African Crop Science Journal, Vol. 28, No. 1, pp. 131 - 140
ISSN 1021-9730/2020 $4.00

DOI: https://dx.doi.org/10.4314/acsj.v28i1.10

TOMATO BREEDING IN SUB-SAHARAN AFRICA - CHALLENGES AND OPPORTUNITIES: A REVIEW

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(*Received 25 October, 2019; accepted 17 February, 2020*)

ABSTRACT

Successful tomato (*Solanum lycopersicum*) production depends on availability of improved cultivars that can withstand biotic and abiotic pressures inflicted by the environment. This paper explores the challenges in tomato breeding and identifies opportunities that can be explored to improve tomato breeding initiatives in Africa. The review focuses on primary sources of information and notes that few existing tomato breeding institutions in Africa can drive a vibrant tomato industry and its downstream enterprises. This is coupled with inadequate breeding policies regarding varietal release and protection, negative effects of climate change, emergence of pests and diseases that impact negatively on tomato production efforts in Africa. There is a chance to tap in the diversity currently existing in wild tomato relatives, and to introduce and strengthen tomato breeding at various research institutes, through capacity building. Furthermore, there is need for Africa to embrace long term breeding strategies such as pre-breeding and the use of modern breeding technologies, if tomato production is to be sustained. Key production challenges in Africa include high incidences of fungal diseases and pests, low soil fertility, limited tomato breeding, climate change induced stresses and lack of adequate inputs due to prohibitive costs. Tomato production opportunities arise as a result of increase in human populations and consequently mounting consumer demands for nutrition and potential use of improved technologies such as CRISPR and gene sequence technologies to produce novel genotypes.

Key Words: Plant breeding, *Solanum lycopersicum*

RÉSUMÉ

La réussite de la production de tomates (*Solanum lycopersicum*) dépend de la disponibilité de cultivars améliorés qui peuvent résister aux pressions biotiques et abiotiques infligées par l'environnement. Cet article scientifique explore les défis de la sélection des tomates et identifie les opportunités qui peuvent être explorées pour améliorer les initiatives de sélection des tomates en Afrique. La revue scientifique se concentre sur les principales sources d'information et note que peu d'institutions de sélection de tomates en Afrique peuvent stimuler une industrie de la tomate dynamique et ses entreprises en aval. Ceci est couplé à des politiques de sélection inadéquates concernant la libération et la protection variétales, les effets négatifs du changement climatique, l'émergence de ravageurs et de maladies qui ont un impact négatif sur les efforts de production de tomates en Afrique. Il est possible d'exploiter la diversité qui existe actuellement chez les parents de tomates sauvages et d'introduire et de renforcer la sélection des tomates dans divers instituts de recherche, grâce au renforcement des capacités. En outre, l'Afrique doit adopter des stratégies de sélection à long terme telles que la pré-sélection et l'utilisation de technologies de sélection modernes, si la production de tomates doit être maintenue. Les principaux défis de production en Afrique comprennent une incidence élevée de maladies fongiques et de ravageurs, une faible fertilité des sols, une reproduction limitée des tomates, des stress induits par le changement climatique et le manque d'intrants adéquats en raison de coûts prohibitifs. Les opportunités de production de tomates résultent de l'augmentation des populations humaines et par conséquent de la demande croissante des consommateurs pour la nutrition et l'utilisation potentielle de technologies améliorées telles que CRISPR et les technologies de séquence de gènes pour produire de nouveaux génotypes.

Mots Clés: Amélioration des plantes, *Solanum lycopersicum*

INTRODUCTION

Nutritional value and production statistics of the tomato. Tomato (*Solanum lycorpersicum*) is a major vegetable/fruit extensively grown world over for human consumption. It belongs to the Solanaceae family, which includes more than 3000 species with origins in both the old (eggplant coming from China and India) and New World (pepper/ potato/tomato came from Central and South America (Bai and Lindhout, 2007). In sub-Saharan Africa (SSA), the tomato fruit is an important cash crop (Fufa *et al*., 2011; Malherebe and Marais, 2015; Ochilo *et al*., 2019). The fruit plays an important role in human nutrition, where it can be eaten as a fresh salad vegetable, processed, stewed, fried, baked and can also be used to produce soup or juice. It may also be put into various dishes as the main ingredient.

Tomato is a good source of phosphorus, iron and vitamin A, B and C, respectively (Cheema and Dhaliwal, 2005). The fruit contains B complex vitamins, thiamin, niacin and riboflavin which are important in a healthy diet. In addition, it contains a significant amount of beta-carotene (pro-vitamin A carotenoid), lycopene, ascorbic acid, phenolic acids and flavonoids, all of which can be phytonutrients which contribute to better health (Hanson and Yang, 2016). Tomato lycopene is vital in human health and chronic disease control (Kumar, 2014). Antioxidants from tomato are protective agents responsible for inactivating reactive oxygen species and, therefore, significantly delaying and preventing oxidative damage (Agarwal and Rao, 2000).

Global production of tomato is estimated to be above 171 million metric tonnes over an area of five million hectares of cultivated land, with major producers being China, United States, Turkey, Egypt and India (Anonymous, 2019). Africa contributes 11.8% of total global tomato production (Anonymous, 2019). Within the African continent, tomato is one of the most widely grown vegetables due to its versatility with production cutting across smallholder and commercial farming communities. Trend analysis done in 2014 and 2017 shows that Egypt was still the leading tomato producer in Africa, followed by Nigeria second (Table 1) (Anonymous, 2019). Production systems differ throughout the continent depending on the agro climates, from greenhouses to open field, with varying levels technological applications.

Past tomato breeding achievements in Africa. Tomato cultivar development and breeding work has been conducted at the Asian Vegetable Research and Development Centre

TABLE 1. Leading tomato producers in Africa based on tonnage at two time intervals, 2014 and 2017

Country	2014 Production (tonnes)	2017 Production (tonnes)
Egypt	8 625 219	7 297 108
Nigeria	1 560 000	4 100 000
Morocco	1 219 071	1 293 761
Tunisia	1 100 000	1 298 000
Cameroon	880 000	1 279 853
Algeria	796 963	1 286 286
South Africa	564 740	608 306
Sudan (former)	529 200	-
Kenya	397 000	283 000
Ghana	321 000	371 811
Tanzania	255 000	565 411
Mozambique	250 000	380 000
Benin	244 742	321 644
Libya	225 000	217 316
Niger	188 767	263 394

FAOSTAT, 2019

(AVRDC) Regional Center for Africa since 1992. The Centre has successfully worked with various private seed partners and non-governmental organisations to collect germplasm, evaluate, test and release targeting Late Blight, Root knot Nematode, Fusarium Wilt, and Tomato Mosaic Virus (Ojiewo *et al.*, 2010; Fufa *et al.*, 2011).

The World Vegetable Center (formerly AVRDC) is the only international nonprofit organisation that makes improved breeding lines and gene bank accessions publicly available. Improved tomato lines so far released include ‘Tengeru 97’, ‘Tanya’, ‘Meru’ and ‘Kiboko’ released to several African countries (Ojiewo *et al.*, 2010). Focus on research to enhance phytonutrient density, yield, adaptation and multiple disease resistance is emphasized (Hanson and Yang, 2016).

Furthermore, the Centre in Africa has routinely distributed released limited tomato lines to countries such as Zambia, Zimbabwe, Sudan, Ethiopia, Madagascar, Cameroon and Nigeria for further evaluation (Ojiewo *et al.*, 2010; Fufa *et al.*, 2011). Development of other tomato breeding institutes in SSA is an opportunity for new researchers and private companies to improve productivity in view of the fast growing and ever-increasing food demands of the region.

Tomato production and breeding constraints. Tomatoes are grown throughout the year in most SSA countries across tropical and sub-tropical areas, in greenhouses and open fields. However, depending on the location, there are seasonal variations that impact on tomato production.

Generally, tomato production in Africa is rarely done without some form of irrigation, due to the constant water supply required by the vegetable (Asgedom *et al.*, 2011). Tomato breeding is currently influenced by a number of constraints that include pests and disease challenges and gaps across the different regions (Malherbe, 2012). Research efforts indicate that prevalence of plant diseases, insect pests, abiotic stresses that include low moisture, heat and low soil fertility have been contributory factors impending plant breeding and production of tomato in SSA (Fufa *et al.*, 2011). Other key contributors to low production are unavailability of markets, labour and irrigation costs, and high transportation charges (Mango *et al.*, 2015).

Diseases and pests. Tomato production and breeding during the rainy season in highland areas of Eastern and Southern Africa is hampered by the spread of fungal diseases, such as Early Blight caused by *Phytophthora infestans*; Late Blight caused by *Alteranaria solani;* fruit rot caused by *Phytophthora parasitica* which are endemic and problematic during the warm summer season (Fufa *et al.,* 2011; Adhikari *et al.*, 2017).

Field tomato production in Southern Africa is also affected by temperature during the cold winter months, which causes a hike in prices during the post winter period. Other diseases such as bacterial wilts, fusarium wilts and viral diseases e.g. Tomato Mosaic Virus are among the main problematic diseases retarding tomato production (Dagnoko *et al*., 2011; Perez *et al*., 2017).

Pests of economic importance include the leaf miner (*Tuta absoluta)*, white flies, root knot nematodes, cotton bollworm and red spider mites (Brévault *et al*., 2014; Sadashiva *et al*., 2017). *Tuta absoluta* is among the most devastating tomato pests and as such it is considered an emerging and threatening pest because of its high damage to the crop (Brévault *et al*., 2014). The losses from these constraints are either qualitative e.g. poor colour, texture and/or quantitative e.g. reduced final yield, and ultimately low famer returns. Accordingly, there is great need to develop cultivars that survive specific pests pressure, which could result in reduced cost of pesticides and other inputs used. Such a practice will further reduce overdependence on use of chemicals which are both expensive and cause environmental polution.

Narrow genetic base and domestication syndrome. Wild tomato relatives are found endemic in narrow geographic regions where they have been found adapted to isolated micro climates (Kulus, 2018). With recent global climatic changes, some wild lines are near extinction due to restricted natural habitats for survival which poses as a great threat to the future breeding programmes (Kulus, 2018). There has been lack of vital information about the origin and relationship of existing landraces in tomato plants, all resulting in restricted growing of certain tomato lines (Peralta and Spooner, 2005). Inadequate information on genetic relationships results in breeding shortcomings, as researchers can hardly trace the genealogy of parentage and transmission of traits for improvement (Kulus, 2018). The limited amount of information on inheritance of specific traits in tomato lines has constrained breeding efforts which depend on this information for their precision and effectiveness. Albercht *et al*. (2010) noted that the reduced genetic diversity found at the important loci of tomato had a bearing in limiting future breeding programmes.

Modern tomato varieties have suffered reduction in genetic variability mainly due to bottlenecks known as the domestication syndrome (Bai and Lindhout, 2007). The continuous selection of beneficial alleles has led to the evolution of a number of distinct morphological and physiological traits (Bai and Lindhout, 2007; Kulus, 2018). Domestication has transformed the once small wild tomato into the present-day large cultivars. In most instances, mutations associated with larger fruit were selected and accumulated during selection by early farmers, which led to the present day large sized tomato fruits. The fruit shapes are now variably round, oblate, pear, torpedo and bell-shape (Bai and Lindhout, 2007). The seed from the cultivated tomato has become several-folds larger than the original size, and the change in seed weight was most likely in response to the selection pressure for uniform germination and seedling vigour. Kulus (2018) concurs that tomato crops have a narrow genetic base, which results in the production of fewer superior lines. Accordingly, this narrow genetic base will ultimately negate the development of superior lines in tomato resulting in slow breeding progress.

Limited funded breeding research. National governments and regional bodies need to strengthen research budgets for crops such as tomato that currently do not have defined research budgets (Mary *et al.*, 2002; Lenne *et al*., 2005). Funding should cover aspects of training plant breeders and establishment of tomato breeding infrastructure among others (Lenne *et al.,* 2005). A few improved tomato breeding lines have been successfully developed for heat tolerance, resistance to late blight and yellow leaf curl disease at the World Vegetable Centre, regional center in Arusha, Tanzania for Africa; but germplasm materials are not enough to meet most tomato breeding needs across the region (Golam *et al*., 2012). Accordingly, there is need for more funding from both National Agricultural Research Systems (NARS) and private seed companies if further gains are realised. Such investment can hinge on utilisation of hybrid technology and biotechnologies that have intellectual protection so that innovators recoup their research investments.

Tomato pre-breeding. In order to speedily exploit the narrow genetic base of cultivars, plant breeders use pre- breeding processes that offer an opportunity to introgress the desirable genes from wild germplasm into cultivated backgrounds readily with minimum linkage drag (Iqbal *et al.,* 2014). It involves activities for identifying breeding lines that cannot be used directly in breeding programmes, and making use of intermediates that are subsequently used in producing new varieties meeting with specific attributes (Jain and Omprakash, 2019). Pre-breeding includes all activities pertaining to the identification of desirable genes from the wild and weedy relatives and other unadapted materials.

Since the tomato gene pool is widely composed of botanical varieties, landraces, inbred lines, obsolete, modern cultivars and related wild genotypes, pre-breeding offers an opportunity to introgress the desirable genes from wild germplasm into cultivated backgrounds readily. It is noteworthy that pre-breeding is a long term endeavour and currently most seed companies in Africa are in survival mode and are interested in quick returns, which leaves National Agricultural Research Systems (NARS) as likely institutions to undertake such research (Iqbal *et al.,* 2014).Global initiatives under the auspices of the Food and Agriculture Organisation can support regional efforts to ensure sustainability of such long term initiatives.

Wild tomato relatives have been crucial in the improvement of cultivated tomato, through classical breeding for pest and disease resistance, abiotic stress tolerance and to a much less extent, fruit quality (Venkadeswaran *et al.,* 2018). *Solanum lycopersicum var. cerasiforme*, the ancestor of the cultivated tomato has broad genetic diversity, with useful traits in plant architecture, fruit attributes, crop phenology and seed characters (Peralta and Spooner, 2005). Furthermore, it is a source of important resistance genes for insect pests such as whiteflies (*Bemisia* spp.) (Passam *et al*., 2007).

Solanum pimpinellifolium, a wild relative of cultivated tomato, offers a wealth of breeding potential for desirable traits such as tolerance to abiotic and biotic stresses. Resistance to *Cladosporium fulvum,* a biotrophic fungal pathogen, was identified for possible exploitation from the *S. pimpinellium* (Joosten and De wit, 1999). The wild fruit exhibits phenotypical robustness that is not present in modern cultivated tomato varieties (Bai and Lindhout, 2007).

Other wild tomatoes such as *S. chilense* and *S. peruvianum* have also been found to possess large genetic diversity. For example, *S. peruvianum* was found to possess genes for resistance to some powdery mildews and to root knot nematodes (Passam *et al.,* 2007). Hence, the wild relatives are important reservoirs of genes that can be characterised and mined to achieve various breeding objectives. Africa is also endowed with a wide variety of wild and weedy tomato relatives that can be used in improvement programmes through breeding. The use of wide genetic diversity found within the cherry tomato landraces, means that their inclusion in modern tomato breeding programmes will undoubtedly improve tomato breeding (Corrado and Rao, 2017). The findings were in line with those of Albercht *et al.* (2010), who argued that the presence of many diverse genes from wild tomato relatives were valuable in tomato breeding. Such lines could be taped through mining for newer alleles from the interspecific gene pool to introgress into modern

Lycopersicum plants. This approach can result in better performing varieties.

Cherry tomato (*Lycopersicum esculentum* var *cerasiforme)* is highly recommended for cross breeding purposes due its known attributes that include higher disease resistance, better sweetness, more succulence, higher carbohydrates, manganese content, potassium, rich vitamin content, calcium, copper, iron, magnesium, phosphorus and zinc; all presenting a possibility of obtaining a better quality plant if successfully hybridised with the modern varieties (Casals *et al*., 2019). The semi-wild cherry plants also contains more carotenoids than most domesticated tomato, such as lycopene and phenolic compounds which are antioxidants in the control of various human diseases (Berni *et al*., 2018). African can also benefit from the antioxidant properties and nutritional benefits that the cherry tomato has to offer if they are used in tomato varietal improvement.

Inadequate research capacity and piracy policies. Breeding efforts have also been retarded by inadequate qualified human resources. Private seed companies and NARS are not keen on investing in human capital and resources in tomato research due to free access to release planting material and marketing of Open Pollinated Varieties in tomato (Fufa *et al*., 2011). Anti-piracy policies should be enacted where they are absent, enforced where they are present to protect the plant breeders and ensure return on investment for their plant breeding efforts. Piracy of varieties and no clear variety release procedures in most African countries such as Kenya and Nigeria impede investment in the tomato and other vegetable species breeding (Afari-Sefa *et al*., 2011; Plaisier *et al*., 2019).

Tomato breeding opportunities in Africa. The ever changing and increasing human population in Africa means that the demand for tomato as a food source will remain critical. However, most countries in SSA still use old open pollinated varieties that have since become susceptible to prevalent pests and disease (Fufa *et al.,* 2011). Furthermore, some existing varieties have relatively low yielding capacities, exposing the population to food and nutrition insecurity and poverty. Africa, however, has favourably warm temperatures suitable for tomato farming and breeding (Tshiala, 2014).

Tomato has a lot of hybrid potential particularly for earliness, yield, diseases and uniformity in low input systems (Cheema and Dhaliwal, 2005). These are the attributes of importance in Africa were farmers grow the vegetable with minimal inputs. Furthermore, hybrid technology could stimulate the interest of private seed companies to do research and invest in tomato improvement programmes. As demand for the tomato increases stirred by fast food outlet growth for products such as pizzas (Fufa *et al*., 2011), there is potential for increased wider, year round production which will be underpinned by active breeding programmes.

Modern breeding methods. For tomato, saturated linkage maps have been developed and several genes and QTLs, for various traits identified (Passam *et al*., 2007). Therefore, the use of marker assisted selections (MAS) in identification of chromosomal regions responsible for specific traits complemented with conventional breeding techniques can enable development of new tomato cultivars that can be adapted to various regions (Devran *et al.,* 2018). This is more important if pre-breeding is done to minimise linkage drag during foreground and background selection, during trait introgression. Such initiatives can be coupled with the short-term practical training of breeders offered by AVRDC, so that they can initiate their own country specific tomato breeding programmes.

Use of high potential breeding technologies such as Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) to incorporate disease and pest resistance on tomato plants can help to reduce the costs for buying pesticides and herbicides in tomato production (Mudziwapasi *et al.,* 2018). Clustered Regularly Interspaced Short Palindromic Repeats technology has not been fully embraced in Africa, despite its potential benefits in crop improvement programmes. This is attributed to lack of human resource capacity and requisite infrastructure. Other modern approaches of using genetic linkage maps in breeding and Genome Wide Association Studies (GWAS) may facilitate learning of chromosomal locations of QTLs for improving yielding, fruit abscission, fruit sizes, flavour, texture and colour (Kulus, 2018).

Marker Assisted Selection (MAS) can also expedite gene pyramiding for multiple genes or traits which can achieve quicker end result than conventional methods in tomato breeding (Sadashiva *et al.*, 2017). Plant breeding approaches can be complemented with modern biological tools, such as sequencing technologies, genomic selection and multi-omic analysis that may further translate to better good quality results. Use of such specific omic approaches such as transcriptomics, proteomics and metabolomics can help to improve productivity; yet chromatographic sequencing techniques may be used in the sequencing of tomato genomes during crop breeding (Kusamo and Fukushira, 2013).

Potential tomato breeding objectives for Africa. Some countries such as South Africa, Ghana and Tanzania are making frantic efforts to solve various tomato breeding problems they currently face (Lenné *et al.*, 2005). In Ghana, where most of the varieties currently grown are highly acidic, watery, poor colour, poor shelve life and susceptible to Tomato Yellow Leaf Curl Disease (TYLCD); their breeding programmes earmark towards addressing these challenges (Leander *et al.,* 2019). Breeding efforts at WACCI, University of Ghana are towards TYLCD resistant varieties and prolonged shelf life, processing quality and bacterial wilt resistance. In pursuance of excellence, future breeding objectives should ear mark developing more disease resistance, more tolerance to problematic emerging pests such as *Tuta absoluta*, improved chemical traits, improved morphometric traits, developing plants with improved physiological disorder tolerance and improved phytonutrient composition. Such objectives are seen in tomato plant breeding in Africa to position output for worldwide exports. As AVRDC continues to train breeders from private seed companies and the NARS, more country specific breeding objectives should be explored. These will also take into consideration quality attributes and climate change induced stresses which most countries in SSA are facing. Furthermore, with increased globalisation, there is scope for tomato breeding to go beyond the needs of local farmers as there are export opportunities to countries beyond the continent.

CONCLUSION

Tomato, though a vital fruit vegetable in the diet of human beings, has not received adequate improvements, especially in Africa because of a trail of challenges. Breeding efforts are needed against biotic factors such as pests, and disease causing organisms that include bacteria, fungi, virus and nematodes among others. For sustainable breeding, there is need to explore the use of wild relative in tomato breeding which will curb the use of pesticide overuse. New tools of biotechnology, human resource capacity building and collaborations need to be explored as a long term solution to enhanced tomato breeding in SSA.

ACKNOWLEDGEMENT

The authors are grateful for the support granted by Faculty staff and review groups at Lupane State University, Zimbabwe and Horticulture programme in Uganda.

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