Rubus nigrum*, cv. Ben Alder, Ben Hope, Titania	Total polyphenols, Total anthocyanins, Total phenolic acids, quercetin-3-O-glucoside	↑ Organic	Wojdyło, Oszmiański, Milczarek, & Wietrzyk, 2013
	Ribes nigrum L.		No effects	

		Total phenolic content, phenolic acids, flavonols, anthocyanins		Anttonen, & Karjalainen, 2006
Potato	*Solanum tuberosum* L., cv. Arinda, Ditta, Nicola	Total phenolics	↑ Organic	Lombardo, Pandino, & Mauromicale, 2012
Passion fruits	*Passiflora edulis* S.	Total phenolics	↑ Conventional	Oliveira et al., 2017
Apple	*Malus × domestica* Borkh., cv. Starking Delicious	Total phenols, Total flavanols	No effects	Roussos, & Gasparatos, 2009
	Malus pumila, cv. Red Delicious-Starking, Golden Delicious, Granny Smith, Jona Gold, Royal Gala	Total Phenols, (−)-Epicatechin, Procyanidin B2S, Cyanidin 3-galactoside, Phloridzin, Quercetin 3-galactoside	No effects	Valavanidis, Vlachogianni, Psomas, Zovoili, & Siatis, 2009
Tomato	*Solanum lycopersicum* L.	Total phenolics	No effects	Juroszek, Lumpkin, Yang, Ledesma, & Ma, 2009
	Solanum lycopersicum L., cv. Lladò, Antillas	Total phenolics	No effects	Ordonez-Santos, Vazquez-Oderiz, & Romero-Rodriguez, 2011
	Solanum lycopersicum L., cv. Rumba	Total phenolic acids, gallic acid, p-coumaric acid	No effects	Hallmann, Lipowski, Marszałek, & Rembiałkowska, 2013
Eggplants	*Solanum melongena* L., cv. Blackbell, Millionaire	5-caffeoylqunic acid	No effects	Luthria et al., 2010
Cauliflower	*Brassica oleracea*, L., subsp. *Botrytis*, cv. Emeraude, Magnifico	Total polyphenols	No effects	Picchi et al., 2012
Broccoli	*Brassica oleracea*. L., var. *italica*, cv. Belstar, Fiesta	Total phenolics, Total flavonoids	No effects	Valverde et al., 2015

Sunflower seed oil	*Helianthus* spp	Total polyphenols	No effects	Perretti, Finotti, Adamuccio, Della Sera, & Montanari, 2004
Cinnamon	*Cinnamomum* spp	Total phenolics, gallic acid, catechin, (−)-epigallocatechin gallate, vanillic acid, p-Coumaric acid	No effects	Lv et al., 2012
Peppermint	*Mentha* × *piperita*	Total phenolics, gallic acid, catechin, (−)-epigallocatechin gallate, vanillic acid, p-Coumaric acid	No effects	Lv et al., 2012
Pepper	*Capsicum annuum* L.	Total phenolics	No effects	López, Fenoll, Hellín, & Flores, 2014
Citrus juice	*Citrus sinensis* (L.) Osbeck, cv. Maltaise	Total phenolics, gallic acid, caffeic acid, p-Coumaric acid, vanillic acid, naringin	No effects	Letaief, Zemni, Mliki, & Chebil, 2016

6. Total antioxidant capacity

The total antioxidant capacity (TAC) can be defined as the ability of a food matrix or isolated compound to scavenge free radicals or limit their formation, thus decreasing oxidative stress, that together with inflammation, is the main contributor for the development of many common human diseases (Ansary & Cianciosi, 2020). Very few studies have assessed and compared the TAC of plant foods grown under conventional and organic production systems. Some researches on apples (Peck, Andrews, Reganold, & Fellman, 2006), blueberry (Wang, Chen, Sciarappa, Wang, & Camp, 2008), grapes (Bunea et al., 2012), kiwifruits (Amodio et al., 2007; D'Evoli et al., 2013), currants (Wojdyło, Oszmiański, Milczarek, & Wietrzyk, 2013), strawberry (Reganold et al., 2010), peaches and pears (Carbonaro et al., 2002), and sunflower seed oil (Perretti, Finotti, Adamuccio, Della Sera, & Montanari, 2004), have found an increase in the TAC of organic products, while other studies have highlighted opposite results, as occurred for red oranges (Tarozzi et al., 2006), plums (Cuevas et al., 2015), blueberry (Ochmian, Błaszak, Lachowicz, & Piwowarczyk, 2020) and citrus juice (Letaief, Zemni, Mliki, & Chebil, 2016). No differences in TAC were outlined for apple (Valavanidis, Vlachogianni, Psomas, Zovoili, & Siatis, 2009), grapefruits (Chebrolu, Jayaprakasha, Jifon, & Patil, 2012), blackberries (Pinto et al., 2018), blackcurrants (Anttonen, & Karjalainen, 2006), passion fruits (Oliveira et al., 2017), cauliflower (Picchi et al., 2012; Maggio, De Pascale, Paradiso, & Barbieri, 2013) and tomato (Juroszek, Lumpkin, Yang, Ledesma, & Ma, 2009) between conventional and organic production system.

It is not surprising that there is not a well-defined tendency also for the TAC: on one side, this parameter is closely correlated to the phenolic and vitamin content of plant foods, on the other side it depends on other factors, including the genotype, environmental condition, fertilization programs and even the method used to assess it.

7. Impact of organic and conventional farming on society

7.1 Consumers attitude towards organic food

Although there is a wide debate in academic circles on the quality of organic production and health safety issues, organic food is attracting more and more consumer interest (Gomiero, 2018; Yu, Guo, Jiang, Song, & Muminov, 2018). In fact, in recent years consumer concern about the quality and safety of conventional foods has increased and primarily drives the growing demand for organic foods, which are perceived as healthier and safer (free of agrochemical residues, hormones, antibiotics and other potentially harmful substances, higher nutritional value) than those produced by conventional agriculture; also, other more complex factors related to environmental sustainability and ethical, social and cultural beliefs are driving consumers in the choice of organic products (Gomiero, 2018). The usual consumers of organic products are families with children or young people, with a general high level of education (Forman & Silverstein, 2012).

Consumers associate the idea of the organic product with greater safety than conventional food, driven by the principles of organic production, which argue that if organic food is not contaminated with nitrates, pesticides and other contaminants, then it is practically risk-free (Seljåsen et al., 2016) The consumer's belief in finding a safer food when it comes from organic production is not fully supported by the scientific community, given the lack of clear scientific evidence and the presence of often contradictory results (Magkos et al., 2006; Seljåsen et al., 2016). This ambiguity of evidence and anecdotal accounts has often led to unsubstantiated claims about organic , which is automatically misperceived as synonymous with "safe", and often emotional rather than rational paths have led to divergences of views between the public and scientists (Forman & Silverstein, 2012; Gomiero, 2018; Magkos et al., 2006; Yu, Guo, Jiang, Song, & Muminov, 2018).

7.2 Socio-economic impact

Organic farming presents a rationality in which economic profit is often not the motivation for producers and implies "specific relationships with nature and technology and social relationships" (Pudak & Bokan, 2011). The industrial-conventional and agrarian-organic perspectives are often presented as diametrically opposed, each with its own proponents. The first one is criticized for the excessive emphasis on cost efficiency and productivity, in despite of social and environmental outcomes (Ponisio & Ehrlich, 2016), while the agrarian approach, has been criticized for producing inadequate yields and for being dogmatic and misled by some agronomists (Connor, 2008).

From the socio-economic point of view, organic farming has shown several interesting aspects. In fact, it has been reported that organic farming represents a profitable activity for farmers: despite having total management costs not significantly different from those of conventional agriculture, but labor costs higher by about 10% for farming practices and about 20-30% lower profits than conventional farming, organic farming is about 25-35% more profitable when organic premiums are accounted for (Meemken & Qaim, 2018). This finding has been confirmed by a meta-analysis of 54 crops and their rotations, which concluded that organic farming is generally more profitable than conventional agriculture due to price premiums (Crowder & Reganold, 2015). Although labor costs tend to be higher in organic systems, the costs of inputs are often lower and, when combined with price premiums, this can reduce the financial risk for farmers (Patil et al., 2014). In the EU, for example, premiums on organic prices and subsidies from the common agricultural policy significantly increased profitability (Jaime, Coria & Liu, 2016). Organic subsidies can, however, benefit larger farms and create a cycle of dependency to maintain profitability. Furthermore, organic certification bodies can facilitate farmers' transition to organic production, fostering knowledge exchange and in both developed and developing countries. However, the costs of certification itself can be prohibitive and an insurmountable barrier to entry for smallholders (Shennan et al., 2017).

In addition to profitability, various factors affect entry and survival in the organic market. Access to knowledge and resources, and participation in training have a large impact on entry and are frequent barriers for resource-poor farmers in developing countries (Rezvanfar, Eraktan, & Olhan, 2011).

In the debate comparing conventional and organic agriculture, the negative impacts of agrochemical exposure for human health, especially farmworkers, is an important issue. The US Environmental Protection Agency estimates that 10,000-20,000 pesticide poisonings are diagnosed in US farm workers each year (Simelton et al., 2009). Humans are exposed to field pesticides during application or from contaminated food and water. Numerous reviews identify important adverse health effects of various pesticides, but warn that limited data are available (Saillenfait, Ndiaye & Sabate, 2015; Popp, Peto & Nagy, 2013).

The ability of agricultural systems to survive socio-economic and biophysical disturbances and stress is a crucial aspect of sustainability, especially in the context of global climate change. Terms such as resilience (or robustness, adaptability) are widely used to describe the susceptibility and ability of a system to absorb, adapt to or recover from environmental or socioeconomic stresses (Shennan et al., 2017).

There have been few attempts to directly compare the resilience of conventional versus organic systems. Diversification is a key element of resilience, which for agricultural systems can take the form of habitat, business, genetic, crop and land use diversification (Shennan et al., 2017).

However, there are rare studies that integrate the examination of social and biophysical differences in the resilience of conventional and organic farming systems. Jacobi et al. (2014, 2015) provide two of the few in-depth studies on the resilience of organic and conventional manufacturing. They found that organic cocoa crops, particularly those using agroforestry succession, scored the highest on a number of indicators including tree crop diversity, soil quality, yields and incomes, and social connectivity (from participation of local farmers in learning and certification organizations). The data was collected from a modest number of farms for just one year, so it is not sufficient to argue conclusions. There is a clear need for further in-depth, long-term studies addressing resilience in a variety of cultivation systems.

8. Conclusion

The evaluation of the effects of applying organic agriculture instead of conventional agriculture is a difficult process to apply, both in terms of food quality and environmental sustainability (Table 11).

Table 11. Main differences between organic and conventional farming system.

	Organic	**Conventional**
Soil utilization	Increasing trend of land use to counteract the reduced yield	Possibility of reduction of land use thanks to higher yield
Pesticide use	Use of natural toxic pesticides – high limitations in finding more sustainable chemical solutions for crop protection	Use of more efficient synthetic/natural pesticides with reduced impact
Biological contamination	Difficulties to control aflatoxins and bacterial contamination	Safety advanced tools to prevent contaminations
Biodiversity	Increased biodiversity at small scale through reduced pesticides use and semi-natural landscapes	Risk for biodiversity at small scale for more intensive cultivation
Soil and water quality	Increased through longer crop rotation, manure application and less use of synthetic products, but risk of eutrophication	Less soil quality due to more intensive use and risk of water contamination with synthetic pesticides and fertilizer, but more accurate source management
Yield	Reduced yield – difficult management of fertilization and pests protection	Maintain yield with the use of synthetic chemicals for optimal fertilization and pests protection
Sensorial quality	For the sensory quality it is not possible to highlight clear differences between the different agricultural practices, depending on several other factors, such as plant background, soil type or seasonality	For the sensory quality it is not possible to highlight clear differences between the different agricultural practices, depending on several other factors, such as plant background, soil type or seasonality
Nutritional quality	For the nutritional quality it is not possible to highlight clear differences between the different agricultural practices, depending on several other factors, such as plant background, soil type or seasonality	For the nutritional quality it is not possible to highlight clear differences between the different agricultural practices, depending on several other factors, such as plant background, soil type or seasonality
Food loss	Higher risk of food loss for lower shelf life and reduced tools for post-harvest diseases control	Advanced tools to prevent food loss of higher safety for the consumer
Operator security	Reduced risk for low exposure to carcinogenic. Some organic	More risk for higher exposure to dangerous synthetic pesticides and fertilizers. More

	fertilizers/pesticides are also dangerous	risk for environmental pollution.
Socio-economic impact	Higher profitability with Government subsidies, but risk to be dependent from these. Difficult access to organic product from poorer population	Lower profitability than organic, but not dependent from subsidies. Easier accessibility to products.

In this review, we have compared the organic farming with the conventional one because there are plenty of studies in the literature comparing these two farming methods, considered as alternatives. It has already been described how the consumer chooses the organic product for a series of reasons, mainly related to the increased healthiness of the product (more nutritional compounds, less pesticides and antibiotics), but also to the effect on the environment, animal welfare and fair remuneration of farmers. At the same time, however, these numerous benefits attributed to organic farming are not fully supported by scientific evidences . Organic products are not less contaminated by heavy metals, mycotoxins and bacteria than conventional products , indeed, organic farming presents less instruments to counteract the presence of mycotoxins and bacteria in its products, and this could be a serious concern for the consumer. The scientific evidence of safer, more nutritious and healthier organic foods is not convincing at all. In this work we have highlighted indeed how the nutritional quality of fruits and vegetables is affected by several other parameters, including the weather conditions, the crop fertilization or the plant genetic background.

The premium granted to organic products is certainly a reward that recognizes the careful work of farmers who follow organic cultivation practices, but at the same time represents an obstacle for the large number of people who are unable to sustain high costs for the purchase of food, and therefore will not have access to this type of product. Even the environmental sustainability of organic productions is questioned: if on the one hand organic farming practices are more attentive to the reduction of synthetic inputs, on the other hand they have dramatically lower productive yields than conventional agriculture; consequently, the massive adoption of organic farming techniques, at present, would entail the need for large surfaces to meet the global demand for food, resulting in a greater impact on the environment than the more efficient conventional agriculture. Transdisciplinary research would have an important role for a better understanding of the complexities of the ecological approach to agriculture characterized by organic farming, and more knowledge transfer from conventional to organic farming and vice versa is desirable in the next few years . In addition, the effects of the agricultural systems on the physicochemical characteristics, nutrition quality and safety of fruits and vegetables require more deeper studies in order to understand the role of the molecular and physiological determinants, the abiotic and biotic stress and the secondary metabolism that can influence the quality of plant foods.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figure captions

Figure 1: Agriculture area under organic agriculture – Share in agricultural land by Country (%). Data are referred to 2019 year. Source: FAOSTAT (http://www.fao.org/faostat/en/#data/EL/visualize), accessed on 26th July 2021.