Chapter

Perspective Chapter: Accelerating Demand-Led Tomato Breeding for Emerging Markets in Africa

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Abstract

Tomato production in Africa has increased due to increased population, rising consumer demands for nutritious and healthy food and potential use of improved technologies. Demand-led' plant breeding puts producers and consumers at the heart of research and development involving stakeholders even before the research starts. These 'stakeholders' are not only farmers but key actors along the tomato value chain. They influence how the tomato is traded as: fresh food and processing product. This chapter focuses on different approaches to fast-track tomato breeding so as to contribute to the transformation of African agriculture by enabling small scale farmers to compete in local and regional markets, by increasing the availability and adoption of high performing tomato varieties that meet market demands. It further outlines development of varieties that meet farmer needs, consumer preferences, and market demand in Africa. These new varieties are designed to meet client needs by connecting plant breeders with crop value chains, seed distribution organizations, and encouraging enterprise and entrepreneurship in transforming agriculture in Africa. Lastly, it outlines the prospects and challenges associated with demand-led breeding of tomato and offers suggestions to increase food security in Africa.

Keywords: demand-led, tomato, breeding, emerging markets, consumers, producers

1. Introduction

The production and utilization of tomato has increased over the years in Africa [1]. However, demand for the crop exceeds supply owing to its economic importance and increasing popularity as a result of processing, value addition and consumption [2]. According to ref. [3], open field cultivation dominates production of tomato in Africa hence exposes the crop to biotic and abiotic stresses, resulting in yield reduction and poor fruit quality [4, 5]. Increasing population, reduced natural resources as well as extreme climate change has further worsened the glitches of food security. The focus of most plant breeding programmes is to develop and make available to end-users, crop varieties that meet their needs and capable of solving their everyday problems. Therefore, to facilitate the adoption and utilization of the end product, there is the need to take into consideration the expectations or demands of the prevailing market. Plant breeding approaches that consider active participation of farmers in the identification of their challenges, mitigation approaches and preferences in new varieties is crucial in the adoption of the resultant varieties [6].

Conventional methods of crop improvement require longer period, are time-consuming, costly, and restrict supply of genetic diversity. These challenges are exacerbated by the growth of human population (7.8 billion) in 2020, projected to nearly 10 billion by 2050 [7]. The need for strategies to increase the genetic advance in foods crops including tomatoes [8] for achieving food and nutrition security especially in Africa cannot be overemphasized. Speed breeding (SB) provides an opportunity to fast-track the breeding cycle, a key component of breeder's equation [9]. In diverse and marginal environments like Africa [10], appropriate plant breeding strategies should be developed to enhance the adoption and utilization of new varieties by farmers, consumers and industry.

The demand-led breeding approach will not only increase development of new tomato varieties but meet the needs of changing market preferences. Demand-led breeding combines the best practices in market led new variety design with innovative plant breeding methods and integrates both of these with the best practices in business as a new way of breeding crops to deliver benefits. The approach puts stakeholders especially producers and consumers at the heart of research and development by involving stakeholders even before the research starts. These 'stakeholders' are not only farmers but include other actors along the tomato value chain. They influence how the tomato is traded either as fresh food or processed product. According to ref. [11], demand-led breeding takes an integrated approach to new variety development and requires a comprehensive analysis that takes into consideration the target clients, their needs and how these may change.

This chapter focuses on different approaches to fast-track demand-led tomato breeding so as to contribute to the transformation of African agriculture, by empowering small-scale farmers to better compete in local and regional markets. It stresses on demand-led breeding and strategies to hasten breeding of tomato varieties that will be appropriate for consumers as well as other relevant stakeholders. It further discusses seed system in the sub-Sahara Africa and projects seed security as paramount in food security. It outlines the development of varieties that meet farmer needs, consumer preferences, and market demand in Africa. Finally, it outlines the challenges and prospects associated with demand-led breeding of tomato and offers suggestions to enhance food security in Africa.

2. Tomato breeding objectives in Africa

Tomato production in Africa has increased [1], but demand for the vegetable crop continues to surpass supply due to its economic relevance and growing popularity as a result of processing, value addition, and consumption [2, 5]. In Africa, less than 5% of areas dedicated to vegetable crop production including tomato are subjected to protected or controlled environments such as greenhouses [12]. Open field cultivation is paramount in tomato production in Africa [3, 13], exposing the crop to numerous biotic and abiotic stresses, causing reduction in yield and fruit quality [4, 5, 14].

Approaches to improve tomato resilience as well as productivity include breeding for resistance/tolerance to biotic and abiotic stresses and improvement of fruit quality to meet consumer/industry preferences.

2.1 Breeding for resistance/tolerance to biotic stresses

In Africa, one of the limiting factors impeding tomato production is biotic stress. This is induced by the living components of the environment [15] such as weeds, insect pests and diseases [2, 16–18]. In an attempt to address this situation, the indiscriminate use of chemicals such as pesticides which is harmful to human health [19] and the environment [18, 20] has made the demand-led breeding approach environmentally safe. Plant breeding is one of the most cost-effective and environmentally friendly methods of controlling biotic stresses in tomato production. In Africa, a number of breeding programmes have been undertaken to enable breeders develop tomato cultivars that are resistant to diseases and insect-pests [21]. In the tropics, major diseases affecting tomato production include bacterial wilt caused by *Ralstonia solanacearum*, late blight caused by *Phytophthora infestans, Stemphyllium spp* and Fusarium wilt caused by *Fusarium oxysporum* [22, 23]. Major pests of tomato include nematodes, thrips, aphid, cotton bollworm and mites [24]. Outbreaks of the tomato leaf miner (*Tuta absoluta*) have caused substantial damages in some West African countries [25, 26].

The pests and pathogens causing the above-mentioned diseases are genetically diverse with vast potential to generate new forms and hence difficult to control [16]. In view of this, conventional breeding together with marker-assisted selection (MAS) [21, 23], Quantitative Trait Loci analysis, and Hybridization [27] have been adopted for improving tomato resistance to biotic stresses. For instance, in recent decades extensive breeding programmes via the use of a series of in-region trials and collection of germplasm have been used to screen and develop varieties that are commercially acceptable and resistant to diseases [24]. Currently, the Crops Research Institute under the Council for Scientific and Industrial Research (CSIR), Ghana and West African Centre for Crop Improvement (WACCI), University of Ghana have released tomato varieties that have shown reasonable tolerance to late blight, Fusarium wilt and nematodes [28, 29].

2.2 Breeding for tolerance to abiotic stress

Similarly, abiotic factors tend to cause a myriad of considerable qualitative and quantitative crop losses to tomato production, especially in open field production. Due to threats posed as a result of climate change, tomato-producing environments are bedevilled with abiotic stresses such as heat, drought, water logging and salinity [24, 30]. Water deficit [31] and heat stress [32] are the most predominant abiotic factors that threaten tomato production in sub-Saharan Africa. Abiotic stresses can cause up to 70% yield losses [33]. Though considerable efforts have been made to ameliorate the continental menace through the use of agronomic approaches such as increased irrigation and temperature regulation, some of these efforts have proven futile over recent decades. An alternative promising approach to address these stresses is the development of tolerant tomato cultivars/lines through breeding [30]. One of the major constraints affecting tomato production is heat stress [34]. This is due to the increasing day and night temperatures as a result of climate change [35]. Breeding for heat tolerance has become one of the primary objectives of breeding programmes in

Africa [5]. In Ghana, Nkansah, King 5, DV2962 have been identified as heat-tolerant tomato cultivars [21, 32]. Currently, the CSIR-Crops Research Institute is developing heat tolerant tomato varieties with funding from the Korea government through Korea Africa Food and Agriculture Co-operation Initiative (KAFACI).

Most farmers in Africa grow tomatoes under open field conditions and as such rely solely on rainfall. Under such conditions, drought stress which is one of major constraints in open field tomato production [36] occurs due to erratic rainfall pattern. This consequently affects plant growth and development, resulting from reduced nutrient uptake [37] leading to increase in flower abscission, low percentage of fruit set, reduction in yield as well as fruit quality [38, 39]. There is therefore the need to breed and develop improved drought-tolerant varieties [38]. However, developing tomato cultivars tolerant to drought stress has been a neglected objective in many tomatoes breeding programmes [40], since the breeding objectives tend to focus much more on biotic stresses, prolonging shelf life, and determination of genetic variability among continental accessions. Although advances in molecular research and plant breeding have resulted in the introduction of drought-tolerant tomato cultivars in most developed countries, breeding efforts in sub-Saharan Africa (SSA) have focused on yield as the primary selection criteria, with little attention for drought tolerance [5, 40]. Nonetheless, a few screening trials have been conducted in countries such as Kenya to evaluate the susceptibility and tolerance of tropical cultivars derived from the AVDRC-The World Vegetable Center and the National Gene Bank of Kenya to drought stress [31].

2.3 Breeding to improve tomato fruit quality to meet consumer/industry preferences

Breeding for fruit quality is one of the major objectives of the tomato breeding programmes in Africa [41]. Due to the economic and nutritional importance of this perishable crop, breeders over the decades have put in great efforts to prolong its shelf life and organoleptic quality. Extensive studies have been reported on fruit quality traits such as the size, shape, total soluble solids, pH, colour, firmness, ripening, nutritional content, and flavour [42–44]. Therefore, tomato breeding initiatives have focused on boosting fruit quality and understanding its genetic and molecular diversity [44]. Recently, fruit colour is becoming increasingly important in the fresh market due to the awareness of the health benefits of carotenoids in the tomato fruit. Regarding processing of the tomato fruit in the industries, content of total soluble solids has also received lot of attention [44]. For instance, technologies such as pure line selection, hybridization, irradiation-induced mutation, and the crossing of local cultivars with exotic ones are ongoing breeding schemes in African countries such as Ghana to improve the fruit quality and shelf life of tomato [5, 14]. In addition, [45] reported studies on the utilization of single nucleotide polymorphism (SNPs) to evaluate the shelf life and fruit quality of F1 tomato progenies.

3. Demand-led tomato breeding

3.1 Overview of demand-led breeding

To facilitate the adoption and utilization of the end product, there is the need to take into consideration the expectations or demands of the prevailing market.

According to [6, 46, 47] plant breeding approaches that consider active participation of farmers in the identification of their challenges, mitigation approaches and preferences in new varieties is crucial in the adoption of the resultant varieties. The concept of demand-led breeding encompasses the approach whereby the situation in the prevailing market for new crop varieties considers the type of traits to incorporate into new varieties that will meet the expectations and satisfy the consumer or end-user needs. Whereas, participatory plant breeding or variety selection considers farmers involvement at different stages of the breeding programme, demand-led breeding encompasses various considerations from different actors such as processors, aggregators, marketers and consumers [48].

3.2 Demand-led principles and approaches for tomato breeding

Unlike participatory breeding that is more localized with limited scope, demand-led breeding involves more global focus. It takes into consideration a broader range of tools such as market research, value addition and modern product promotion strategies. It focuses more on the demands of the market rather than adoption for cultivation thereby producing a product that would be in high demand once released for cultivation. Demand-led approaches focus on the use of market information and intelligence to develop indices that are used to rank traits based on the monetary value and preferences from all potential end-users of the final product [49]. According to [50] demand-led variety design is based on six core principles; client needs and preferences, value chain analysis, market research, market trends and drivers, public and private sector linkages and multidisciplinary teams.

Demand-led or client-oriented breeding should consider client needs and preferences. This is crucial in considering the breeding objectives whether for industrial processing or home consumption. In Ghana, tomato production is either for processing into paste or direct consumption by consumers who purchase from the open market [51]. A demand-led programme should consider value chain analysis and innovation systems that involve all the actors in the value chain of the crop. For instance, in the value chain, common actors include farmers, aggregators or middlemen, transporters, traders, processors and consumers. Another consideration for demand-led breeding is market research. This allows the breeder to define the standard and priority for the traits or client preferences and validate the key assumptions at every stage of the breeding process. As a result, the breeder is kept abreast with the demands of the market in order to provide a product which will be readily adopted by the producers, marketers and consumers alike.

Demand-led breeding is also based on market trends and drivers which normally influence farmers' choices of crop varieties to adopt for cultivation. Prevailing circumstances and future occurrences such as climate change, national policies regarding certain commodities can all influence the kind of varieties that would be needed for cultivation [50]. For instance, a government initiative on tomato production or establishment of tomato processing factory may change the focus of variety design towards home consumption to varieties with good processing attributes. Another key principle guiding demand-led breeding is integration or linkage between private and public sector. It focuses on fostering cordial relationships between breeders and other actors in the value chain such as seed producers and distributors as well as other actors in the value chain. All these actors are involved in the identification and priority setting of client needs that result from the market research. Through this approach, breeders know what to breed for, the farmers also know what to cultivate to meet the market requirements. Farmers are also linked to ready market. This approach promotes synergies between the various actors and culminates in benefits that far exceed what can be achieved with the different actors acting independently [51]. Demand-led breeding relies on multidisciplinary teams to achieve its objective. Demand-led breeding follows an innovative approach that utilizes a broad range of expertise and competencies of different actors with specific roles towards the design and development of the proposed variety. It is expected that the different experts will contribute to the development of the ideal product profile which possesses all the desired attributes and is responsive to the needs of the target group irrespective of the gender [52].

3.3 New variety design and product profile for tomato breeding: Ghana as a case study

To facilitate large scale adoption and commercialization of a new crop variety, such variety must meet the needs and expectations of the intended end-users [53]. Therefore, product profiles are developed for such a desired variety. A product profile encompasses a number of traits in a new variety that farmers would prefer compared to the variety they are already cultivating [54]. Product profiles are developed based on the array of clients that are targeted by the breeding programme following market research or broadscale stakeholder consultation. Several factors may influence the choice of crops to cultivate or the variety of a particular crop a farmer may cultivate and these have implications on the overall product design. A study by ref. [55, 56] revealed that the number of attributes or traits preferred by tomato farmers in the Wenchi municipal was positively influenced by the gender, education level, access to credit, household size, level of education, contact with extension staff, membership of farmer-based organization, farm size and off-farm income. This implies that different varieties are likely to be adopted by farmers in the different categories. As a result, these factors need to be considered by breeders and breeding programmes in designing and developing product profiles of new tomato varieties to meet the needs of the different clientele. For this reason, a particular breeding programme can have several product profiles that will define the type of varieties that would be developed [48].

Another survey carried out in seven regions of Ghana (Bono, Ahafo, Bono East, Ashanti, Greater Accra, Eastern and Upper East regions) involving 12 tomato growing communities found that tomato farmers in these areas prefer tomato varieties with large fruit size, high rounded shaped and red in colour [51]. A similar study by ref. [55, 56], indicated that majority of the farmers interviewed prefer firmness and extended shelf-life in their new tomato varieties. Though past plant breeding efforts in tomato have focused on morphological and molecular diversity studies, screening against biotic and abiotic stresses [5], breeding objectives must target other traits that may be of benefits to a wide array of end-users. Current efforts have targeted breeding for extended shelf-life through incorporation of genes from wild relatives [21, 45, 55, 56]. Development of an early maturing tomato varieties was achieved through hybridization of cherry tomato and Pectomech, a popular commercial variety [27].

In order to meet the current market demands and changing climate, there is the need to design and develop new tomato varieties that meet the requirements of different clients. As must-have traits, all new tomato varieties must be resistant to common pests and diseases such as whiteflies (*Bemisia tabaci*), tomato leaf miner (*Tuta absoluta*), bacterial wilt, Fusarium wilt as well as resilient to the prevailing environmental conditions such as heat and drought. For home consumption, the new tomato varieties must be rounded in shape with large fruit sizes and red in colour. In order to meet the industrial market, there is the need to develop new varieties with high pulp content and/or brix for good paste production. To facilitate rapid adoption by farmers, the new varieties need to be resistant to most biotic stresses that prevail in most of the growing ecologies.

4. Fast track/speed breeding for demand-led tomato varieties

Speed Breeding involves manipulation of light, temperature, plant population and application of single seed descent method to identify major traits [57, 58]. Various methods which have been used to improve the cycle of turnover and are extensively classified as speed breeding (SB). SB is exploited in several tomato breeding programmes involving population generation, pyramiding traits, phenotyping, assessment of agronomic traits, genomic selection and genomic editing [58, 59]. Majority of the SB approaches target improvement in the tomatoes for fruit quality, fruit yield, and tolerant to stresses. Tomato is a model crop of the Solanaceae family that supports SB due to it short maturity period, diploid genome, convenience of Agrobacterium-mediated transformation thus supporting mutation breeding, CRISPR-Cas9 application [60, 61]. SB strategies used in developing demand-led tomato varieties such as Flavr Savr in America as the first engineered tomato by biotechnology method [62]. SB strategies such as marker-assisted selection, participatory plant breeding, mutation, and clustered regularly interspaced short palindromic repeat (CRISPR-/Cas9) system could be used by Africans in developing demand-led tomatoes. There is little information as to a tomato variety developed in Africa via the SB strategies. This implies that African tomato breeders must take advantage of current breeding tools.

4.1 Marker assisted breeding

Marker-assisted selection (MAS) and marker assisted breeding (MAB) progresses the effectiveness of crop improvement via accurate transfer of genomic sections of significance and hasten the recovery of the recurrent parent genome. The application of MAS and MAB support genomic selection which rely on molecular markers in assisting crop breeding. MAS in tomato improvement is traced around the 1930s [63]. MAS have been used to improve the traits that are related to disease, morphological, and physiological in most crops [59]. Specifically, in tomatoes, integration of SB into MAS results into transfer of beneficial alleles. For instance, SB and genomic led to purify tomato hybrids [64]; identify heat tolerant tomatoes [20, 65, 66].

The achievement of MAS is highly dependent on several critical issues including the number of target genes to be transferred, the distance between the target gene and the flanking markers, number of genotypes selected in each breeding generation, the nature of germplasm and the technical options available at the marker level. The power and efficacy of genotyping are anticipated to develop with the advent of markers like single nucleotide polymorphisms (SNP).

4.2 Participatory plant breeding

When farmers and other actors are involved in a breeding programme to either to participate or collaborate with scientists in every stage of the breeding programme is termed as a participatory plant breeding (PPB) [67]. PPB is recommended as a one of the breeding approaches that enhance crop improvement, empower and promote farmers right, and increases the acceptance rate when new varieties and or technologies are introduced to farmers [68–70].

Tomato is an essential crop to Africans, hence there is continual increase in demand. Therefore, PPB serves to intensify farmers access and openness to breeding of new tomatoes in Africa. Thus, PPB will aid in rapid improvement and delivery of farmers and customers preferred tomato variety [71]. In Africa, the smallholder farmers serve as the foundation for the food system [72] PPB is observed to be useful to the smallholder farmers, especially in Africa. Application of PPB strategies in Tanzania assisted in evaluating and releasing a tomato variety resistant to late blight resistant [73] PPB has the potential to improve farmers preferred tomato but it has not been fully utilized. Hence, the various actors in the tomato breeding must take full advantage of PPB.

4.3 Mutation

Mutation is among the efficient approaches for enhancing crop traits without changing the well-optimized genomic background of the crop. Mutation is used to study variation and traits of interest for improving fruit quality, male fertility and disease resistance [74, 75].

For instance, tomato variety M82 through mutation developed mutant line with a variant of eIF4E 1 showed resistance to the potyvirus strains [76]. Tomato fruits are known to be influenced by *rin* (ripening inhibitor) and PL gene that relates to fruit softening. Mutating of *rin* and silencing of PL gene results in delaying ripening. However, *rin* reduced nutritional components, flavour and colour of the fruits but PL gene had recorded otherwise [77, 78]. Tomato mutant iaa9-3 line is capable of developing parthenocarpic variety that would be seedless and of high quality [79]. Mutation resulted in generating heat-tolerant tomatoes which exhibited high pollen fertility and fruit set [80, 81]. These are evidence which support the contribution of mutation breeding to the tomato industry around the globe. Tomato breeding in Africa has not witnessed the anticipated progress hence breeders should be encouraged to use mutation.

4.4 Clustered regularly interspaced short palindromic repeat (CRISPR-/Cas9) system

Gene editing technologies (zinc finger nuclease—ZFN; transcription activator-like effector nucleases—TALENs; and clustered regularly interspaced short palindromic repeat—CRISPR/Cas) applications have witnessed some successes in some crops within the Solanaceae family [82]. These technologies aim at modifying genome by generating novel desirable alleles that will foster the improvement and subsequent release of a new varieties and/or augmenting the genetic pool of desired alleles. The CRISPR/cas9 is the desired technology due to its high specificity and low cost [83]. Gene editing in tomatoes has been successful due the availability of its genome sequence (https://solgenomics.net/organism) and its annotation [84]. Thus, resulting in several research relating to improvement to stresses (biotic & abiotic), fruit quality (nutritional value, shelf life, & colour), and plant architecture [85].

CRSPR-Cas9 was first used in tomatoes in generating the first needle-leaf mutant in 2014 by knocking out *Argonaute 7* [86]. Most products produced by gene editing have no commercial value [87, 88] but tomato is an exception [61]. Application of gene editing in tomato by Mlo1 mutant showed resistance to powdery mildew. Then again, through selfing at T0, a mutant of mlo1 T-DNA was achieved [89]. Tomato is more sensitive to fusarium wilt disease by knocking out Solyc08g075770 by CRISPR-Cas9 [90]. Similarly, tomato bzr1 mutant via CRISPR reduced the production of hydrogen peroxide (H_2O_2) which improved heat tolerance in tomato [91]. Tomato plant's response to drought has been improved through gene editing technologies by manipulating CBF1 (C-repeat binding factor 1) and MAPK3 [92, 93]. CRISPR-Cas9 application have resulted in obtaining herbicide-resistant tomatoes plants. A study by ref. [94] resulted in over 70% edited tomatoes plants exhibiting resistant to the pesticide chlorsulfuron. Similarly, CRISPR-Cas9 mutated carotenoid dioxygenase 8 (*CCD8*) and more Axillary Growth1 (*MAX1*) involved in the promotion of strigolactone synthesis, a key component required for the germination of *Phelipanche aegyptiaca* seeds thereby resulting in producing *Podalirius aegyptiaca*-resistant tomato plants [95, 96]. Fruit set in tomatoes is influenced by pollination and fertilization, a CRISPR/Cas9 via mutation developed parthenocarpic tomato which is attractive to farmers as it reduces labour cost of fruit setting [97].

There is numerous evidence that support that, CRISPR-/Cas9 system has the potential to facilitate SB in tomatoes. However, there is little evidence that show it application in Africa. Other researchers confirm that, agricultural production is low in Africa compared to other continents [98]. A study by ref. [14] recommended that Africa should embrace technologies such as CRISPER to develop novel crops such as tomato genotypes to sustain its production. It is time that Africa embrace modern breeding technologies that support SB for tomato industry to be sustained due to increase demand.

5. Tomato seed system in sub-Saharan Africa

Achieving food security is dependent on seed security as well as timely availability of quality seed in adequate quantity at the right price and time. This is very fundamental in increasing production and productivity. Population increase, depleted natural resources and extreme climate variability has worsened the problems of food security to help mitigate this problem, a functional seed system is needed. Seed systems include interrelated institutions that develop new cultivar, produce, test, certify and market the seed. An effective seed system has the potential to increase productivity in a marginal way as good quality seed alone has the potential of increasing yield of crop by up to 20–30% [99]. Tomato is a food security and high value crop that improves the livelihood and income among smallholder farmers in the sub-Saharan Africa. Farmer's access to high quality tomato seeds is the surest way to ensure a resilient tomato industry in Africa.

5.1 Types of tomato seed system

In Africa, farmers have different ways of obtaining their quantity and quality of seed which they need for production. Tomato seed system varies greatly depending on the locality, market availability and farmers knowledge on seed system and supply and can be basically grouped into formal, informal or the combination of the formal and the informal.

5.1.1 Formal seed system

Formal seed system in Africa is usually government supported with the active involvement of the public institutions (**Figure 1**). It is a holistic approach involving evaluations of genetic resources, breeding and the development of new materials, certification and distribution of the planting materials to farmers. The tomato seed system is not formalized in most parts of Africa but a form of semi-formal seed system where seed companies are involved in the distribution of imported tomato seed to farmers. In sub-Saharan Africa tomato seed is still imported from outside the continent, while local companies continue to produce seed of open-pollinated varieties. Countries like South Africa and Tanzania have a formal tomato seed system where both the government and the private sector (Seed companies) are involved in

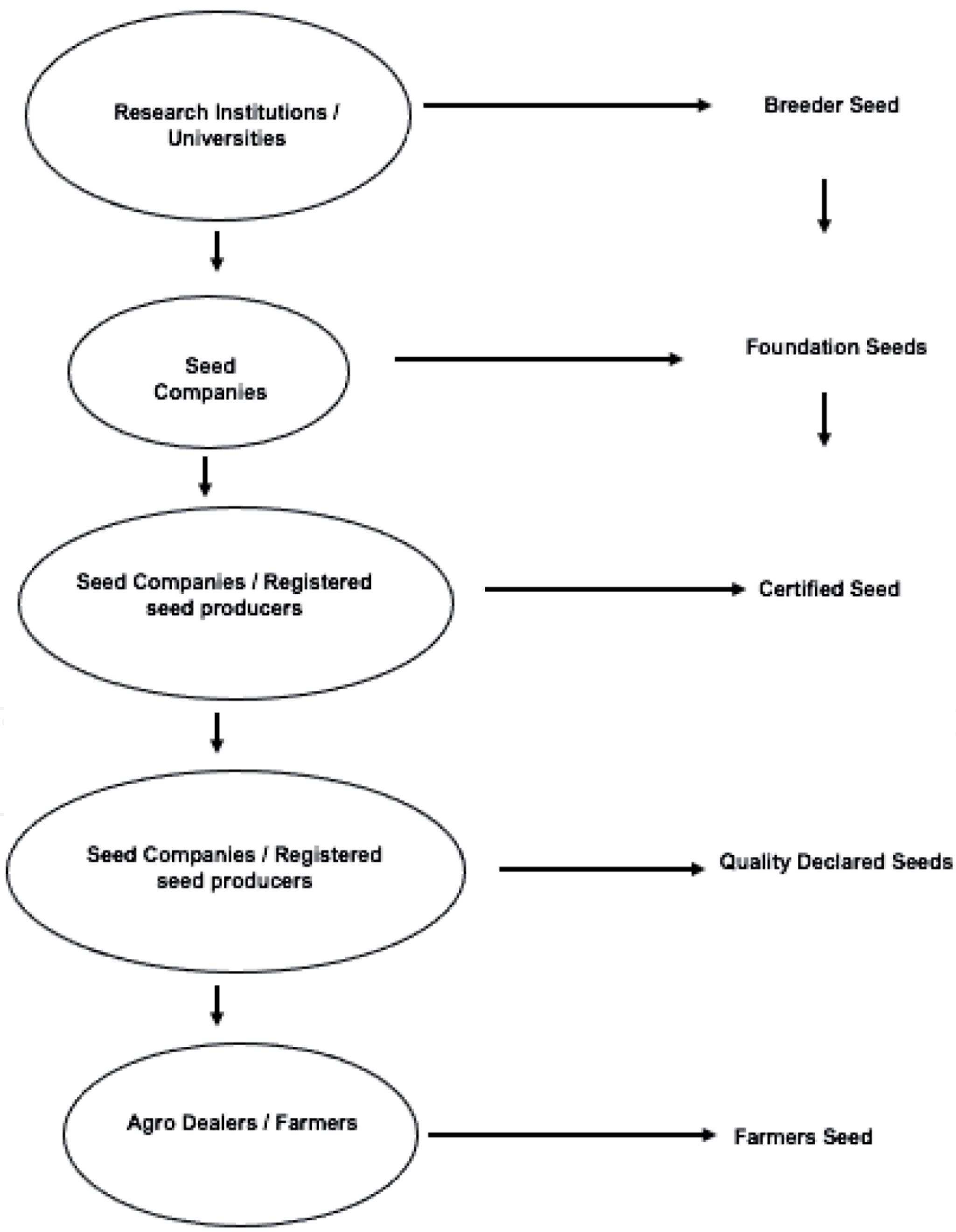

Figure 1.
Schematic distribution of the formal seed system.

the development and distribution of tomato varieties [100]. The first private seed company in Tanzania (Alpha seed) was established almost three decades ago. It was into the sale of open-pollinated tomato varieties developed by the World Vegetable Centre [100].

Currently, Tanzania can boast of about 25 vegetable seed companies involved in tomato seed production and is expected to grow from 25 million USD in 2018 to 65 million USD by 2023 [101]. In most African countries for example., Ghana and Nigeria, seed companies are involved in on-farm trials of breeding and participatory cultivar selection, seed- related research, seed multiplication, seed conditioning and quality assurance, repackaging of the seeds, storage and distribution to final end users in this case farmers [102]. Currently, in Ghana, a formal tomato seed system is about springing up due to the release of the first official tomato varieties by CSIR-Crops Research Institute, Kumasi, Ghana and West Africa Centre for Crop Improvement (WACCI) at the University of Ghana.

5.1.2 Informal tomato seed systems

The informal tomato seed system, otherwise termed as "local or farmers saved-seed system" account for about 80% of the seed stock [103] supply to the farmers. It is an unorganized system that includes identification, seed saving, seed exchange, production and distribution by the farmer according to his/her knowledge of the plant and it is highly localized (**Figure 2**). The informal tomato seed system in Africa apart from being farmer or community-based practices; also includes different local level seed production initiatives organized by either farmer group, non-governmental organization or both, working outside the formal regime of the organized seed sector. Other characteristics of the informal tomato seed sector within the sub-region includes the non-law regulatory system, farmer to farmer seed exchange and this deals with individual community with small seed quantities usually demanded by farmers [104].

In Africa, countries like Tanzania, Ethiopia, Mali, Burkina Faso, Nigeria, Kenya, and South Africa although have some kind of formal seed system for some vegetables but the tomato seed system is largely informal [24]. Farmers within these countries purchase the imported hybrid or open pollinated tomato seed from agro-dealers and seed companies to produce their own tomato seed. These seeds once they are produced are easily marketed and exchanged from farmer to farmer by irregular means for many seed generations. On the other hand, farmers after acquiring some seed production skills from the extension officers often develop their own seeds from hybrid tomatoes i.e., they advance it to the F_2 themselves for local marketing. This is usually as a result of high cost of the F1 hybrids [104].

5.2 Tomato seed value chain

A seed value chain is a series of actors or stakeholders. The value chain involves input suppliers, producers and processors, to exporters and buyers engaged in the activities required to bring an agricultural product from production to end consumer through various actors as shown in **Figure 3**. A value chain, therefore, incorporates productive transformation and value addition at each stage of any value chain. At each stage in the tomato value chain, the product changes hands through chain actors, transportation costs are incurred, and generally, some form of value is added. Tomato value chain results from diverse activities including input

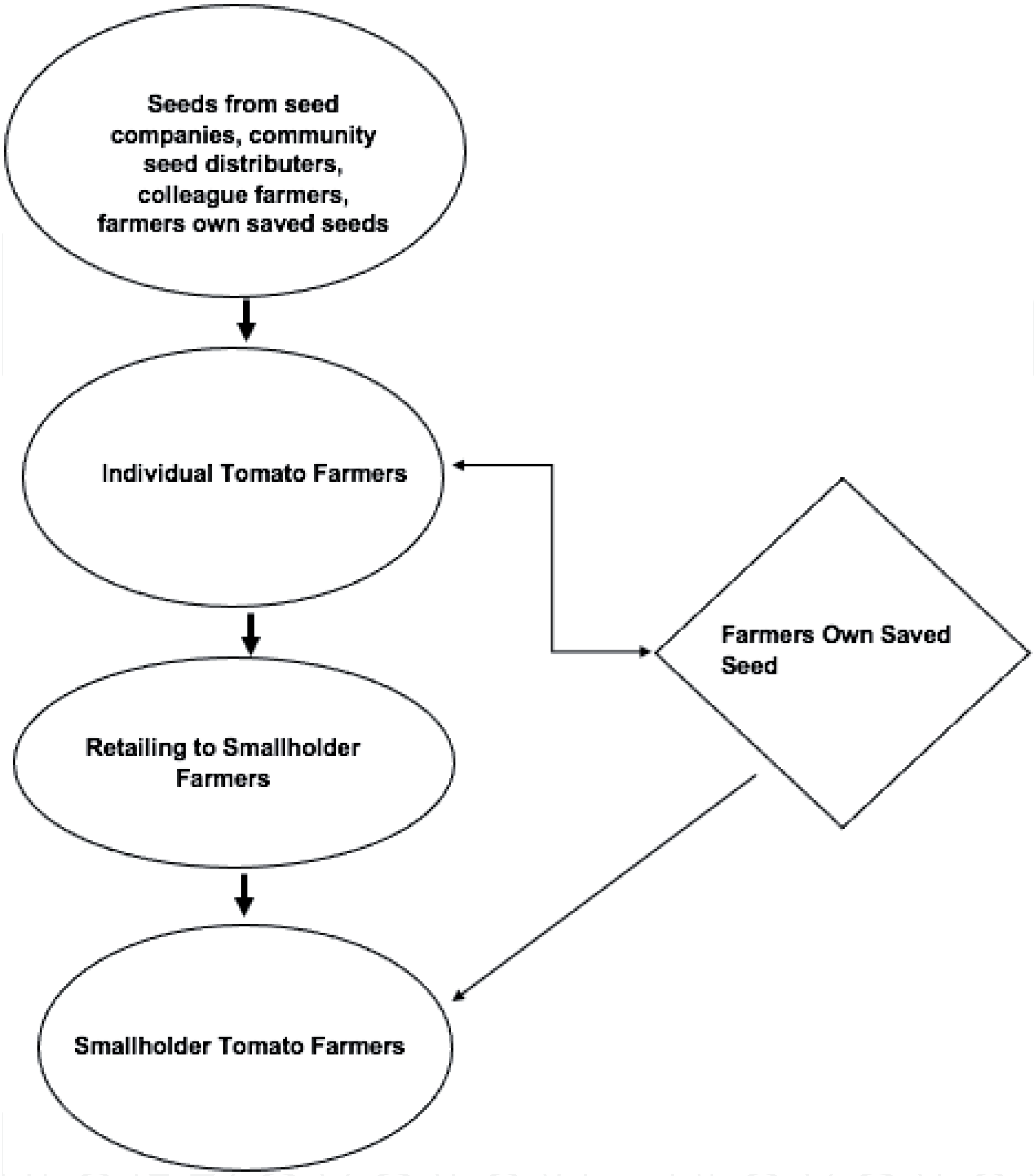

Figure 2.
Schematic distribution of the informal tomato seed system.

supply, production, transportation, marketing, processing, distributions, retailing, and consumption.

5.2.1 Input suppliers

Input suppliers are the producers of agricultural inputs such as seeds, pesticides, fertilizers, mulching sheets, etc. needed for the production of tomatoes. Through company owned, and other company dealers they sell their products to the farmers. Moreover, they also provide technical guidance on inputs usage and timely supply of inputs to the tomato farmers. They do maintain good relationships with the farmers and act as one of the informal sources of finance. Regarding the delivery of inputs like

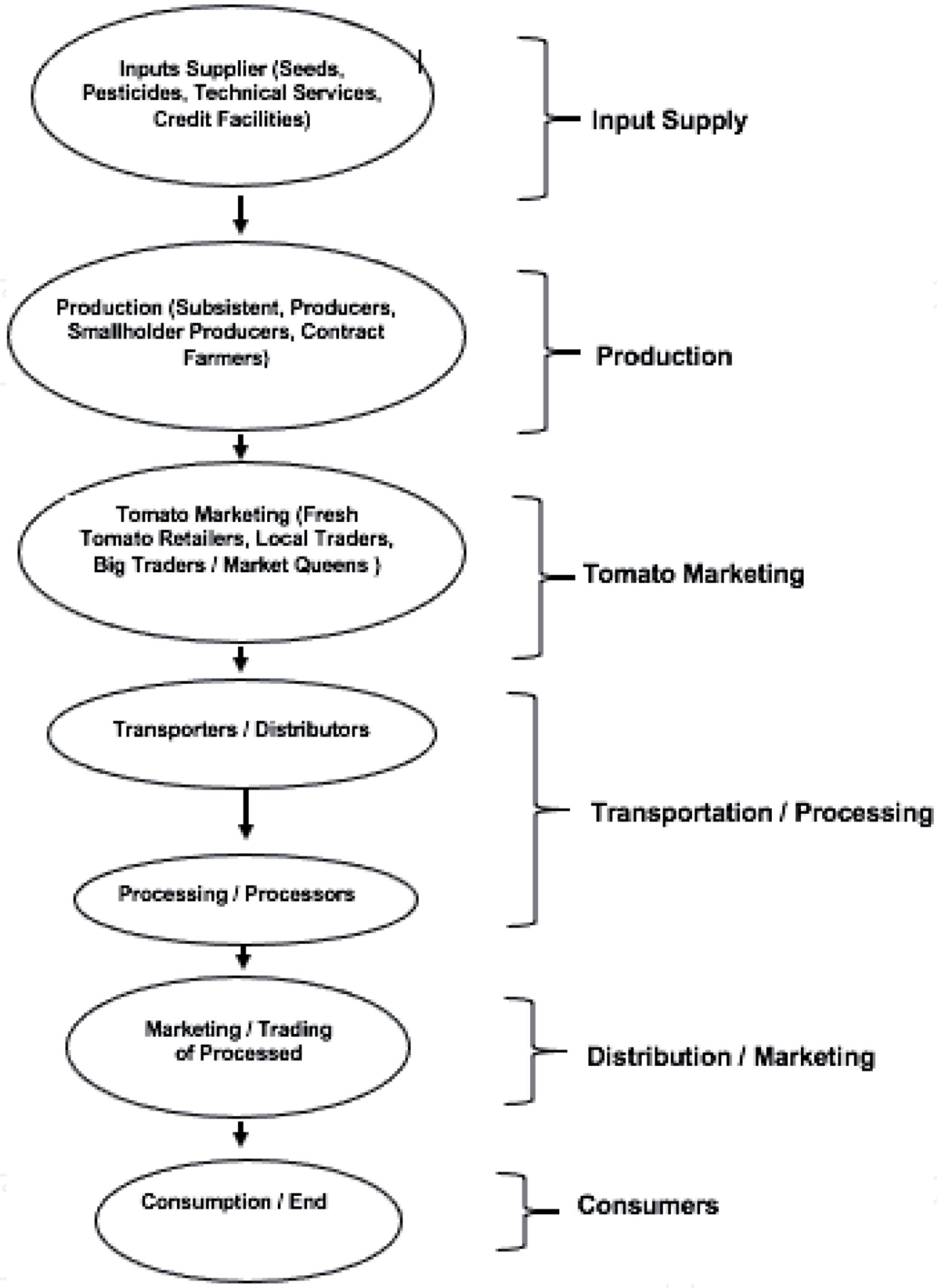

Figure 3.
Linkages and flow of tomato value chain in Africa.

improved seed, herbicides and pesticides, and credit among others, public and private extension services provide extension services to the farmers.

5.2.2 Producers

They are the initial link in tomato value chain. Producers decide what to produce, how much to produce when to grow and sell. Three types of the production system can be observed viz., subsistence production, small-scale commercial production, and largescale commercial production. Subsistence production is carried out for household consumption and produced in small quantities. The produce from the first category of farmers generally does not enter the market or enters in a very limited quantity especially in the local marketplace. Small- and large-scale commercial farmers sell most of their products to various market intermediaries. The producers generally deal with traders and wholesalers. In most cases, farmers depend on village level traders for price information.

5.2.3 Marketing

The main aggregators usually buy the initial tomato from the main farmers to a special location within the village where traders buy them and transport to desired markets. Such collection and transporting activities are carried out either by the local trader, or an outside trader regularly visiting the location.

5.2.4 Wholesalers

They usually depend on the various intermediate sized loads and put the tomatoes into large uniform units. These activities all contribute to price determination Wholesalers are market participants who buy large quantities of tomato and resell to other traders. Wholesalers often buy the tomatoes at the farm gate and other road site.

5.2.5 Processors

Processors are the secondary processing industries. The tomato processed products manufactured by the sample processors include tomato paste, sauce and ketchup. They usually collect fresh tomatoes from wholesalers and other sellers in major tomato production areas during peak season and glut in the market at cheaper prices.

5.2.6 Distributors

The distributors normally buy processed tomato products from processors and supply to small grocery stores and supermarkets. They generally sell products of different companies in different formats of retailers.

5.2.7 Retailers

They are the middlemen that include the supermarket and another large-scale retailer who divide large shipments of produce and sell it to consumers in small units. The basic function they provide is bulk breaking. Retailers are the sellers of tomatoes to the ultimate consumers through multiple channels such as small grocery stores, exclusive fruits and vegetable shops, supermarkets and exporters. They normally buy from wholesalers and sell both fresh tomatoes and other tomato processed products in smaller quantities with a higher profit margin. The retailers are the final connection that deliver tomato to consumers. They are many as compared to others and their function is selling tomato to consumers in small volumes after receiving large volumes from producers.

5.2.8 Consumers

It is the last link in the tomato market value chain. The consumers always make production meaningful and they usually set the pace for production. From the consumers' perspective, the shorter the value chain the more likely the retail price going to be cheaper and affordable. The consumers are mostly classified into individual/household consumers and larger consumers like the restaurants, hotels and local food joints [105].

5.3 Constraints in tomato seed production

In Africa, the production and supply of most agricultural commodities is seasonal and tomato is not an exception [106] This has contributed to the price adjustment of tomatoes based on the trend of supply [107] which follows the normal curve of demand and supply, as the demand increase the supply decreases and the reverse is true. In Ghana, Nigeria and most African countries where tomatoes production is considered as the game changer in both nutritional and in the economic sense, but yet cannot meet their production demand has for the past decades seen fluctuation in the rural wholesale price by a marginable percentage [108, 109].

This trend in price fluctuation of tomatoes in Africa has not only affected the quantity and quality of the tomatoes [110] but also affected the tomato seed production. The following are some of the challenges faced by tomatoes producers in the sub-region;

- Inadequate government support
- Lack of quality germplasm for fresh and processing markets
- Insufficient numbers of trained tomato breeders and seed producers
- Absence of seed laws and enabling environment
- Underdeveloped private sector and seed system
- Biotic and abiotic challenges to productivity: tomato yellow leaf curl, viruses, nematodes, heat and drought stress among others

6. Challenges and prospects of demand-led tomato breeding

The demand-led breeding approach will not only increase development of new tomato varieties but rather meet the needs of changing market preferences. Below are few highlighted prospects and challenges of demand-led tomato breeding methods in Africa.

6.1 Challenges

The major challenge for demand-led tomato breeding is lack of adequate funding covering aspects of research, training of researchers and technical officers, establishment of tomato breeding infrastructures, etc. [111]. Researchers, governments and private investors should partner to strategize and examine the potential benefits, implementation and how to sustain demand-led tomato breeding.

In addition, there is inadequate genetic resources to meet demand-led tomato breeding programmes in Africa [112]. To improve future tomato breeding programmes, countries in Africa should prioritize the collection and conservation of local landraces which possess useful agronomic genes to sustain future breeding programmes [113]. Overreliance of improved exotic tomato lines/cultivar in most African countries, however, makes demand-led tomato breeding programmes unsustainable. This is because, the imported tomato variety may not meet the actual needs of the actors in the tomato value chain.

Last but not least, well- resourced laboratories to explore modern techniques in crop improvement are lacking in Africa. Most African countries are lagging behind regarding the utilization of basic to advanced biotechnology techniques such as marker assisted selection, genetic engineering and genome editing to facilitate plant breeding programmes [14]. Demand-led tomato breeding programmes would require most of these above-mentioned techniques to reduce the time for variety development.

6.2 Prospects

Tomato breeding based on demand has the potential to gather and understand information about tomato value chain actors' preferences for single or multiple traits. In order to accomplish this, more comprehensive quantitative research methodologies will be required to identify well-informed preferred traits by tomato value chain actors. To develop excellent demand-driven tomato breeding, scouting for traits insights along the value chain is a key [49]. Furthermore, using market intelligence, a comprehensive quantitative breeding index to rank the preferred traits for demand-led tomato breeding schemes can be developed. The "monetary values, preferences from all potential breeding clients, from the farm to the consumer's table" [49] may be the basis for trait ranking. As a result, this analysis will aid in determining trait improvement priorities and maximizing not only genetic gains, but also actual variety adoption, while ensuring that released varieties have traits that are preferred by all key value chain actors and stakeholders. This strategy will hasten the adoption of new tomato varieties.

Demand-driven tomato breeding can facilitate and harness the adoption of a customer- and data-driven approach that adds value to released tomato variety, whiles meeting the actual needs of a diverse range of customers and breeding clients [114]. Thus, involving various actors along the value chain especially in the early breeding process will promote early adoption, acceptance and consumption of newly released tomato varieties. As such, this breeding method will contribute enormously in achieving broader societal goals including increased food and nutrition securities concomitant with improved health, poverty reduction, climate resilience and environmental conservation.

Again, demand-led tomato breeding can help increase the economic value for targeted tomato traits. Since, traits of significant importance to various actors in the tomato value chain are known and ranked, economic value for specific or highly ranked traits could be improved. For instance, a change in dietary preferences and requirements has caused a shift for tomato fruits with improved quality such as fruits with high lycopene content [115] and sugar level [116]. A situation where consumers' preferred traits are successfully introgressed into a newly released tomato varieties, they will be willing to pay premium prices for these tomato fruits. Thus, the market value can be increased and then improve the livelihoods of various actors in the tomato value chain.

7. Conclusion

Tomato breeding programmes have focused on breeding for resistance to biotic and abiotic constraints which cause severe yield reduction. In addition to yield, tomato varieties are also bred for quality traits such as colour, firmness, flavour and extended shelf-life to meet consumer or industry preferences. Demand-led breeding which targets consumer and market preferences is based on six core principles which need to be considered in designing new tomato varieties Attributes desired by Ghanaian and tomato producers from other African countries considered in new variety designs include pests and diseases resistance, tolerance to environmental conditions as well as for quality traits and attributes such as shape, colour, and high pulp content.

Various fast-track breeding approaches are employed for rapid progress in tomato breeding. Speed breeding techniques reduce the long breeding cycle compared to conventional tomato breeding. Examples of such approaches include marker assisted breeding (MAB), participatory plant breeding (PPB), mutation breeding and clustered regularly interspaced short palindromic repeat (CRISPR-/Cas9) system which have been used to accelerate the breeding process in tomato. Two key seed systems are common in the tomato seed value chain. These are the formal system which is regulated, and the informal system which mainly operates in the rural areas. The tomato seed system is faced with challenges such as: inadequate government support, absence of seed laws and enabling environment, under-developed private sector among others. Challenges facing demand-led tomato breeding include lack of involvement of all stakeholders in the tomato value chain. Inadequate research infrastructure, few trained personnel and inadequate genetic resources. These have limited to scope of most tomato breeding programmes to meet consumer needs.

Finally, demand-led tomato breeding has the potential to gather relevant information on the preferences of tomato value chain actors to inform breeders on what product profile to develop. Comprehensive quantitative research methodologies will help identify the requisite traits that would be preferred by current and future markets. Demand-driven tomato breeding can help breeders to design products that have the potential of satisfy consumer needs and facilitate rapid adoption by farmers and other end-users. Adequate funding, governmental support and active collaboration between researchers, private investors and farmers, and education on the potential benefits demand-led breeding are needed to implement and sustain demand-led tomato breeding.

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