

Review Article

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Breeding Approaches for Sustainable Vegetable Production – A Review

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ABSTRACT

Vegetables are considered as an essential component of well-balanced diets. On global scale, the production and marketing of vegetables crops are undergoing continuous changes. This is mainly due to growing demands of consumers for safe and healthy vegetables, increased urbanization of societies and growth in scale and influence of super market chains. Moreover, in recent days, peoples are suffering due to variety of metabolic disorders. Awareness about health and healthy foods are rapidly increasing and people are ready to spend more money towards the food which are free from synthetic fertilizers, pesticide residues and any other contaminants *i.e.* *Organic Food*. Organic farming aim at low input system and at refraining from agro-chemical inputs. More than 95% of organic agriculture largely depended on crop varieties that were bred for conventional high-input sector (fertilizers & agro-chemicals). Hence, the traits associated with conventional varieties, which are unsuitable for organic production system needs to be improved. Organic plant breeding is a holistic approach, which respects natural crossing barriers and is based on fertile plants that can establish a viable relationship with the living soil. Breeding organic varieties is essential for the development of quality of organic products, which enhance the potential of organic farming and biodiversity in sustainable way. This review summarizes the breeding approaches essential for improving the traits required for successful vegetable cultivation under organic farming system or in low-input conditions

Keywords

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Introduction

Modern agriculture largely depends on the use of inputs such as chemical fertilizers, pesticides, herbicides and labour saving but energy intensive farm machinery. Application of these high input technologies undoubtedly increased the production. However, those high input agriculture degrades some of the natural resources on which this system rest. Beyond the adverse effect on soil productivity and environment quality, it does not guarantee sufficient food production in the next decades in a sustainable way. Hence, there is an urgent

need to develop farming techniques which are sustainable from environment, production and socio economic point of view. In the recent days, agricultural community is setting its hopes on sustainable agriculture, which will maintain the cycles of inputs and ecosystem balance.

There are different concepts of sustainable agriculture that often referred as organic, alternative, ecological or low input agriculture. Off which, organic farming is the

most widely recognized alternative farming system which gained social, political and scientific recognition for its contribution to sustainable agriculture. Organic agriculture is a production system, which avoids or largely excludes the use of synthetic fertilizers, pesticides, growth regulators and livestock feed additives. To the maximum extent feasible, it largely rely upon crop rotations, crop residues, animal manures, legumes, green manures, off farm organic wastes, mechanical cultivation, mineral bearing rocks and biological pest and disease control measures to maintain soil productivity and tilth to supply plant nutritions and to control insects, weeds and other pests (USDA Report, 1980).

Current status

The latest survey on certified organic agriculture worldwide shows 50.9 million hectare (FiBL statistics, 2015-16). On global scale, Organic agriculture is practiced in 172 countries by 2.4 million producers or farmers approximately and the countries with highest numbers of producers are India, Ethiopia and Mexico (FiBL statistics 2015-16 and Anonymous, 2017). In India, the total area under organic certification is 5.71million hectare (2015-16). This includes 26% cultivable area with 1.49 million hectare and rest 74% (4.22 million hectare) forest and wild area for collection of minor forest produces.

India produced around 1.35 million MT (2015-16) of certified organic products which includes all varieties of food products *viz.*, Fruits, dry fruits, vegetables, spices, tea, coffee sugarcane, oil seeds, cereals, millets, cotton, pulses, medicinal plants *etc.*, The production is not limited to the edible sector but also produces organic cotton fiber, functional food products *etc.*, Among all the states, Madhya Pradesh has covered largest

area under organic certification followed by Himachal Pradesh and Rajasthan. The total volume of export during 2015-16 was 263687 MT. The organic food export realization was around 298 million USD. Organic products are exported to European Union, USA, Canada, Switzerland, Korea, Australia, New Zealand, South East Asian countries, Middle East, South Africa *etc.*, Oil seeds (50%) lead among the products exported followed by processed food products (25%), Cereals and Millets (17%), Tea (2%), Pulses (2%), Spices (1%), Dry fruits (1%) and others (APEDA report, 2016).

Reasons for development of varieties/hybrids suitable for organic farming

The characteristics of organic agricultural systems are their biodiversity at soil, crop, field, crop rotation or polyculture, landscape level and the greater focus on integration of crop and livestock production systems on the farm compared with conventional farming systems (Mader *et al.*, 2002). Organic farmers have long depended on conventional variety and seed production, which requires high levels of artificial fertilizers and agro-chemicals to obtain targeted yield. However, organic farming aims at a low input system and at refraining from agro-chemical inputs (Lammerts van Bueren, 2003).

To date, there are only few varieties that were specifically bred for organic and low-input systems in developed countries. It is estimated that more than 95% of organic agriculture is based on crop varieties that were bred for the conventional high-input sector with selection in conventional breeding programmes (Lammerts van Bueren *et al.*, 2011). Recent studies have shown that such varieties lack important traits required under organic and low-input production conditions (Lammerts van Bueren *et al.*, 2002; Murphy *et al.*, 2007; Wolfe *et al.*, 2008).

A range of breeding goals desired for organic sector, such as yield, resistance to biotic and abiotic stress and sensory qualities demanded by consumers which do not differ from conventional breeding goals, but it is essential that such traits are expressed under low-input conditions (Lammerts van Bueren *et al.*, 2011). Hence, development of genetic diversity focused crop breeding approaches may be essential to improve yield and quality parameters in foods from organic and low-input farming systems, especially in the context of the challenges expected due to global climate change (Ostergard *et al.*, 2009). Moreover, the worldwide standards of organic agriculture (OA) do not allow genetic engineering (GE) or any products derived from genetic engineering. The standards in OA are an expression of underlying principles of health, ecology, fairness and care (Nuijten *et al.*, 2017).

Brandt *et al.*, (2011) and Crowder and Reganold (2015) stated that organic farming systems produce lower yields compared to conventional agriculture. However, they are more profitable and environment friendly and deliver more nutritious fruits and vegetables that contain low to no chemical-synthetic pesticide residues compared with conventional farming (Reganold and Wachter, 2016). Ponti *et al.*, (2012); Seufert *et al.*, (2012) and Kniss *et al.*, (2016) accounted an average yield gap of approximately 20% between conventional and organic agriculture. However, Ponisio *et al.*, (2015) and Kniss *et al.*, (2016) reported that the 20% yield gap does not count for all crops and all regions, as in some cases difference has not been noticed in some crops. Therefore, the future challenge is to further optimize the productivity of organic farming systems to overcome the average yield gap between conventional and organic agriculture. Another factor of limited yield under organic agriculture is the lack of cultivars adapted to low-input growing

conditions without use of herbicides, pesticides and fungicides. Van Bruggen and Finckh (2016) stated that organic farmers loose potential yield due to lack of sufficient weed suppression, pest and disease resistance traits (e.g. onion against downey mildew and in potato against late blight).

It often takes 10 years or more from the initial inter-varietal crosses to develop a new crop variety. To realize the varietal improvements needed in organic farming in the coming decades, crosses between appropriate parental varieties have to be made now. Therefore it is essential to identify the primary limiting factors of existing varieties for organic production and target them in the breeding programmes for organic farming. In this circumstance, the main traits required for successful vegetable cultivation under organic farming or low-input conditions are described hereunder.

Nutrient-use efficiency

The greatest difference between organic and conventional systems relates to soil management practices used and processes in the rhizosphere (Baresel *et al.*, 2008). Organic systems often rely on organic matter based fertilizer inputs and mineralization driven N and P supplies to crops. Macronutrient availability patterns during the growing period therefore differ significantly from those in conventional systems. Warman (1998) stated that organic crops often experience limited macronutrient (N and P) availability especially during periods when soil temperatures and water availability reduce mineralization capacity by soil biota. However, regular organic matter inputs have shown to increase soil biological activity, biodiversity and mineralization capacity of the soil (Fliessbach *et al.*, 2007). Przystalski *et al.*, (2008) and Van Bruggen and Finckh (2016) reported that organic farmers often

apply 50-80% of nitrogen through organic matter based fertilization compared to the amount of nitrogen in conventional farming systems. While the nitrogen of organic matter will slowly released and it also prevents nitrate leakage to surface and ground water. In addition, organic matter based fertilization have shown to suppress diseases (Ghorani *et al.*, 2008) and induce biochemical pathways in crops involved in pathogen defense and stress tolerance (Kumar *et al.*, 2004). Concomitant to this finding, Van Bruggen and Finckh (2016) enumerated that limited nitrogen supply reduces too luxurious vegetative growth that could limit the pests (e.g., aphids) and foliar diseases (e.g., mildew) as in cereal production. From comparative studies between conventional and organic/reduced-input systems, Van Bruggen (1995) concluded that in organic or reduced input system, root diseases and pests are generally less of problem than foliar diseases, because foliar disease development is much more determined by climatic factors. Many root diseases can be eliminated by broad rotation in organic systems. Therefore, an essential element in organic farming systems is to gain and maintain soil fertility with an active soil life contributing to the nutrient availability, good soil structure and crop specific manuring for buffering and resistance to unbalanced plant growth.

In this context it is likely that organic systems require crop genotypes that are able to form active symbiotic relationships with beneficial organisms in the rhizosphere and thereby establish mechanisms that increase nutrient-use efficiency (e.g. vigorous root systems, ability to form active mycorrhizal associations, reduced root losses due to pathogens, ability to maintain a high mineralization activity in the rhizosphere via root exudates, increased rooting depth and associated ability to recover N leached from the top soil).

According to Dawson *et al.*, (2008), nutrient-uptake efficiency of plants can be improved by maintenance of photosynthesis under nutrient stress condition, nutrient uptake capacity, nutrient-utilization capacity and translocation efficiency will contribute to higher yield and quality under low input conditions. Therefore, adaptation of varieties to efficient nutrient use derived from slow nutrient releasing organic fertilizer is of special importance in organic farming, which is not addressed in conventional systems with no or less inorganic fertilizer. Nutrient-uptake efficiency of plants can be improved by plant-growth promoting-rhizosphere (PGPR) bacterial communities (Gosling *et al.*, 2006; Wissuwa *et al.*, 2009) and arbuscular mycorrhizas (AMs) known as “rhizosphere competence”. PGPR-bacteria promotes N-uptake efficiency since they protect root systems against soil-borne pathogens attack (Cook, 2007), maintains efficient mineralization driven nutrient supplies to plant roots (Rengel and Marschner, 2005; Shaharoon *et al.*, 2008) and support the establishment of active AM associations (Dawson *et al.*, 2008). Similarly, Gosling *et al.*, (2006) and Mader *et al.*, (2000); Wissuwa *et al.*, (2009), stated that AMs are essential for efficient phosphorus, micronutrient and water uptake of plants grown under organic farming and low-input conditions respectively.

Larkan *et al.*, (2007) identified genes in tomato which has the ability to form mycorrhizal root symbiosis and Kumar *et al.*, (2004) inferred that association of specific microorganisms on roots can influence gene expression in the plant. Greenwood *et al.*, (2005 and 2006) and White (2007) studied P-use efficiency in *B. oleracea* and showed that there is genetic variation in this trait and that it is under quantitative control White (2007). Kage *et al.*, (2003) reported that cauliflower varieties with proportionally more fine roots have shown more N-use efficiency.

According to Kramer (1979) and Bertin and Gallais (2000) agronomic practices like fertilizer applications and environmental or climatic conditions like temperature, light intensity and soil moisture have a significant impact on nutrient-use efficiency (NUE). Hence, the crop plants should be selected within the context of different agronomic and climatic environments.

Weed competition

Weed control also remains a problem in many crop plants. However, weed management in row crops grown from transplants, including many Brassica and some Allium crops, tends to be less problematic than in these crops grown from seed. This is primarily due to more rapid development and associated competitiveness against weeds as well as the greater suitability of transplanted row crops for inter-row mechanical weeding methods (Lammerts van Bueren *et al.*, 2011). Broccoli seedlings are small and may take longer time for germination and establishment than competing weeds. For organic production, broccoli varieties suitable for direct seeding should have rapid emergence and growth habit and shade neighboring weeds. Since, *B. oleracea* has great diversity of cultivated morphological types, sufficient genetic variation should be present in these species for development of varieties with more weed competition under organic cultivation.

Allelopathy is another potentially important weed suppression trait that has received little attention in recent years. Fay and Duke (1977) and Wu *et al.*, (1999) stated that allelopathy is a chemical process where plants provide themselves with a competitive advantage due to direct or indirect effect on germination, growth or development of neighbouring plants. Hence, allelopathic potential of crop germplasm should be evaluated initially for development of

varieties with allelopathic activity. Wu *et al.*, (1999) suggested that identification of varieties with high allelopathic activity and transfer of such characteristic into modern varieties could restore an important trait that has inadvertently been lost during the process of selection for higher yields.

In Brassicaceae, glucosinolate breakdown products have weed and pathogen suppressive effects (Lammerts van Bueren *et al.*, 2011). Myrosinase catalyzes the conversion of glucosinolates to isothiocyanates and related compounds but is not released until plant tissue disruption (Vaughn and Boydston, 1997). The effect has been most clearly demonstrated in crops following ploughing under a cruciferous green manure crop. Jimenezosornio and Gliessman (1987) and Itulya and Aguyoh (1998) examined allelopathic effect of Brassica crops on weeds and observed no significant effect. It is unlikely that weed suppression through allelopathy could be directly used in broccoli, but varieties bred with increased glucosinolate levels in vegetative tissues could be part of a long-term weed control strategy in crop rotations (Lammerts van Bueren *et al.*, 2011).

Tolerance/ resistance to mechanical weed control

Selection of genotypes with tolerance or resistance to mechanical weed control (especially tine weeders) also becoming an efficient component of breeding strategies for weed competitiveness. Especially in reduced tillage systems, mechanical weed control is applied more frequently due to higher weed pressure. Tillage systems have a direct effect on soil carbon balances, soil organic matter, rooting depths and loss of top soil by wind and water erosion. Types of tillage systems include no tillage, minimum tillage and deep ploughing. No tillage systems are dependent upon herbicides, so that soil erosion and

carbon losses are reduced. However, in reduced or minimum tillage systems, herbicide-free protocols are feasible (Berner *et al.*, 2008; Krauss *et al.*, 2010) and could be further implemented into organic farming if varieties have increased competitiveness and/or resistance to mechanical weed control.

Rao and Dao (1994); Weisz and Bowman (1999) and Carr *et al.*, (2003) observed varieties suitable for reduced tillage and no tillage systems are also perform well under conventional tillage systems and inferred that tillage system does not need to play a role in varietal selection.

According to Donner and Osman (2006) and Murphy *et al.*, (2008) mechanical weed control is usually done with tine weeders early in the season, supplemented in some regions by inter-row cultivation. Therefore, the ability to tolerate damage and/or rapid recovery following mechanical weed treatments is an important trait for varieties used in organic and low input systems.

Resistance to major seed borne diseases

Resistance to seed borne diseases in organic seed production is an important issue as few seed treatments are permitted for use under organic farming standards. According to Hetrick *et al.*, (1995); Rengel and Marschner (2005) and Wissuwa *et al.*, (2009) resistance to seed-borne diseases is an important trait because root systems are required for crops to express their genetic potential for nutrient-use efficiency and yield. Seed borne diseases of tomato include tomato mosaic virus (ToMV), bacterial speck and bacterial spot (caused by *Pseudomonas syringae* and *Xanthomonas campestris* pv. *vesicatoria*, respectively) and fungal pathogens such as *Clavibacter michiganensis*. ToMV become a major threat to conventional and organic tomato production, whereas bacterial and fungal

diseases are more serious problem in organic systems restrictions in the use of fungicides and antibiotics (other than sulphur and copper based products). The two basic strategies to control seed-borne diseases in tomato are: (1) the use of seed treatments (e.g. antagonistic micro-organisms, compost extracts, fermentation, acids and acidified nitrite) and hot water treatment and/or (2) use of resistant varieties.

ToMV become a major yield limiting constrain in greenhouse grown tomatoes because the virus is stable and easily spreads through handling. Seed treatment to inactivate the virus does not work well, particularly if the virus is present in the endosperm of the seed. Therefore, the uses of resistant varieties become a viable option for organic production systems. The ToMV resistance gene 'Tm-22' has been derived from *Solanum peruvianum* through embryo rescue technique and incorporated into commercial varieties (Hall, 1980). Another resistance gene 'Tm-1' from *S. habrochaites* provides resistance against the predominant strain of ToMV which can be incorporated into commercial varieties through conventional crossing technique (Pelham, 1966). Similarly, bacterial speck and bacterial spot resistance sources are available in tomato germplasm and should be incorporated into commercial varieties bred for organic production system. Bacterial wilt (*Rastonia solanacearum*) is also major seed borne problem in tomato and Indian Institute of Horticultural Research, Bangalore released a bacterial wilt resistant varieties *viz.*, Arka Abha (BWR-1) and Arka Alok (BWR-5) which could be used for organic cultivation.

The major seed-borne disease of broccoli is black rot (caused by *Xanthomonas campestris* pv. *campestris*). As in tomato, it can be controlled by seed treatment with antibiotics and copper based products in conventional production systems. However, the best option

for organic production would be use of resistance varieties. Tonguc and Griffiths (2004) found incomplete resistance in *B. oleracea*, but more complete forms of resistance have been identified in *B. napus* and *B. carinata*. They also inferred that early attempts to introduce resistance from *B. carinata* into *B. oleracea* were made using somatic hybridization and recently *in vitro* embryo culture was used to introgress resistance.

Disease resistance

Tolerance to diseases that may cause injuries and are likely to affect plant health and quality is crucial for minimizing the gap between yield potential and actual yield. This applies to conventional high-input as well as to low-input or organic farming. Stone *et al.*, (2004) stated that *Fusarium* wilt (*Fusarium oxysporum* f. sp. *lycopersici*) and *Verticillium* wilt (*Verticillium dahlia*) of tomato may be of less concern in organic production systems compared with their impact on conventional ones due to the suppressive effects of organic matter based fertilization regimes. On the otherhand, viral diseases such as Tomato mosaic virus (ToMV) and tomato spotted wilt virus (TSWV) are more universal occur regionally and TSWV become independent of production system. Whereas late blight (*Phytophthora infestans*) is of less concern in conventional systems due to greater choice and efficacy of fungicides available compared with organic systems, where only protective copper fungicides can be used. Several sources of resistance for late blight are known (Myers, 2009) which can be used for development of late blight resistance varieties in tomato intended for organic production systems (Horneburg and Becker, 2008; Myers, 2009).

Although a number of diseases may affect broccoli regionally, head rot is a complex of

soft rot bacteria (*Erwinia* and *Pseudomonas* spp.), can cause problems whenever water accumulates on the developing broccoli head. Darling *et al.*, (2000) found head rot resistance in broccoli is associated with smooth, domed heads and small, tight beads.

Black leg (*Leptosphaeria maculans*, formerly *Phoma lingam*) and Alternaria (caused by various *Alternaria* spp., but mainly *A. brassicola*) are two diseases that cause significant economic losses in Europe and eastern USA where pesticide based control options used by conventional growers are not available to organic growers (Lammerts van Bueren *et al.*,2002). Dixon (2007) recommended hot water treatment to disinfect the seed, but it is not completely reliable and may reduce germination. Resistance source have been observed among various Brassica species and needs to be transferred into *B. oleracea* background.

Insect resistance

Due to avoidance of insecticide applications under organic farming, organic growers has to follow alternative measures includes cultural management tools such as establishment of beetle banks to maintain high predator or parasite populations; companion plants to repel or distract pests; mass trapping systems, pheromone-based mating disruption and barrier-based approaches to control invertebrate pests (use of insect-proof net houses).

Many Brassica vegetables were grown under row covers to prevent cabbage fly infestation (*Erioischia brassicae*), flea beetle (*Phyllotreta* spp.) and lepidopteran pests (*Plutella xylostella*, *Pieris rapae*) during early season. Biological control products such as *Bacillus thuringiensis* and Spinosad are widely used to control lepidopteran pests (diamond back moth) and aphids. Plant

phenotypes or morphological traits may positively or negatively associated with insect pest populations. Eigenbrode (1995) found glossy (waxless) variants of white head cabbage (*B. oleracea*) showed less damage from lepidopteran pests, reduced whitefly (*Aleyrodes brassicae*, *Bemisia tabaci*) populations and resulted in fewer eggs laid by cabbage maggots.

Moreover, the glossy phenotype also associated with reduced tissue damage from thrips. However, flea beetle damage was higher on glossy plants and both an increase and a decrease in aphid populations have been reported. Voorrips *et al.*, (2008) observed a positive correlation between wax layer thickness and cabbage root fly infestation in white head cabbage and inferred that wax less trait would be best option in glasshouse production where only thrips and no other pests are predominant problem.

Abiotic stress resistance/ tolerance

Breeding for tolerance to abiotic stresses is another important issue. Apart from nutrient stress, drought, salinity, aluminium toxicity, cold and heat stress are other important abiotic stress factors that cause yield reductions (Witcombe *et al.*, 2008). With climate change, the importance of drought and the area under saline soils are expected to increase significantly.

But, Breeding for drought and salinity tolerance has proved to be difficult (Blum, 2005) as the mechanisms of tolerance are very complex and poorly understood (Witcombe *et al.*, 2008; Cattivelli *et al.*, 2008; Ortiz *et al.*, 2008). However, tolerance to abiotic stresses is important not only for organic but also for conventional agriculture. In some cases such as drought stress, organic farmers may give higher priority as they want to build up a system that is less dependent on inputs.

Nutritive value or quality

The demand for organic products is partially driven by the belief that organically grown products are healthier and more nutritious than conventionally grown products (Lotter, 2003). It is therefore plant breeder should consider the nutritional and quality parameters, while developing varieties for organic sector. Frossard *et al.*, (2008) stated that significant variation in mineral and vitamin contents exists among varieties within crops and nutritional quality is often dependent on specific management practices. Similarly in broccoli, heterogeneity exists for important nutritional components (e.g. vitamin C, carotenoids, flavonoids and glucosinolates) and some breeding programmes has already selected for improving the contents of these nutritionally desirable compounds (Jeffery *et al.*, 2003). The traits associated with tomato fruit quality depend very much on the market type. In general, higher levels of carotenoids (lycopene, β -carotene), vitamin C and flavonoids are considered beneficial. Tomatoes are a major source of carotenoids and vitamin C in the diet, but flavonoid content was fairly low compared to other vegetables. Jordan (2007) and Behrendt (2009) stated that flavour is one of the most difficult trait, tomato breeding programmes often include the selection steps designed to improve the tomato flavour. Tomato growers prefer good flavour, but cannot agree bad flavor, soft mealy texture, bland taste with low sugar content or a bad balance of sugar to acid ratio.

Breeding approaches

Over the last 40 years, organic farmers have mainly aimed at optimizing their farming systems by agronomic approaches. More and more the sector now also aims at genetic improvements to enhance yield stability under

low-input conditions (Lammerts van Bueren *et al.*, 2011). In vegetable sector, only a few organic farming focused breeding programmes have been started so far and farmers still largely depend on varieties bred for conventional, high-input farming systems. Although many breeding goals are identical for conventional and organic production, such as yield and disease resistance, the priorities can nevertheless be different. This is mainly due to the fact that conventional agriculture is able to compensate certain traits via inputs, including inorganic fertilizers and chemosynthetic crop protection chemicals that are not available for use in organic farming systems. Many traits desired for development of varieties suitable for organic and low-input farming systems should focus on organic crop ideotype with overall yield stability and include morphological and physiological characteristics, such as plant and root architecture and vigour (Lammerts van Bueren *et al.*, 2011). For leafy vegetables, it is important that they have the ability to grow in early spring conditions when the soil temperature is low. Hence, more attention needs to be paid to the development of a better root geometry (deeper and finer rooting system) with efficient water and nutrient uptake and the ability to maintain steady plant growth without stress under fluctuating water and nutrient availability. Furthermore, the organic sector demands breeding to focus on optimizing soil processes relevant for plant nutrition, soil fertility and crop disease resistance. Comparing to conventional farming systems, this implies a greater need for 'reliable' varieties, which means varieties with a greater flexibility to cope with such conditions. An essential element of organic farming is that it looks at agriculture as process based on a complex intertwining of agro-ecological, socio-economic and ethical principles. In addition, organic farmers are certified based on their farming process. Hence, organic farming looks at the breeding

of new varieties in a holistic way. Thus, not only the varietal characteristics itself but also the process of varietal development must comply with the guiding principles of organic agriculture (Crespo and Ortiz, 2015).

As a consequence of rejecting certain breeding techniques like genetic engineering (GE) and techniques related to genetic engineering, appropriate breeding methods should be identified as a good alternative. The degree of overlap between varieties suitable for conventional and/or organic farming systems depends on the crop requirements and applied breeding techniques. In some specific crops, the problem to find suitable varieties that can perform well without high levels of mineral fertilizers and chemical-synthetic fungicides, herbicides and pesticides is larger than for other crops. Cultivars for OA also need to have high weed competition or tolerance, high level of tolerance against soil and seed borne diseases and especially high requirements for shelf-life, as synthetic conservatives are not allowed. There is not only a need for varieties that fit in an organic system with good yield potential and nutritional quality but also that allow organic systems to work, meaning that the resilience of the whole farming system is supported and enhanced. Luby *et al.*, (2013) argued that the organic sector has not yet reached its full potential until growers have access to regional adapted and organically bred varieties that balance yield with nutritional quality. According to Lammerts van Bueren *et al.*, (2011), many of the selection approaches that are used in conventional breeding programmes can also be utilized in organic farming focused breeding programmes and were described hereunder.

Sources of genetic diversity

The creation and exploitation of genetic diversity is the main requirement for

successful plant breeding. Breeders differentiate between the primary gene pool (elite breeding lines), secondary gene pool (landraces, lines not adapted to local conditions or gene bank material) and tertiary gene pool (related species or wild relatives). A vast unexploited genetic diversity is exist in all the vegetables which includes wild relatives, land races and germplasms/ accessions with biotic and abiotic stress (drought, high temperature, salinity, water logging and soil micronutrient imbalances) resistance/ tolerance was available and were not fully exploited. However, fair number of varieties and hybrids were developed by using the wild relatives.

Hence, the unexploited/untapped genetic variability available in the land races, wild relatives and germplasms /accessions may effectively utilized for development of varieties/ hybrids suitable for organic cultivation. Many vegetable varieties/ hybrids resistant to biotic and abiotic stress were developed using the wild recourses by public organizations and private companies. These may be utilized for organic cultivation without using plant protection chemicals. However, the package of practices may be optimized for organic cultivation of the same.

Exploiting genetic variation within the released varieties

Genetic variation within released varieties is relatively small in self-pollinated crops. An alternative method employed by Phillips and Wolfe (2005), maintaining genetic diversity and evolutionary fitness within varieties, is to create composite cross populations. Composite cross populations are formed by assembling seed stocks with diverse evolutionary origins and characteristics, recombination of these stocks by cross pollination, bulking of F₁ progenies and subsequent propagation of the bulked

progenies in successive natural cropping environments. Natural selection takes place if more adapted genotypes produce more progenies than less adapted ones. Composite cross populations can provide dynamic gene pools, which in turn provide a means of conserving genetic resources *in situ*. They can also allow selection of heterogeneous crop varieties. According to Phillips and Wolfe (2005), composite cross populations may have the potential to allow evolutionary changes based on biotic and abiotic environmental interactions and might be an alternative for selecting superior pure lines especially for low input systems characterized by unpredictable stress conditions.

Participatory plant breeding

Participatory plant breeding (PPB) programmes originated in developing countries to meet the needs of low-input, small-scale farmers in marginal environments that are not targeted by commercial breeding companies (Ceccarelli *et al.*, 2011). PPB involves breeders, farmers, as well as consumers, extension specialists, vendors, industry and rural co-operatives in plant breeding research.

It is termed 'participatory' because all stakeholders can influence all major stages of the breeding and selection process. These stakeholders become co-researchers as they can help to set overall goals, determine specific breeding priorities, make crosses, screen germplasm entries in the pre-adaptive phases of research, take charge of adaptive testing and lead the subsequent seed multiplication and diffusion process (Sperling *et al.*, 2001).

Due to special need of farmers and small organic market not always being attractive for commercial plant breeders, this approach gained greater attention in breeding

programmes for development of varieties suitable for organic farming systems (Dawson *et al.*, 2008; Osman *et al.*, 2008).

In conventional systems, inorganic fertilizers and synthetic crop protection chemicals often encourage homogeneity across a diversity of agro-environments. Organic and traditional low-input farms are often more heterogeneous and experience greater diversity of weed, pest and disease pressure and use more diverse rotational designs and soil management, tillage, fertilization and crop protection protocols.

To develop varieties suitable to these diverse agro-environments, Suneson (1956) recommended integration of evolutionary breeding with strong participatory selection components (Murphy *et al.*, 2005 and Dawson *et al.*, 2008).

This type of breeding strategy utilizes a combination of natural selection (survival and more progenies of the fittest genotype due to adaptation to local conditions) and farmer selection (active selection of genotypes that fit the defined breeding goals) to develop varieties with optimal adaptation to specific organic farming systems. Such integrated breeding approaches are known as evolutionary participatory breeding (EPB), which utilizes the skills and knowledge of both breeders and farmers to develop heterogeneous landrace populations and has demonstrated to be an effective breeding method for both traditional and modern farmers throughout the world (Dawson *et al.*, 2008).

The Oregon State University (OSU) has developed few open pollinated (OP) broccoli varieties with similar productivity and quality traits available in F1 hybrids and suitable for organic production using a farmer participatory approach.

Indirect phenotypic selection methods

Some morphologic traits have been correlated with quantitative biotic or abiotic stress resistance. However, indirect selection for such morphological traits has not yet been widely implemented in plant breeding programmes (Lammerts van Bueren *et al.*, 2011).

Marker aided selection

With the advent of molecular markers it became possible to dissect quantitatively inherited traits into single genes. A marker-assisted breeding approach has been used to develop high-flavonoid tomato lines. More than 50% of the sequenced tomato genome has been assembled (http://sgn.cornell.edu/about/tomato_sequencing.pl; accessed 23 March 2010) and as annotated sequence becomes available, it will be possible to identify and directly select candidate genes.

In some cases, the size of the organic market is too small to be economically attractive for professional breeding companies. Participatory approaches could represent an efficient alternative to develop new varieties for organic farming and should be further developed to reduce the reliance on commercial conventional farming focused breeding companies. However, more recently developed collaborative strategies involving both breeding companies and farmers and other supply chain stakeholder should also be encouraged to utilize commercial breeding expertise and facilities where this is possible.

This is an important opportunity not only to integrate farmers' and breeders' knowledge, but also the farmers' and breeders' eye. Finally, the introgression of traits urgently needed by the farmers to optimize organic farming systems and improve yield stability

will also have a positive influence on conventional production systems that aim to reduce agrochemical input use while improving environmental impacts and long-term agricultural sustainability. Breeding for organic agriculture therefore deserves significantly more attention and support.

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