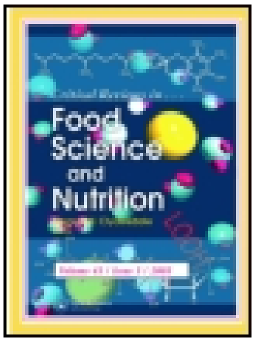

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REVIEW

Smart agriculture for food quality: facing climate change in the 21st century

Caterina Agrimonti, Marta Lauro, and Giovanna Visioli

Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Parma, Italy

ABSTRACT
Climate change, with increasing temperatures and atmospheric carbon dioxide levels, constitutes a severe threat to the environment and all living organisms. In particular, numerous studies suggest severe consequences for the health of crop plants, affecting both the productivity and quality of raw material destined to the food industry. Of particular concern is the reduction of proteins and essential micronutrients as iron and zinc in crops. Fighting this alarming trends is the challenge of Climate-Smart Agriculture with the double goal of reducing environmental impacts (use of pesticides, nitrogen and phosphorus leaching, soil erosion, water depletion and contamination) and improving raw material and consequently food quality. Organic farming, biofertilizers and to a lesser extent nano-carriers, improve the antioxidant properties of fruits, but the data about proteins and micronutrients are rather contradictory. On the other hand, advanced devices and Precision Agriculture allow the cultivations to be more profitable, efficient, contributing more and more to reduce pest diseases and to increase the quality of agricultural products and food safety. Thus, nowadays adoption of technologies applied to sustainable farming systems is a challenging and dynamic issue for facing negative trends due to environmental impacts and climate changes.

KEYWORDS
Environment; food nutritional value; food safety; greenhouse gases; sustainable agriculture

Agriculture and global climate change

During the last centuries, significant changes in the global climate and temperatures have been registered. Since industrial revolution, massive burning of fossil fuels started and progressively led to an increase of the atmospheric concentration of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane and nitrogen dioxide affecting global temperatures. Due to its strong dependence on climate, agriculture is an easy target of climate change.

The increase of temperature is responsible for abiotic stresses that drastically affect crop quality, resulting in dramatic yield losses. Such stresses can interfere with germination, vegetative growth, dry matter partitioning, reproductive processes and grain filling and quality (Sehgal et al. 2018). In particular, the frequent combination of drought and heat stresses has pronounced impacts during early phases of the reproductive process (sporogenesis, anthesis, pollination, fertilization and early embryo development). Global warming also increases frequency and severity of plant pests and diseases with consequent loss of yield and quality (Trębicki et al. 2015).

In theory, an increase in primary production is expected at elevated CO_2 (eCO_2) levels but experiments show that long term exposure to eCO_2 increases or decreases photosynthetic efficiency depending on the species (Ghildiyal and Sharma-Natu 2000; Sánchez-Guerrero et al. 2005; Ziska and Bunce 2007). Moreover, CO_2 beneficial effects on plant growth appear to be limited by low nutrients concentration in soils, light and water availability (Reich et al. 2016). All these concomitant factors can affect not only crop yields but also food quality.

On the other hand, current intensive agricultural practices, including land clearing, excessive and inefficient use of fertilizers, irrigation and the use of fossil fuels for agricultural machines, make agriculture a significant contributor to GHG emissions (Heidecke et al. 2018). Therefore, as summarized in Figure 1, modern agriculture has two great challenges: facing climate change effects (adaptation) and developing sustainable practices, counteracting also the negative effects on yields and food quality (mitigation). This goal may be reached with a more efficient and respectful use of natural resources and a reduction of wastes and pollutants. Climate-Smart Agriculture (CSA) is an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate (FAO 2017). It includes traditional organic farming techniques as well as innovative precision farming practices which apply Information Technology (IT) aiming to optimize the use of water and fertilizers. In this review we summarize the effects of climate change and the different CSA practices, highlighting their potential positive effects on food safety and healthy proprieties.

Climate change effects on food quality

Food quality is a concept that includes healthy properties and safety. Healthy properties are determined by the content of beneficial nutritional compounds as micronutrients,

CONTACT Giovanna Visioli giovanna.visioli@unipr.it Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Parma, Italy.

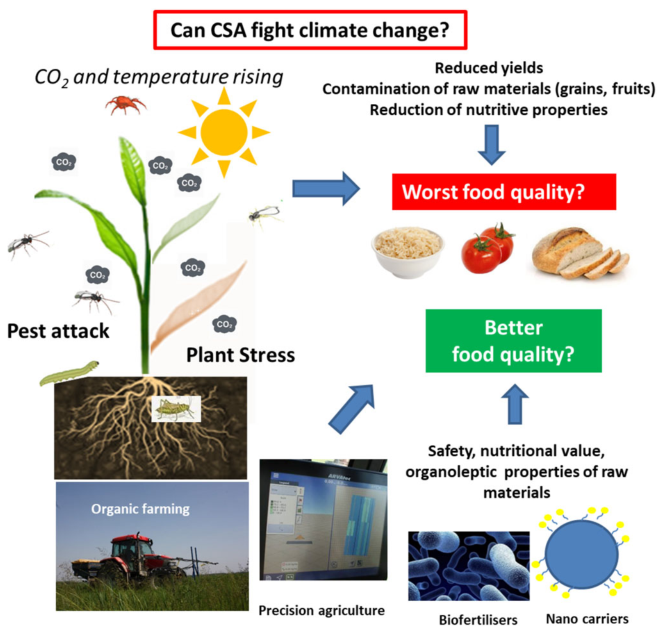

Figure 1. Different sustainable agronomic practices and their possible effects on climate change mitigation and quality and safety of food products. CSA = Climate Smart Agriculture.

especially Fe and Zn, antioxidants or bioactive molecules such as carotenoids, tocopherols and phenolic compounds. Safety is determined by the absence of toxic compounds derived both from herbicides and pesticides and/or toxic metabolites derived from pest attack.

Food safety

Mycotoxins are a great threat to food safety: they are low molecular weight toxic and cancerogenic compounds produced by fungi *Aspergillus*, *Fusarium* and *Penicillium* which infect mostly cereals, a staple food for many people and thus their impact on global health risks is not negligible. Aflatoxins, the most common mycotoxins, are furanocoumarin derivatives produced by *Aspergillus flavus* and *A. parasiticus*: AFB_1, AFB_2, AFG_1, AFG_2 are the most toxic molecules (Zain 2011). They are potent carcinogens and sometimes cause acute and lethal intoxication. Moreover, AFB_1 is toxic for lactating animals and may be converted by their digestive system in the hydroxylated form, AFM_1 which is excreted in milk (Applebaum et al. 1982). European Community has set restrictive limits for the combined presence of the above-mentioned aflatoxins in feed and food (Commission Regulation (EC) N. 1881/2006 2006). The infection of maize crop by A. *flavus* is highly facilitated by warm climate, humidity and drought. Following some predictive models, an increase of +5 °C can shift the European area of possible aflatoxin production in maize, from the actual below the 45° North latitude to 60° North. This means that the area with high aflatoxin risks will be considerably extended in Eastern Europe, the Balkan Peninsula and the Mediterranean regions (Battilani et al. 2016). These effects seem less dramatic for wheat: even if the models predict an increase of *A. flavus* growth by 60% and 100% in the + 2 °C and + 5 °C scenarios, the probability of aflatoxin contamination in wheat is considered irrelevant.

An integrated model was elaborated to predict the effect of global climatic change on the risk of aflatoxin contamination in cow milk, carrying out a study on AFB_1 production in maize grown in Eastern Europe and imported to the Netherlands for feeding livestock (Van der Fels-Klerx et al. 2019). In general, most of the calculations suggest an increase, up to 50%, of maximum mean aflatoxin AFM_1 in milk and a stable or slight increase (up to 0.6%) of probability to find AFM_1 in milk above the EC limits by 2030. However, the authors highlighted that the results depend on the type of model used.

The aflatoxins constitute a threat also for grape and wine production. A survey of 942 samples showed higher concentrations of grape aflatoxin ochratoxin A in wines from the warmer southern European countries than from northern ones (de Orduña 2010). Moreover, a correlation between grape and wine ochratoxin A levels and the warm climate was described (Blesa et al. 2006).

Food nutritional and organoleptic properties

An extensive meta-analysis (Loladze 2014) considering 130 food plant varieties over 30 years around the world evidenced a general decline due to eCO_2 of the principal nutrients (N, P, Ca, S, Mg, Fe, Zn, Cu) except for Mn and K. N is the most affected element (about −15%), followed by Zn (−11%) and Fe (−10%). Cereal grains (barley, rice and wheat) showed an overall decrease of above nutrients (around −7%), while potato tubers seem less affected (−3.5%). The overall nutrient reduction in all edible tissues is around −6.5%. In contrast to the lower N and mineral content, eCO_2 increased C content by 6%, with a significant increase of total nonstructural carbohydrate, like starch, fructose, glucose, sucrose and maltose.

In wheat, the world's third most important cereal crop, the eCO_2 reduces N, proteins, and amino acids and modifies gluten composition (Broberg, Högy, and Pleijel 2017). This negatively affects bakery properties reducing dough elasticity and strength, bread volume and increasing mixing time. Also a significant reduction of the concentration of various minerals (Ca, Cd, Cu, Fe, Mg, Mn, P, S, and Zn) was observed, while no effect was reported on starch accumulation (Broberg, Högy, and Pleijel 2017).

Also rice, a staple food for a large part of the world population, especially in Eastern Countries, is highly affected by climate change. High temperatures during grain filling increase the breakage of kernels with a dramatic reduction of yields, up to 10% in South-East Asian countries (Lyman et al. 2013). eCO_2 accelerates the grain filling at an early stage, but inhibits it at later one leading to small, light and chalky grains (Tsukaguchi and Iida 2008; Yang and Wang 2019). Moreover, under eCO_2 rice proteins decrease but the percentage of large starch granules increases; this generates voids among the granules that increase chalkiness (Yang et al. 2007). On the other hand, eCO_2 does not seem to affect the amylose content in the starch, the key factor in determining the organoleptic quality of cooked rice, as well as aroma, taste and overall palatability (Yang and Wang 2019). Under eCO_2 vitamin B concentration in grains declines, probably as a consequence of reduced N assimilation, but that of vitamin E increases (Zhu et al. 2018).

The reduction of proteins and micronutrients content and increasing of sugars under eCO_2 have been observed also in potato, tomato and lettuce (Bhat, Ahsan, and Husain 2017; Dong et al. 2018). In potato tubers, eCO_2 increases the concentration of glucose (22%), fructose (21%) and reducing sugars (23%), responsible for browning and acrylamide formation in fried potatoes (Högy and Fangmeier 2009). eCO_2 decreases also the content of Zn, citrate and glycoalkaloids. The reduction of citrate concentration leads to a higher risk of discoloration but improves the taste. Glycoalkaloids are toxic compounds, therefore their reduction may be positive in terms of safety, but is generally considered negative in term of taste. However, the data about glycoalkaloids and citrate are not concordant among all authors. In tomato and lettuce, the increase of soluble sugars potentially enhances their quality, as well as the antioxidant ascorbic acid but, the concomitant reduction of proteins content worsens their nutritional properties (Dong et al. 2018).

The effect of eCO_2 on phytate concentration in wheat, rice, peas, soybeans and in C4 maize and sorghum was also evaluated (Myers et al. 2014). Phytate is a phosphate storage molecule present in many plants, that is not absorbed by the human digestive tract and inhibits the absorption of Zn and therefore is considered an anti-nutrient (Miller, Krebs, and Hambidge 2007). Phytate decreased significantly at eCO_2 only in wheat, but not sufficiently to counteract the strong decrease of Zn in the same crop.

A more recent study showed that eCO_2 affects proteins and micronutrients content of seeds and fruits in most C3 plant species with the exception of legumes that absorb atmospheric N through symbiotic bacteria (Uddling et al. 2018). However, the magnitude of the effect is influenced by different factors like cultivar, soil type or concomitant environmental conditions (Dong et al. 2018).

As far as carbohydrates content is concerned, high temperature has a larger effect than eCO_2 (Bhat, Ahsan, and Husain 2017). In soybean seeds, an increase from 18°/13 °C to 33/28 °C (day/night average) significantly raises sucrose concentration. In wheat, an increase of 2–4 °C alters starch content, starch grain size, number and gelatinization, while eCO_2 has no or little effect (Williams et al. 1995). Studies on combined effects of high temperature and CO_2 on red kidney bean seeds showed that their composition was unaffected by eCO_2 but high temperature (34/24 °C) dramatically reduced glucose concentration (−44%) and increased the concentration of sucrose (33%) and raffinose (116%) (Thomas et al. 2009). The increase in raffinose harms seed quality because human intestinal mucosa does not contain the galactosidase enzyme necessary for its digestion and this may cause digestive problems (Sebastian et al. 2000).

High temperature lowers malic acid concentration and the overall acidity of grape at maturity and increases the sugar concentration, probably as a consequence of berry evaporation (de Orduña 2010). Lower acidity negatively affects winemaking because of flavors spoilage by indigenous microorganisms that compete also with fermenting yeasts for nutrients. This may slow down or stuck alcoholic fermentation and lead to the production of undesirable metabolites like acetic acid, acetaldehyde and pyruvate (de Orduña 2010). High temperature favors the synthesis of metoxypyrazines that are agreeable at low concentrations but are perceived negatively at high concentrations, with a negative impact on grape aroma and taste.

The beneficial effects of higher temperatures are mainly the increase of flavonoids and antioxidants in strawberry fruits (Bhat, Ahsan, and Husain 2017; Wang and Zheng 2001).

Most of the data present in the literature report the effects of temperature and CO_2 separately, but their effect is the results of complex interactions between them and other environmental factors, therefore, it is important to evaluate at least CO_2 and temperature together. The response to dual CO_2 and temperature stress is crop-specific: stressed soybean plants produce seeds with a higher content of proteins but lower oil content (Dornbos and Mullen 1992). In cereals such as barley and wheat combined stresses reduce starch accumulation but increase protein content, while in *Brassica* species seed proteins content increases but seed weight is reduced (Savin and Nicolas 1996; Gan et al. 2004).

Köhler et al. (2019) observed that high temperatures reduce yields of soybean plants but increase the concentration of some minerals (Ca, Fe, Zn) in seeds, counteracting the overall negative effects of eCO_2. Differently of what observed in other crops, eCO_2 does not affect the concentration of seed proteins and oil while, in contrast, elevated temperatures tend to reduce the concentration of these components. The authors concluded that the combined eCO_2 and temperature effect may restore the seed Fe and Zn at normal levels but their experiments are limited to one cultivar and concentration of minerals and proteins varies with node position.

A predictive model evaluated climate change impact on wheat proteins considering the effects of CO_2, water, nitrogen and temperature (Asseng et al. 2019). The authors concluded that potential benefits of eCO_2 can be outcompeted by rising temperatures and changes in rainfall pattern, with significant differences among regions. In fact, grain and protein yields are expected to be lower and more variable in low rainfall regions, where nitrogen availability can affect the growth stimulus of eCO_2.

Climate smart agriculture

The concept of CSA has been introduced by FAO at the 2010 Hague Conference on Agriculture, Food Security and Climate Change and since then has gained international interest and support (FAO 2017). The main objectives of CSA are: (i) the sustainable increase of agricultural productivity; (ii) the adaptation to climate change and the increase of resilience in the agricultural sector; (iii) reducing GHG emissions (when possible) and contributing to the mitigation of climate change effects (Beddington et al. 2012). For these strategies to be successful they have to be adapted to the local situation as there is no universally valid solution. At the same time, however, national and international plans will be necessary and the whole value chain, from the field to the consumer, should be considered.

The massive use of chemical fertilizers and pesticides is considered a threat to health, soils and ecosystem biodiversity. Nitrogen fertilization is essential for obtaining high crop yields but a surplus of this nutrient can cause serious problems for the environment and human health. If not uptaken by plants, N can leach through the soil as nitrate (NO_3^-) and pollute surface and groundwater. This excess of nutrients leads to planktonic algae proliferation in rivers, lakes and estuaries, a phenomenon known as eutrophication (Entry and Sojka 2007; Liu et al. 2013; Riley, Ortiz-Monasterio, and Matson 2001; Smith and Schindler 2009). According to the Environmental Protection Agency, in the US less than 50% of the total N fertilizer applied is actually up-taken by crops so a more site-specific application, tailored to crop needs, has a great potential to mitigate environmental risks (http://www.epa.gov/ncea/efh/report.html). The situation is not any better in Europe, where the estimated indirect costs of nitrogen pollution on human health and ecosystems outweigh the direct benefits of agriculture (Brownlie et al. 2015). CSA promotes the use of organic alternatives of fertilization and pesticide and/or fertilization use targeted on the real needs of cultivation avoiding unnecessary and polluting applications, which can also have a positive impact on climate change and may also be beneficial to food quality.

Organic farming

Organic farming consists of a low-input agro-ecosystem in which crop productivity is based on the natural availability of plant nutrients, the use of green manure and biological pathogen control. These practices are regulated by international and national institutional bodies that certify organic products in all steps of the supply chain (European Commission 2016; USDA (United States Department of Agriculture) 2016). Organic farming practices are surely safer for the environment but some studies revealed that organic farming reduces on average the crop yields (Gomiero 2018). This implies that to obtain the same quantity of product as with conventional agriculture it is necessary to extend the cultivable land and to disrupt forestry and other natural habitats. Besides, organic farming employs animal manure instead of inorganic easy soluble fertilizers but, this does not necessarily imply less N leaching or less eutrophication (Kirchmann and Thorvaldsson 2000). Seufert, Ramankutty, and Foley (2012) used a comprehensive meta-analysis to examine the relative yield performance of organic and conventional farming. They examined 66 studies representing 62 sites and reporting 316 organic-to-conventional yield comparisons on 34 different crop species. The results showed that, overall, organic yields are typically lower than conventional ones: these differences ranged from 5% to 34% depending on system, crop and site characteristics. However, organic farming may be highly competitive under stress conditions: for example, under drought stress organically managed crops produce higher yields than those conventionally managed, up to 70–90% more under severe stress, thanks to the better ability of organically managed soil to store water (Gomiero 2013; Gomiero 2018).

Data on soil biodiversity in organic and conventional farming are rather controversial: some authors (Hartmann et al. 2015) found that organic farming increases the diversity of the microbiome, while others (Liu et al. 2007; Reilly et al. 2013) reported no differences or less diversity than in conventional farming. Lupatini et al. (2017) compared microbiomes around several crops (wheat, barley, potato, carrot and lily) in organic and conventional farming on the same soil. This study revealed that organic practices effectively increase microbial diversity, richness and community heterogeneity. However, the authors conclude that the response of the microbial community to farming practices is diverse and complex and increasing soil biodiversity does not necessarily mean an improvement of soil health and plant productivity (Lupatini et al. 2017). Moreover, the impact of diversity loss in conventional farming and how microbial diversity is related to ecosystem functions is not very well understood yet. Also, the long-term consequences of the microbial community enrichment in organic practices shift remain to be explored.

Biofertilizers and nano-fertilizers

The use of plant growth-promoting rhizobacteria (PGPR) has been investigated as an alternative to conventional N and P fertilizers to obtain high yields with lower environmental impacts. Rhizobacteria are microorganisms naturally living in soils in association with plant roots, forming an active part of the so-called rhizosphere. Their activities include stimulation and/or production of phytohormones and the regulation of nutrients uptake so, inoculating these organisms in the cultivated field should enhance plant and soil productivity, especially under stress condition (Egamberdieva and Adesemoye 2016). In addition to PGPR, vesicular-arbuscular mycorrhizal (VAM) fungi are nonpathogenic microorganisms that are able to establish symbioses with many spontaneous and cultivated species, and have the ability to boost water and nutrient uptake, especially in poor, arid soils, and to protect plants against pathogens (Fiorilli et al. 2018). A two-year field trial demonstrated that the use of a combination of PGPR and N-fixing bacteria improves root growth in wheat and increases plant resilience to environmental stresses. In addition, they help to reduce N losses from agricultural ecosystems thereby mitigating environmental constraints of the application of chemical fertilizers (Dal Cortivo et al. 2017). Application of PGPR and VAM consortia has also been shown to improve plant growth, in particular in conditions of abiotic stress, as a result of synergistic interactions between microorganisms. However, despite good results in the laboratory (Bhattacharyya and Jha 2012), inoculation of PGPR and VAM in the field does not always lead to the expected benefits because of the competition with native species and adverse or unstable conditions (Bréant, Jézéquel, and Lebeau 2002). A new emerging technology in agriculture is the design and use of nano-carriers for the controlled release of fertilizers and pesticides to increase their efficacy and reduce their toxicity and the environmental impact. The nanoscale delivery vehicles are designed to "anchor" to plant roots or the surrounding soil structures increasing the surface contact between plant roots and fertilizers (Chen and Yada 2011; Chen, Seiber, and Hotze 2014; He, Deng, and Hwang 2019). Nano-carriers have been utilized to encapsulated the 2,4-dichlorophenoxy acetic acid (2,4-D) which is one of the most commonly used herbicides worldwide because it is cheap and selective but very soluble in water and therefore easily dispersed in the soil (Cao et al. 2018). The fungicide carbendazim entrapped into polymeric nanoparticles showed higher activity against *Aspergillus parasiticus* and *Fusarium oxysporum* than pure and commercial preparation and was less phytotoxic (Kumar, Kumar, and Dilbaghi 2017). However, the majority of nanofertilizers have been tested only in laboratories, greenhouses, or small plots without facing the field complexity, thus, it is difficult to draw a conclusion at this point (Liu and Lal 2015; Dimkpa and Bindraban 2018). Soil characteristics such as pH, inorganic or organic compounds and biological factors (plant root exudates, bacteria and fungi) influence micronutrients behavior and modulate nanomaterial dissolution, aggregation/disaggregation and surface properties. Dimkpa and Bindraban (2018) summarized the results obtained mostly about Zn nanomaterial since it is a relevant element in human nutrition and concluded that the effects on crops are often positive with respect to conventional micronutrients but negative at doses higher than plant requirements. These authors concluded that the risks from nanoparticles under field conditions could be either less or as strong as those from conventional fertilizers at similar dose. An important issue of nano-carriers used as fertilizers or pesticides is their possible toxicological profiles which can be new potential hazards to human and environmental health. Nano-agrochemicals may interfere with important plant-microbial relationships which are all critical for soil fertility and agricultural productivity. In addition, human exposure to nanomaterials is expected to increase including both chronical exposure of agricultural workers and increase in nano-residues in soil and crops which leads to their accumulation in the food chain (Iavicoli et al. 2017; Walker et al. 2018).

Precision agriculture

Precision agriculture (PA) is a relatively new frontier in agriculture applied for nutrient management (nitrogen and phosphorous), herbicides and pesticides modulated on the basis of the real needs of plants thanks to the application of information technology to the production system, which makes possible to address intra-field variability with potential economic and environmental benefits (Bongiovanni and Lowenberg-Deboer 2004). PA started to develop in USA, Canada, Australia and Western Europe in the 1980s and has gained importance in the last decade (Zhang, Wang, and Wang 2002).

Variable-rate application (VRA) is the most spread and investigated precision technology to increase fertilizer inputs efficiency. It is used in combination with other technologies such as Global Positioning Systems (GPS), Geographic Information Systems (GIS), soil sampling and integrated pest management and can be applied to seeding, weed and pests control, lime distribution and fertilizers application (Pallottino et al. 2018). There are two VRA technologies: Map-based VRA and Sensor-based VRA. In the first one, the input concentration is regulated thanks to the use of so-called prescription maps previously prepared and downloaded on a specific software on the applicator connected to a GPS device. In the second case, optical sensors on the applicator measure the targeted property in real-time. There is, however, an effort to integrate remote sensing and real-time data in order to develop an accessible database for site-specific fertilization. Research is progressing through an integrated approach as new studies are combining sensors, prediction models and real-time weather data to maximize yields and inputs efficiency.

Nitrogen VRA has the highest potential, but it is still the most controversial part of PA techniques, due to the complexity of the N cycle, highly impacted by wheatear, soil type, agricultural management and the great field variability (Rogovska et al. 2019).

Climate smart agriculture and food quality

Organic farming is the most ancient practice of CSA and the majority of studies are focused on differences between organic and conventional products and therefore this chapter will be mainly focused on this subject. Recent data are available also about the food quality of other CSA practices, and some indications about food quality are available about PA practices and biofertilizers utilization. Traceability is also an important parameter to guarantee food quality and therefore PA issues will be discussed also on this point of view.

Climate smart agriculture and food safety

The main concern for the environment and human health is the utilization of pesticides and their presence in foods, that may be responsible or contribute to the development of cancer, Parkinson's disease and endocrine disorders (Gomiero 2013; Johansson et al. 2014)·

European Food Safety Authority (ESFA) analyzed the residual presence of 191 pesticides in 82,649 samples produced in the EU (EFSA (European Food Safety Authority) 2016). Organic food showed a higher percentage (86.4%) of samples without any quantifiable pesticide residual than conventional ones (51.6%). The percentages of samples above the Maximum Residue Levels permitted by EU legislation were lower in organic products (1.2%) than in conventional ones (3%). However, being these percentages so low, EFSA concluded that the general level of pesticide residues in both conventional and organic food is well below the threshold risk for health. The differences are particularly evident in fruits and nuts, where 69.4% of conventional products contained residues, against only 9.6% of organic products. Possible contamination occurring in fields or during food processing can explain the presence of pesticide residuals, not allowed in organic agriculture, in organic food. Conventional food is richer in toxic residuals of organophosphates (OPs) (EFSA (European Food Safety Authority) 2016) classified as carcinogenic, neurotoxicants and endocrine disruptors by World Health Organization.

An extensive study recently conducted on 33,000 French adult volunteers showed significantly lower urinary levels of residual pesticides diethylthiophosphate, dimethylthiophosphate, dialkylphosphates, and free 3-phenoxybenzoic in organic food consumers than in conventional food consumers (Baudry et al. 2019). Moreover, exposure to certain OPs and pyrethroïd pesticides is reduced by switching from conventional to organic foods, especially fruits and vegetables, while no significant differences were found for other compounds. The authors pointed out that the study may be biased by the honesty of volunteers in answering about their eating habits and/or other possible sources of contamination of OPs than food. However, these results were confirmed by Hyland et al. (2019) that observed significant reductions in urinary levels of thirteen pesticide metabolites and related compounds (OPs, neonicotinoid, and pyrethroid insecticides and the herbicide 2,4-D) after the introduction of organic food in the diet, in children and adults of USA families differing for race and geographic origin.

Literature about heavy metals is quite contradictory: some authors did not found a significant difference in their contents between organic and conventional food (Magkos, Arvaniti, and Zampelas 2006), others found higher levels of Cd and Pb in organic tomatoes (Rossi et al. 2008). Lower levels of Cd were found in organic cereals, while no differences were found in fruits (Barański et al. 2014). The higher content of Cd in conventional products may be related to the use of phosphate fertilizers that are often contaminated with this metal, or to its native concentration in the soil. High concentrations of Cd are considered a significant cause of vascular disorders, various common cancers, osteoporosis and other health disorders, therefore, the lower Cd levels in organic food are certainly a positive fact (McCarty and Nicolantonio 2014).

As reported previously, mycotoxin contamination constitutes a serious concern for food, especially for those derived from cereals. Because synthetic fungicides were banned in organic agriculture, it has been argued that organic crops may be more susceptible to fungal contamination. In fact, higher concentrations of mycotoxins deoxynivalenol and nivalenol were found in organic than in conventional grain samples (Eltun 1997). Moreover, an extensive comparison of more than a thousand organic and conventional cereal-based products from EU countries found a higher content of fumonisins (*Fusarium* derived mycotoxins) in organic products (Rubert et al. 2013). However, no statistical analysis was provided and it was not stated if differences were significant or not. Moreover, organic and conventional food types analyzed were not the same in the various studies and it can have introduced some bias in the analysis. A similar work carried out in the USA on 50 conventional and 50 organic foods, did not show a significant difference in mycotoxin content (Gourama 2015). In general, the majority of the studies does not report significant differences in mycotoxin content in organic and conventional food (Gomiero 2018) but the discordant results should be taken into consideration before concluding that organic is absolutely safe.

Climate smart agriculture and food technological quality and nutritional proprieties

It was previously documented that eCO_2 has negative impacts on food quality such as reduction of proteins and micronutrients, especially Zn and Fe, and increase of sugars content. It is not easy to say if organic farming and other CSA practices are able to counteract these food deficiencies since studies conducted so far, in particular the comparisons between organic and conventional food, were done on sites differing not only for agricultural practices but also for different type of soil, crop genotypes and time and conditions of harvesting.

However, despite these limitations, more positive than negative trends can be resumed by literature data. In particular, as far as technological quality is concerned, PA techniques gives the possibility to differentiate the quality of raw materials in the field. As an example, cereal quality is becoming more important than yield especially as the price of cereals reduces on world markets. There is well-substantiated evidence that quality, as well as yields, is spatially variable within fields and systems are being developed to exploit such variation to add value to the harvested crop (Stafford 2013). Recent advances in PA offer new potential for meeting grain quality standards. In particular, nitrogen-VRA could play a pivotal role in driving quality-oriented fertilization and on the other hand, precision harvesting could be an alternative method to maximize the tonnage of higher quality. Recently in Northern Italy, field spatial distribution of yield and protein content of durum wheat was assessed through the application of VR fertilization in three management zones with increasing soil fertility (Morari et al. 2018). In addition, prescription maps and optical sensors drove the precision harvesting of grains with different protein contents allowing the production of semolina with higher or lower protein contents in order to produce pasta with different characteristics (Visioli et al. 2018).

Regarding nutritional proprieties, the literature about Zn and Fe content in organic and conventional food is very contradictory: some studies showed a higher content of Fe and Zn in the organic crops (Vrček et al. 2014), others in the conventional ones (Ciołek et al. 2012; Drakou et al. 2015; Kristl et al. 2013). A meta-analysis study reported a major content of Ca, Mg, K and P in organic food but the authors concluded that only the data about P can be considered statistically significant (Smith-Spangler et al. 2012). The same study showed that protein content is lower in organic fruits and vegetables, as well as fiber content, even though the results were not considered significant. On the contrary, a 21 years-long survey of organic and conventional grain, concludes that protein content and amino acid composition are not affected by farming practice (Mäder et al. 2007).

Few data are available on sugar content in organic products. Studies on wheat reported that sucrose concentration was higher in conventional than in organic ears, but this difference was nullified in mature grains. No differences were found for other sugars (Zörb et al. 2009).

Since the 90's some studies evidenced how organic plant food possesses higher amounts of secondary metabolites, and therefore they may be more health-promoting than conventional foods (Brandt and Mølgaard 2001; Johansson et al. 2014; Woese et al. 1997). In particular, phenolic compound content seems highly influenced by farming practices. Compared to conventional farming, higher levels of phenols and polyphenols were found in organic cabbage, spinach, Welsh onion, green pepper, organics corn and strawberry (Asami et al. 2003; Ren et al. 2001). Moreover, an extensive meta-analysis study indicated that a switch from conventional to organic crop consumption would result in a 20–40% (and for some compounds more than 60%) increase in crop-based antioxidant/(poly)phenolic intake (Barański et al. 2014).

Tocopherol is another class of antioxidants. Three studies conducted with comparative experiments evidenced higher contents of tocochromanol in organic barley (Tsochatzis, Bladenopoulos, and Papageorgiou 2012), higher content of α- and γ-tocopherols in organic plums (Lombardi-Boccia et al. 2004) and higher α-tocopherol content in organic pears (Carbonaro et al. 2002), but in general, most investigations showed no difference in the content of tocopherols between organic and conventional crops. The same conclusions were drawn for carotenoid content (Johansson et al. 2014).

Biofertilizers seem to have a positive effect on the content of macro and micronutrients, vitamins and antioxidants (Alori and Babalola 2018). The application of VAM-PGPR commercial biofertilizer to wheat seeds improved the uptake of low-mobility nutrients from roots in wheat plants, with quality benefits of the grains (Dal Cortivo et al. 2018; Dal Cortivo et al. 2020). The beneficial effect of some fungi and bacteria strains endures also during post-harvest phases (Rillig et al. 2018). In particular, VAM has been used to enhance the plant growth and yield of medicinal crops because they are able to stimulate the secondary metabolism of plants to produce compounds with health properties, like antioxidants, phenylpropanoid, or carotenoid pathways (Baslam, Garmendia, and Goicoechea 2011). Resistance to storage diseases has been evidenced in potato (Diallo et al. 2011) and also correlated to arbuscular mycorrhizal fungi-species richness (Slininger et al. 2010).

Inoculation of lettuce with fungi *Azotobacter chroococcum* and *Glomus fasciculatum* increased the concentration of total phenolic compounds, anthocyanins and carotenoids, while inoculation with *G. fasciculatum* and *Glomus mosseae* highly increased the flavonoid content (Baslam, Garmendia, and Goicoechea 2011). Eftekhari, Alizadeh, and Ebrahimi (2012) observed an increased production of the flavonoid quercetin in the leaves of grape inoculated with *Glomus* sp. but the response depended on grape genotype. Inoculation of biofertilizer containing VAM and bacterial species considerably augmented the concentration of total phenolic compounds, flavonoids and phenolic acid and consequently the antioxidant capacity of the spinach (Khalid et al. 2017).

Recent data are also available on positive effects of nano-fertilizers on food quality. They improve the vegetative and reproductive traits of fruit trees, such as strawberry, mango, date, coffee and grape (Zahedi, Karimi, and Teixeira da Silva 2020). In addition, they implement the uptake of Fe, Zn and Cu, but no paper reports if this uptake led to higher micronutrients level in consumable fruits and seeds. Only an increase in the concentration of phenols and polyphenols in pomegranate fruits is reported after the application of nano-selenium (Zahedi, Karimi, and Teixeira da Silva 2020). In this emerging context, the perspective of a "green nanotechnology" should combine the benefits provided by nano-products in solving environmental challenges with the assessment and management of environmental, health, and safety risks potentially posed by nanoscale materials (Iavicoli et al. 2017; Guo et al. 2018). It is urgent to take into account all the phases in which nano-carriers may be found in the environment, from application into the field to potential incorporation into food supply and possible influences exerted by the pedo-climatic conditions that may all affect nanomaterial hazardous properties and risks (Iavicoli et al. 2017; Walker et al. 2018).

Conclusions

Global climate change has generally negative effects on crop quality. In particular, the decrease of N, proteins and the essential micronutrients such as Fe and Zn have been shown by almost all studies examined in this paper. The reduction of N and essential minerals can have significant impacts on human nutrition. Fe and Zn deficiency is already an urgent issue in many parts of the world especially in regions where people depend on C3 grains such as wheat as their primary source of these micronutrients. Organic farming is the most ancient and widespread sustainable agricultural practice, but studies on organic food are fragmentary and contradictory, and so far there is not strong scientific evidence that they have better healthy properties than conventional food, except less pesticide content. However, organic food seems to have better antioxidant properties than conventional ones and this has been found also in response to different types of biofertilizers. The impact of nano-fertilizers on quality and nutritional characteristics of food is still unexplored, but their potential positive effects on plant growth and productivity make their utilization a promising technology for sustainable agriculture.

PA technologies will contribute more and more to food safety (Gebbers and Adamchuk 2010). PA makes farming more transparent by improving tracking, tracing and documenting. Crop and livestock monitoring will give better predictions on the quality of agricultural products. The food chain will be easier to monitor for producers, retailers and customers. It will also play a significant role in terms of plant health. Diseases undetectable by traditional means will be prevented by automated optical sensing and intelligent planning options. In conclusion, we urgently need a new research and technology paradigm to address the important issue of climate change and its impact on agriculture. New dedicated fertilizers, agronomic practice, e.g. precision agriculture, and ad-hoc policies will invariably shape the future of agriculture.

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The authors declare no conflict of interest.

Abbreviations

CO_2	Carbon dioxide
CSA	Climate Smart Agriculture
eCO_2	Elevated Carbon dioxide
EC	European Commission
EFSA	European Food Safety Authority
GCG	Greenhouse Gases
GIS	Geographic Information System
GPS	Global Positioning System
IT	Information Technology
NO2	Nitrogen dioxide
OPs	Organophosphates
PA	Precision Agriculture
PGPR	Plant Growth-Promoting Rhizobacteria
USDA	United States Department of Agriculture
VAM	Vesicular-Arbuscular Mycorrhiza

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Author contributions

CA, ML and GV designed the research. CA and ML independently did literature research and screening; CA, ML and GV wrote the manuscript and ML helped improve English writing. All authors read and approved the final manuscript.

ORCID

Giovanna Visioli https://orcid.org/0000-0001-9712-3223

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