Trends in Organic Vegetable Crop Production

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Organic farming is a holistic production management system that promotes and enhances agroecosystem health, including biodiversity, biological cycles and soil biological activity, and consequently, it is an efficient and promising approach for sustainable agriculture within a circular and green economy. There has been a rise in the consumption of organic vegetables in the last years because of their organoleptic properties, higher nutritive value and lower risk of chemical residues harmful to health. The scientific evidence regarding the use of the major elements responsible for organic vegetable crop production indicates plant material, soil management and crop nutrition, soil disinfection, crop management and pest, disease and weed management.

organic production vegetable organic crop nutrition

1. Introduction

Organic agriculture, named in some countries as biological or ecological agriculture, is a holistic production management system that promotes and enhances agroecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasises the use of management practices as preferred to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems [1]. This management system combines tradition, innovation and science to benefit the shared environment and promote fair relationships and good quality of life for all involved [2].

The extent of organically managed farmlands, the number of organic farms, and the global market size for organically grown foods have increased steadily [3]. The latest data show that this tendency was accentuated due to a substantial increase in consumer demand for organic food during the COVID-19 pandemic [4]. Expanding organic production has implied the production of nutritionally improved food crops while using fewer external inputs and reducing environmental impacts [5]. As stated by Willer et al. [4], in 2019, organic agricultural land reached 72.3 million hectares (1.5 percent of the total agricultural land), being managed organically by at least 3.1 million farmers from 187 countries. According to the previous researchers, the five countries with the largest areas of organic land were: Australia (35.7 million hectares), Argentina (3.67 million hectares), Spain (2.35 million hectares), USA (2.33 million hectares) and India (2.30 million hectares), and the distribution of organic agricultural land by continent was: Oceania (50%), Europe (23%), Latin America (12%), Asia (8%), North America (5%) and Africa (3%).

The diets based on organic products seem to be healthier and tastier, providing a better quality of life for people, compared to diets based on conventional foods, although the potential role of the production system has not yet adequately been investigated [6]. Previously published studies on nutritional differences between organic and conventional foods show that the variation in results is very high, depending on several factors such as genotype, fertilisation of plants, ripening stage and plant age at harvest, weather conditions and growing system [7][8]. Therefore, it is not possible to conclude that organic certification can be considered an indication of better overall nutritional quality [9] and that despite the evident toxicological safety guaranteed by organic products, the association between the consumption of organic foods and a reduction in the risk of developing chronic diseases is generally weak [10]. Within organic agriculture, the ecological production of vegetables plays an important role for the sustainable production of organic food and the preservation of the environment. Organic vegetable growers provide healthy food and are a source of livelihood for many farming communities, especially small farmers. Organic horticultural production can improve the quality of life of producers, increase agricultural employment, reduce health risks and improve the sustainability of the agrosystems [11][12].

2. Plant Material

The sustainability of food and agricultural systems depends on seed diversity [13][14], and it is known that wild and traditional cultivars are under enormous human-driven pressures, including industrialised agriculture and climate changes [15].

Currently, organic production mainly relies on cultivars bred in and for conventional production, and only the seeds are organically produced [16], which may not perform as well in organic systems as in conventional systems [17][18]. Orsini et al. reported that the use of organic seed by organic farmers in Europe is low [19], and Knapp and van der Heijden have argued that at least part of the yield gap in organic crop production compared to conventional agriculture might be due to the restricted availability of organic cultivars [18]. However, there are a diversity of landraces that are well-adapted to their local environmental conditions and consumers' preferences, originated through evolutionary processes that include introgression from wild relatives, hybridisation between cultivars, mutations and natural and human selections [15]. These cultivars are often bred under low-input agricultural conditions and show different levels of genetic diversity, which allows them to cope with the limited use of external inputs in organic agriculture, namely in weeds competition, resistance or tolerance to pests and diseases, nutrient-use efficiency and efficient mineralisation of soil organic matter. Together with crop yield and quality, these are the aims of organic plant breeding [17][20][21][22].

Many species that are recognised as neglected or underutilised are traditional crops in different regions of the world and important as nutrient supply but unknown in the global market [23]. These species/cultivars could be very important in the context of unpredictable climate change conditions, and some of them were introduced in an organic market that usually values greater diversity, including minor crops [24]. Great efforts can be exemplified by the ongoing projects that boost vegetable organic seed and plant breeding across Europe [25], as well as in the United States [24] and India [26], where studies have shown that organically produced seeds enable better adaptability against climate change, namely better germination under water and salt stress. Further, they support sustainable agriculture through higher nutrient use efficiency and disease resistance. For example, an open-pollinated, early maturing, blocky red bell pepper with broad genetics was released commercially as the 'Renegade Red' pepper, led by the Ecological Farmers Association of Ontario, USA [27].

Organic agriculture has played an important role in the preservation of traditional species and cultivars all over the world and is crucial for sustainable food security, biodiversity conservation and climate change adaptation [28][29]. For example, in Japan, organic farmers use locally available seeds or non-hybrid seeds from seed companies, and many organic farmers save their seeds, aiming to develop their own cultivars adapted to local environmental conditions [30]. A similar approach was reported in other East Asian countries [31]. Across the United States, Canada and Europe, plant breeders, farmers and other stakeholders work jointly to breed new or improved organic crop cultivars in a participatory plant-breeding approach that seems to fill gaps in access to suitable seed, which is not available in the formal seed sector [32][33]. For example, a participatory tomato bred for organic conditions in Italy resulted in an important genetic material for organic agriculture, since these tomatoes assure good productive capacity and seed availability at a low cost [34]. Another example is the breeding of potatoes for organic farming that are resistant to late blight (*Phytophthora infestans*) in a collaborative model of participatory plant breeding in the Netherlands [35]. In participatory breeding, consumers must be involved not only for the input of their taste preferences but also to be acquainted with the importance of agrobiodiversity preservation. In addition, training organic seed producers as well as supporting existing producers is considered essential to increase the organic seed supply.

In Europe, if no organic seed is available, there is a possibility to get derogations for the use of conventionally untreated seed, but the Organic Regulation EU 848/2018 [36] stated that non-organic seed and vegetative planting material are not allowed from 2036 onwards. This regulation also identifies the need to develop cultivars suitable to organic agriculture, namely Organic Heterogeneous Material (OHM) and Organic Varieties suited for organic production (OV). The former, derived from complex crosses between different populations, evolutionary populations (EPs) or farmers' selections, has a high level of phenotypic and genotypic diversity, which allow it to evolve and adapt its phenology to the area of cultivation. As these OHM cultivars are not homogeneous, they cannot pass DUS testing (distinctiveness, uniformity and stability) that is required for the seed market in Europe. However, this obstacle was overcome in 2022, and these seeds can now be marketed after simple notification (delegated regulation (EU) 2021/1189). The OV are derived from organic plant breeding and should comply with the EU Seed Directives. They are suitable to propagate unchanged with stable characteristics of interest over time. To allow for an adequate organic seed market, the European Consortium for Organic Plant Breeding suggested the integration of traits that are important for organic farming in VCU testing (value of cultivation and use). The EU Green Deal integrates the Farm-to-Fork and Biodiversity strategies [37] and aims for sustainable, climate-neutral food systems, a reduction in pesticides and synthetic fertiliser input and an increase in the organic production area from 9.1% in 2020 [38] to 25% in 2030, signalling the need for fast organic plant breeding and seed production improvement.

Traditional and open pollinated seeds are available in some seed companies in many countries, but the marketing of these seeds by local small-scale seed companies should be developed in order to maintain and distribute these seeds. Bhutan is a good example, as organic agriculture became a national mandate in 2007, and the distribution of seeds for family and market-oriented farmers is ensured by the National Seed Centre [39]. The reduced genetic diversity of the domesticated gene pool has led to the consideration that organic plant breeding should include crop wild relatives, as these are a source of additional genetic diversity that might cope with actual pest and disease pressures, climate changes and market demands [40][41].

The aims of organic plant breeding include obtaining new cultivars resilient to abiotic and biotic stresses associated with organic growing conditions; meeting the market requirements of both quality characteristics and agronomic performance; allowing cultivar reproduction as farm-saved seed; adapting to mixed cropping systems; and taking the best advantage of plant–soil microorganism interactions [17][42].

The grafting of several horticultural crops from the Solanaceae and Cucurbitaceae families on rootstocks of the same species or of another species of the same botanical family has been widely used in conventional horticulture to improve yield and fruit quality under biotic and abiotic stress conditions [43][44][45]. The interest of vegetable grafting is also centred on the fact that it is an environmentally friendly and easy-to-manage technique that is suitable for organic production. In organic melon production, the cultivars 'Honey Yellow' and 'Arava' grafted onto *Cucumis metulifer* did not increase yield but presented lower galling and reduced root-knot nematode (*Meloidogyne* spp.; RKN) population in the soil, which may be beneficial in double-cropping systems with RKN-susceptible vegetables [46]. For example, in the Netherlands, grafted pepper and cucumber plants are not commonly used in conventional production due to a lack of yield increase, but they are recommended in the organic system to prevent soil-borne disease problems [47]. Grafting green bean with *Phaseolus coccineus* L. rootstocks also appears to be a suitable strategy to increase crop tolerance to the soil-borne fungus disease caused by *Fusarium oxysporum* f.sp. *phaseoli* and to allow a more efficient nutrient uptake, important features for organic production [48].

Grafting that may increase tomato quality under different stress conditions has been reported [49], but results may vary, as, for example, grafting traditional tomato cultivars can induce lower sensory attributes [50]. Similar results were found in Spain, with organic traditional tomato cultivars grafted onto cv. 'Beaufort', that induced negative effects on sensory attributes, reducing sweetness, acidity and the intensity of flavour, and only one grafted cultivar increased yield [51].

The responses of grafted plants to stress conditions depend on the genotype of the graft and rootstock cultivars, the interactions between the two partners and the environmental and soil conditions of the production system. This means that specific studies with different combinations for different conditions are needed, as well as further studies to determine the seedling growth and yield of grafted organic crops. In addition, the progress of a molecular study that clarifies the functions of many genes, proteins and networks of metabolites involved in the responses of grafted plants under different environmental and soil conditions will be important for a more effective selection of rootstocks.

3. Organic Crop Nutrition

Worldwide, the organic agriculture regulations do not allow for the utilisation of synthetic products such as fertilisers and industrially manufactured agrochemicals. For this reason, organic farmers use different techniques to increase soil fertility, such as organic amendments, rotations, and cover crops. These agronomic practices are used to improve the biological, chemical, and physical properties of the soil, in addition to supplying nutrients to plants [52].

Fertilisation with animal manure, composted crop residues and leguminous plants as main and intermediate crops are most widely used. There is currently no global regulation on the use of organic fertilisers to be developed all over the world. However, the EU provided a legal framework for organic fertilisers, soil conditioners and nutrients authorised for use in EU organic production, which are specified in the Annex 1 Regulation (EU) 2018/848 [36]. In addition, an adequate crop rotation design should be carried out, including cover crops, green manures and the application of permitted mineral and organic fertilisers [53][54]. These activities produce an increase in the organic matter content of the soil, and the activity of beneficial invertebrates and microbes improves soil physical properties, increases plant nutrient availability, decreases disease risks and increases crop health [53][55].

Likewise, biological nitrogen fixation by legumes instead of chemically synthesised nitrogenous fertilisers is essential for fertility management [54][56]. Poultry, pig, sheep and cattle manure including urine are the main fertilisers of animal origin used in organic production. The use and availability of each is based on the amount available in each region, its price, transportation to the farm and handling [57][58].

Composting is the best strategy for managing organic solid waste. It is based on the bio oxidative decomposition of the original organic materials [59]. Composting transforms organic waste into a humified, stable, odourless, and pathogen-free material that can be used to improve degraded soils [60][61][62]. Compost is a high-quality product that is used in organic agriculture due to its profitability, respect for the environment, and easy handling [63][64]. Keep in mind that compost provides the crop with a small amount of nutrients, mainly nitrogen, and other materials such as organic or permitted mineral fertilisers are commonly used.

Vermicompost is a product that is increasingly in demand as organic fertiliser in organic farming. It consists of the stabilisation of organic matter by means of earthworms. It has been shown that the content of macronutrients and micronutrients in vermicompost is generally higher than in traditional compost; it contains high levels of the main nutrients in more soluble forms such as nitrogen, phosphorus, potassium, calcium, magnesium and trace elements. In addition, it provides a highly beneficial enzymatic-bacterial microbial load with suppressive and antibiotic action on pathogenic organisms, growth-regulating substances or humic acids that are responsible for plant growth [65]. These properties improve soil fertility physically, chemically and biologically, resulting in higher crop yields.

Another example of organic waste management is biochar, carbon-rich charcoal produced by thermal treatment (pyrolysis) of agricultural residues and organic biomass. It constitutes a sustainable and effective product as a source of organic and mineral nutrients [66][67]. Biochar is used to improve soil health and low soil fertility, raise crop yields, immobilise heavy metals and decrease plant stress. It can retain ammonia, ammonium and nitrates, and it sequesters carbon, contributing to the reduction of global warming [68][69][70][71].

Biostimulants and biofertilisers have received increasing interest in the last twenty-five years from the scientific community and the agrochemical industry. Their complementary role in the integrated management of crop nutrition, especially organic crops, has been increasing, positioning itself as an agroecological solution to the problems of fertility, abiotic stress tolerance and quality of organic food production [72][73].

Biostimulants are defined as "*fertilizer products whose function is to stimulate plant nutrition processes regardless of their own nutrient content, with the main objective of improving one or more of the following characteristics: (i) efficiency in the use of nutrients, (ii) tolerance to abiotic stress, (iii) quality, (iv) availability of nutrients confined in the rhizosphere*" [73]. On the other hand, the biofertilisers are living substances, containing living organisms that increase the supply of primary nutrients to the main crop [72].

The benefits of using biostimulants and biofertilisers in horticulture crops are reported, with studies focused on the main scientific knowledge produced in the 2015–2021 period about the use of these technologies around the world. This was carried out by using Google Scholar for "biostimulants + organic farming" and "biofertilizers + organic farming".

The plant biostimulants include natural substances such as betain, chitin, humic and fulvic acids, vegetal hydrolyzed proteins, phenolic compounds and seaweed extracts (including algae and cyanobacteria) [74].

The biofertilisers that contribute to the growth of plants are: (i) nitrogen-fixing biofertilisers, (ii) phosphate biofertilisers, (iii) biofertilisers for micro-nutrients, (iv) plant growth-promoting rhizobacteria and (v) compost [75].

Regarding the application of biostimulants, researchers can cite important advances in the study of the use of extracts of macro- and microalgae and cyanobacteria, compounds obtained from crop waste, vegetable hydrolysed proteins and extracts from other plants. Within the biostimulants of marine origin (seaweed), the presence of plant growth regulators (PGRs) with an auxin- and cytokinin-type effect was verified within species of cyanobacteria of the genus *Lithothamium* in studies on some horticultural crops (*Allium cepa, Solanum lycopersicum* and *Vigna radiata*) [76][77][78]. From crop waste, the obtainment of humic and fulvic acids with the contribution of micro and macro nutrients showed a promising effect in abiotic stress scenarios (salinity, low temperatures) in lettuce crops [79]. Further, the use of extracts from other plants as new sources of biostimulants was studied exploratory, achieving promising results from the phenolic compounds isolated from them [80].

The application of biofertilisers and especially their combination with different forms of organic matter has also been studied recently. The literature cites the positive effects of different consortia of microorganisms with a strong presence of the genus *Azotobacter* [72][79][81] not only in the plant growth and development but also in produce quality [82][83].

Both biostimulants and biofertilisers appear to have a central role in sustainable food production in the future and could be a reliable complement in organic crop nutrition, although an adequate regulatory framework should be developed all over the world. Nevertheless, the new Regulation (EU) no 2019/1009 [84] provides a clear definition of biostimulants linked to their function.

4. Soil Disinfection

Worldwide, soil diseases and pests cause difficulties in the management and yield of crops grown in the field or in a greenhouse. The use of synthetic chemical products for soil disinfection is not allowed in organic agriculture, and non-chemical alternatives include biofumigation, solarisation, cultural practices, disinfection of soils with steam, biological control, the application of preventive sanitary measures and innate genetic resistance [85][86].

Biofumigation is based on the action of volatile substances or other chemical or biological processes generated during the decomposition of organic matter for the management of soilborne plant pathogens and weeds [87][88][89]. The effectiveness of this technique is increased when it is combined with solarisation (biosolarisation) by covering the soil with transparent polyethylene, causing an increase in temperature and retaining volatile biocidal compounds [87][88][90].

The inclusion of organic matter in the soil of vegetal and animal origin that present a C/N ratio between 8–20 has a biofumigant effect. In addition, the incorporation of organic residues can significantly modify the biological, physical and chemical properties of the soil [87], and the procedures for using them may vary depending on the plant species or agroindustrial organic residues, pest or disease to be controlled, quantity and exposure time of the organic material incorporated into the soil [91].

The species of the Brassicaceae family, and within it the genera *Brassica*, *Raphanus*, *Sinapis* and *Eruca*, are the most well-investigated, and their biofumigant effect is because different parts of the plant contain sulphur compounds known as glucosinolates (GSLs). When these compounds are hydrolysed by the enzyme myrosinase, they release volatile compounds, mainly isothiocyanates (ITCs), which have fungal, herbicide, insecticide and nematicide properties [87][88][89]. These Brassicaceae species can be used as green manure, rotational cultivation, and the incorporation of fresh or dry residues [88][89]. The efficiency of biofumigation with *Brassica* spp. depending on the stage of development, being the pre-flowering phase the most suitable due to the greater accumulation of GSL and, also, biomass fragmentation. The plant residues should be chopped, and the more irregular and larger the pieces, the more heterogeneous the distribution and release of volatile compounds will be [87]. In the greenhouse, the biofumigant efficiency of *Raphanus sativus* and *Eruca sativa* was verified by incorporating them in pieces in plots that were biosolarised for 4 weeks, and results showed a reduction in the population of *Meloidogyne arenaria* and a yield increase of tomato (*Solanum lycopersicum*) plants [90]. Another essential factor in biofumigation or biosolarisation is soil moisture, since water is essential for the hydrolysis of GSLs after cell rupture. The soil must be irrigated up to field capacity immediately after the incorporation of residues to optimise this reaction. Furthermore, as ITCs are volatile, losses can be reduced if the soil is covered with a transparent plastic film after incorporation. The surface is sealed by rolling and/or irrigation in large areas of cultivation [87][89].

Biosolarisation causes a change in the microbial composition of the soil and increases the proportion of antagonists, augmenting the biological control of soilborne diseases and pests. Some bacteria and fungi were very tolerant to ITCs. Among them are different species of *Trichoderma* spp., which are important pathogens' antagonists. The results of an in vitro test confirmed the compatibility of biosolarisation with *Brassica juncea* and *Sinapis alba* on the growth of *Trichoderma* spp. and *Azospirillum brasilense* [92]. The effect of *Brassica juncea* as a biofumigant on bacterial communities showed promising results, because it causes less damage to the quantity and richness of the bacterial community in the soil [93] and has less impact on the process of nitrification and the abundance of microorganisms involved in the soil nitrogen cycle [94]. In the cultivation of strawberries (*Fragaria x ananassa*) in the field or the greenhouse, this species caused an increase in the abundance of arbuscular mycorrhizal fungi and some endophytic taxa, which are beneficial for the roots, favouring plant growth and increasing the yield of commercial fruits [95][96].

Other materials of plant origin (non-brassicas) have insecticidal, nematicidal, and fungicidal properties in their different plant organs, which by soil incorporation exert their biofumigant action. This is the case of *Melia azedarach* (chinaberry) (*Meliaceae*), which possesses limonoid terpenes [86][88]. The degradation of its fruits stimulates the growth of young plants and reduces the severity of pink root disease (*Setophoma terrestris*) in onion crops (*Allium cepa*) [86].

In contrast, *Tagetes* spp. (*Asteraceae*) were more efficient in crop rotations because they present in their tissues the α-terthienyl secondary metabolite, which is found in higher concentrations in the roots [87]. The intercropping of *T. erecta* (African marigold) with tomato proved to be a good management alternative for *Meloidogyne* spp., reducing galls in the susceptible crop and increasing the number and weight of fruits compared to the control without intercropping [85].

Using manure of animal origin as fertiliser is widespread, and soil disinfection generates rapid degradation and high fermentation heat. Poultry manure, especially fresh waste, has a high nitrogen content, producing ammonium in a greater proportion, a compound associated with the biocidal action of biofumigation [88][89]. In addition, biosolarisation with chicken manure was beneficial for the control of bacterial wilt (*Ralstonia solanacearum*) and increased tomato productivity in the greenhouse and the field [97].

Other organic materials for soil disinfection would be provided by the industrial subproducts. Those from the oil extraction chain result in mustard meals without oil, which were previously incorporated into the tomato plantation, resulting in an easy application and avoiding the work involved in green manure, especially in areas where the frost-free growing season is relatively short [98]. Another would be the chitin or chitosan from the biocomposites industry, which were added to the soil for 6 years causing an increase of 60% in yields in potatoes (*Solanum tuberosum*), carrots (*Daucus carota*), and *Lilium* spp. [99]. The researchers argued that the yield increases were not influenced by changes in the chemical properties of the soil, but were a consequence of the variation in the soil microbiota, especially organisms controlling the population of *Pratylenchus penetrans* and *Verticillium dahlia* [99]. Finally, the biosolids or sewage sludge from the processing plants for wastewater depuration present great potential in the suppression of pests and diseases by improving soil quality. Its practical applications as amendments are still strongly limited in field conditions [100].

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