Review

Recent developments in breeding approaches of tomato (*Solanum lycopersicum* L)– a review

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ABSTRACT

Tomato (*Solanum lycopersicum* L) is an important vegetable crop under family Solanaceae. It is a diploid plant having chromosome number 2n=2x=24. In tomato breeding great advances are achievable due to the possibility of hybridization within and among species in a controlled manner, the variability present in the species, the presence of self-pollination which further leads to the recessive mutation expression and the lack of gene duplication. In tomato, fruit yield, quality and resistance to pests and diseases are the general breeding goals. For improvement of the qualitative traits by gene transfer from wild species to the cultivated ones, tomatoes are believed to be a classical example. The achievements in breeding of tomato are based on traditional breeding-genetic methods till now. Also a change in the introduced cultivars possessing useful and desired traits, is not exploited yet. For enhancing the productivity in future, it is believed that conventional breeding would not help out. Different techniques are established using molecular genetics and molecular markers for significant progress. So altogether, the valuable tools for tomato breeding might be the combined application of traditional breeding and plant biotechnology including selection based on molecular markers and marker-assisted selection.

Keywords: Tomato; genomes; quality; yield; chromosomes; molecular markers

INTRODUCTION

Tomato (*Solanum lycopersicum* L) is grown widely under indoor and outdoor conditions throughout the world. So far the contribution towards human nutrition is concerned, it has become an important commercial crop. It has covered a large area under cultivation giving higher production and productivity. It has got a huge industrial value. Solanaceae family includes more than 3,000 species. The presence of genetic diversity in wild tomatoes, particularly the self-incompatible species like *S chilense* and *S peruvianum* is extensive. Although tomato was first domesticated in Mexico, it originated in Peru and Ecuador area of south America. Today tomatoes are popular and grown extensively throughout the world. When grown in open field condition, it requires at least three frost-free months in a year. It is also one of the popular greenhouse crops (Atherton and Rudich 1986).

Tomato is an economically important crop and ranks first in vegetable production worldwide and is a model plant species because of its diploid, compact, relatively sequenced genome and its large genetic and genomic resources (Ranjan et al 2012). It is an important source of vitamin A and C and can be cultivated throughout the tropics and subtropics. It is an important vegetable crop grown in sub-Saharan Africa for fresh market and processing. Being a high value crop, sometimes it offers small holding farmers the opportunity to shift from small scale to commercial farming which in turn increases their income. Cultivars of tomato can be distinguished depending upon the growth habit like indeterminate or determinate. The determinate types are mostly suitable for processing purposes and plants have a compact growth habit with grouped fruits which ripen at a single moment and are suitable for harvesting mechanically. Certain characteristics that are related to processing quality, such as high viscosity, dry extract, pH value and higher levels of total soluble acids are needed to be maintained. For typical fresh market, indeterminate types are cultivated in greenhouses. Important characteristics for fresh market are long shelf-life, external quality of fruits such as shape, size and colour and internal quality including flavour, sweetness and juiciness (Acquaah 2012).

Tomato is having an annual global production of about 50 million MT. After China, India is the second largest producer of vegetables having 11 per cent of production share in the world. Globally it is the second largest producer of tomato, first being the potato (Kaushik et al 2011). It can be used as raw, cooked and in processed form (Afzal et al 2013). Tomatoes for local market, domestic consumption and fresh use are produced either in open field or in greenhouses so as to make them available round the year. It is considered as a protective food because of its high nutritive value such as lycopene, beta-carotene, flavonoids, vitamin C and derivatives of hydroxycinnamic acid. Due to the presence of lycopene which is having anti-oxidative activities and anti-cancerous properties, tomato is achieving tremendous popularity (Wu et al 2011, Raiola et al 2014). As a result its production and consumption are increasing constantly.

Due to the affect of biotic and abiotic stresses, the production and productivity of tomato are getting affected. There is a negative influence on the production of this crop due to involvement of many environmental stresses (Renaud 2014). The main objective for plant molecular and genetic breeding is the development and improvement of stress tolerance of crops. For development of disease resistant cultivars, an important role is played by genetic engineering. Although by using chemicals, disease infestation is mostly controlled but it may occasionally reach the level of toxicity. Thus keeping in view the above facts to overcome the constraints of tomato production, current improvement programme is a critical task.

Floral biology

The crop duration is about 95-115 days when grown under optimal conditions. The appearance and opening of first flower occurs after 7 to 8 weeks after seeding followed by mature fruits 6 to 8 weeks later. It bears perfect flowers with both functional male and female parts. The flowering period which lasts for weeks, facilitates the ability to make crosses between varieties. The flowers are borne in clusters with at least 4 to 8 in number. A single plant produces more than 20 inflorescences over a season which gives ample scope for making crosses. Generally the anther from a tight protective surrounding around stigma greatly reduces the chances for natural cross fertilization. Modification of stigma position using genetic and environmental factors can affect both fruit set and degree of cross fertilization (Maiti et al 2014).

For controlled pollination, emasculation must be done one day prior to anthesis to avoid accidental self-pollination. The sepals, anthers and corolla show characteristics of fully ripen flowers. This allows pollination immediately after emasculation as the stigma appears to be fully receptive at this stage (White and Connolly 2011). From a single pollination, we can obtain about 200 or more seeds. Controlled pollination under open field conditions may be less efficient as compared to greenhouse conditions as hot and dry winds may lead to rapid desiccation of the exposed pistil before fertilization is achieved. Emasculation is done between 55 and 65 days after planting. For emasculation, flower buds are selected from the second cluster which would open within 2 to 3 days. Pollen collection needs to be completed before it sheds. The anther cones are removed from the flowers and placed in suitable containers (Chetelat and Peacock 2013). When corolla of emasculated flower turns bright yellow, the stigma is ready for pollination. The process of pollination is repeated 2 to 3 times a week for 3 to 5 weeks. Successful pollination is visible within one week as the fruit starts to enlarge. For small fruited cultivars, 50 fruits should be allowed per plant and the number of fruits may be up to 30 for large-fruited cultivars.

Tomato breeding

Breeding technologies involved for improving crop production are critical in the changing world with an exponentially growing population and in the face of extreme environmental changes (Tester and Langridge 2010). The development of molecular biology and bioinformatics has offered wide scope for improving the effectiveness of traditional plant breeding programmes. Advances in genomics and genetics improved the understanding of structural and functional aspects of plant genomes (Lei et al 2011, Mir et al 2012). Among the fruit bearing plants, tomato has been selected preferably to study the fruit development process and significant improvement in the understanding of the molecular basis of fruit set and development has been made due to advances in functional genomic techniques and molecular tools (Saito et al 2013).

Breeding objectives

Fruit yield: The most important breeding trait is yield in crops. Fruit formation directly affects yield (Ariizumi et al 2013). The ultimate fruit size depends on the number and volume of cell layers in the fruit pericarp which is judged by the extent of cell division and expansion in the fertilized ovaries. Thus fruit yield is determined by the efficiency of fruit set and size of the fruits. Fruit yield in tomato has been increased significantly as a result of mutations associated with fruit size through domestication and through genetic studies it has been identified that the genes influence the cell cycle, carpel number and fruit set. For increasing yield, a critical role has been played by exploitation of heterosis and the development of hybrids. The F_1 hybrids are preferred to develop not only for heterosis but also for their uniformity and the protection against illegal reproduction (Azzi et al 2015).

Resistance to diseases and pests: It is very important to breed cultivars possessing resistance to the most destructive pests and pathogens. If molecular markers to all the known genes for resistance are available, a significant advance in exploitation of polygenic resistance could be obtained (Foolad and Panthee 2012). Among all contributions of modern plant breeding to tomato improvement, development of disease resistant cultivars is one of the most important aspects (Foolad and Panthee 2012). Selection process and the sequence of field, laboratory, greenhouse and molecular marker protocols applied by AVRDC– The World Vegetable Center to a segregating population led to the development of fresh market tomato lines resistant to late blight, tomato yellow leaf curl disease, bacterial wilt, *Fusarium* wilt, grey leaf spot and tobacco mosaic virus (Hanson et al 2016). From wild to cultivated species, some pests and pathogens resistance has been transferred. For example the resistance to *Cladosporium fulvum* was obtained from *Solanum pimpinellifolium*. The diseases such as late blight, *Fusarium* wilt and tomato spotted wilt virus are also included under the interest of breeders (Foolad and Panthee 2012).

Breeding of tomato for insect resistance has not been as successful as disease resistance breeding. It is not due to the restricted variability for resistance to insects, as a matter of fact, the *Lycopersicon* genus is replete with good reports on resistance to various mites and insect pests (Prins 2013). Firstly the insect resistance has received low priority in traditional and applied breeding programmes because the use of pesticides has controlled most of the insect pests effectively in tomato and secondly the screening and selection methods to exploit the existing genetic variability for insect resistance are difficult to develop (Lucatti et al 2013).

Tolerance to heat and drought stress: For abiotic stress tolerance in crop plants, mutation breeding is an important breeding approach (Firon et al 2012). It is reported that never ripe pollen grains exhibited higher heat stress sensitivity manifested by a significant reduction in total number of pollen grains, reduction in number of viable pollens and elevation in number of non-viable pollens compared with wild type plants. In tropical and sub-tropical environments, heat and drought resistant tomato cultivars are required. Thus for routine production of heat and drought resistant tomato cultivars, a combination of traditional breeding protocols and marker-assisted breeding are required. To achieve this successfully, proper and long term research is required, scientifically proven works have to be incorporated, best approaches need to be utilised and effective methods sustained to overcome the effects of abiotic stresses on tomato (Solankey et al 2015).

Fruit quality: This includes traits like shape, size and colour as well as chemical factors such as soluble solids, acidity, taste and sensory factors. For domestic market and fresh consumption, growers are interested for shelf-life of ripened fruits. This includes other traits like colour, flavour and soluble solids content. Flavour is the sum of the interaction between sugars, acids and a set of nearly 30 volatile compounds (Sacco et al 2013). By genetic manipulation, tomato flavour can be improved significantly by increasing the sugar and acid contents in fruits. However breeding for volatiles has not been performed intensively as little is known about the relations between flavour, aroma and volatiles (Lin et al 2014).

The nutritional quality is also required to be focused upon which is mainly determined by its lycopene and vitamin C and E contents. A great success has also been achieved in enhancing the level of lycopene by using transgenic approaches of breeding. Wild tomato accessions rich in lycopene have been identified making them a promising resource in tomato breeding programmes (Foolad 2013). For example *Solanum pimpinellifolium* is having five times higher level of lycopene as compared to that in cultivated varieties.

Methods of breeding

The widely used breeding technique for improving tomato has been hybridization followed by pedigree selection. When desirable traits are to be transferred from wild species to or from relatively unimproved cultivated varieties, back cross breeding has been the method of choice. In some breeding programmes, combinations of methods such as pedigree breeding and single decent have been found to be a useful approach (Palmgren et al 2015).

Mass selection: This method includes selection of a number of phenotypically superior plants and fruits from the field population and harvesting and bulking them together for sowing in the next year's crop. This process is repeated till desired characters are achieved. By simply growing the variety in field and rouging out the off-types, this may be achieved. The selection intensity is to be taken care of. Modern plant breeding usually employs mass selection to preserve the characteristics of established varieties (Frankel and Galun 1977).

Pedigree method: This method involves making a controlled cross followed by several successive generations of single plant selection. The ultimate aim is to develop at least one new variety from a single cross (Acquaah 2012). The pedigree method is although a reliable and successful way of developing new tomato cultivars, it can be restricted genetically for on-farm and diverse system breeding work (Atherton and Rudich 1986). By visual selection among individual plants in early generations, as the pedigree method uses selection in each generation, each generation must be known in an experiment where genetic differences will be expressed. This method produces new varieties faster than mass selection (Kalloo 2012).

Heterosis method: Hybrids are more popularised and in demand among cross-pollinated crops but it has been achieved successfully in a number of self-pollinated crops too such as tomato even though the heterozygote advantage has not been unequivocal. The F_1 hybrids have some favourable traits such as uniformity and better resistance to diseases but their economic advantages over standard checks have not been as high as in cross-pollinated crops. The F_1 hybrids development in self-pollinated crops follows to a large extent scheme used for cross-pollinated species (Jiang 2018).

Biotechnology in breeding of tomato

Still today to satisfy and fulfil the requirements of future, conventional breeding methods are exploited to a great extent. Also the genetic diversity and variability present among the cultivated and wild relatives of tomato help in achieving the success. Although traditional methods of breeding are time consuming and labour intensive, there is no choice left for appropriate breeding purposes. Thus developing and utilising genetically-transformed plants, commercial applications are coming into picture. The in vitro culture is used successfully in different biotechnological applications including the clonal propagation of high value commercial varieties, virus-free plants and genetic transformation (Namitha and Negi 2013, Li et al 2011, Yarra et al 2012).

Now advanced tomato lines are available that can resist the major diseases like bacterial wilt, tomato mosaic virus, nematodes, extreme hot and cold weather and can bear fruits that are firm, improved sized and resistant to cracking (Gerszberg et al 2015).

The first commercially developed genetically modified tomato cultivar is Flavr Savr. It was developed after 10 years of intensive research work by the Calgene Company in 1992. Although it was managed to slow down the fruit rotting but altering the problems of skin softening have not been achieved which makes it still susceptible to damage during transportation and handling (Foolad 2013). Another issue with the new product was that the variety was not very tasty to start with which made the genetically modified tomato less acceptable by consumers as compared to the conventional varieties. Crossing the transgenic tomato with a tastier non-genetically modified tomato may have corrected the problem (Kato et al 2010).

The genetic engineering allowed for increased productivity by enhancing efficiencies of metabolic or photosynthetic pathways (Mishra et al 2012). Along with enhanced resistance for wide range of stresses, transgenic tomato lines have been generated (Khare et al 2010). By knowing the physiological and genetics basis of stress tolerance, genetic transformation technologies will prove to be beneficial for improving stress tolerance in tomato cultivars. In addition using genetically modified technology, researchers are able to obtain tomato fruits with improved nutritional and organoleptic values (Andersen et al 2015).

CONCLUSION

It is believed that for fulfilling the increased demand in the future, conventional breeding wouldn't be able to meet the productivity. Thus it is required to establish the significant progress in molecular genetics and use of molecular marker techniques. Therefore it is suggested to go for the combined application of traditional and modern plant breeding methods including selection based on molecular markers and marker-assisted selection which might prove to be the valuable tools for tomato breeding.

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