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

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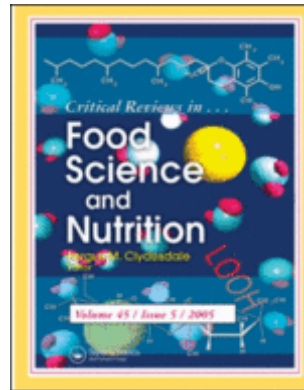
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Smart Agriculture for food quality: facing climate changes in the 21st century

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1 To Prof. Clydesdale
2 Editor, Critical Reviews in Food Science and Nutrition

Parma, 27/03/2020

Dear Editor,

We thank you for the positive evaluation of our manuscript and we have modified it according to the reviewer's suggestions. We hope that it can now be acceptable for publication in Critical Review of Food Science and Nutrition.

Best Regards,

Giovanna Visioli and co-authors

Below you can find Point by point our answers to the reviewer's comments (**in bold letters**)

Reviewer: 1

Comments to the Author

The manuscript entitled "Smart Agriculture for food quality: facing climate changes in the 21st century" submitted to Critical Reviews in Food Science and Nutrition under the ID: BFSN-2020-4800, is under an important subject with an integrated view of how Smart agriculture can assist the issues that are raised with climate change.

The work is overall well written and the references are adequate.

We thank the reviewer for the positive evaluation of the manuscript and for the useful suggestions that we incorporated in the R1 version. Listed below there are point by point changes that were made according to his/her suggestions.

The minor considerations are detailed below:

Throughout the text a series of acronyms are used and sometimes they are difficult to recall I would suggest that at least the first time they are used in a chapter they should be extensively written, or instead a acronym list should be included.

DONE. We have added an acronym list at the end of the manuscript

Line 35: the sentence needs to be clarified, "The massive burning of fossil fuels started with the industrial revolution has led to an...".

DONE. The sentence was clarified. The new sentence is the following (Lines 35-38): "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 (CO₂), methane and nitrous oxide affecting global temperatures"

Line 44: the sentence needs to be rewritten: "Global warming increases, also, the distribution of insects and pathogens..."

DONE. The sentence was rewritten as follow (Lines 44-45): *“Global warming also increases frequency and severity of plant pests and diseases with consequent loss of yield and quality (Trebicki et al. 2015)”*

Line 52: remove the: “clearing, the”

DONE

Line 59-60: the phrase needs to be rewritten: *“Agriculture (CSA), that includes traditional organic farming and the innovative precision farming practices aiming to optimize the use of water and fertilizers by informatics technologies (FAO 2017),”*

DONE. The phrase is now changed (Lines 58-64): *“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 aiming to optimize the use of water and fertilizers”.*

Lines 77-79, it would be clearer if all the acronyms could have in front the molecule.

AFB1, AFB2, AFG1, AFG2 is the conventional denomination of the four most toxic aflatoxins. For more clarity we have added this information in the text (Lines 76-81) *“Aflatoxins, the most common mycotoxins, are furanocoumarin derivatives produced by *Aspergillus flavus* and *A. parasiticus*: AFB₁, AFB₂, AFG₁, AFG₂ are the most toxic molecules (Zain, 2010). They are potent carcinogens and sometimes cause acute and lethal intoxication. Moreover, AFB₁ is toxic for lactating animals and may be converted by their digestive system in the hydroxylated form, AFM₁ which is excreted in milk (Applebaum et al. 1982).”*

Line 15 : mistyping, should be flavors instead of favors.

DONE

Line 282: The authors refer to the use of nanoparticles, however the toxicity effects that these particles may have are not mentioned. This a issue that should be considred in the manuscript.

The reviewer is right, at this purpose we inserted the following sentences with the appropriate references (Lines 285-291) *“An important issue of nano-carriers used as fertilisers 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 a., 2018).”*

and

(Lines 448-454) *“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*

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1 *conditions that may all affect nanomaterial hazardous properties and risks (Iavicoli et al. 2017;*
2 *Walker et al. 2018)”*.

3 Line 294: the acronyms should all be clarified before their use (GPS and GIS)
4 **DONE. We inserted the full name in the text and in the abbreviation list**

5
6 Lines 308, 316, 368: Do not use acronyms in titles.
7 **DONE We eliminated all acronyms in the titles**

8
9 Line 384: Instead of Norther should be Northern
10 **Sorry for the mistake, we modified accordingly**

11
12 Line 438: place . of the phrase, after seeds
13 **DONE**

For Peer Review Only

1 Smart Agriculture for food quality: facing climate changes in the 21st century

2

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4

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13 Abstract

14 Climate change, with increasing temperatures and atmospheric carbon dioxide levels, constitutes a
15 severe threat to the environment and all living organisms. In particular, numerous studies suggest
16 severe consequences for the health of crop plants, affecting both the productivity and quality of raw
17 material destined to the food industry. Of particular concern are the reduction of proteins and essential
18 micronutrients as iron and zinc in crops. Fighting this alarming trends is the challenge of Climate-
19 Smart Agriculture with the double goal of reducing environmental impacts (use of pesticides, nitrogen
20 and phosphorus leaching, soil erosion, water depletion and contamination) and improving raw
21 material and consequently food quality. Organic farming, biofertilizers and to a lesser extent nano-
22 carriers, improve the antioxidant properties of fruits, but the data about proteins and micronutrients
23 are rather contradictory. On the other hand, advanced devices and Precision Agriculture allow the

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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: greenhouse gases, environment, food safety, food nutritional value, 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 (CO₂), 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 and 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 (Trebicki et al. 2015).

In theory, an increase in primary production is expected at elevated CO₂ (eCO₂) levels but experiments show that long term exposure to eCO₂ increases or decreases photosynthetic efficiency depending on the species (Ghildiyal and Sharma-Natu 2000; Sanchez-Guerrero et al. 2005; Ziska et al. 2007). Moreover, CO₂ beneficial effects on plant growth appear to be limited by low nutrients

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3 50 concentration in soils, light and water availability (Reich et al. 2016). All these concomitant factors
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5 51 can affect not only crop yields but also food quality.
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8 52 On the other hand, current intensive agricultural practices, including land clearing, excessive
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10 53 and inefficient use of fertilizers, irrigation and the use of fossil fuels for agricultural machines, make
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12 54 agriculture a significant contributor to GHG emissions (Heidecke et al. 2018). Therefore, as
13
14 55 summarized in Figure 1, modern agriculture has two great challenges: facing climate change effects
15
16 56 (adaptation) and developing sustainable practices, counteracting also the negative effects on yields
17
18 57 and food quality (mitigation). This goal may be reached with a more efficient and respectful use of
19
20 58 natural resources and a reduction of wastes and pollutants. Climate-Smart Agriculture (CSA) is an
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22 59 approach that helps to guide actions needed to transform and reorient agricultural systems to
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24 60 effectively support development and ensure food security in a changing climate (FAO 2017). It
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26 61 includes traditional organic farming techniques as well as innovative precision farming practices
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28 62 which apply Information Technology (IT) aiming to optimize the use of water and fertilizers. In this
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30 63 review we summarize the effects of climate change and the different CSA practices, highlighting their
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32 64 potential positive effects on food safety and healthy proprieties.
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40 66 **Climate change effects on food quality**

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42 67 Food quality is a concept that includes healthy properties and safety. Healthy properties are
43
44 68 determined by the content of beneficial nutritional compounds as micronutrients, especially Fe and
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46 69 Zn, antioxidants or bioactive molecules such as carotenoids, tocopherols and phenolic compounds.
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48 70 Safety is determined by the absence of toxic compounds derived both from herbicides and pesticides
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50 71 and/or toxic metabolites derived from pest attack.
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56 73 **Food Safety**

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58 74 Mycotoxins are a great threat to food safety: they are low molecular weight toxic and cancerogenic
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60 75 compounds produced by fungi *Aspergillus*, *Fusarium* and *Penicillium* which infect mostly cereals, a

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76 staple food for many people and thus their impact on global health risks is not negligible. Aflatoxins,
77 the most common mycotoxins, are furanocoumarin derivatives produced by *Aspergillus flavus* and *A.*
78 *parasiticus*: AFB₁, AFB₂, AFG₁, AFG₂ are the most toxic molecules (Zain, 2010). They are potent
79 carcinogens and sometimes cause acute and lethal intoxication. Moreover, AFB₁ is toxic for lactating
80 animals and may be converted by their digestive system in the hydroxylated form, AFM₁ which is
81 excreted in milk (Applebaum et al. 1982). European Community has set restrictive limits for the
82 combined presence of the above-mentioned aflatoxins in feed and food (EC Regulation N:
83 1881/2006). The infection of maize crop by *A. flavus* is highly facilitated by warm climate, humidity
84 and drought. Following some predictive models, an increase of +5 °C can shift the European area of
85 possible aflatoxin production in maize, from the actual below the 45° North latitude to 60° North.
86 This means that the area with high aflatoxin risks will be considerably extended in Eastern Europe,
87 the Balkan Peninsula and the Mediterranean regions (Battilani et al. 2016). These effects seem less
88 dramatic for wheat: even if the models predict an increase of *A. flavus* growth by 60% and 100% in
89 the + 2 °C and + 5 °C scenarios, the probability of aflatoxin contamination in wheat is considered
90 irrelevant.

91 An integrated model was elaborated to predict the effect of global climatic change on the risk
92 of aflatoxin contamination in cow milk, carrying out a study on AFB₁ production in maize grown in
93 Eastern Europe and imported to the Netherlands for feeding livestock (Van der Fels-Klerx et al.
94 2019). In general, most of the calculations suggest an increase, up to 50%, of maximum mean
95 aflatoxin AFM₁ in milk and a stable or slight increase (up to 0.6%) of probability to find AFM₁ in
96 milk above the EClimits by 2030. However, the authors highlighted that the results depend on the
97 type of model used.

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

102

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 eCO₂ 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, eCO₂ increased C content by 6%, with a significant increase of total non-structural carbohydrate, like starch, fructose, glucose, sucrose and maltose.

In wheat, the world's third most important cereal crop, the eCO₂ reduces N, proteins, and amino acids and modifies gluten composition (Broberg et al. 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 et al. 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). eCO₂ 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 eCO₂ 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, eCO₂ 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 eCO₂ vitamin B concentration in grains declines, probably as a consequence of reduced N assimilation, but that of vitamin E increases (Zhu et al. 2018).

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3 128 The reduction of proteins and micronutrients content and increasing of sugars under eCO₂
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5 129 have been observed also in potato, tomato and lettuce (Bhat et al. 2017; Dong et al. 2018). In potato
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8 130 tubers, eCO₂ increases the concentration of glucose (22%), fructose (21%) and reducing sugars
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10 131 (23%), responsible for browning and acrylamide formation in fried potatoes (Högy and Fangmeier
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12 132 2009). eCO₂ decreases also the content of Zn, citrate and glycoalkaloids. The reduction of citrate
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15 133 concentration leads to a higher risk of discoloration but improves the taste. Glycoalkaloids are toxic
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17 134 compounds, therefore their reduction may be positive in terms of safety, but is generally considered
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19 135 negative in term of taste. However, the data about glycoalkaloids and citrate are not concordant
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22 136 among all authors. In tomato and lettuce, the increase of soluble sugars potentially enhances their
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24 137 quality, as well as the antioxidant ascorbic acid but, the concomitant reduction of proteins content
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26 138 worsens their nutritional properties (Dong et al. 2018).

28 139 The effect of eCO₂ on phytate concentration in wheat, rice, peas, soybeans and in C4 maize
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31 140 and sorghum was also evaluated (Myers et al. 2014). Phytate is a phosphate storage molecule present
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33 141 in many plants, that is not absorbed by the human digestive tract and inhibits the absorption of Zn
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35 142 and therefore is considered an anti-nutrient (Miller et al. 2007). Phytate decreased significantly at
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38 143 eCO₂ only in wheat, but not sufficiently to counteract the strong decrease of Zn in the same crop.

40 144 A more recent study showed that eCO₂ affects proteins and micronutrients content of seeds
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42 145 and fruits in most C3 plant species with the exception of legumes that absorb atmospheric N through
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45 146 symbiotic bacteria (Uddling et al. 2018). However, the magnitude of the effect is influenced by
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47 147 different factors like cultivar, soil type or concomitant environmental conditions (Dong et al. 2018).

49 148 As far as carbohydrates content is concerned, high temperature has a larger effect than eCO₂
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51 149 (Bhat et al. 2017). In soybean seeds, an increase of 18°/13 °C to 33/28 °C (day/night average)
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54 150 significantly raises sucrose concentration. In wheat, an increase of 2-4 °C alters starch content, starch
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56 151 grain size, number and gelatinization, while eCO₂ has no or little effect (Williams et al. 1995). Studies
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58 152 on combined effects of high temperature and CO₂ on red kidney bean seeds showed that their
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153 composition was unaffected by eCO₂ but high temperature (34/24 °C) dramatically reduced glucose

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3 154 concentration (-44%) and increased the concentration of sucrose (33%) and raffinose (116%)
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5 155 (Thomas et al. 2009). The increase in raffinose harms seed quality because human intestinal mucosa
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8 156 does not contain the galactosidase enzyme necessary for its digestion and this may cause digestive
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10 157 problems (Sebastian et al. 2000).

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12 158 High temperature lowers malic acid concentration and the overall acidity of grape at maturity
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15 159 and increases the sugar concentration, probably as a consequence of berry evaporation (de Orduña
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17 160 2010). Lower acidity negatively affects winemaking because of flavors spoilage by indigenous
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19 161 microorganisms that compete also with fermenting yeasts for nutrients. This may slow down or stuck
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21 162 alcoholic fermentation and lead to the production of undesirable metabolites like acetic acid,
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24 163 acetaldehyde and pyruvate (de Orduña 2010). High temperature favors the synthesis of
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26 164 metoxypyrazines that are agreeable at low concentrations but are perceived negatively at high
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28 165 concentrations, with a negative impact on grape aroma and taste.

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31 166 The beneficial effects of higher temperatures are mainly the increase of flavonoids and
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33 167 antioxidants in strawberry fruits (Bhat et al. 2017; Wang and Zheng 2001).

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35 168 Most of the data present in the literature report the effects of temperature and CO₂ separately,
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38 169 but their effect is the results of complex interactions between them and other environmental factors,
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40 170 therefore, it is important to evaluate at least CO₂ and temperature together. The response to dual CO₂
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42 171 and temperature stress is crop-specific: stressed soybean plants produce seeds with a higher content
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44 172 of proteins but lower oil content (Dombos and Mullen 1992). In cereals such as barley and wheat
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47 173 combined stresses reduce starch accumulation but increase protein content, while in *Brassica* species
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49 174 seed proteins content increases but seed weight is reduced (Savin and Nicolas 1996; Gan et al. 2004).

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51 175 Köhler et al. (2019) observed that high temperatures reduce yields of soybean plants but
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54 176 increase the concentration of some minerals (Ca, Fe, Zn) in seeds, counteracting the overall negative
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56 177 effects of eCO₂. Differently of what observed in other crops, eCO₂ does not affect the concentration
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58 178 of seed proteins and oil while, in contrast, elevated temperatures tend to reduce the concentration of
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60 179 these components. The authors concluded that the combined eCO₂ and temperature effect may restore

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3 180 the seed Fe and Zn ambient but their experiments are limited to one cultivar and concentration of
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5 181 minerals and proteins varies with node position.

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8 182 A predictive model evaluated climate change impact on wheat proteins considering the effects
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10 183 of CO₂, water, nitrogen and temperature (Asseng et al. 2019). The authors concluded that potential
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12 184 benefits of eCO₂ can be outcompeted by rising temperatures and changes in rainfall pattern, with
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14 185 significant differences among regions. In fact, grain and protein yields are expected to be lower and
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16 more variable in low rainfall regions, where nitrogen availability can affect the growth stimulus of
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18 eCO₂.
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25 189 **Climate Smart Agriculture**

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28 190 The concept of CSA has been introduced by FAO at the 2010 Hague Conference on Agriculture,
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30 191 Food Security and Climate Change and since then has gained international interest and support (FAO
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32 192 2017). The main objectives of CSA are: *i*) the sustainable increase of agricultural productivity; *ii*) the
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34 193 adaptation to climate change and the increase of resilience in the agricultural sector; *iii*) reducing
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36 GHG emissions (when possible) and contributing to the mitigation of climate change effects
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38 (Beddington et al. 2012). For these strategies to be successful they have to be adapted to the local
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40 situation as there is no universally valid solution. At the same time, however, national and
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42 international plans will be necessary and the whole value chain, from the field to the consumer, should
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44 197 be considered.
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49 199 The massive use of chemical fertilizers and pesticides is considered a threat to health, soils
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51 200 and ecosystem biodiversity. Nitrogen fertilization is essential for obtaining high crop yields but a
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53 201 surplus of this nutrient can cause serious problems for the environment and human health. If not
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55 202 uptaken by plants, N can leach through the soil as nitrate (NO₃⁻) and pollute surface and groundwater.
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57 203 This excess of nutrients leads to planktonic algae proliferation in rivers, lakes and estuaries, a
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59 204 phenomenon known as eutrophication (Entry and Sojka 2007; Liu et al. 2013; Riley et al. 2001; Smith

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3 205 and Schindler 2009). According to the Environmental Protection Agency, in the US less than 50% of
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5 206 the total N fertilizer applied is actually up-taken by crops so a more site-specific application, tailored
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8 207 to crop needs, has a great potential to mitigate environmental risks
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10 208 (<http://www.epa.gov/ncea/efh/report.html>). The situation is not any better in Europe, where the
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12 209 estimated indirect costs of nitrogen pollution on human health and ecosystems outweigh the direct
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15 210 benefits of agriculture (Brownlie et al. 2015). CSA promotes the use of organic alternatives of
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17 211 fertilization and pesticide and/or fertilization use targeted on the real needs of cultivation avoiding
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19 212 unnecessary and polluting applications, which can also have a positive impact on climate change and
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22 213 may also be beneficial to food quality.

23 24 214 25 26 215 ***Organic farming***

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28 216 Organic farming consists of a low-input agro-ecosystem in which crop productivity is based on the
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31 217 natural availability of plant nutrients, the use of green manure and biological pathogen control. These
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33 218 practices are regulated by international and national institutional bodies that certify organic products
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35 219 in all steps of the supply chain (European Commission 2016; USDA 2016). Organic farming practices
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38 220 are surely safer for the environment but some studies revealed that organic farming reduces on
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40 221 average the crop yields (Gomiero 2018). This implies that to obtain the same quantity of product as
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42 222 with conventional agriculture it is necessary to extend the cultivable land and to disrupt forestry and
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45 223 other natural habitats. Besides, organic farming employs animal manure instead of inorganic easy
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47 224 soluble fertilizers but, this does not necessarily imply less N leaching or less eutrophication
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49 225 (Kirchmann and Thorvaldsson 2000). Seufert et al. (2012) used a comprehensive meta-analysis to
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51 226 examine the relative yield performance of organic and conventional farming. They examined 66
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54 227 studies representing 62 sites and reporting 316 organic-to-conventional yield comparisons on 34
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56 228 different crop species. The results showed that, overall, organic yields are typically lower than
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58 229 conventional ones: these differences ranged from 5% to 34% depending on system, crop and site
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60 230 characteristics. However, organic farming may be highly competitive under stress conditions: for

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3 231 example, under drought stress organically managed crops produce higher yields than those
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5 232 conventionally managed, up to 70–90% more under severe stress, thanks to the better ability of
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8 233 organically managed soil to store water (Gomiero 2013; Gomiero 2018).
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10 234 Data on soil biodiversity in organic and conventional farming are rather controversial: some
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12 235 authors (Hartmann et al. 2015) found that organic farming increases the diversity of the microbiome,
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14 236 while others (Liu et al. 2007; Reilly et al. 2003) reported no differences or less diversity than in
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17 237 conventional farming. Lupatini et al. (2017) compared microbiomes around several crops (wheat,
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19 238 barley, potato, carrot and lily) in organic and conventional farming on the same soil. This study
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22 239 revealed that organic practices effectively increase microbial diversity, richness and community
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24 240 heterogeneity. However, the authors conclude that the response of the microbial community to
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26 241 farming practices is diverse and complex and increasing soil biodiversity does not necessarily mean
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28 242 an improvement of soil health and plant productivity (Lupatini et al. 2017). Moreover, the impact of
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31 243 diversity loss in conventional farming and how microbial diversity is related to ecosystem functions
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33 244 is not very well understood yet. Also, the long-term consequences of the microbial community
34
35 245 enrichment in organic practices shift remain to be explored.
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40 247 ***Biofertilizers and nano-fertilizers***

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42 248 The use of plant growth-promoting rhizobacteria (PGPR) has been investigated as an alternative to
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44 249 conventional N and P fertilizers to obtain high yields with lower environmental impacts.
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47 250 Rhizobacteria are microorganisms naturally living in soils in association with plant roots, forming an
48
49 251 active part of the so-called rhizosphere. Their activities include stimulation and/or production of
50
51 252 phytohormones and the regulation of nutrients uptake so, inoculating these organisms in the cultivated
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54 253 field should enhance plant and soil productivity, especially under stress condition (Egamberdieva and
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56 254 Adesemoye 2016). In addition to PGPR, vesicular-arbuscular mycorrhizal (VAM) fungi are non-
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58 255 pathogenic microorganisms that are able to establish symbioses with many spontaneous and
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60 256 cultivated species, and have the ability to boost water and nutrient uptake, especially in poor, arid

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3 257 soils, and to protect plants against pathogens (Fiorilli et al. 2018). A two-year field trial demonstrated
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5
6 258 that the use of a combination of PGPR and N-fixing bacteria improves root growth in wheat and
7
8 259 increases plant resilience to environmental stresses. In addition, they help to reduce N losses from
9
10 260 agricultural ecosystems thereby mitigating environmental constraints of the application of chemical
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12 261 fertilisers (Dal Cortivo et al. 2017). Application of PGPR and VAM consortia has also been shown
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15 262 to improve plant growth, in particular in conditions of abiotic stress, as a result of synergistic
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17 263 interactions between microorganisms. However, despite good results in the laboratory (Bhattacharyya
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19 264 and Jha 2012), inoculation of PGPR and VAM in the field does not always lead to the expected
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21
22 265 benefits because of the competition with native species and adverse or unstable conditions (Bréant et
23
24 266 al. 2002). A new emerging technology in agriculture is the design and use of nano-carriers for the
25
26 267 controlled release of fertilizers and pesticides to increase their efficacy and reduce their toxicity and
27
28 268 the environmental impact. The nanoscale delivery vehicles are designed to “anchor” to plant roots or
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30
31 269 the surrounding soil structures increasing the surface contact between plant roots and fertilizers (Chen
32
33 270 and Yada 2011; Chen et al. 2014; He et al. 2019). Nano-carriers have been utilized to encapsulated
34
35 271 the 2,4-dichlorophenoxy acetic acid (2,4-D) which is one of the most commonly used herbicides
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37
38 272 worldwide because it is cheap and selective but very soluble in water and therefore easily dispersed
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40 273 in the soil (Cao et al. 2018). The fungicide carbendazim entrapped into polymeric nanoparticles
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42 274 showed higher activity against *Aspergillus parasiticus* and *Fusarium oxysporum* than pure and
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44
45 275 commercial preparation and was less phytotoxic (Kumar et al. 2017). However, the majority of
46
47 276 nanofertilizers have been tested only in laboratories, greenhouses, or small plots without facing the
48
49 277 field complexity, thus, it is difficult to draw a conclusion at this point (Liu and Lal 2015; Dimpka and
50
51
52 278 Bindraban 2018). Soil characteristics such as pH, inorganic or organic compounds and biological
53
54 279 factors (plant root exudates, bacteria and fungi) influence micronutrients behavior and modulate
55
56 280 nanomaterial dissolution, aggregation/disaggregation and surface properties. Dimpka and Bindraban
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58 281 (2018) summarized the results obtained mostly about Zn nanomaterial since it is a relevant element
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282 in human nutrition and concluded that the effects on crops are often positive with respect to

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3 283 conventional micronutrients but negative at doses higher than plant requirements. These authors
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5 284 concluded that the risks from nanoparticles under field conditions could be either less or as strong as
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8 285 those from conventional fertilizers at similar dose. An important issue of nano-carriers used as
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10 286 fertilizers or pesticides is their possible toxicological profiles which can be new potential hazards to
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12 287 human and environmental health. Nano-agrochemicals may interfere with important plant-microbial
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15 288 relationships which are all critical for soil fertility and agricultural productivity. In addition, human
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17 289 exposure to nanomaterials is expected to increase including both chronic exposure of agricultural
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19 290 workers and increase in nano-residues in soil and crops which leads to their accumulation in the food
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21
22 291 chain (Iavicoli et al., 2017; Walker et al., 2018).

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28 294 ***Precision Agriculture***

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30 295 Precision agriculture (PA) is a relatively new frontier in agriculture applied for nutrient management
31
32 296 (nitrogen and phosphorous), herbicides and pesticides modulated on the basis of the real needs of
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34
35 297 plants thanks to the application of information technology to the production system, which makes
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37 298 possible to address intra-field variability with potential economic and environmental benefits
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39
40 299 (Bongiovanni and Lowenberg-Deboer 2004). PA started to develop in USA, Canada, Australia and
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42 300 Western Europe in the 1980s and has gained importance in the last decade (Zhang et al. 2002).

43
44 301 Variable-rate application (VRA) is the most spread and investigated precision technology to
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46 302 increase fertilizer inputs efficiency. It is used in combination with other technologies such as Global
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49 303 Positioning Systems (GPS), Geographic Information Systems (GIS), soil sampling and integrated
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51 304 pest management and can be applied to seeding, weed and pests control, lime distribution and
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53 305 fertilizers application (Pallottino et al. 2018). There are two VRA technologies: Map-based VRA and
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56 306 Sensor-based VRA. In the first one, the input concentration is regulated thanks to the use of so-called
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58 307 prescription maps previously prepared and downloaded on a specific software on the applicator
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60 308 connected to a GPS device. In the second case, optical sensors on the applicator measure the targeted

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3 309 property in real-time. There is, however, an effort to integrate remote sensing and real-time data in
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5 310 order to develop an accessible database for site-specific fertilization. Research is progressing through
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8 311 an integrated approach as new studies are combining sensors, prediction models and real-time
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10 312 weather data to maximize yields and inputs efficiency.

11
12 313 Nitrogen VRA has the highest potential, but it is still the most controversial part of PA techniques,
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14 314 due to the complexity of the N cycle, highly impacted by wheatear, soil type, agricultural management
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16
17 315 and the great field variability (Rogovska et al. 2019).

18 19 316 20 21 22 317 **Climate Smart Agriculture and food quality**

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25 318 Organic farming is the most ancient practice of CSA and the majority of studies are focused on
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27 319 differences between organic and conventional products and therefore this chapter will be mainly
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29
30 320 focused on this subject. Recent data are available also about the food quality of other CSA practices,
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32 321 and some indications about food quality are available about PA practices and biofertilizers utilization.
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34 322 Traceability is also an important parameter to guarantee food quality and therefore PA issues will be
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36
37 323 discussed also on this point of view.

38 39 324 40 41 325 ***Climate Smart Agriculture and food safety***

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43 326 The main concern for the environment and human health is the utilization of pesticides and their
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45
46 327 presence in foods, that may be responsible or contribute to the development of cancer, Parkinson's
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48 328 disease and endocrine disorders (Gomiero 2013; Johansson et al. 2014).

49
50 329 European Food Safety Authority (EFSA) analyzed the residual presence of 191 pesticides in
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52
53 330 82,649 samples produced in the EU (EFSA 2016). Organic food showed a higher percentage (86.4%)
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55 331 of samples without any quantifiable pesticide residual than conventional ones (51.6%). The
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57 332 percentages of samples above the Maximum Residue Levels permitted by EU legislation were lower
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60 333 in organic products (1.2%) than in conventional ones (3%). However, being these percentages so low,

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3 334 EFSA concluded that the general level of pesticide residues in both conventional and organic food is
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5 335 well below the threshold risk for health. The differences are particularly evident in fruits and nuts,
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8 336 where 69.4% of conventional products contained residues, against only 9.6% of organic products.
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10 337 Possible contamination occurring in fields or during food processing can explain the presence of
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12 338 pesticide residuals, not allowed in organic agriculture, in organic food. Conventional food is richer in
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15 339 toxic residuals of organophosphates (OPs) (EFSA 2016) classified as carcinogenic, neurotoxicants
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17 340 and endocrine disruptors by World Health Organisation.

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19 341 An extensive study recently conducted on 33,000 French adult volunteers showed
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22 342 significantly lower urinary levels of residual pesticides diethylthiophosphate, dimethylthiophosphate,
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24 343 dialkylphosphates, and free 3-phenoxybenzoic in organic food consumers than in conventional food
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26 344 consumers (Baudry et al. 2019). Moreover, exposure to certain OPs and pyrethroid pesticides is
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29 345 reduced by switching from conventional to organic foods, especially fruits and vegetables, while no
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31 346 significant differences were found for other compounds. The authors pointed out that the study may
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33 347 be biased by the honesty of volunteers in answering about their eating habits and/or other possible
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35 348 sources of contamination of OPs than food. However, these results were confirmed by Hyland et al.
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37
38 349 (2019) that observed significant reductions in urinary levels of thirteen pesticide metabolites and
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40 350 related compounds (OPs, neonicotinoid, and pyrethroid insecticides and the herbicide 2,4-D) after
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42 351 the introduction of organic food in the diet, in children and adults of USA families differing for race
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44
45 352 and geographic origin.

46

47 353 Literature about heavy metals is quite contradictory: some authors did not found a significant
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49 354 difference in their contents between organic and conventional food (Magkos et al. 2006), others found
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51 355 higher levels of Cd and Pb in organic tomatoes (Rossi et al. 2008). Lower levels of Cd were found in
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54 356 organic cereals, while no differences were found in fruits (Barański et al. 2014). The higher content
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56 357 of Cd in conventional products may be related to the use of phosphate fertilizers that are often
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58 358 contaminated with this metal, or to its native concentration in the soil. High concentrations of Cd are
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359 considered a significant cause of vascular disorders, various common cancers, osteoporosis and other

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3 360 health disorders, therefore, the lower Cd levels in organic food are certainly a positive fact (McCarty
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5 361 2014).

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8 362 As reported previously, mycotoxin contamination constitutes a serious concern for food,
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10 363 especially for those derived from cereals. Because synthetic fungicides were banned in organic
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12 364 agriculture, it has been argued that organic crops may be more susceptible to fungal contamination.
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15 365 In fact, higher concentrations of mycotoxins deoxynivalenol and nivalenol were found in organic than
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17 366 in conventional grain samples (Eltun 1997). Moreover, an extensive comparison of more than a
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19 367 thousand organic and conventional cereal-based products from EU countries found a higher content
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21 368 of fumonisins (*Fusarium* derived mycotoxins) in organic products (Rubert et al. 2013). However, no
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24 369 statistical analysis was provided and it was not stated if differences were significant or not. Moreover,
25
26 370 organic and conventional food types analyzed were not the same in the various studies and it can have
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29 371 introduced some bias in the analysis. A similar work carried out in the USA on 50 conventional and
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31 372 50 organic foods, did not show a significant difference in mycotoxin content (Gourama 2015). In
32
33 373 general, the majority of the studies does not report significant differences in mycotoxin content in
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35 374 organic and conventional food (Gomiero 2018) but the discordant results should be taken into
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37
38 375 consideration before concluding that organic is absolutely safe.

39 40 376 41 42 377 ***Climate Smart Agriculture and food technological quality and nutritional proprieties***

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44 378 It was previously documented that eCO₂ has negative impacts on food quality such as reduction of
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46
47 379 proteins and micronutrients, especially Zn and Fe, and increase of sugars content. It is not easy to say
48
49 380 if organic farming and other CSA practices are able to counteract these food deficiencies since studies
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51 381 conducted so far, in particular the comparisons between organic and conventional food, were done
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54 382 on sites differing not only for agricultural practices but also for different type of soil, crop genotypes
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56 383 and time and conditions of harvesting.

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58 384 However, despite these limitations, more positive than negative trends can be resumed by
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60 385 literature data. In particular, as far as technological quality is concerned, PA techniques gives the

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3 386 possibility to differentiate the quality of raw materials in the field. As an example, cereal quality is
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5 387 becoming more important than yield especially as the price of cereals reduces on world markets.
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8 388 There is well-substantiated evidence that quality, as well as yields, is spatially variable within fields
9
10 389 and systems are being developed to exploit such variation to add value to the harvested crop (Stafford
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12 390 2013). Recent advances in PA offer new potential for meeting grain quality standards. In particular,
13
14 391 nitrogen-VRA could play a pivotal role in driving quality-oriented fertilization and on the other hand,
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17 392 precision harvesting could be an alternative method to maximize the tonnage of higher quality.
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19 393 Recently in Northern Italy, field spatial distribution of yield and protein content of durum wheat was
20
21 394 assessed through the application of VR fertilization in three management zones with increasing soil
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24 395 fertility (Morari et al. 2018). In addition, prescription maps and optical sensors drove the precision
25
26 396 harvesting of grains with different protein contents allowing the production of semolina with higher
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28
29 397 or lower protein contents in order to produce pasta with different characteristics (Visioli et al. 2018).

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31 398 Regarding nutritional proprieties, the literature about Zn and Fe content in organic and
32
33 399 conventional food is very contradictory: some studies showed a higher content of Fe and Zn in the
34
35 400 organic crops (Vrček et al. 2014), others in the conventional ones (Ciołek et al. 2012; Drakou et al.
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37 401 2015; Kristl et al. 2013). A meta-analysis study reported a major content of Ca, Mg, K and P in
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39
40 402 organic food but the authors concluded that only the data about P can be considered statistically
41
42 403 significant (Smith-Spangler et al. 2012). The same study showed that protein content is lower in
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44 404 organic fruits and vegetables, as well as fiber content, even though the results were not considered
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46
47 405 significant. On the contrary, a 21 years-long survey of organic and conventional grain, concludes that
48
49 406 protein content and amino acid composition are not affected by farming practice (Mäder et al. 2007).

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51 407 Few data are available on sugar content in organic products. Studies on wheat reported that
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53
54 408 sucrose concentration was higher in conventional than in organic ears, but this difference was
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56 409 nullified in mature grains. No differences were found for other sugars (Zörb et al. 2009).

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58 410 Since the 90's some studies evidenced how organic plant food possesses higher amounts of
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60 411 secondary metabolites, and therefore they may be more health-promoting than conventional foods

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3 412 (Brandt and Mølgaard 2001; Johansson et al. 2014; Woese et al. 1997). In particular, phenolic
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5 413 compound content seems highly influenced by farming practices. Compared to conventional farming,
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8 414 higher levels of phenols and polyphenols were found in organic cabbage, spinach, Welsh onion, green
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10 415 pepper, organics corn and strawberry (Asami et al. 2003; Ren et al. 2001). Moreover, an extensive
11
12 416 meta-analysis study indicated that a switch from conventional to organic crop consumption would
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15 417 result in a 20–40% (and for some compounds more than 60 %) increase in crop-based
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17 418 antioxidant/(poly)phenolic intake (Barański et al. 2014).

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19 419 Tocopherol is another class of antioxidants. Three studies conducted with comparative
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21
22 420 experiments evidenced higher contents of tocopherol in organic barley (Tsochatzis et al. 2012),
23
24 421 higher content of α - and γ -tocopherols in organic plums (Lombardi-Boccia et al. 2004) and higher α -
25
26 422 tocopherol content in organic pears (Carbonaro et al. 2002), but in general, most investigations
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28
29 423 showed no difference in the content of tocopherols between organic and conventional crops. The
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31 424 same conclusions were drawn for carotenoid content (Johansson et al. 2014).

32
33 425 Biofertilizers seem to have a positive effect on the content of macro and micronutrients,
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35 426 vitamins and antioxidants (Alori and Balabola 2018). The application of VAM-PGPR commercial
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37
38 427 biofertilizer to wheat seeds improved the uptake of low-mobility nutrients from roots in wheat plants,
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40 428 with quality benefits of the grains (Dal Cortivo et al. 2018; Dal Cortivo et al. 2020). The beneficial
41
42 429 effect of some fungi and bacteria strains endures also during post-harvest phases (Rilling et al. 2018).
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44
45 430 In particular, VAM has been used to enhance the plant growth and yield of medicinal crops because
46
47 431 they are able to stimulate the secondary metabolism of plants to produce compounds with health
48
49 432 properties, like antioxidants, phenylpropanoid, or carotenoid pathways (Baslam et al. 2011).
50
51 433 Resistance to storage diseases has been evidenced in potato (Diallo et al. 2011) and also correlated to
52
53
54 434 arbuscular mycorrhizal fungi-species richness (Slininger et al. 2010).

55
56 435 Inoculation of lettuce with fungi *Azotobacter chroococcum* and *Glomus fasciculatum*
57
58 436 increased the concentration of total phenolic compounds, anthocyanins and carotenoids, while
59
60 437 inoculation with *G. fasciculatum* and *Glomus mosseae* highly increased the flavonoid content

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2
3 438 (Baslam et al. 2011). Eftekhari et al. (2012) observed an increased production of the flavonoid
4
5 439 quercetin in the leaves of grape inoculated with *Glomus* sp. but the response depended on grape
6
7
8 440 genotype. Inoculation of biofertilizer containing VAM and bacterial species considerably augmented
9
10 441 the concentration of total phenolic compounds, flavonoids and phenolic acid and consequently the
11
12 442 antioxidant capacity of the spinach (Khalid et al. 2017).

13
14 443 Recent data are also available on positive effects of nano-fertilizers on food quality. They improve
15
16
17 444 the vegetative and reproductive traits of fruit trees, such as strawberry, mango, date, coffee and grape
18
19 445 (Zahedi et al. 2020). In addition, they implement the uptake of Fe, Zn and Cu, but no paper reports if
20
21 446 this uptake led to higher micronutrients level in consumable fruits and seeds. Only an increase in the
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23
24 447 concentration of phenols and polyphenols in pomegranate fruits is reported after the application of
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26 448 nano-selenium (Zahedi 2020). In this emerging context, the perspective of a “green nanotechnology”
27
28 449 should combine the benefits provided by nano-products in solving environmental challenges with the
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31 450 assessment and management of environmental, health, and safety risks potentially posed by nanoscale
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33 451 materials (Iavicoli et al., 2017; Guo et al., 2018). It is urgent to take into account all the phases in
34
35 452 which nano-carriers may be found in the environment, from application into the field to potential
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38 453 incorporation into food supply and possible influences exerted by the pedo-climatic conditions that
39
40 454 may all affect nanomaterial hazardous properties and risks (Iavicoli et al. 2017; Walker et al. 2018).

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43 44 456 **Conclusions**

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46
47 457 Global climate change has generally negative effects on crop quality. In particular, the
48
49 458 decrease of N, proteins and the essential micronutrients such as Fe and Zn have been shown by almost
50
51 459 all studies examined in this paper. The reduction of N and essential minerals can have significant
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54 460 impacts on human nutrition. Fe and Zn deficiency is already an urgent issue in many parts of the
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56 461 world especially in regions where people depend on C3 grains such as wheat as their primary source
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58 462 of these micronutrients. Organic farming is the most ancient and widespread sustainable agricultural
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60 463 practice, but studies on organic food are fragmentary and contradictory, and so far there is not strong

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3 464 scientific evidence that they have better healthy properties than conventional food, except less
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6 465 pesticide content. However, organic food seems to have better antioxidant properties than
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8 466 conventional ones and this has been found also in response to different types of biofertilizers. The
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10 467 impact of nano-fertilizers on quality and nutritional characteristics of food is still unexplored, but
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12 468 their potential positive effects on plant growth and productivity make their utilization a promising
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15 469 technology for sustainable agriculture.

16
17 470 PA technologies will contribute more and more to food safety (Gebbers and Adamchuk 2010).
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19 471 PA makes farming more transparent by improving tracking, tracing and documenting. Crop and
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21
22 472 livestock monitoring will give better predictions on the quality of agricultural products. The food
23
24 473 chain will be easier to monitor for producers, retailers and customers. It will also play a significant
25
26 474 role in terms of plant health. Diseases undetectable by traditional means will be prevented by
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28
29 475 automated optical sensing and intelligent planning options. In conclusion, we urgently need a new
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31 476 research and technology paradigm to address the important issue of climate change and its impact on
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33 477 agriculture. New dedicated fertilizers, agronomic practice, e.g. precision agriculture, and ad-hoc
34
35 478 policies will invariably shape the future of agriculture.

37 38 479 39 40 41 480 **Disclosure statement**

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44 481 The authors declare no conflict of interest

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488 **Author contributions**

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

493 **Abbreviations**

494	CO ₂	Carbon dioxide
495	CSA	Climate Smart Agriculture
496	eCO ₂	Elevated Carbon dioxide
497	EC	European Commission
498	EFSA	European Food Safety Authority
499	GCG	Greenhouse Gases
500	GIS	Geographic Information System
501	GPS	Global Positioning System
502	IT	Information Technology
503	NO ₂	Nitrogen dioxide
504	OPs	Organophosphates
505	PA	Precision Agriculture
506	PGPR	Plant Growth-Promoting Rhizobacteria
507	USDA	United States Department of Agriculture
508	VAM	Vesicular-Arbuscular Mycorrhiza

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52 870 **Figure Caption**

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54 871 **Figure 1:** Different sustainable agronomic practices and their possible effects on climate change
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56 872 mitigation and quality and safety of food products. CSA= Climate Smart Agriculture
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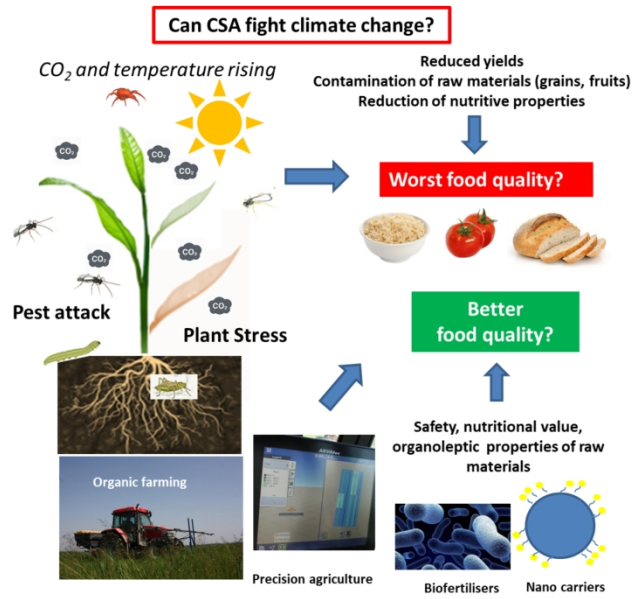


Figure 1: Different sustainable agronomic practices and their possible effects on climate change mitigation and quality and safety of food products. CSA= Climate Smart Agriculture

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