



UNIVERSITÀ DI PARMA

ARCHIVIO DELLA RICERCA

University of Parma Research Repository

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

This is the peer reviewed version of the following article:

Original

Smart agriculture for food quality: facing climate change in the 21st century / Agrimonti, Caterina; Lauro, Marta; Visioli, Giovanna. - In: CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION. - ISSN 1040-8398. - (2020), pp. 1-11. [10.1080/10408398.2020.1749555]

Availability:

This version is available at: 11381/2875071 since: 2024-12-11T15:19:48Z

Publisher:

Bellwether Publishing, Ltd.

Published

DOI:10.1080/10408398.2020.1749555

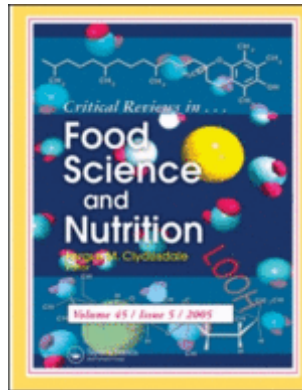
Terms of use:

Anyone can freely access the full text of works made available as "Open Access". Works made available

Publisher copyright

note finali coverpage

(Article begins on next page)



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

Journal:	<i>Critical Reviews in Food Science and Nutrition</i>
Manuscript ID	BFSN-2020-4800.R1
Manuscript Type:	Review
Date Submitted by the Author:	n/a
Complete List of Authors:	Agrimonti, Caterina; University of Parma Lauro, Marta; University of Parma Visioli, Giovanna; University of Parma,
Keywords:	greenhouse gases, environment, food safety, food nutritional value, sustainable agriculture

SCHOLARONE™
Manuscripts

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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..."

1
2
3 1 **DONE. The sentence was rewritten as follow (Lines 44-45):** *“Global warming also increases frequency*
4 2 *and severity of plant pests and diseases with consequent loss of yield and quality (Trebicki et al.*
5 3 *2015)”*

6 4
7 5
8 5 Line 52: remove the: “clearing, the”

9 6 **DONE**

10 7
11 8 Line 59-60: the phrase needs to be rewritten: *“Agriculture (CSA), that includes traditional organic farming*
12 9 *and the innovative precision farming practices aiming to optimize the use of water and fertilizers by*
13 10 *informatics technologies (FAO 2017),”*

14 11
15 12 **DONE. The phrase is now changed (Lines 58-64):** *“Climate-Smart Agriculture (CSA) is an approach that*
16 13 *helps to guide actions needed to transform and reorient agricultural systems to effectively support*
17 14 *development and ensure food security in a changing climate (FAO 2017). It includes traditional*
18 15 *organic farming techniques as well as innovative precision farming practices which apply*
19 16 *Information Technology aiming to optimize the use of water and fertilizers”.*

20 17
21 18 Lines 77-79, it would be clearer if all the acronyms could have in front the molecule.

22 19
23 20
24 21 **AFB1, AFB2, AFG1, AFG2 is the conventional denomination of the four most toxic aflatoxins. For more**
25 22 **clarity we have added this information in the text (Lines 76-81)** *“Aflatoxins, the most common*
26 23 *mycotoxins, are furanocoumarin derivatives produced by *Aspergillus flavus* and *A. parasiticus*: AFB₁,*
27 24 *AFB₂, AFG₁, AFG₂ are the most toxic molecules (Zain, 2010). They are potent carcinogens and*
28 25 *sometimes cause acute and lethal intoxication. Moreover, AFB₁ is toxic for lactating animals and*
29 26 *may be converted by their digestive system in the hydroxylated form, AFM₁ which is excreted in milk*
30 27 *(Applebaum et al. 1982).”*

31 28 Line 15 : mistyping, should be flavors instead of favors.

32 29 **DONE**

33 30
34 31 Line 282: The authors refer to the use of nanoparticles, however the toxicity effects that these particles may
35 32 have are not mentioned. This a issue that should be considred in the manuscript.

36 33
37 34 **The reviewer is right, at this purpose we inserted the following sentences with the appropriate references**
38 35 **(Lines 285-291)** *“An important issue of nano-carriers used as fertilisers or pesticides is their possible*
39 36 *toxicological profiles which can be new potential hazards to human and environmental health. Nano-*
40 37 *agrochemicals may interfere with important plant-microbial relationships which are all critical for*
41 38 *soil fertility and agricultural productivity. In addition, human exposure to nanomaterials is expected*
42 39 *to increase including both chronical exposure of agricultural workers and increase in nano-residues*
43 40 *in soil and crops which leads to their accumulation in the food chain (Iavicoli et al., 2017; Walker et*
44 41 *a., 2018).”*

45 42 **and**

46 43 **(Lines 448-454)** *“In this emerging context, the perspective of a “green nanotechnology” should*
47 44 *combine the benefits provided by nano-products in solving environmental challenges with the*
48 45 *assessment and management of environmental, health, and safety risks potentially posed by*
49 46 *nanoscale materials (Iavicoli et al., 2017; Guo et al., 2018). It is urgent to take into account all the*
50 47 *phases in which nano-carriers may be found in the environment, from application into the field to*
51 48 *potential incorporation into food supply and possible influences exerted by the pedo-climatic*
52 49
53 50
54 51
55 52
56 53
57 54
58 55
59 56
60 57

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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

3 Caterina Agrimonti, Marta Lauro, Giovanna Visioli*

4

5 Department of Chemistry, Life Sciences and Environmental Sustainability- University of Parma

6 v.le Parco Area delle Scienze, 43124. Parma (ITALY).

7

8 *Corresponding author:

9 Dr. Giovanna Visioli

10 E-mail: giovanna.visioli@unipr.it11 [ORCID: https://orcid.org/0000-0001-9712-3223](https://orcid.org/0000-0001-9712-3223)

12

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

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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

1
2
3 50 concentration in soils, light and water availability (Reich et al. 2016). All these concomitant factors
4
5 51 can affect not only crop yields but also food quality.
6
7

8 52 On the other hand, current intensive agricultural practices, including land clearing, excessive
9
10 53 and inefficient use of fertilizers, irrigation and the use of fossil fuels for agricultural machines, make
11
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
21
22 59 approach that helps to guide actions needed to transform and reorient agricultural systems to
23
24 60 effectively support development and ensure food security in a changing climate (FAO 2017). It
25
26 61 includes traditional organic farming techniques as well as innovative precision farming practices
27
28 62 which apply Information Technology (IT) aiming to optimize the use of water and fertilizers. In this
29
30 63 review we summarize the effects of climate change and the different CSA practices, highlighting their
31
32 64 potential positive effects on food safety and healthy proprieties.
33
34
35
36
37
38
39

40 66 **Climate change effects on food quality**

41
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
45
46 69 Zn, antioxidants or bioactive molecules such as carotenoids, tocopherols and phenolic compounds.
47
48 70 Safety is determined by the absence of toxic compounds derived both from herbicides and pesticides
49
50 71 and/or toxic metabolites derived from pest attack.
51
52
53
54
55

56 73 **Food Safety**

57
58 74 Mycotoxins are a great threat to food safety: they are low molecular weight toxic and cancerogenic
59
60 75 compounds produced by fungi *Aspergillus*, *Fusarium* and *Penicillium* which infect mostly cereals, a

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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).

1

2

3 128 The reduction of proteins and micronutrients content and increasing of sugars under eCO₂
4
5 129 have been observed also in potato, tomato and lettuce (Bhat et al. 2017; Dong et al. 2018). In potato
6
7
8 130 tubers, eCO₂ increases the concentration of glucose (22%), fructose (21%) and reducing sugars
9
10 131 (23%), responsible for browning and acrylamide formation in fried potatoes (Högy and Fangmeier
11
12 132 2009). eCO₂ decreases also the content of Zn, citrate and glycoalkaloids. The reduction of citrate
13
14
15 133 concentration leads to a higher risk of discoloration but improves the taste. Glycoalkaloids are toxic
16
17 134 compounds, therefore their reduction may be positive in terms of safety, but is generally considered
18
19 135 negative in term of taste. However, the data about glycoalkaloids and citrate are not concordant
20
21
22 136 among all authors. In tomato and lettuce, the increase of soluble sugars potentially enhances their
23
24 137 quality, as well as the antioxidant ascorbic acid but, the concomitant reduction of proteins content
25
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
29
30
31 140 and sorghum was also evaluated (Myers et al. 2014). Phytate is a phosphate storage molecule present
32
33 141 in many plants, that is not absorbed by the human digestive tract and inhibits the absorption of Zn
34
35 142 and therefore is considered an anti-nutrient (Miller et al. 2007). Phytate decreased significantly at
36
37
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
41
42 145 and fruits in most C3 plant species with the exception of legumes that absorb atmospheric N through
43
44
45 146 symbiotic bacteria (Uddling et al. 2018). However, the magnitude of the effect is influenced by
46
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
50
51 149 (Bhat et al. 2017). In soybean seeds, an increase of 18°/13 °C to 33/28 °C (day/night average)
52
53
54 150 significantly raises sucrose concentration. In wheat, an increase of 2-4 °C alters starch content, starch
55
56 151 grain size, number and gelatinization, while eCO₂ has no or little effect (Williams et al. 1995). Studies
57
58 152 on combined effects of high temperature and CO₂ on red kidney bean seeds showed that their
59
60
153 composition was unaffected by eCO₂ but high temperature (34/24 °C) dramatically reduced glucose

1
2
3 154 concentration (-44%) and increased the concentration of sucrose (33%) and raffinose (116%)
4
5 155 (Thomas et al. 2009). The increase in raffinose harms seed quality because human intestinal mucosa
6
7
8 156 does not contain the galactosidase enzyme necessary for its digestion and this may cause digestive
9
10 157 problems (Sebastian et al. 2000).

11
12 158 High temperature lowers malic acid concentration and the overall acidity of grape at maturity
13
14
15 159 and increases the sugar concentration, probably as a consequence of berry evaporation (de Orduña
16
17 160 2010). Lower acidity negatively affects winemaking because of flavors spoilage by indigenous
18
19 161 microorganisms that compete also with fermenting yeasts for nutrients. This may slow down or stuck
20
21 162 alcoholic fermentation and lead to the production of undesirable metabolites like acetic acid,
22
23
24 163 acetaldehyde and pyruvate (de Orduña 2010). High temperature favors the synthesis of
25
26 164 metoxypyrazines that are agreeable at low concentrations but are perceived negatively at high
27
28 165 concentrations, with a negative impact on grape aroma and taste.

29
30
31 166 The beneficial effects of higher temperatures are mainly the increase of flavonoids and
32
33 167 antioxidants in strawberry fruits (Bhat et al. 2017; Wang and Zheng 2001).

34
35 168 Most of the data present in the literature report the effects of temperature and CO₂ separately,
36
37
38 169 but their effect is the results of complex interactions between them and other environmental factors,
39
40 170 therefore, it is important to evaluate at least CO₂ and temperature together. The response to dual CO₂
41
42 171 and temperature stress is crop-specific: stressed soybean plants produce seeds with a higher content
43
44 172 of proteins but lower oil content (Dombos and Mullen 1992). In cereals such as barley and wheat
45
46 173 combined stresses reduce starch accumulation but increase protein content, while in *Brassica* species
47
48 174 seed proteins content increases but seed weight is reduced (Savin and Nicolas 1996; Gan et al. 2004).

49
50
51 175 Köhler et al. (2019) observed that high temperatures reduce yields of soybean plants but
52
53
54 176 increase the concentration of some minerals (Ca, Fe, Zn) in seeds, counteracting the overall negative
55
56 177 effects of eCO₂. Differently of what observed in other crops, eCO₂ does not affect the concentration
57
58 178 of seed proteins and oil while, in contrast, elevated temperatures tend to reduce the concentration of
59
60 179 these components. The authors concluded that the combined eCO₂ and temperature effect may restore

1

2

3 180 the seed Fe and Zn ambient but their experiments are limited to one cultivar and concentration of
4
5 181 minerals and proteins varies with node position.

7

8 182 A predictive model evaluated climate change impact on wheat proteins considering the effects
9
10 183 of CO₂, water, nitrogen and temperature (Asseng et al. 2019). The authors concluded that potential
11
12 184 benefits of eCO₂ can be outcompeted by rising temperatures and changes in rainfall pattern, with
13
14 185 significant differences among regions. In fact, grain and protein yields are expected to be lower and
15
16 more variable in low rainfall regions, where nitrogen availability can affect the growth stimulus of
17 186
18 eCO₂.
19 187
20
21

22 188

23

24

25 189 **Climate Smart Agriculture**

26

27

28 190 The concept of CSA has been introduced by FAO at the 2010 Hague Conference on Agriculture,
29
30 191 Food Security and Climate Change and since then has gained international interest and support (FAO
31
32 192 2017). The main objectives of CSA are: *i*) the sustainable increase of agricultural productivity; *ii*) the
33
34 193 adaptation to climate change and the increase of resilience in the agricultural sector; *iii*) reducing
35
36 GHG emissions (when possible) and contributing to the mitigation of climate change effects
37 194
38 (Beddington et al. 2012). For these strategies to be successful they have to be adapted to the local
39 195
40 situation as there is no universally valid solution. At the same time, however, national and
41 196
42 international plans will be necessary and the whole value chain, from the field to the consumer, should
43
44 197 be considered.
45
46 198

47

48

49 199 The massive use of chemical fertilizers and pesticides is considered a threat to health, soils
50
51 200 and ecosystem biodiversity. Nitrogen fertilization is essential for obtaining high crop yields but a
52
53 201 surplus of this nutrient can cause serious problems for the environment and human health. If not
54
55 202 uptaken by plants, N can leach through the soil as nitrate (NO₃⁻) and pollute surface and groundwater.
56
57 203 This excess of nutrients leads to planktonic algae proliferation in rivers, lakes and estuaries, a
58
59 204 phenomenon known as eutrophication (Entry and Sojka 2007; Liu et al. 2013; Riley et al. 2001; Smith

60

1
2
3 205 and Schindler 2009). According to the Environmental Protection Agency, in the US less than 50% of
4
5 206 the total N fertilizer applied is actually up-taken by crops so a more site-specific application, tailored
6
7
8 207 to crop needs, has a great potential to mitigate environmental risks
9
10 208 (<http://www.epa.gov/ncea/efh/report.html>). The situation is not any better in Europe, where the
11
12 209 estimated indirect costs of nitrogen pollution on human health and ecosystems outweigh the direct
13
14
15 210 benefits of agriculture (Brownlie et al. 2015). CSA promotes the use of organic alternatives of
16
17 211 fertilization and pesticide and/or fertilization use targeted on the real needs of cultivation avoiding
18
19 212 unnecessary and polluting applications, which can also have a positive impact on climate change and
20
21
22 213 may also be beneficial to food quality.

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

27
28 216 Organic farming consists of a low-input agro-ecosystem in which crop productivity is based on the
29
30
31 217 natural availability of plant nutrients, the use of green manure and biological pathogen control. These
32
33 218 practices are regulated by international and national institutional bodies that certify organic products
34
35 219 in all steps of the supply chain (European Commission 2016; USDA 2016). Organic farming practices
36
37
38 220 are surely safer for the environment but some studies revealed that organic farming reduces on
39
40 221 average the crop yields (Gomiero 2018). This implies that to obtain the same quantity of product as
41
42 222 with conventional agriculture it is necessary to extend the cultivable land and to disrupt forestry and
43
44
45 223 other natural habitats. Besides, organic farming employs animal manure instead of inorganic easy
46
47 224 soluble fertilizers but, this does not necessarily imply less N leaching or less eutrophication
48
49 225 (Kirchmann and Thorvaldsson 2000). Seufert et al. (2012) used a comprehensive meta-analysis to
50
51 226 examine the relative yield performance of organic and conventional farming. They examined 66
52
53
54 227 studies representing 62 sites and reporting 316 organic-to-conventional yield comparisons on 34
55
56 228 different crop species. The results showed that, overall, organic yields are typically lower than
57
58 229 conventional ones: these differences ranged from 5% to 34% depending on system, crop and site
59
60 230 characteristics. However, organic farming may be highly competitive under stress conditions: for

1
2
3 231 example, under drought stress organically managed crops produce higher yields than those
4
5 232 conventionally managed, up to 70–90% more under severe stress, thanks to the better ability of
6
7
8 233 organically managed soil to store water (Gomiero 2013; Gomiero 2018).
9

10 234 Data on soil biodiversity in organic and conventional farming are rather controversial: some
11
12 235 authors (Hartmann et al. 2015) found that organic farming increases the diversity of the microbiome,
13
14 236 while others (Liu et al. 2007; Reilly et al. 2003) reported no differences or less diversity than in
15
16
17 237 conventional farming. Lupatini et al. (2017) compared microbiomes around several crops (wheat,
18
19 238 barley, potato, carrot and lily) in organic and conventional farming on the same soil. This study
20
21
22 239 revealed that organic practices effectively increase microbial diversity, richness and community
23
24 240 heterogeneity. However, the authors conclude that the response of the microbial community to
25
26 241 farming practices is diverse and complex and increasing soil biodiversity does not necessarily mean
27
28 242 an improvement of soil health and plant productivity (Lupatini et al. 2017). Moreover, the impact of
29
30
31 243 diversity loss in conventional farming and how microbial diversity is related to ecosystem functions
32
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.
36
37
38 246

40 247 ***Biofertilizers and nano-fertilizers***

41
42 248 The use of plant growth-promoting rhizobacteria (PGPR) has been investigated as an alternative to
43
44 249 conventional N and P fertilizers to obtain high yields with lower environmental impacts.
45
46
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
52
53
54 253 field should enhance plant and soil productivity, especially under stress condition (Egamberdieva and
55
56 254 Adesemoye 2016). In addition to PGPR, vesicular-arbuscular mycorrhizal (VAM) fungi are non-
57
58 255 pathogenic microorganisms that are able to establish symbioses with many spontaneous and
59
60 256 cultivated species, and have the ability to boost water and nutrient uptake, especially in poor, arid

1
2
3 257 soils, and to protect plants against pathogens (Fiorilli et al. 2018). A two-year field trial demonstrated
4
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
11
12 261 fertilisers (Dal Cortivo et al. 2017). Application of PGPR and VAM consortia has also been shown
13
14
15 262 to improve plant growth, in particular in conditions of abiotic stress, as a result of synergistic
16
17 263 interactions between microorganisms. However, despite good results in the laboratory (Bhattacharyya
18
19 264 and Jha 2012), inoculation of PGPR and VAM in the field does not always lead to the expected
20
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
29
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
36
37
38 272 worldwide because it is cheap and selective but very soluble in water and therefore easily dispersed
39
40 273 in the soil (Cao et al. 2018). The fungicide carbendazim entrapped into polymeric nanoparticles
41
42 274 showed higher activity against *Aspergillus parasiticus* and *Fusarium oxysporum* than pure and
43
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
57
58 281 (2018) summarized the results obtained mostly about Zn nanomaterial since it is a relevant element
59
60
282 in human nutrition and concluded that the effects on crops are often positive with respect to

1
2
3 283 conventional micronutrients but negative at doses higher than plant requirements. These authors
4
5 284 concluded that the risks from nanoparticles under field conditions could be either less or as strong as
6
7
8 285 those from conventional fertilizers at similar dose. An important issue of nano-carriers used as
9
10 286 fertilizers or pesticides is their possible toxicological profiles which can be new potential hazards to
11
12 287 human and environmental health. Nano-agrochemicals may interfere with important plant-microbial
13
14
15 288 relationships which are all critical for soil fertility and agricultural productivity. In addition, human
16
17 289 exposure to nanomaterials is expected to increase including both chronic exposure of agricultural
18
19 290 workers and increase in nano-residues in soil and crops which leads to their accumulation in the food
20
21
22 291 chain (Iavicoli et al., 2017; Walker et al., 2018).

23
24
25 292
26 293
27
28 294 ***Precision Agriculture***

29
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
33
34
35 297 plants thanks to the application of information technology to the production system, which makes
36
37 298 possible to address intra-field variability with potential economic and environmental benefits
38
39
40 299 (Bongiovanni and Lowenberg-Deboer 2004). PA started to develop in USA, Canada, Australia and
41
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
45
46 302 increase fertilizer inputs efficiency. It is used in combination with other technologies such as Global
47
48
49 303 Positioning Systems (GPS), Geographic Information Systems (GIS), soil sampling and integrated
50
51 304 pest management and can be applied to seeding, weed and pests control, lime distribution and
52
53 305 fertilizers application (Pallottino et al. 2018). There are two VRA technologies: Map-based VRA and
54
55
56 306 Sensor-based VRA. In the first one, the input concentration is regulated thanks to the use of so-called
57
58 307 prescription maps previously prepared and downloaded on a specific software on the applicator
59
60 308 connected to a GPS device. In the second case, optical sensors on the applicator measure the targeted

1
2
3 309 property in real-time. There is, however, an effort to integrate remote sensing and real-time data in
4
5 310 order to develop an accessible database for site-specific fertilization. Research is progressing through
6
7
8 311 an integrated approach as new studies are combining sensors, prediction models and real-time
9
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,
13
14 314 due to the complexity of the N cycle, highly impacted by wheatear, soil type, agricultural management
15
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**

23
24
25 318 Organic farming is the most ancient practice of CSA and the majority of studies are focused on
26
27 319 differences between organic and conventional products and therefore this chapter will be mainly
28
29
30 320 focused on this subject. Recent data are available also about the food quality of other CSA practices,
31
32 321 and some indications about food quality are available about PA practices and biofertilizers utilization.
33
34 322 Traceability is also an important parameter to guarantee food quality and therefore PA issues will be
35
36
37 323 discussed also on this point of view.

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

42
43 326 The main concern for the environment and human health is the utilization of pesticides and their
44
45
46 327 presence in foods, that may be responsible or contribute to the development of cancer, Parkinson's
47
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
51
52
53 330 82,649 samples produced in the EU (EFSA 2016). Organic food showed a higher percentage (86.4%)
54
55 331 of samples without any quantifiable pesticide residual than conventional ones (51.6%). The
56
57 332 percentages of samples above the Maximum Residue Levels permitted by EU legislation were lower
58
59
60 333 in organic products (1.2%) than in conventional ones (3%). However, being these percentages so low,

1

2

3 334 EFSA concluded that the general level of pesticide residues in both conventional and organic food is
4
5 335 well below the threshold risk for health. The differences are particularly evident in fruits and nuts,
6
7
8 336 where 69.4% of conventional products contained residues, against only 9.6% of organic products.
9
10 337 Possible contamination occurring in fields or during food processing can explain the presence of
11
12 338 pesticide residuals, not allowed in organic agriculture, in organic food. Conventional food is richer in
13
14
15 339 toxic residuals of organophosphates (OPs) (EFSA 2016) classified as carcinogenic, neurotoxicants
16
17 340 and endocrine disruptors by World Health Organisation.

18

19 341 An extensive study recently conducted on 33,000 French adult volunteers showed
20
21 342 significantly lower urinary levels of residual pesticides diethylthiophosphate, dimethylthiophosphate,
22
23
24 343 dialkylphosphates, and free 3-phenoxybenzoic in organic food consumers than in conventional food
25
26 344 consumers (Baudry et al. 2019). Moreover, exposure to certain OPs and pyrethroid pesticides is
27
28 345 reduced by switching from conventional to organic foods, especially fruits and vegetables, while no
29
30
31 346 significant differences were found for other compounds. The authors pointed out that the study may
32
33 347 be biased by the honesty of volunteers in answering about their eating habits and/or other possible
34
35 348 sources of contamination of OPs than food. However, these results were confirmed by Hyland et al.
36
37 349 (2019) that observed significant reductions in urinary levels of thirteen pesticide metabolites and
38
39
40 350 related compounds (OPs, neonicotinoid, and pyrethroid insecticides and the herbicide 2,4-D) after
41
42 351 the introduction of organic food in the diet, in children and adults of USA families differing for race
43
44
45 352 and geographic origin.

46

47 353 Literature about heavy metals is quite contradictory: some authors did not found a significant
48
49 354 difference in their contents between organic and conventional food (Magkos et al. 2006), others found
50
51 355 higher levels of Cd and Pb in organic tomatoes (Rossi et al. 2008). Lower levels of Cd were found in
52
53
54 356 organic cereals, while no differences were found in fruits (Barański et al. 2014). The higher content
55
56 357 of Cd in conventional products may be related to the use of phosphate fertilizers that are often
57
58 358 contaminated with this metal, or to its native concentration in the soil. High concentrations of Cd are
59
60
359 considered a significant cause of vascular disorders, various common cancers, osteoporosis and other

1
2
3 360 health disorders, therefore, the lower Cd levels in organic food are certainly a positive fact (McCarty
4
5 361 2014).

7
8 362 As reported previously, mycotoxin contamination constitutes a serious concern for food,
9
10 363 especially for those derived from cereals. Because synthetic fungicides were banned in organic
11
12 364 agriculture, it has been argued that organic crops may be more susceptible to fungal contamination.
13
14
15 365 In fact, higher concentrations of mycotoxins deoxynivalenol and nivalenol were found in organic than
16
17 366 in conventional grain samples (Eltun 1997). Moreover, an extensive comparison of more than a
18
19 367 thousand organic and conventional cereal-based products from EU countries found a higher content
20
21 368 of fumonisins (*Fusarium* derived mycotoxins) in organic products (Rubert et al. 2013). However, no
22
23
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
27
28
29 371 introduced some bias in the analysis. A similar work carried out in the USA on 50 conventional and
30
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
34
35 374 organic and conventional food (Gomiero 2018) but the discordant results should be taken into
36
37
38 375 consideration before concluding that organic is absolutely safe.

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

43
44 378 It was previously documented that eCO₂ has negative impacts on food quality such as reduction of
45
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
50
51 381 conducted so far, in particular the comparisons between organic and conventional food, were done
52
53 382 on sites differing not only for agricultural practices but also for different type of soil, crop genotypes
54
55
56 383 and time and conditions of harvesting.

57
58 384 However, despite these limitations, more positive than negative trends can be resumed by
59
60 385 literature data. In particular, as far as technological quality is concerned, PA techniques gives the

1
2
3 386 possibility to differentiate the quality of raw materials in the field. As an example, cereal quality is
4
5 387 becoming more important than yield especially as the price of cereals reduces on world markets.
6
7
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
11
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,
15
16
17 392 precision harvesting could be an alternative method to maximize the tonnage of higher quality.
18
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
22
23
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
27
28
29 397 or lower protein contents in order to produce pasta with different characteristics (Visioli et al. 2018).

30
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.
36
37 401 2015; Kristl et al. 2013). A meta-analysis study reported a major content of Ca, Mg, K and P in
38
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
43
44 404 organic fruits and vegetables, as well as fiber content, even though the results were not considered
45
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).

50
51 407 Few data are available on sugar content in organic products. Studies on wheat reported that
52
53
54 408 sucrose concentration was higher in conventional than in organic ears, but this difference was
55
56 409 nullified in mature grains. No differences were found for other sugars (Zörb et al. 2009).

57
58 410 Since the 90's some studies evidenced how organic plant food possesses higher amounts of
59
60 411 secondary metabolites, and therefore they may be more health-promoting than conventional foods

1
2
3 412 (Brandt and Mølgaard 2001; Johansson et al. 2014; Woese et al. 1997). In particular, phenolic
4
5 413 compound content seems highly influenced by farming practices. Compared to conventional farming,
6
7
8 414 higher levels of phenols and polyphenols were found in organic cabbage, spinach, Welsh onion, green
9
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
13
14
15 417 result in a 20–40% (and for some compounds more than 60 %) increase in crop-based
16
17 418 antioxidant/(poly)phenolic intake (Barański et al. 2014).

19 419 Tocopherol is another class of antioxidants. Three studies conducted with comparative
20
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
27
28
29 423 showed no difference in the content of tocopherols between organic and conventional crops. The
30
31 424 same conclusions were drawn for carotenoid content (Johansson et al. 2014).

33 425 Biofertilizers seem to have a positive effect on the content of macro and micronutrients,
34
35 426 vitamins and antioxidants (Alori and Balabola 2018). The application of VAM-PGPR commercial
36
37
38 427 biofertilizer to wheat seeds improved the uptake of low-mobility nutrients from roots in wheat plants,
39
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).
43
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).

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

1
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
22
23
24 447 concentration of phenols and polyphenols in pomegranate fruits is reported after the application of
25
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
29
30
31 450 assessment and management of environmental, health, and safety risks potentially posed by nanoscale
32
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
36
37
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).

41
42 455

43 44 456 **Conclusions**

45
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
52
53
54 460 impacts on human nutrition. Fe and Zn deficiency is already an urgent issue in many parts of the
55
56 461 world especially in regions where people depend on C3 grains such as wheat as their primary source
57
58 462 of these micronutrients. Organic farming is the most ancient and widespread sustainable agricultural
59
60 463 practice, but studies on organic food are fragmentary and contradictory, and so far there is not strong

1
2
3 464 scientific evidence that they have better healthy properties than conventional food, except less
4
5
6 465 pesticide content. However, organic food seems to have better antioxidant properties than
7
8 466 conventional ones and this has been found also in response to different types of biofertilizers. The
9
10 467 impact of nano-fertilizers on quality and nutritional characteristics of food is still unexplored, but
11
12 468 their potential positive effects on plant growth and productivity make their utilization a promising
13
14
15 469 technology for sustainable agriculture.

16
17 470 PA technologies will contribute more and more to food safety (Gebbers and Adamchuk 2010).
18
19 471 PA makes farming more transparent by improving tracking, tracing and documenting. Crop and
20
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
27
28
29 475 automated optical sensing and intelligent planning options. In conclusion, we urgently need a new
30
31 476 research and technology paradigm to address the important issue of climate change and its impact on
32
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**

42
43
44 481 The authors declare no conflict of interest
45
46

47 482 **Funding**

48
49
50 483 The work was funded by AGER Fondazioni in Rete per la Ricerca Agroalimentare grant n° 2017-
51
52 484 2194.
53
54

55 485 **Acknowledgments**

56
57
58
59 486 The authors thank Prof. Francesco Visioli, University of Padua (Italy) for the critical review of the
60
487 manuscript and for useful suggestions.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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.

492

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

509

510

1
2
3 511 **References**
4
5

- 6 512 Alori, E. T., and O. O. Babalola. 2018. Microbial inoculants for improving crop quality and human
7 health in Africa. *Frontiers in Microbiology* 9: 1–12 <https://doi.org/10.3389/fmicb.2018.02213>
8
9 513
10
11 514 Applebaum, R. S., R. E. Brackett, D. W. Wiseman, and E. H. Marth. 1982. Aflatoxin: toxicity to
12 dairy cattle and occurrence in milk and milk products - A Review. *Journal of Food* 45(8): 752–
13 515 77. <https://doi.org/10.4315/0362-028X-45.8.752>.
14
15 516
16
17
18 517 Asami, D. K., Y. J. Hong, D. M. Barrett and A. E. Mitchell. 2003. Comparison of the total phenolic
19 and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry, and corn grown
20 518 using conventional, organic, and sustainable agricultural practices. *Journal of Agricultural and*
21 Food Chemistry 51(5): 1237–41. <https://doi.org/10.1021/jf020635c>.
22 519
23
24
25 520
26
27 521 Asseng, S., P. Martre, A. Maiorano, R. P. Rötter, G. J. O'Leary, G. J. Fitzgerald, C. Girousse, R.
28 Motzo, F. Giunta, M. A. Babar, *et al.* 2019. Climate change impact and adaptation for wheat
29 522 protein. *Global Change Biology* 25(1): 155–73. <https://doi.org/10.1111/gcb.14481>.
30 523
31
32
33
34 524 Barański, M., D. Srednicka-Tober, N. Volakakis, C. Seal, R. Sanderson, G. B. Stewart, C. Benbrook,
35 B. Biavati, E. Markellou, C. Giotis, *et al.* 2014. Higher antioxidant and lower cadmium
36 525 concentrations and lower incidence of pesticide residues in organically grown crops: a
37 systematic literature review and meta-analyses. *British Journal of Nutrition* 112(5):794-11.
38 526 <https://doi.org/10.1017/S0007114514001366>.
39
40
41 527
42
43 528
44
45 529 Baslam, M., I. Garmendia and N. Goicoechea. 2011. Arbuscular mycorrhizal fungi (AMF) improved
46 growth and nutritional quality of greenhouse-grown lettuce. *Journal of Agricultural and Food*
47 530 *Chemistry* 59(10): 5504–15. <https://doi.org/10.1021/jf200501c>.
48
49
50 531
51
52 532 Battilani, P., P. Toscano, H. J. Van Der Fels-Klerx, A. Moretti, M. Camardo Leggieri, C. Brera, A.
53 Rortais, T. Goumperis, and T. Robinson. 2016. Aflatoxin B1 contamination in maize in Europe
54 533 increases due to climate change. *Scientific Reports* 6: 24328.
55
56
57 534 <https://doi.org/10.1038/srep24328>.
58
59 535
60

- 1
2
3 536 Baudry J, Debrauwer L, Durand G, Limon G, Delcambre A, Vidal R *et al.* 2019. Urinary pesticide
4
5 537 concentrations in French adults with low and high organic food consumption: results from the
6
7
8 538 general population-based NutriNet-Santé. *Journal of Exposure Science and Environmental*
9
10 539 *Epidemiology*. 29:366-78. <https://doi.org/10.1038/s41370-018-0062-9>
11
12 540 Beddington, J. R., M. Asaduzzaman, M. E. Clark, A. Fernández Bremauntz, M. D. Guillou, D. J.
13
14 541 Howlett, M. M. Jahn, E. Lin, T. Mamo, C. Negra, *et al.* 2012. Agriculture. What next for
15
16 542 agriculture after Durban? *Science* 335(6066):289-90. <https://doi.org/10.1126/science.1217941>.
17
18
19 543 Bhat, M. A., H. Ahsan, and S. Husain. 2017. Climate change and its impact on food quality.
20
21 544 *International Journal of Pure and Applied Bioscience* 5(3): 709-725.
22
23 545 <http://dx.doi.org/10.18782/2320-7051.3090>.
24
25
26 546 Bhattacharyya, P. N., and D. K. Jha. 2012. Plant growth-promoting rhizobacteria (PGPR): emergence
27
28 547 in agriculture. *World Journal of Microbiology and Biotechnology* 28:1327-50.
29
30 548 <https://doi.org/10.1007/s11274-011-0979-9>.
31
32
33 549 Blesa, J., J. M. Soriano, J. C. Moltó and J. Mañes. 2006. Factors affecting the presence of ochratoxin
34
35 550 a in wines. *Critical Reviews in Food Science and Nutrition* 46(6): 473–78.
36
37 551 <https://doi.org/10.1080/10408390500215803>.
38
39
40 552 Bongiovanni, R. and J. Lowenberg-Deboer. 2004. Precision agriculture and sustainability. *Precision*
41
42 553 *Agriculture* 5(4): 359–87.
43
44 554 Brandt, K. and J. P. Mølgaard. 2001. Organic agriculture: does it enhance or reduce the nutritional
45
46 555 value of plant foods? *Journal of the Science of Food and Agriculture* 81(9): 924–31.
47
48 556 <https://doi.org/10.1002/jsfa.903>.
49
50
51 557 Bréant, D., K. Jézéquel, and T. Lebeau. 2002. Optimisation of the cell release from immobilised cells
52
53 558 of *Bacillus simplex* cultivated in culture media enriched with Cd²⁺: Influence of Cd²⁺, inoculum
54
55 559 size, culture medium and alginate beads characteristics. *Biotechnology Letters* 24(15): 1237–
56
57 560 41.
58
59
60 561 Broberg, M. C., P. Högy and H. Pleijel. 2017. CO₂ -induced changes in wheat grain composition:

- 1
2
3 562 Meta-analysis and response functions. *Agronomy* 7(32): 1–20.
4
5 563 <https://doi.org/10.3390/agronomy7020032>.
6
7
8 564 Brownlie, W. J., C. -M Howard, G. Pasda, B. Navé, W. Zerulla, and M. A. Sutton. 2015. Developing
9
10 565 a global perspective on improving agricultural nitrogen use. *Environmental Development* 15:
11
12 566 145–51. <https://doi.org/10.1016/j.envdev.2015.05.002>.
13
14
15 567 Cao, L., Z. Zhou, S. Niu, C. Cao, X. Li, Y. Shan, and Q. Huang. 2018. Positive-charge functionalized
16
17 568 mesoporous silica nanoparticles as nanocarriers for controlled 2,4-dichlorophenoxy acetic acid
18
19 569 sodium salt release. *Journal of Agriculture and Food Chemistry* 66 (26): 6594–03.
20
21
22 570 <https://doi.org/10.1021/acs.jafc.7b01957>.
23
24 571 Carbonaro, M., M. Mattera, S. Nicoli, P. Bergamo, and M. Cappelloni. 2002. Modulation of
25
26 572 antioxidant compounds in organic vs conventional fruit (peach, *Prunus persica* L., and pear,
27
28 573 *Pyrus communis* L.). *Journal of Agricultural and Food Chemistry* 50(1): 5458–62.
29
30
31 574 <https://doi.org/10.1021/jf0344690>.
32
33 575 Chen, H. and R. Yada. 2011. Nanotechnologies in agriculture: New tools for sustainable
34
35 576 development. *Trends in Food Science and Technology* 22(11): 585–94.
36
37
38 577 <https://doi.org/10.1016/j.tifs.2011.09.004>.
39
40 578 Chen, H., J.N. Seiber, and M. Hotze. 2014. ACS select on nanotechnology in food and agriculture: A
41
42 579 perspective on implications and applications. *Journal of Agriculture and Food Chemistry* 62(6):
43
44 580 1209–12. <https://doi.org/10.1021/jf5002588>.
45
46
47 581 Ciołek, A., E. Makarska and M. Wesołowski. 2012. Content of selected nutrients in wheat, barley
48
49 582 and oat grain from organic and conventional farming. *Journal of Elementology* 17(2): 181-89.
50
51
52 583 <https://doi.org/10.5601/jelem.2012.17.2.02>
53
54 584 Commission Regulation (EC) N. 1881/2006. Setting maximum levels for certain contaminants in
55
56 585 foodstuffs, Text with EEA relevance (2006), Available: [https://eur-](https://eur-lex.europa.eu/eli/reg/2006/1881/oj)
57
58 586 [lex.europa.eu/eli/reg/2006/1881/oj](https://eur-lex.europa.eu/eli/reg/2006/1881/oj)
59
60 587 Dal Cortivo, C., G. Barion, G. Visioli, M. Mattarozzi, G. Mosca and T. Vameralli. 2017. Increased

- 1
2
3 588 root growth and nitrogen accumulation in common wheat following PGPR inoculation:
4
5 589 assessment of plant-microbe interactions by ESEM. *Agriculture Ecosystems and Environment*
6
7 247: 396-08. <https://doi.org/10.1016/j.agee.2017.07.006>.
8
9
10 591 Dal Cortivo, C., G. Barion, M. Ferrari, G. Visioli, L. Dramis, A. Panozzo, and T. Vamerali. 2018.
11
12 592 Effects of field inoculation with VAM and bacteria consortia on root growth and nutrients
13
14 593 uptake in common wheat. *Sustainability* 10(9): 3286. <https://doi.org/10.3390/su10093286>.
15
16
17 594 Dal Cortivo, C., Ferrari, M., Visioli, G., Lauro, M., Fornasier, F., Barion, G., Panozzo A, Vamerali
18
19 595 T. [Effects of seed-applied biofertilizers on rhizosphere biodiversity and growth of common](#)
20
21 596 [wheat \(*Triticum aestivum* L.\) in the Field](#). *Frontiers in Plant Science* 26, 11:72. doi:
22
23 10.3389/fpls.2020.00072.
24
25
26 598 de Orduña, M. R. 2010. Climate change associated effects on grape and wine quality and production.
27
28 599 *Food Research International* 43(7): 1844–55. <https://doi.org/10.1016/j.foodres.2010.05.001>.
29
30
31 600 Diallo, S., A. Crépin, C. Barbey, N. Orange, J. F. Burini, and X. Latour. 2011. Mechanisms and recent
32
33 601 advances in biological control mediated through the potato rhizosphere. *FEMS Microbiology*
34
35 602 *Ecology* 75(3): 351–64. <https://doi.org/10.1111/j.1574-6941.2010.01023.x>.
36
37
38 603 Dimkpa, C. O. and P. S. Bindraban. 2018. Nanofertilizers: New Products for the Industry? . *Journal*
39
40 604 *of Agriculture and Food Chemistry* 66(26): 6462–73. <https://doi.org/10.1021/acs.jafc.7b02150>.
41
42 605 Dong, J, N. Gruda, S. K. Lam, X. Li, and Z. Duan. 2018. Effects of elevated CO₂ on nutritional quality
43
44 606 of vegetables: A review. *Frontiers in Plant Science* 9: 1–11.
45
46 <https://doi.org/10.3389/fpls.2018.00924>
47
48
49 608 Dornbos, D. L., and R. E. Mullen. 1992. Soybean seed protein and oil contents and fatty acid
50
51 609 composition adjustments by drought and temperature. *Journal of the American Oil Chemists*
52
53 610 *Society* **69**: 228–31.
54
55
56 611 Drakou, M., A. Birmpa, A. E. Koutelidakis, M. Komaitis, E. Z. Panagou and M. Kapsokefalou. 2015.
57
58 612 Total antioxidant capacity, total phenolic content and iron and zinc dialyzability in selected
59
60 613 Greek varieties of table olives, tomatoes and legumes from conventional and organic farming.

- 1
2
3 614 *International Journal of Food Sciences and Nutrition* 66(2) :197-
4
5 615 02.<https://doi.org/10.3109/09637486.2014.979320>.
6
7
8 616 EC (European Commission), *Organic Certification* [on line], European Commission, DG Agriculture
9
10 617 and Rural Development, Unit Agricultural modelling and outlook, Brussels (2016). Available
11
12 618 at [http://ec.europa.eu/agriculture/organic/organicfarming/what-is-organic-farming/organic-](http://ec.europa.eu/agriculture/organic/organicfarming/what-is-organic-farming/organic-certification_en)
13
14 619 [certification_en](http://ec.europa.eu/agriculture/organic/organicfarming/what-is-organic-farming/organic-certification_en).
15
16
17 620 EFSA (European Food Safety Authority). 2016. *The 2014 European Union Report on Pesticide*
18
19 621 *Residues in Food* [on line]. European Food Safety Authority, Parma, Italy. Available:
20
21 622 <https://www.efsa.europa.eu/en/efsajournal/pub/4611>.
22
23
24 623 Eftekhari, M., M. Alizadeh, and P. Ebrahimi. 2012. Evaluation of the total phenolics and quercetin
25
26 624 content of foliage in mycorrhizal grape (*Vitis vinifera L.*) varieties and effect of postharvest
27
28 625 drying on quercetin yield. *Industrial Crops and Products* 38: 160–65.
29
30 626 <https://doi.org/10.1016/j.indcrop.2012.01.022>
31
32
33 627 Egamberdieva, D., and A. O. Adesemoye. 2016. Improvement of Crop Protection and Yield in Hostile
34
35 628 Agroecological Conditions with PGPR-Based Biofertilizer Formulations. In *Bioformulations:*
36
37 629 *for Sustainable Agriculture* ed N. Arora, S. Mehnaz, R. Balestrini, 199-11. New Delhi:
38
39 630 Springer.
40
41
42 631 Eltun, R. 1997. The Apelsvoll (Norway) cropping system experiment III. Yield and grain quality of
43
44 632 cereals. *Norwegian Journal of Agricultural Sciences* 10: 7-21.
45
46
47 633 Entry, J. A., and R. E. Sojka. 2007. Matrix based fertilizers reduce nitrogen and phosphorus leaching
48
49 634 in greenhouse column studies. *Water Air and Soil Pollution* 180(1-4): 283–92.
50
51 635 <https://doi.org/10.1007/s11270-006-9270-3>.
52
53
54 636 Environmental Protection Agency (U.S. EPA), *Exposure Factors Handbook: 2011 Edition*, [on line],
55
56 637 U.S. Environmental Protection Agency, National Center for Environmental Assessment Office
57
58 638 of Research and Development: Washington, DC. EPA/600/R-09/052F (2011). Available at
59
60 639 <http://www.epa.gov/ncea/efh/report.html>.

- 1
2
3 640 FAO, The Future of Food and Agriculture, Trends and Challenges [on line], Food and Agriculture
4
5 641 Organization of the United Nations (2017). Available: <http://www.fao.org/3/a-i6583e.pdf>
6
7
8 642 Fiorilli, V., C. Vannini, F., Ortolani, D. Garcia-Seco, M. Chiapello, M. Novero, V. Terzi, C. Morcia,
9
10 643 P. Bagnaresi, L. Moulin, *et al.* 2018. Omics approaches revealed how arbuscular mycorrhizal
11
12 644 symbiosis enhances yield and resistance to leaf pathogen in wheat. *Scientific Reports* 8:9625.
13
14 645 <https://doi.org/10.1038/s41598-018-27622-8>.
15
16
17 646 Gan, Y, S. V. Angadi, H. Cutforth, D. Potts, V. V. Angadi, and C. L. McDonald. 2004. Canola and
18
19 647 mustard response to short periods of temperature and water stress at different developmental
20
21 648 stages. *Canadian Journal of Plant Science* 84(3): 697–04. <https://doi.org/10.4141/P03-109>.
22
23
24 649 Gebbers, R. and V. I. Adamchuk. 2010. Precision agriculture and food security. *Science* 237(5967):
25
26 650 828-31. <https://doi.org/10.1126/science.1183899>
27
28
29 651 Ghildiyal, M. C., and P. Sharma-Natu. 2000. Photosynthetic acclimation to rising atmospheric carbon
30
31 652 dioxide concentration. *Indian Journal of Experimental Biology* 38(10): 961–66.
32
33 653 Gomiero, T. 2013. Alternative land management strategies and their impact on soil conservation.
34
35 654 *Agriculture* 3: 464–83. <https://doi.org/10.3390/agriculture3030464>.
36
37
38 655 Gomiero, T. 2018. Food quality assessment in organic vs. conventional agricultural produce: findings
39
40 656 and issues. *Applied Soil Ecology* 123:714-28. <https://doi.org/10.1016/j.apsoil.2017.10.014>
41
42 657 Gourama, H. 2015. A preliminary mycological evaluation of organic and conventional foods. *Food*
43
44 658 *Protection Trends* 35(5): 385–91.
45
46
47 659 Guo, H., White, J.C., Wang, Z., Xing B. 2018. Nano-enabled fertilizers to control the release and use
48
49 660 efficiency of nutrients. *Current Opinion and Environmental Science and Health* 6: 77-83.
50
51 661 <https://doi.org/10.1016/j.coesh.2018.07.009>
52
53
54 662 Hartmann, M., B. Frey, J. Mayer, P. Mäder, and F. Widmer. 2015. Distinct soil microbial diversity
55
56 663 under long-term organic and conventional farming. *The ISME Journal* 9(5): 1177–94.
57
58 664 <https://doi.org/10.1038/ismej.2014.210>.
59
60
665 He, X., H. Deng, and H. Hwang. 2019. The current application of nanotechnology in food and

- 1
2
3 666 agriculture. *Journal of Food and Drug Analysis* 27(1): 1–21.
4
5 667 <https://doi.org/10.1016/j.jfda.2018.12.002>.
6
7
8 668 Heidecke, C., H. Montgomery, H. Stalb, and L. Wollenberg (eds). 2018. *International Conference*
9
10 669 *on Agricultural GHG Emissions and Food Security – Connecting research to policy and*
11
12 670 *practice – Volume of Abstracts*, Braunschweig: Johann Heinrich von Thünen-Institut Berlin,
13
14 671 Germany.
15
16
17 672 Högy, P., and A. Fangmeier. 2009. Atmospheric CO₂ enrichment affects potatoes: 2. Tuber quality
18
19 673 traits. 2009. *European Journal of Agronomy* 30(2): 85–94
20
21 674 <https://doi.org/10.1016/j.eja.2008.07.006>.
22
23
24 675 Hyland, C, A. Bradman, R. Gerona, S. Patton, I. Zakharevich, R. B. Gunier, and K. Kendra. 2019.
25
26 676 Organic diet intervention significantly reduces urinary pesticide levels in U.S. children and
27
28 677 adults. *Environmental Research* 171:568-75. <https://doi.org/10.1016/j.envres.2019.01.024>
29
30
31 678 Iavicoli, I, Leso, V., Beezhold, D.H., Shvedova, A.A. 2017. Nanotechnology in agriculture:
32
33 679 Opportunities, toxicological implications, and occupational risks. *Toxicology and Applied*
34
35 680 *Pharmacology* 329: 96–111. <https://doi.org/10.1016/j.taap.2017.05.025>.
36
37
38 681 Johansson, E., A. Hussain, R. Kuktaite, S. C. Andersson and M. E. Olsson. 2014. Contribution of
39
40 682 organically grown crops to human health. *International Journal of Environmental Research*
41
42 683 *and Public Health* 11(4): 3870–93. <https://doi.org/10.3390/ijerph110403870>.
43
44
45 684 Khalid, M., D. Hassani, M. Bilal, F. Asad, and D. Huang. 2017. Influence of bio-fertilizer containing
46
47 685 beneficial fungi and rhizospheric bacteria on health promoting compounds and antioxidant
48
49 686 activity of *Spinacia oleracea* L. *Botanical Studies* 58:35. [https://doi.org/10.1186/s40529-017-](https://doi.org/10.1186/s40529-017-0189-3)
50
51 687 [0189-3](https://doi.org/10.1186/s40529-017-0189-3)
52
53
54 688 Kirchmann, H., and G. Thorvaldsson. 2000. Challenging targets for future agriculture. *European*
55
56 689 *Journal of Agronomy* 12(3-4): 145–161. [https://doi.org/10.1016/S1161-0301\(99\)00053-2](https://doi.org/10.1016/S1161-0301(99)00053-2).
57
58
59 690 Köhler, I. H., S. C. Huber, C. J. Bernacchi, and I. R. Baxter. 2019. Increased temperatures may
60
691 safeguard the nutritional quality of crops under future elevated CO₂ concentrations. *The Plant*

- 1
2
3 692 *Journal* **97**: 872–86. <https://doi.org/10.1111/tpj.14166>
4
5 693 Kristl, J., A. U. Krajnc, B. Kramberger and S. G. Mlakar. 2013. Strawberries from integrated and
6
7 organic production: mineral contents and antioxidant activity. *Acta Chimica Slovenica*
8 694 60(1):19-25.
9
10 695
11
12 696 Kumar, S., D. Kumar and N. Dilbaghi. 2017. Preparation, characterization, and bio-efficacy
13
14 evaluation of controlled release carbendazim-loaded polymeric nanoparticles. *Environmental*
15 697 *Science and Pollution Research* 24(1): 926–37. <https://doi.org/10.1007/s11356-016-7774-y>
16
17 698
18
19 699 Liu, B., C. Tu, S. Hu, M. Gumpertz, and J. B. Ristaino. 2007. Effect of organic, sustainable, and
20
21 conventional management strategies in grower fields on soil physical, chemical, and biological
22 700 factors and the incidence of Southern blight. *Applied Soil Ecology* 37(3): 202–14.
23
24 701 <https://doi.org/10.1016/j.apsoil.2007.06.007>.
25
26 702
27
28 703 Liu, J., Y. Su, Q. Li, Q. Yue and B. Gao. 2013. Preparation of wheat straw based superabsorbent
29
30 resins and their applications as adsorbents for ammonium and phosphate removal. *Bioresource*
31 704 *Technology* **143**: 32–39. <https://doi.org/10.1016/j.biortech.2013.05.100>.
32
33 705
34
35 706 Liu, R. and R. Lal. 2015. Potentials of engineered nanoparticles as fertilizers for increasing agronomic
36
37 productions. *Science of the Total Environment* 514: 131–39.
38 707 <https://doi.org/10.1016/j.scitotenv.2015.01.104>.
39
40 708
41
42 709 Loladze, I. 2014. Hidden shift of the ionome of plants exposed to elevated CO₂ depletes minerals at
43
44 the base of human nutrition. *Elife* 3: e02245 (2014). <https://doi.org/10.7554/eLife.02245.001>.
45 710
46
47 711 Lombardi-Boccia, G., M. Lucarini, S. Lanzi, A. Aguzzi, and M. Cappelloni. 2004. Nutrients and
48
49 antioxidant molecules in yellow plums (*Prunus domestica* L.) from conventional and organic
50
51 productions: a comparative study. *Journal of Agricultural and Food Chemistry* 52(1): 90–94.
52 713 <https://doi.org/10.1021/jf0344690>.
53
54 714
55
56 715 Lupatini, M., G. W. Korthals, M. Hollander, T. K. S. de Janssens, and E. E. Kuramae. 2017. Soil
57
58 microbiome is more heterogeneous in organic than in conventional farming system. *Frontiers*
59 716 *in Microbiology* **7**: 1–13. <https://doi.org/10.3389/fmicb.2016.02064>.
60
61 717

1

2

- 3 718 Lyman, N. B., K. S. V. Jagadish, L. L. Nalley, B. L. Dixon and T. Siebenmorgen. 2013. Neglecting
4
5 719 rice milling yield and quality underestimates economic losses from high-temperature stress.
6
7
8 720 *PLoS One* 8(8): e72157. <https://doi.org/10.1371/journal.pone.0072157>.
- 9
10 721 Mäder, P., D. Hahn, Dubois, D., L. Gunst, T. Alfoldi, H. Bergmann, M. Oehme, R. Amadò, H.
11
12 722 Schneider, U. Graf, *et al.* 2007. Wheat quality in organic and conventional farming: results of
13
14 723 a 21year field experiment. *Journal of the Science of Food and Agriculture* 87(10):1826–35.
15
16
17 724 <https://doi.org/10.1002/jsfa.2866>.
- 18
19 725 Magkos, F., F. Arvaniti and A. Zampelas. 2006. Organic food: buying more safety or just peace of
20
21 726 mind? A critical review of the literature. *Critical Reviews in Food Science and Nutrition* 46:23-
22
23 56. <https://doi.org/10.1080/10408690490911846>.
- 24 727
25
26 728 McCarty, M. F. and J. Di Nicolantonio. 2014. Are organically grown foods safer and more healthful
27
28 729 than conventionally grown foods? *British Journal of Nutrition* 112(10): 1589–91.
29
30
31 730 <https://doi.org/10.1017/S0007114514002748>.
- 32
33 731 Miller, L. V. N., F. Krebs, and K.M. Hambidge. 2007. A mathematical model of zinc absorption in
34
35 732 humans as a function of dietary zinc and phytate. *The Journal of Nutrition* 137(1): 135–41.
36
37
38 733 <https://doi.org/10.1093/jn/137.1.135>.
- 39
40 734 Morari, F., V. Zanella, L. Sartori, G. Visioli, P. Berzaghi, and G. Mosca. 2018. Optimising durum
41
42 735 wheat cultivation in North Italy. Understanding the effects of site-specific fertilization on yield
43
44 736 and protein content. *Precision Agriculture* 19: 257-77. [https://doi.org/10.1007/s11119-017-](https://doi.org/10.1007/s11119-017-9515-8)
45
46 9515-8.
47 737
48
- 49 738 Myers, S. S., A. Zanobetti, I. Kloog, P. Huybers, A. D. B. Leakey, A. J. Bloom, E. Carlisle, L. H.
50
51 739 Dietterich, G. Fitzgerald, T. Hasegawa, *et al.* 2014. Increasing CO₂ threatens human nutrition.
52
53 740 *Nature* **510**: 139–42. <https://doi.org/10.1038/nature13179>.
- 54
55
56 741 Pallottino, F., M. Biocca, P. Nardi, S. Figorilli, P. Menesatti, and C. Costa. 2018. Science mapping
57
58 742 approach to analyze the research evolution on precision agriculture: world, EU and Italian
59
60 743 situation. *Precision Agriculture* **19**: 1011–26. <https://doi.org/10.1007/s11119-018-9569-2>

- 1
2
3 744 Lambert D and J. Lowenberg-DeBoer. 2000. *Precision Agriculture Profitability Review Site-*
4
5 745 *Specific Management Center, Purdue University. Available:*
6
7
8 746 <http://www.agriculture.purdue.edu/ssmc/>.
9
- 10 747 Reich, M., A. N. Meerakker, S. van den Parmar, M. J. Hawkesford and L. J. De Kok. 2016.
11
12 748 Temperature determines size and direction of effects of elevated CO₂ and nitrogen form on yield
13
14
15 749 quantity and quality of Chinese cabbage. *Plant Biology* 18(S1): 63–75.
16
17 750 <https://doi.org/10.1111/plb.12396>
18
- 19 751 Reilly, K., E. Cullen, T. Lola-Luz, D. Stone, J. Valverde, M. Gaffney, N. Brunton, J. Grant, and B.
20
21 752 S. Griffiths. 2003. Effect of organic, conventional and mixed cultivation practices on soil
22
23
24 753 microbial community structure and nematode abundance in a cultivated onion crop. *Journal of*
25
26 754 *the Science of Food and Agriculture* 93: 3700–09. <https://doi.org/10.1002/jsfa.6206>.
27
- 28 755 Ren, H., H. Bao, H. Endo and T. Hayashi. 2001. Antioxidative and antimicrobial activities and
29
30
31 756 flavonoid contents of organically cultivated vegetables. *Nippon Shokuhin Kagaku Kogaku*
32
33 757 *Kaish* 48(4): 246–52. <https://doi.org/10.3136/nskkk.48.246>.
34
- 35 758 Riley W. J., I. Ortiz-Monasterio, and P. A. Matson. 2001. Nitrogen leaching and soil nitrate, nitrite,
36
37
38 759 and ammonium levels under irrigated wheat in Northern Mexico. *Nutrient Cycling in*
39
40 760 *Agroecosystems* 61(3): 223–36. <https://doi.org/10.1023/A:1013758116346>.
41
- 42 761 Rillig, M. C., A. Lehmann, J. Lehmann, T Camenzind, and C. Rauh. 2018. Soil biodiversity effects
43
44
45 762 from field to fork. *Trends in Plant Science* 23(1): 17–24.
46
47 763 <https://doi.org/10.1016/j.tplants.2017.10.003>
48
- 49 764 Rogovska, N., D. A. Laird, C. P. Chiou and L. J Bond. 2019. Development of field mobile soil nitrate
50
51
52 765 sensor technology to facilitate precision fertilizer management. *Precision Agriculture* 20: 40–
53
54 766 55. <https://doi.org/10.1007/s11119-018-9579-0>.
55
- 56 767 Rossi, F., F. Godani, T. Bertuzzi, M. Trevisan, F. Ferrari and S. Gatti. 2008. Health-promoting
57
58
59 768 substances and heavy metal content in tomatoes grown with different farming techniques.
60
61 769 *European Journal of Nutrition* 47(5): 266–72. <https://doi.org/10.1007/s00394-008-0721-z>.

- 1
2
3 770 Rubert, J., J. M. Soriano, J. Mañes, and C. Soler. 2013. Occurrence of fumonisins in organic and
4
5 771 conventional cereal-based products commercialized in France, Germany and Spain. *Food and*
6
7 *and Chemical Toxicology* 56: 387–91. <https://doi.org/10.1016/j.fct.2013.02.039>.
8 772
9
10 773 Sánchez-Guerrero, M. C., P. Lorenzo, E. Medrano, N. Castilla, T. Soriano, and A. Baille. 2005. Effect
11
12 774 of variable CO₂ enrichment on greenhouse production in mild winter climates. *Agriculture and*
13
14 *Forest Meteorology* 1328(3-4): 244–52 <https://doi.org/10.1016/j.agrformet.2005.07.014>
15 775
16
17 776 Savin, R. and M. E. Nicolas. 1996. Effects of short periods of drought and high temperature on grain
18
19 777 growth and starch accumulation of two malting barley cultivars. *Australian Journal of Plant*
20
21 *Physiology* 23(2): 201–10. <https://doi.org/10.1071/PP9960201>.
22 778
23
24 779 Sebastian, S., P. Kerr, R. Pearlstein, and W. Hitz. 2000. Soybean germplasm with novel genes for
25
26 780 improved digestibility. In *Soy in animal nutrition*, ed. K. Drackley, 56-74. Savoy, Illinois,
27
28 781 USA: Federation of Animal Science Societies.
29
30
31 782 Sehgal, A., K. Sita, K. H. M. Siddique, R. Kumar, S. Bhogireddy, R. K. Varshney, B. H. Rao, R. M.
32
33 783 Nair, P. V. Prasad, and H. Nayyar. 2018. Drought or/and heat-stress effects on seed filling in
34
35 784 food crops: impacts on functional biochemistry, seed yields, and nutritional quality. *Frontiers*
36
37 *in Plant Science* 9 :1705. <https://doi.org/10.3389/fpls.2018.01705>
38 785
39
40 786 Seufert, V., N. Ramankutty, and J. A. Foley. 2012. Comparing the yields of organic and conventional
41
42 787 agriculture. *Nature* 485: 229–32. <https://doi.org/10.1038/nature11069>.
43
44
45 788 Slininger, P. J., D. A. Schisler, M. A. Shea-Andersh, J. M. Sloan, L. K. Woodell, M. J. Frazier, and
46
47 789 N. L. Olsen. 2010. Multi-strain co-cultures surpass blends for broad spectrum biological control
48
49 790 of maladies of potatoes in storage. *Biocontrol Science and Technology* 20(8): 763–86..
50
51 791 <https://doi.org/10.1080/09583151003717201>.
52
53
54 792 Smith, V. H. and D. W. Schindler. 2009. Eutrophication science: where do we go from here? *Trends*
55
56 793 *in Ecology and Evolution* 24(4): 201–07. <https://doi.org/10.1016/j.tree.2008.11.009>.
57
58 794 Smith-Spangler, C., M. L. Brandeau, G. E. Hunter, J. C. Bavinger, M. Pearson, P. J. Eschbach, V.
59
60 795 Sundaram, H. Liu, P. Schirmer, C. Stave, *et al.* 2012. Are organic foods safer or healthier than

- 1
2
3 796 conventional alternatives? *Annals of Intern Medicine* 157(5): 348–66.
4
5 797 <https://doi.org/10.7326/0003-4819-157-5-201209040-00007>.
6
7
8 798 Stafford, J. V. 2013. *Precision Agriculture '13*. Wageningen Academic Publishers, The Netherlands.
9
10 799 Thomas, J.M.G., P. V. V. Prasad, K. J. Boote, and L. H. Allen. 2009. Seed composition, seedling
11
12 800 emergence and early seedling vigour of red kidney bean seed produced at elevated temperature
13
14 801 and carbon dioxide. *Journal of Agronomy and Crop Science*. 195(2): 148–56.
15
16 802 <https://doi.org/10.1111/j.1439-037X.2008.00348.x>
17
18
19 803 Trebicki, P., N. Nancarrow, E. Cole, N. A. Bosque-Pérez, F. E. Constable, A. J. Freeman, B. Rodoni,
20
21 804 A. L. Yen, J. L. Luck, and G. J. Fitzgerald. 2015. Virus disease in wheat predicted to increase
22
23 805 with a changing climate. *Global Change Biology* 21(9): 3511–19.
24
25 806 <https://doi.org/10.1111/gcb.12941>
26
27
28 807 Tsochatzis, E. D., K. Bladenopoulos, and M. Papageorgiou. 2012. Determination of tocopherol and
29
30 808 tocotrienol content of Greek barley varieties under conventional and organic cultivation
31
32 809 techniques using validated reverse phase high-performance liquid chromatography method.
33
34 810 *Journal of the Science of Food and Agriculture* 92(8): 1732–39.
35
36 811 <https://doi.org/10.1002/jsfa.5539>.
37
38
39
40 812 Tsukaguchi, T. and Y. Iida. 2008. Effects of assimilate supply and high temperature during grain-
41
42 813 filling period on the occurrence of various types of chalky kernels in rice plants (*Oryza sativa*
43
44 814 L.). *Plant Production Science* 11(2): 203–10. <https://doi.org/10.1626/pps.11.203>.
45
46
47 815 Uddling, J., M. C. Broberg, Z. Feng, and H. Pleijel. 2018. Crop quality under rising atmospheric CO₂.
48
49 816 *Current Opinion in Plant Biology* 45: 262–67. <https://doi.org/10.1016/j.pbi.2018.06.001>.
50
51
52 817 USDA (United States Department of Agriculture), *Organic Regulations* [on line] (2016). Available
53
54 818 at <https://www.ams.usda.gov/rules-regulations/organic>.
55
56 819 Van der Fels-Klerx, H.J., L. C. Vermeulen, A. K. Gavai, and C. Liu. 2019. Climate change impacts
57
58 820 on aflatoxin B1 in maize and aflatoxin M1 in milk: A case study of maize grown in Eastern
59
60 821 Europe and imported to the Netherlands. *PLoS One* 14(6): e0218956.

1
2
3 822 <https://doi.org/10.1371/journal.pone.0218956>
4

5 823 Visioli, G., T. Vamerli, C. Dal Cortivo, S. Trevisan, B. Simonato, and G. Pasini. 2018. Pasta-making
6
7 824 properties of the new durum wheat variety *Biensur* suitable for the northern Mediterranean
8
9 environment. *Italian Journal of Food Science* 30(4): 673-83. [https://doi.org/10.14674/IJFS-](https://doi.org/10.14674/IJFS-1163)
10 825
11 1163.
12 826

13
14 827 Vrček, I. V., D. V. Čepo, D. Rašić, M. Peraica, I. Žuntar, M. Bojić, G. Mendaš, and M. Medić-Šarić.
15
16 2014. A comparison of the nutritional value and food safety of organically and conventionally
17 828
18 produced wheat flours. *Food Chemistry* 143(15):522-29.
19 829
20 <https://doi.org/10.1016/j.foodchem.2013.08.022>.
21 830
22

23
24 831 Glen W. Walker, G.W., Kookana, R.S., Smith, N.E., Kah, M., Doolette, C.L., Reeves, P.T., Lovell,
25
26 832 W., Darren J. Anderson, D.J., Terence, W., Turney, T.W., Divina A., Navarro, D.A. 2018.
27
28 Ecological risk assessment of nano-enabled pesticides: A perspective on problem formulation.
29 833
30 *Journal of Agriculture and Food Chemistry* 66, 6480–6486 DOI: [10.1021/acs.jafc.7b02373](https://doi.org/10.1021/acs.jafc.7b02373)
31 834
32

33 835 Wang, S. Y., and W. Zheng. 2001. Effect of plant growth temperature on antioxidant capacity in
34
35 836 strawberry. *Journal of Agriculture and Food Chemistry* 49(10): 4977–82.
36
37 <https://doi.org/10.1021/jf0106244>.
38 837
39

40 838 Williams, M., P. R. Shewry, D. W. Lawlor, and J. L. Harwood. 1995. The effects of elevated
41
42 839 temperature and atmospheric carbon dioxide concentration on the quality of grain lipids in
43
44 840 wheat (*Triticum aestivum* L.) grown at two levels of nitrogen application. *Plant Cell and*
45
46 *Environment* 18(9): 999–09. <https://doi.org/10.1111/j.1365-3040.1995.tb00610.x>.
47 841
48

49 842 Woese, K., D. Lange, C. Boess and K. W. Bögl. 1997. A comparison of organically and
50
51 843 conventionally grown foods-results of a review of the relevant literature. *Journal of the Science*
52
53 *of Food and Agriculture* 74(3): 281–93. [https://doi.org/10.1002/\(SICI\)1097-001](https://doi.org/10.1002/(SICI)1097-001).
54 844
55

56 845 Yang, L. and Y. Wang. 2019. Impact of climate change on rice grain quality. In *Rice* (Fourth Edition),
57
58 846 ed J. Bao 427-41. St. Paul, MN 55121 USA: AACC International Press.

59
60 847 Yang, L., Y. Wang, G. Dong, H. Gu, J. Huang, J. Zhu, H. Yang, G. Liu, and Y. Han. 2007. The

- 1
2
3 848 impact of free-air CO₂ enrichment (FACE) and nitrogen supply on grain quality of rice. *Field*
4
5 849 *Crop Research* 102(2): 128–40. <https://doi.org/10.1016/j.fcr.2007.03.006>.
6
7
8 850 Zahedi, S. M., M. Karimi, J. A. Teixeira da Silva. 2020. The use of nanotechnology to increase quality
9
10 851 and yield of fruit crops. *Journal of the Science of Food and Agriculture* 100(1):25-31.
11
12 852 <https://doi.org/10.1002/jsfa.10004>
13
14
15 853 Zain, M.E. 2011. Impact of mycotoxins on humans and animals. *Journal of Saudi Chemical Society*
16
17 854 15: 129-144. <https://doi.org/10.1016/j.jscs.2010.06.006>
18
19 855 Zhang, N., M. Wang, and N. Wang. 2002. Precision agriculture: a worldwide overview. *Computers*
20
21 856 *and Electronics in Agriculture* 36(2-3): 113-132. <https://doi.org/10.1016/S0168->
22
23 857 1699(02)00096-0
24
25
26 858 Zhu C., K. Kobayashi, I. Loladze, J. Zhu, Q. Jiang, X. Xu, G. Liu, S. Seneweera, K. L. Ebi, A.
27
28 859 Drewnowski, N. K., Fukagawa, and L. H. Ziska. 2018. Carbon dioxide (CO₂) levels this century
29
30 860 will alter the protein, micronutrients, and vitamin content of rice grains with potential health
31
32 861 consequences for the poorest rice-dependent countries. *Science Advances* 4(5): 4–11.
33
34 862 <https://doi.org/10.1126/sciadv.aaq1012>.
35
36
37 863 Ziska, L. H., and J. A. Bunce. 2007. Predicting the impact of changing CO₂ on crop yields: some
38
39 864 thoughts on food. *New Phytologist* 175(4): 607– 18. <https://doi.org/10.1111/j.1469->
40
41 865 8137.2007.02180.x
42
43
44 866 Zörb, C., K. Niehaus, A. Barsch, T. Betsche, and G. Langenkämper. 2009. Levels of compounds and
45
46 867 metabolites in wheat ears and grains in organic and conventional agriculture. *Journal of*
47
48 868 *Agricultural and Food Chemistry* 57(20): 9555-62. <https://doi.org/10.1021/jf9019739>.
49
50
51 869

52 870 **Figure Caption**

53
54 871 **Figure 1:** Different sustainable agronomic practices and their possible effects on climate change
55
56 872 mitigation and quality and safety of food products. CSA= Climate Smart Agriculture
57
58
59
60

873

1
2
3 874
4
5
6 875
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

For Peer Review Only

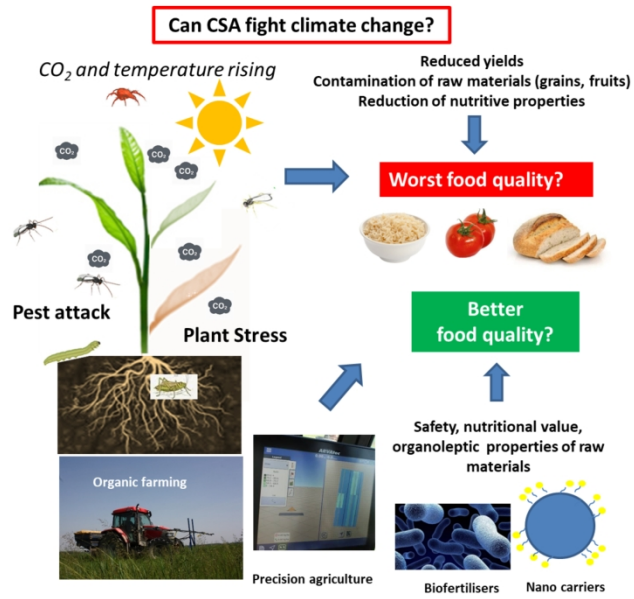


Figure 1: Different sustainable agronomic practices and their possible effects on climate change mitigation and quality and safety of food products. CSA= Climate Smart Agriculture

296x209mm (300 x 300 DPI)