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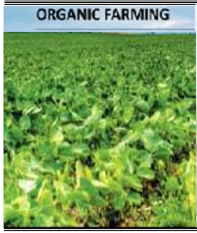

Breeding crops for organic agriculture

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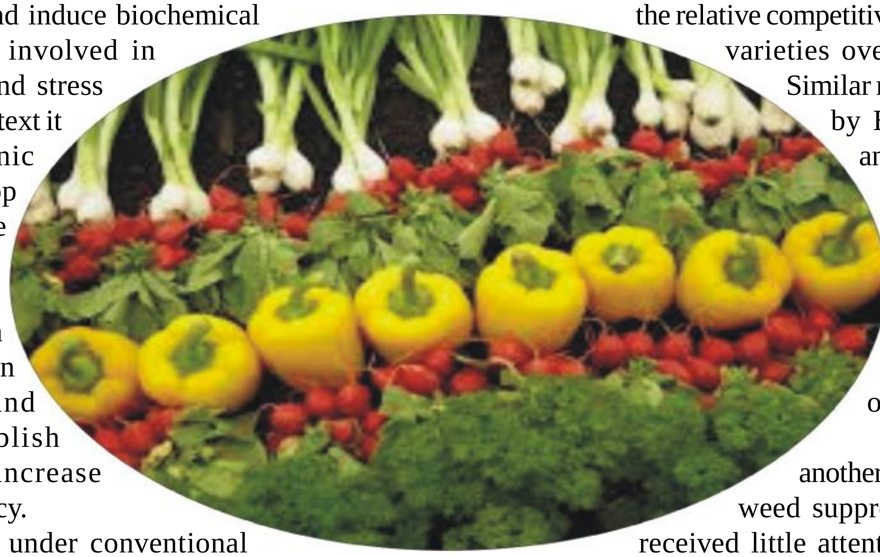
Abstract : Owing to the adverse effects of chemicals on human, soil, animal and environmental health, organic agriculture is gaining momentum all over the world. Basic axiom of organic farming has been the ban of synthetic chemical products in agriculture to decrease their possible negative impact on the environment and to improve the overall food safety. In the developing countries like India, where organic movement is at the initial stage of development, varieties that are specifically bred for organic and low-input systems are almost nil whereas in developed countries, it is estimated that more than 95 per cent of organic agriculture is based on crop varieties that were bred for the conventional high-input sector with selection in conventional breeding programmes. It is found that such varieties lack important traits required under organic and low-input production condition. The breeding goals for developing varieties for organic system such as yield, resistance to biotic and abiotic stresses and quality traits do not differ from conventional breeding goals, but it is essential that such traits are expressed under low-input conditions, which cannot be guaranteed if selection is done in high-input agronomic backgrounds. Most of the efforts in optimizing yield under organic system are based on the management of various agronomic practices. Efforts on the genetic improvements to enhance yield stability under organic conditions are meagre. The different breeding goals for organic systems should include breeding for enhanced nutrient use efficiency and weed competition, ideotype breeding for organic systems, resistance to biotic and abiotic stresses and quality. This review paper lays emphasise on the main goals of plant breeding under organic input conditions and achievements made so far in this area.

Owing to the adverse effects of chemicals on human, soil, animal and environmental health, organic agriculture is gaining momentum all over the world. The basic axiom of organic farming has been the ban of synthetic chemical products in agriculture to decrease their possible negative impact on the environment and to improve the overall food safety. However, as this method of farming expands, plant breeding is becoming a major bottleneck. In the developing countries like India, where organic movement is at the initial stage of development, varieties that are specifically bred for organic and low-input systems are almost nil, in developed countries, It is estimated that more than 95 per cent of organic agriculture is based on crop varieties that were bred for the conventional high-input sector with selection in conventional breeding programmes. It is found that such varieties lack important traits required under organic and low-input production conditions. This is primarily due to selection in conventional breeding programmes being carried out in the background of high inorganic fertilizer and crop protection inputs. Also, some of the traits (e.g., semi-dwarf genes) that were introduced to address problems like lodging in cereals in high-input systems were shown to have negative side-effects (reduced resistance to diseases, lower protein content and poorer nutrient-use efficiency) on the performance of varieties under organic and low-input agronomic conditions. Thus, there is a strong need to breed varieties responsive to organic inputs in order to enhance production and productivity of the crops.

The breeding goals for developing varieties for organic system such as yield, resistance to biotic and abiotic stresses and quality traits do not differ from conventional breeding goals, but it is essential that such traits are expressed under low-input conditions, which cannot be guaranteed if selection is done in high-input agronomic backgrounds. However, there are certain traits which are of primary interest for organic farming like increased competitiveness against weeds and resistance to seed-borne diseases. 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. It is essential therefore to identify the primary limiting factors of existing varieties for organic production and target them in the breeding programmes for organic farming.

Breeding goals for organic agriculture:

Nutrient-use efficiency : The greatest difference between organic and conventional systems relates to soil management practices used. Organic systems often rely on organic matter based 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. Organic crops often experience limited macronutrient (N and P) availability especially during periods when soil temperatures and water availability reduce mineralization capacity. However, regular organic matter inputs have shown to increase soil biological activity and biodiversity and associated mineralization capacity of the soil. Organic matter based fertilization regimes have also shown to suppress diseases and induce biochemical pathways in crops involved in pathogen defence and stress tolerance. 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.



Breeding crops under conventional fertilizer regimes with abundant N may have resulted in varieties that are dependent on readily and consistently available N. For example, older wheat varieties have shown to be superior in N extraction in low-N environments to modern ones. Crop varieties respond to varying systems of fertility management in different ways and mechanisms for the uptake of different nutrients from soil also differ. In addition, varieties have different nutrient requirements and growth capacities. A genotype with high N-use efficiency is able to realize high yields at low soil-N availability. The adaptation of varieties to efficient nutrient-use derived from slow-nutrient-releasing organic fertilizer is of great significance in organic breeding programmes.

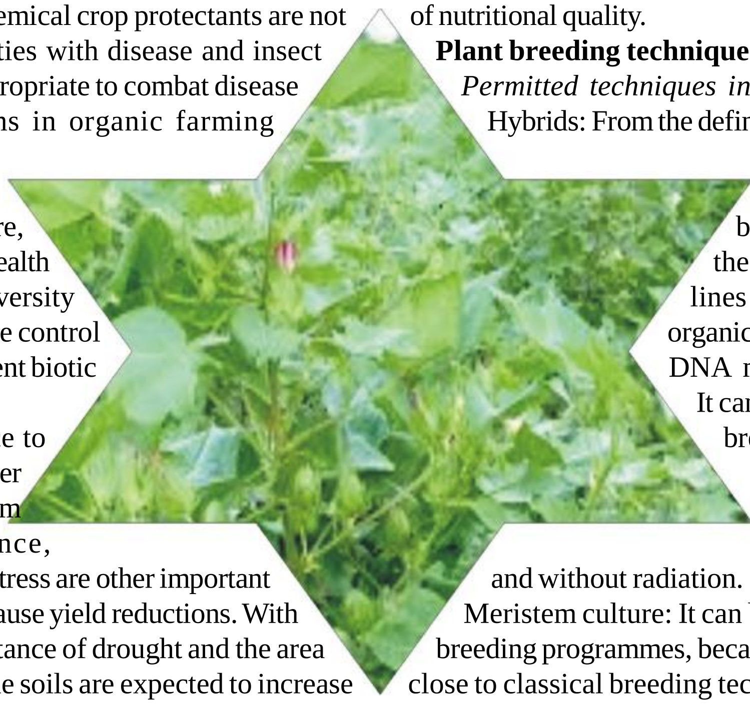
Recently, genes have been identified in tomato and in wheat that control the ability to form mycorrhizal root symbiosis (Larkan *et al.*, 2007 and Hetrick *et al.*, 1995). Moreover, studies have shown that the association of specific micro-organisms on roots can influence gene expression in the plant, but breeders have yet to exploit these findings. This area of research is complex and difficult to study because it involves not only the genotype of the plant, but also its influence on and interaction with the soil micro-organism population. Environmental conditions, especially fertilizer applications, temperature, light intensity and soil moisture also have a significant impact on nutrient-use efficiency. Since agronomic practices and climatic conditions significantly affect NUE, it is important to quantify genotype × environment interactions of traits in order to breed varieties for different agro-climatic conditions.

Weed competition : Weed control is the also one of the major problems in organic agriculture owing to the high labour cost. It has been found that genotypes vary in their ability to compete with the weeds. Wicks *et al.* (1994) and Cosser *et al.* (1997) found considerable variation in the relative competitive advantage of wheat varieties over annual rye grass. Similar results were observed by Balyan *et al*.(1991) and he reported that the grain yield of wheat was reduced by 17–62 per cent depending on the variety's ability to compete with wild oats.

Allelopathy is another potentially important weed suppression trait that has received little attention in recent years. Allelopathy is a chemical process where plants provide themselves with a competitive advantage due to the direct or indirect effect on germination, growth or development of neighbouring plants. An initial step towards the development of varieties with allelopathic activity is to evaluate the allelopathic potential of crop germplasm in bioassay-based studies. The identification of varieties with high allelopathic activity and the transfer of such a characteristic into modern varieties could restore an important trait that has inadvertently been lost during the process of selection for higher yields.

Organic crop ideotype: The organic systems approach require varieties that match a different crop ideotype in which it is more important to adapt the crop variety to the organic environment rather than the environment to the variety. This includes adaptation to organic soil fertility management, ability to suppress weeds, contributing to crop and soil health, good product quality, high yield level with yield stability and ability to produce healthy seed under organic conditions.

Breeding for biotic and abiotic stresses : 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 organic farming. Since chemical crop protectants are not allowed in organic, varieties with disease and insect resistances seem most appropriate to combat disease and insect-pest problems in organic farming systems. However, resistance for all diseases are not available. Therefore, enhancing the ecosystem health through the use of biodiversity can prove to be an effective control measure against the different biotic stresses.



Breeding for tolerance to the abiotic stresses is another important issue. Apart from nutrient stress resistance, drought, salinity and heat stress are other important abiotic stress factors that cause yield reductions. With climate change, the importance of drought and the area of irrigated land with saline soils are expected to increase significantly. Breeding for drought and salinity tolerance has proved to be difficult as the mechanisms of tolerance are very complex and poorly understood. Introgression of resistance genes from wild relatives can be used to improve tolerance to abiotic stresses. Abiotic stress tolerance is important not only for organic but also for conventional agriculture. In some cases such as drought stress, organic farmers may give higher priority to such traits as they want to build up a system that is less dependent on inputs.

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. It is, therefore, important for a plant breeder developing varieties for the organic sector to also select for nutritional quality parameters. Significant variation in mineral and vitamin contents exists among varieties within crops and nutritional quality is often dependent on specific management practices. For example, for wheat, differences in mineral content and/or mineral bioavailability among genotypes have been reported for iron, zinc and other micronutrients (Murphy *et al.*, 2008). Grain micronutrient content can also be influenced by environmental and soil conditions, including soil organic matter, pH and the bioavailability of soil minerals. Soils with a low pH have been shown to reduce uptake of the macronutrients Ca and Mg and to increase uptake of the micronutrients Zn, Mn and Fe (Frossard *et al.*, 2000). Genotype × environment interactions should, therefore, be considered when developing breeding programmes that focus on nutritional quality parameters, since selection under specific soil conditions may allow further optimization of nutritional quality.

Plant breeding techniques for organic agriculture:

Permitted techniques in organic plant breeding :

Hybrids: From the definition of the concepts behind organic breeding, hybridization as such can be permitted, provided that the F_1 is fertile and the parent lines can be propagated under organic conditions.

DNA marker assisted selection : It can be permitted in an organic breeding programme, if DNA screening is performed without enzymes originating from GMOs and without radiation.

Meristem culture: It can be used in certified organic breeding programmes, because it is considered as being close to classical breeding technique.

Non-permitted techniques :

–GMO
–CMS
–Protoplast fusion
–Patenting
–Radiation
–*In vitro* pollination and selection

Characteristics of organic varieties: An organic variety is obtained by breeding methods that compliance with the above concept and is the result of a certified organic plants breeding programme.

–Fertile and able to be propagated under organic (soil) conditions.
–Adapted to organic farm conditions.
–Efficient uptake and use of nutrients.
–Good rooting system.
–Broad durable tolerance to disease and pests.
–Weed suppressive ability.
–Maintaining variation within varieties to be maintained to allow for buffered response in relation to variation in the local environment.

Traits for organic variety : A focus on breeding for organic agriculture would require a shift from emphasis on maximizing the yield level in combination with the use of crop protectants to an emphasis on optimal yield stability. One of the main characteristics of organic farming is a multilevel approach to increase stability system to reduce risk of failures. A similar approach could apply to cultivar development to adapt to less controllable and unfavourable growing conditions. The aim would then not only be adaption to low nutrients levels supported by improved interaction with beneficial soil mycorrhizae, but also morphological and phytochemical traits that reduce disease susceptibility (wax layer in *Brassica* species, open plant architecture etc.), enhance weed competition (early vigour and planophile growth habit) and increase in flavonoids and glucosinolates.

Conclusion: Most of the efforts in optimizing yield under organic system are based on the management of various agronomic practices. Efforts on the genetic improvements to enhance yield stability under organic conditions are meagre. 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 for the lack of certain traits via inputs, including inorganic fertilizers and chemosynthetic crop protection chemicals that are not available for use in organic farming systems. Therefore, the use of breeding programmes that are focused on conventional farming selection priorities can result in varieties that perform well under high-input conditions but fail under low-input and organic conditions. Many traits desired for varieties for organic and low-input farming systems are required to provide overall yield stability and include morphological and physiological characteristics, such as plant and root architecture and vigour. Biotic and abiotic stress tolerance is a highly complex inherited trait with high genotype × environment interactions, resulting in the 'masking' of the genotypic value of breeding lines. The improvement of all these traits with the limited resources available in organic farming focused breeding programmes is therefore extremely challenging.

An important strategy to further improve performance and product quality parameters in organic and low-input production systems is to integrate the development of novel genotypes and agronomic approaches. However, there may be significant genotype × environment × management interactions and the organic sector is known to use more variable management systems. It is, therefore, more important to evaluate genotype × management interactions in different agro- climatic regions as part of organic farming focused breeding programmes than in conventional breeding programmes.

From an organic agriculture perspective, a successful plant breeding programme must go hand in hand with farm and crop management. This demands close cooperation between farmers and breeders, optimising the use of mutual knowledge and experience. Plant breeding should be open to greater participation from outside and should take into account the socio-economic consequences of organic farming principles. Thus, 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. This is an important opportunity not only to integrate farmers' and breeders' knowledge, but also the farmers' and breeders' eye.

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