



VEGETABLE BREEDING FOR ORGANIC FARMING: OPPORTUNITIES AND PERSPECTIVES

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Vegetable breeding for organic farming is the science and practice of developing new varieties suitable for organic production systems. The main aim is to enhance the potential of organic farming through development of new varieties. It is a holistic approach that respects natural crossing barriers and based on fertile plants that can establish a viable relationship with the living soil. A variety suitable for organic farming is obtained by breeding methods that are in compliance with the organic farming concept and is the result of a certified organic plant breeding programme. Breeding organic vegetable varieties is essential for the development of the organic vegetable sector and for the quality of organic vegetables. But at the same time it is an ambitious striving because it is not yet realised on a large scale, and still very much in development. Breeding vegetables for organic farming requires a systematic approach that considers the complexity of natural ecosystems and operates across multiple levels of plant biology.

Key words: biodiversity, local genotypes, methods and strategies, specific traits, sustainability, vegetable breeding

INTRODUCTION

Organic farming is based on the principle of working with natural systems to develop sustainable farming methods. As defined by International Federation of Organic Agriculture Movements (IFOAM, 2005) organic farming mainly works on the four principles of health, ecology, fairness, and care. It is reported to have lower productivity than conventional agriculture (SIVA MUTHUPRAKASH and DAMINI, 2019), and various researchers have proposed several strategies to overcome this gap (FOLEY *et al.* 2011); GARNETT *et al.* (2013); BENNETT *et al.* (2014). The very well-known characteristic is that it produces food without the use of any

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synthetic inputs (fertilizers, herbicides, fungicides and pesticides) and neither with the use of genetically modified organisms. Worldwide it has gain popularity via providing healthy food, environment and quality of life for the consumers and producers. In 2020 FiBL (Research Institute of Organic Agriculture was founded by organic farmers and scientists in Switzerland in 1973) surveyed and found that there were 74.9 million hectares of organic agricultural land (including in-conversion areas) worldwide (WILLER *et al.* 2022). Among largest organic agricultural land areas Oceania and Europe comprises of 70 per cent of total organic farmland and Asia accounts for an 8.2 per cent share. India has an area of 2.7 million hectares which account for 1.4 per cent alone of organic agricultural land. Worldwide there are about 3.4 million organic producers among them 1.6 million belong to India (GILL and JOHAL, 2023). In organic farming there are only few vegetable varieties which were specifically bred for low input conditions. Recent studies have shown that varieties developed for conventional agriculture lack important attributes that required under organic production system (LAMMERTS VAN BUEREN *et al.* 2002; MURPHY *et al.* 2007; WOLFE *et al.* 2008). It has observed that more than 95 per cent varieties used in organic farming is based on crop that were bred for the conventional agriculture with selection in high input conventional breeding programmes, therefore, it is unreasonable that all varieties bred for conventional agriculture will always perform well in organic farming system (CONNOR 2008; LAMMERTS VAN BUEREN *et al.* 2011; DE SEUFERT *et al.* 2012; PONISIO *et al.* 2015). Breeding for organic farming aimed on adaptation to local growing conditions, whereas conventional breeding focused on production of varieties suitable for wide growing areas. It is defined by the IFOAM and bears a high potential to provide farms with varieties perfectly adapted to organic farming. A range of breeding goals such as yield, resistance to biotic and abiotic stress, and sensory qualities demanded by consumers in organic farming do not differ from conventional breeding goals. Characteristics of crop plants which are required for organic farming includes enhanced competitiveness against weeds and resistance to insect-pest and diseases (LAMMERTS VAN BUEREN *et al.* 2011; MURPHY *et al.* 2007). Breeders typically require eight to ten years from the initial crosses to the release of a new crop variety. To meet the future need for improved vegetable varieties in organic farming it is essential to initiate crosses between suitable parental genotypes at present (ØSTERGÅRD *et al.* 2009). Organic plant breeding concepts emphasize using and maintaining a broader genetic base than conventional high-input breeding, although most present organic production still depends on conventionally bred, often genetically narrow varieties (LAMMERTS VAN BUEREN *et al.* 2011). The emphasis of organic breeders mainly lies on plants with good morphological characters with adequate yields and excellent quality attributes. Many modern day crop cultivars have very low genetic diversity for the selection of desired attributes (TESTER and LANGRIDGE, 2010; VAN *et al.* 2011).

Breeding for organic or low input conditions should be done in a separate environment with local adaptation, in which the desired traits and selection methods can be incorporated. This article will provide an overview on vegetable breeding for organic farming with a perspective from conventional vegetable breeding, highlights the main characteristics, their source of variation, and what methods and tools are available. It concludes listing some breeding achievements and providing an outlook on what needs to be done for vegetable breeding under organic farming conditions (WIER *et al.* 2008; LUSK and 52009).

VEGETABLE BREEDING FOR ORGANIC FARMING NEED OF THE HOUR

Nowadays consumers have become more interested in organic farming of vegetables, because they are generally consumed fresh. Due to the increasing demand in the market vegetable breeding for organic farming require special attention for the selection of cultivars and varieties suitable for organic farming (LAMMERTS VAN BUEREN *et al.* 2002). In wheat, the ancient varieties are gaining importance due to their capacity to withstand climate variability, lower dependency on agricultural inputs, and superior nutritional value (MIGLIORINI *et al.*, 2016, BOUKID *et al.*, 2020, FATHOLAH *et al.*, 2020). As discussed in the introduction part that there are very less varieties which are suitable for organic farming generally the production relies on those varieties which are selected under conventional farming systems (ZDRAVKOVIĆ *et al.* 2010; LAMMERTS VAN BUEREN *et al.* 2011; VERDI *et al.* 2022). While, conventional breeding has caused losses in genetic variability with a reduction in crop adaptability to different ecosystems and pedoclimatic variations (DÖRING *et al.*, 2015). Each and every seed of vegetables has a long history because generations of vegetable growers and plant breeders have put efforts for the development of genome of vegetables. Local genotypes offer a wide range of diversity, various insect pest and disease resistant characteristics but are generally not suited for enhancing yields. Breeding vegetables for organic farming require conservation and exploitation of traditional and local genotypes in a breeding programme to keep a broad range of genetic resources for varietal improvement under low input conditions (BERENJI, 2008; HASAN and ABDULLAH, 2016). In organic vegetable breeding, all steps of varietal improvement or development from selection of genotypes, crossing of selected genotypes and development of the variety happen under organic farming/ low input conditions. Therefore, these varieties can perform better under low input farming conditions. They are usually more sturdy and resistant to pest and diseases. In organic vegetable breeding main focus is insect-pest and disease resistance breeding while in conventional breeding these aspects are often ignored due to fungicides and pesticides use. Another main aim is the development of varieties that quickly cover the ground and suppress the weed growth. Moreover vegetable varieties developed under organic standards can be saved and used again and again in the fields (BRDAR-JOKANOVIĆ *et al.* 2011). Consumers generally like the taste of vegetables produced organically. In markets there is a huge demand of organic plant-based protein for that purpose field peas show great prospects to meet the consumers demand. However, very little varietal development and improvement has been done in vegetable crops under organic farming conditions to sustain the productivity and improving the nutritional quality for consumers. However, better performing varieties are required under low-input conditions for local and regional marketing (OSMAN *et al.* 2008). Applying breeding methods specifically adapted to organic farming is essential to fully exploit organic systems, address their unique constraints, and meet rising demand for high-quality, residue-free produce. Integrating organic-focused breeding with participatory and evolutionary approaches is increasingly viewed as “need of the hour” for sustainable agriculture and resilient value chains (SHARMA and THAKUR, 2018; DEVI and KHUNDRAPAM, 2025). The organic breeding strategies including mass and recurrent selection and intra-specific crossing, participatory plant breeding, evolutionary breeding etc. needs to be focused in future.

BACKGROUND OF ORGANIC PLANT BREEDING

Breeding plants organically and varieties suitable for organic farming concept were developed by several growers and breeders in 1950 that were searching for the cultivars that can meet the specific needs of organic farmers. The need for organic varieties came to light in Britain for the *Brassica* species due to poor performance of modern cultivar under low input conditions. First plant breeders were farmers who developed various crop varieties unknowingly for food and fibre need through different breeding approaches *viz.*, selection, introduction and domestication. After that scientists found the genetic basis for selection which farmers had already been used for selection of plants with desirable attributes. Breeding for organic agriculture was stimulated when it came under the European Organic Agriculture Regulation (2092/91) in 2004. The private sector of plant breeding finds it economically difficult to satisfy the demand from organic agriculture characterized by a great diversity of quality and adaptability criteria, and by breeding methods which must respect the natural characteristic of species (LAMMERTS VAN BUEREN *et al.* 2005), and the integrity of the organisms. In 2014, an organic plant breeding standard was laid down in chapter 4.8 of the IFOAM organic standard. The new European Organic Regulation (2021) includes provisions on organic breeding, and if a variety is organically bred, it will then be declared within the organic seed databases. In the current era, plant breeding has been professionalized and general public suppose that it is something done in a lab with equipments by specialized degree holders. Mostly vegetable growers depend on seed companies for their seed requirements. Researchers working in seed companies have motive to develop varieties that have wider adaptability and high yield potential under conventional agriculture conditions. Nowadays pressure is to develop varieties that are high yielding. In private sector main emphasis is given for the development of hybrid cultivars and yet they are not ready to invest in organic breeding programs due to small land holdings in organic and less awareness among vegetable growers about organic standards for the cultivation of vegetables (LAMMERTS VAN BUEREN *et al.* 2011).

BREEDING METHODS AND SELECTION STRATEGIES UNDER ORGANIC FARMING

Vegetable varieties suitable for organic farming can be successfully developed if breeding programs are performed under organic or low-input conditions. It has been observed in the shuttle breeding programme in which segregating generations were exchanged between different environmental conditions to get wider adaptation or broad disease resistance during Green Revolution time (BRAUN *et al.* 1996; MUELLNER *et al.* 2014; MIKÓ *et al.* 2014; BAENZIGER *et al.* 2011). Some researcher appraised that it is necessary to carry out the breeding programme under organic farming conditions as it is the only way for the plants to fully express their genetic potential (MURPHY *et al.* 2007; REID *et al.* 2009). Therefore, participatory and evolutionary breeding, have been considered as suitable breeding methods for organic farming (CHIFFOLEAU and DESCLAUX 2006; DAWSON *et al.* 2008; DAWSON *et al.* 2011; DÖRING *et al.* 2011). Participatory plant breeding leads to faster development of varieties because it is done with farmer researcher collaboration. Varieties developed as per the need of farmers under local climatic conditions (CECCARELLI, 2014; DESCLAUX, 2005). Vegetable breeding for organic farming requires the breeding methods that are in accordance with the organic farming principles. It is restricted to specific breeding techniques such as crossing methods that do not

break the reproductive barriers between species, and selection methods based on the evaluation and selection of whole plant performance (ZDRAVKOVIC *et al.* 2010; TALSI 2005; VAN BUEREN *et al.* 2003). For the source of genetic variation both breeding system (conventional and organic) depend upon the wild relatives and landraces. The processes through which these genetic variations are incorporated in the development of new cultivar should be regulated and subjected to organic farming principles (VAN BUEREN *et al.*, 2011). In 2000 the IFOAM has set some basic standards for organic plant breeding and these can be classified as permitted methods such as intra specific crossing, combination breeding, bridge and backcrossing, variety crosses, mass and individual selection, temperature treatment, selection *via* DNA markers; grafting and cutting style hybrid cultivars as long as next generation is fertile and the hybrid production does not chemically induce sterility and meristem & tissue culture, generative and vegetative propagation (BERENJI, 2008). The technologies that modify the plants at cell level or the DNA level are not permitted in organic plant breeding *ie.*, genetically modified organisms and protoplast fusion etc. The application of plant growth regulators *viz.*, silver nitrate, silver thiosulfate, synthetic hormones, antibiotics, cytoplasmic male sterility inducing products and colchicines is also banned (ZDRAVKOVIC *et al.* 2010; TALSI 2005; VAN BUEREN *et al.* 2003; VERHOOG 2007). Some details on the breeding techniques which are permitted for organic breeding are hybridization, if the F₁-offsprings are fertile and the parents genotypes can be propagated under organic farming conditions.

BREEDING ADAPTED VEGETABLE VARIETIES FOR SUSTAINABLE ORGANIC PRODUCTION SYSTEMS

Breeding new vegetable varieties for organic agriculture must address unique challenges and consumer demands by developing regionally adapted varieties suited to low-input production systems. Organic growers face significant obstacles including a lack of organic seed sources and scarcity of information on varietal performance under low-input conditions. Researchers believe that varieties developed under such conditions have greater potential for successful adaptation to organic systems compared to conventionally bred varieties. Developing such varieties requires combining diverse attributes including nutrient use efficiency, disease resistance, nutritional quality, and yield potential, along with higher stress tolerance to abiotic stresses such as heat, cold, drought, and flood (WOLFE *et al.* 2008). A broad analysis of USDA data from over 10,000 organic farmers showed that nearly 2 million acres of organic farmland is dominated by wheat, maize, common bean, potato, and vegetables, with yields at 80 percent of conventional production levels, varying according to crop selection, variety choice, and local conditions (KIRCHMANN *et al.* 2008; KNISS *et al.*, 2016; SEUFERT *et al.*, 2012; PALMGREN *et al.* 2014). To succeed in organic farming, varieties must demonstrate competitive ability against weeds and require a high level of disease resistance to seed-borne, soil-borne, airborne, and viral pathogens; this is particularly critical during the conversion period when seed treatments are unavailable (VAN BRUGGEN and TERMORSHUIZEN, 2003; BAILEY and LAZAROVITS, 2003). For example, in tomato, the Tm-1 gene, present in *Solanum habrochaites*, confers resistance to the prevalent strain of ToMV and has been successfully introgressed into tomato germplasm through conventional crossing without requiring specialized molecular techniques (PELHAM, 1966). Consequently, Tm-1 should be prioritized as the resistance source for organic variety

development. Moreover, genetic variation in head rot resistance exists in broccoli and is associated with smooth, domed heads and small, tight heads (DARLING *et al.* 2000), can also be considered. The unavailability of organically-developed seeds has forced farmers to use conventional varieties, which perform poorly under organic conditions (MURPHY *et al.* 2007). Several researchers have delineated the ideotypes of different vegetables for organic farming (LAMMERTS VAN BUEREN *et al.* 2011; ZDRAVKOVIC *et al.* 2010; WOLFE *et al.* 2008; KONVALINA *et al.* 2007). Thus, organic farmers need crop varieties well-adapted to the low-input conditions of organic systems (ZYSTRO, 2012). Since quality of organic produce commands a price premium and influences market value, post-harvest handling standards for storage, processing, and nutritional quality become critically important as no chemical additives are permitted. Therefore, long-term breeding research must systematically identify and develop varieties with ideotypes specifically suited to the regional soil, climate, and production systems of organic farming, rather than continuing to rely on conventionally-bred varieties that lack the necessary attributes for low-input environments.

BIOTECHNOLOGICAL APPROACHES IN ORGANIC FARMING

Organic farming, as defined by IFOAM principles, excludes biotechnological approaches with unpredictable safety consequences, such as genetic modification, while accepting suitable technologies that present manageable risks (IFOAM 2005). However, advanced biotechnological tools including marker-assisted selection (when performed without GMO-derived enzymes or radiation) and meristem culture can be integrated into organic breeding programmes, as they facilitate the incorporation of desirable traits from wild relatives and landraces into cultivated crops. The role of marker assisted selection for improvement of various traits in vegetable crops is reviewed by many researchers, which can be used to develop elite genotypes for organic farming (SIMKO *et al.* 2021; SHEKHAR *et al.* 2024; MAJI *et al.* 2023; TEJASWINI *et al.* 2024). Modern cultivars can be redeveloped using these technologies provided they align with organic farming's four foundational principles (VAN BEUREN *et al.* 2007; ANDERSEN *et al.* 2015). Breeding for organic and low-input agriculture demands robust and flexible varieties that balance molecular understanding with broader agronomic considerations. Key breeding objectives include enhanced knowledge of germplasm gene pools, efficient introgression of resistance genes from wild relatives, and strategic deployment of pyramided genes—concerns that reflect the need for comprehensive approaches beyond molecular-level focus alone (LAMMERTS VAN BUEREN *et al.* 2002; WYSS *et al.* 2001; WOLFE, 2002).

CERTIFICATION OF BREEDING PROGRAMMES

Certification of breeding programmes required for the confirmation that only allowed breeding techniques have been used in organic breeding programme. Breeding techniques for organic seed production is an important criterion to develop varieties which perform well under organic farming conditions. It is essentially aimed at regulating and facilitating the sale of organically produced varieties seed to the end consumers. It addresses a growing worldwide demand for organic food. Many organic vegetable growers produce seed organically but lack of legal certification make them unable to catch the price premium as certified organic seed producers can fetch. Organic certification follows a set of standards for production technology

from sowing to marketing and it differs from country to country. It is intended to provide quality produce and prevent fraud. It helps both producers and consumers as it identifies suppliers of products approved for use in certified operations and it gives product assurance (similar to "low fat", "100% whole wheat", or "no artificial preservatives") respectively (MULLER, 2002; LAMMERTS VAN BUEREN, 2002).

ADVANCES IN THE DEVELOPMENT OF VEGETABLE VARIETIES FOR ORGANIC FARMING

Breeding plants for commercial purpose has been monopolised since 1920. Private sector has focussed on breeding high yielding varieties under high input conditions. As a result these varieties are very sensitive under low input/nutrient deficient conditions as well as susceptible to various insect-pest and diseases. Further development of hybrids via seed companies made farmers totally dependent on them due to segregation in F₂ generation. Breeding varieties suitable for organic farming work started since 1950 despite continuous lack of finance and legislation. In Europe and North America there are some public institutions which have established organic plant breeding programs. Winter wheat breeding programs for organic agriculture have been started in Austria, Canada, France, Germany, Switzerland, and USA (LAMMERTS VAN BUEREN *et al.* 2011; LÖSCHENBERGER *et al.* 2008). For organic farming participatory plant breeding projects have been initiated in tomato (CAMPANELLI *et al.* 2015; HORNEBURG and BECKER, 2011) and cauliflower (CHABLE *et al.* 2008). For other vegetable crops *viz.*, cabbage, broccoli, onion and spinach organic plant breeding has initiated in The Netherlands and France respectively (VAN BEUREN *et al.* 2005; LAMMERTS VAN BUEREN *et al.* 2011; SERPOLAY *et al.* 2011). In Germany and Austria a handful of varieties have been released from BFOA (breeding for organic agriculture) programmes (LÖSCHENBERGER *et al.* 2008). Based on the demand of organic seed by farmers for increasing area under organic farming researchers concluded that old varieties adapted to local conditions are the best choice for this purpose. Because expression of particular trait depend upon the particular environmental conditions therefore the varieties which are widely adapted are more likely to be successful under organic farming conditions (OBERFORSTER *et al.* 2000; PRZYSTALSKI *et al.* 2008). It also holds true for varieties which are developed under high input conditions perform low under low-input conditions (HILL *et al.* 1998). Nevertheless, as more number of farmers adopts organic practices to take advantage of the associated price premiums, the average motivation of organic producers may change (RIGBY and CACERES, 2001). This could imply a higher potential for acceptance of rewilded crops among some organic producers in the long run.

FUTURE PROSPECTS

In order to maintain the quality of vegetables for the organic industry, breeding elite varieties suitable for cultivation in organic farming is very essential. To meet out this, there is a need to develop such breeding strategies which prioritises the complexity and biodiversity of agro ecosystems and works as the highest level of plant organization. In addition, it is necessary to develop a number of novel techniques that are effective in accordance with the aforementioned directive. Organic breeding differentiates itself from conventional in the sense that it emphasizes more on ecological, ethical, and edible aspects. Farmers producing vegetables

organically have a requirement for varieties that have adaptation to organic soils, perform better in low organic inputs, with better and deep root system, wider plant frame which can suppress weeds, tolerance to biotic and abiotic factors, morphological traits which can repel insect-pests, high yield, stability in yield etc. In organic breeding the cultivar should be used in a sustainable way *i.e.*, there should not be any interference with the reproductive capability of the plant. The strategies, materials, and methods used in organic breeding should strictly follow the principles of organic agriculture; the inherent value and truthfulness of plants and other living organisms must be admired stringently. That is why organisms with modified genetic backgrounds (GMOs) are not allowed to be used in organic agriculture. The breeding system used for developing cultivars must be sustainable and varieties developed by this way should not be sterile or patented, so that the unrestricted exchange of genetic inputs can protect the future of plants, which are the cultural heritage of humanity. In potato and onion, to develop quality post-harvest products, there is a great demand for varieties with long-term storage potential without the use of chemical suppressants. Other quality traits, such as taste, structure, vitality, colour, firmness, and nutritional value, need to be focused on in the organic breeding of vegetables. Following the socio-economic principles of organic plant breeding, farmers and breeders should work together to ensure the exchange of knowledge, technical know-how, experience, and genetic inputs. The status of the farmers should be maintained, and regulations regarding the marketing of organic varieties must be formulated. There should be an unrestricted exchange of genetic seed stock between organic breeders. Any kind of legal requirements and regulations should take into account the interests of organic farmers. For an organic breeding system, a novel financial structure should be developed. Genetic variability is an important concept that needs to be emphasized here. To maintain genetic variability, the introduction of novel germplasm in organic breeding systems should be a continuous process (CARR *et al.* 2006). After rigorous testing under organic conditions, organic producers can select varieties that are either specifically or broadly adapted to specific situations.

CONCLUSION

Creating vegetable varieties for organic farming is essential because most current organic production relies on conventionally bred strains that do not perform well in low-input environments. Organic breeding prioritizes adaptation, disease and pest resistance, competitiveness against weeds, and tolerance to abiotic stresses, all without synthetic inputs. These varieties perform better than conventional ones when developed and selected specifically for organic conditions. Guidelines from IFOAM and European Organic Regulations support techniques that align with natural species traits, permitting methods like marker-assisted selection and meristem culture. Furthermore, participatory and evolutionary breeding approaches effectively adapt varieties to agroecological conditions and market needs through farmer-researcher collaborations. Looking ahead, vegetable breeding should focus on nutrient efficiency, strong disease and insect resistance, weed control, consistent yields, and improving nutritional and post-harvest quality that affect market value and pricing. Achieving these goals requires not just technical advancements but also adequate public funding, reliable certification, long-lasting relationships between farmers and breeders, and continued financial support, particularly in regions like Asia and India where organic farming is growing quickly but

breeding assistance is lacking. Genetic variation is both the foundation and outcome of developing organic varieties, making it essential to continuously include and evaluate wild relatives and landraces in organic settings. Moreover, breeders and farmers need to freely share diverse seeds to maintain genetic diversity and strengthen system resilience. A shift towards organically bred vegetable varieties, incorporating participatory methods, compatible biotechnological tools, strict selection under organic management, and supportive policies can create high-performing, market-ready cultivars that enhance food security, nutrition, and environmental sustainability in organic vegetable farming.

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OPLEMENJIVANJE POVRĆA ZA ORGANSKU POLJOPRIVREDU: MOGUĆNOSTI I PERSPEKTIVE

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Izvod

Oplemenjivanje povrća za organsku poljoprivredu je nauka i praksa razvoja novih sorti pogodnih za organske proizvodne sisteme. Glavni cilj je poboljšanje potencijala organske poljoprivrede kroz razvoj novih sorti. To je holistički pristup koji poštuje prirodne barijere ukrštanja i zasnovan je na fertilnim biljkama koje mogu uspostaviti održiv odnos sa zemljištem. Sorta pogodna za organsku poljoprivredu dobija se metodama oplemenjivanja koje su u skladu sa konceptom organske poljoprivrede i rezultat je sertifikovanog programa oplemenjivanja organskih biljaka. Oplemenjivanje sorti organskog povrća je neophodno za razvoj sektora organskog povrća i za kvalitet organskog povrća. Ali istovremeno je to ambiciozan poduhvat jer se još uvek ne realizuje u velikim razmerama i još uvek je u velikoj meri u razvoju. Oplemenjivanje povrća za organsku poljoprivredu zahteva sistematski pristup koji uzima u obzir složenost prirodnih ekosistema i deluje na više nivoa biljne biologije.

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