African Journal of Rural Development, Vol. 4 (3): July-September 2019: pp. ISSN 2415-2838

Advances in market-oriented approaches for legume breeding in eastern Africa

P. M. KIMANI[1*] and V.M. ANTHONY[2]
[1]Department of Plant Science and Crop Protection, College of Agriculture and Veterinary Sciences, University of Nairobi, P.O Box 29053-00625 Nairobi, Kenya
[2]Syngenta Foundation for Sustainable Agriculture, B8.4 Rosentalstrasse 67 CH-4058 Basel, Switzerland
***Corresponding author:** pmkimani@uonbi.ac.ke

ABSTRACT

The overall objective of plant breeding is genetic improvement of whole plants or specific parts or traits to increase their economic value and meet needs of end-users. In eastern Africa, several approaches have been used in legume breeding ranging from classical to molecular. However, emphasis has been genetic and agronomic improvement with limited attention given to the business side. This has contributed to low adoption and utilisation of improved varieties in Africa (38%) compared to 60-80% reported in other regions of the world. Before 1985, breeding programmes were monolithic focusing on yield and disease resistance with little consideration of farmer and consumer preferences. Farmer participatory and on-farm approaches developed in the early 1990s, focused on household food security resulted in slightly improved adoption. Market-led strategy was developed in 2000, and implemented in bean breeding programmemore than 20 African countries, further improved adoption but only to modest rate of 36%. Between 2014 and 2017, a demand-led strategy was developed by a consortium of institutions. Unlike previous breeding approaches, demand-led is business oriented, and is based on six cardinal principles: client preferences, value chain analysis, market research, market trends and drivers, integration of public and private sector expertise, and a multidisciplinary approach in variety design and solution development. Case studies of breeding pigeonpea, dry and canning beans indicate that application of this approach requires breeders to learn new skills, working with non-traditional partners and understanding market dynamics.

Key words: Adoption, demand-led, breeding, East Africa variety, development

RÉSUMÉ

The overall objective of plant breeding is genetic improvement of whole plants or specific parts or traits to increase their economic value and meet needs of end-users. In eastern Africa, several approaches have been used in legume breeding ranging from classical to molecular. However, emphasis has been genetic and agronomic improvement with limited attention given to the business side. This has contributed to low adoption and utilisation of improved varieties in Africa (38%) compared to 60-80% reported in other regions of the world. Before 1985, breeding programs were monolithic focusing on yield and disease resistance with little consideration of farmer and consumer preferences. Farmer participatory and on-farm approaches developed in the early 1990s, focused on household food security resulted in slightly improved adoption. Market-led strategy was developed in 2000, and implemented in bean breeding program more than 20 African countries, further

Cite as: Kimani, P.M. and Anthony, V.M. 2019. Advances in market-oriented approaches for legume breeding in eastern Africa. *African Journal of Rural Development* 4 (3):

Received: 24 June 2019
Accepted: 03 September 2019
Published: 30 September 2019

improved adoption but only to modest rate of 36%. Between 2014 and 2017, a demand-led strategy was developed by a consortium of institutions. Unlike previous breeding approaches, demand-led is business oriented, and is based on six cardinal principles: client preferences, value chain analysis, market research, market trends and drivers, integration of public and private sector expertise, and a multidisciplinary approach in variety design and solution development. Case studies of breeding pigeonpea, dry and canning beans indicate that application of this approach requires breeders to learn new skills, working with non-traditional partners and understanding market dynamics.

Key words: Adoption, demand-led, breeding, variety design

INTRODUCTION

The overall objective of plant breeding is genetic improvement of whole plants or specific parts or traits to increase their economic value and meet needs of end-users. In eastern Africa, several approaches have been used in legume breeding ranging from classical to molecular. However, emphasis has been on genetic and agronomic improvement with limited attention given to the business side. This has contributed to low adoption and utilisation of improved varieties in Africa (38%) compared to 60-80% reported in other regions of the world. The overall goal of public policy in most countries in eastern Africa is not only to accelerate growth of the agricultural sector, but also to transform it from subsistence to an innovative, commercially oriented modern agriculture (GOK/ACDS, 2010; ADB, 2018). Public policy, production environment, consumer behavior, urban migration, lifestyles, technological advances and population growth are key drivers of the transformation in the agricultural sector. Transformation of smallholder agriculture in Africa demand a change or at least a re-orientation of breeding strategies and training of breeders. The development and growth of the agricultural sector is anchored in two strategic thrusts: i) increasing productivity, commercialization and competitiveness of agricultural commodities and enterprises, and ii) developing and managing key factors of production. This implies that new varieties should not only be productive, but also must have market demanded traits, especially those that add to their competitiveness compared to existing varieties. Predicted challenges due to climate change and variability, and declining soil fertility in production environments, demand that future varieties must be more resilient to temperature fluctuations, moisture stress, water logging, and should have better nutrient use efficiency and resistance to emerging strains of fungal, bacterial and viral pathogens, pests, which are key components of climate smart agriculture (FAO, 2010; AGRA, 2014).

Smallholder farmers are generating surpluses of products to sell in local, regional and international markets (AGRA, 2014). However, effective participation in local and regional markets requires accurate identification of market demands, and developing products with suitable characteristics to meet market requirements. Demand for products is rising with population growth, urbanization and changing lifestyles. Africa imports food worth US$40 billion per year. By 2030, World Bank estimates food market for middle class will be US$1 trillion. Consumers are becoming more health conscious; selective of food they buy and are ready to pay for quality. Projections based on population growth and food consumption patterns indicate that agricultural production will need to increase by at least 70 percent to meet demands by 2050 (FAO, 2010). Agriculture in developing countries must therefore undergo a significant transformation in order to meet the related challenges of achieving food security and responding to climate change. Although all breeding programmes are client oriented, the degree differs (Witcombe *et al.,* 2005). Moreover, few programmes adopt the more demanding techniques required to meet client needs effectively. Even fewer consider the full range of the needs of most, or all actors along a commodity value chain.

Several approaches designed to create varieties that better respond to farmer' needs and preferences and to accelerate adoption of new varieties have been used by breeding programmes in Africa and other regions in the world over the last two decades. In eastern Africa, approaches used in legume breeding range from classical to molecular. The objectives of this paper are, i) to briefly review the evolution of client oriented breeding in eastern Africa from 1970 to 2000 with emphasis on legume breeding; ii) Present evidence of progress made from 2001 to date, and iii) highlight the new directions in market oriented breeding in the region.

Market oriented breeding approaches before 1970s. Breeding programmes in eastern Africa before 1970s largely followed top down, traditional approaches in which breeders made all decisions on variety development. New varieties were disseminated through extension services. Smallholder and large scale commercial farmers basically had no contribution in the variety development process and relied wholly on extension officers for variety and management recommendations. Examples of such programmes include maize improvement at Njoro before 1939, and at Kitale from 1959 (Harrison, 1970). Others include cotton improvement at Ukiriguru in the Lake region of Tanzania which started in 1939, and at Namulonge in Uganda (Arnold, 1970). As Arnold notes, cotton improvement, production and ginning was controlled by government. The government provided seed to farmers and bought seed cotton from them. No individual was permitted to gin his/her own produce, but must deliver his seed cotton to a buying post. Similar control applied to other 'cash crops' such as coffee, tea and pyrethrum. The situation for food security crops was not much different. The programmes were conceived, developed and implemented by government officers including breeders and agricultural extension officers. For example, bean improvement work in eastern Africa was based on a World Health Organization recommendation that a crop improvement programme for pulses be initiated (Leakey, 1970). The pulse improvement work was concentrated in Uganda, where Mukasa was assigned to work full time as a breeder at Kawanda Research Station. He was later joined by Leakey as a pathologist in 1961. For sorghum, early improvement work was done by government botanists and agricultural officers from Kenya, Uganda and Tanzania (Dogget, 1970). They made collections of local sorghum cultivars, screened them, and then multiplied the best yielding ones for distribution. From these collections, some good local types were found. In Uganda, L28 and T15; Bukura Mahemba and Msubiji in Tanzania, and Dobbs variety which originated from Nyanza in Kenya, were the best known varieties. The then Tanganyika government started a sorghum breeding program at Ukiriguru in the Lake Region from 1948 to 1957. In 1958, the sorghum work was taken over by the East Africa Agricultural and Forestry Organization (EAAFRO) and moved to Serere Research Station in Uganda.

The role of Lord Delamere on wheat improvement in eastern Africa, is probably an exception. Wheat improvement at Njoro, Kenya, is probably the earliest breeding programme in eastern Africa. This programme was initiated in 1907 by Lord Delamere, a large scale wheat and dairy farmer (Guthrie and Pinto, 1970). Delamere lost more than 1200 acres grown with wheat varieties introduced from Australia, Italy, Canada and Egypt, which succumbed to stem rust (*Puccinia graminis f.sp tritici*) and yellow rust (*Puccinia striiformis* Westend (Guthrie and Pinto, 1970). Delamere responded by hiring a plant breeder, Evans. For several years, Evans was employed by Delamere, and later by the Department of Agriculture. Evans developed a wheat cultivar called Equator from crosses involving Australia cultivars Gluyas, Thew and Bobs, the Italian Rieti, Red and Yellow Fife from Canada, and the durum wheat cultivar, Egypt 3. Evans work was later taken up by the government in 1915.

1970s to 1990s. Despite the progress in developing improved varieties before 1970, adoption was very low especially among smallholder farmers. These farmers practiced subsistence agriculture focusing mainly on food crops. They were probably neither aware of the improved varieties nor the benefits they provided. In some cases, the improved varieties were not available when needed, or not appropriate for the diverse farming systems, ecologies and end-uses. Moreover, breeding programmes and seed delivery systems focused on crops produced by large scale farmers where more profitable bulk sales could be made. However, considering the bulk of the farming population were smallholder farmers, new approaches were needed to develop varieties that better responded to the smallholder needs. This led to on-farm testing of breeding materials in the 1970s and 1980s. The objective of on-farm testing was to involve farmers during technology development, understand their preferences and to test new materials under farmers' conditions. On-farm testing gradually evolved into participatory plant breeding in the 1990s. Breeding short duration pigeonpea for semi-arid regions in eastern Kenya illustrates the role of on-farm testing in variety development (Onim, 1983; Kimani, 1990).

The case of Pigeonpea. Pigeonpea (*Cajanus cajan* L. Millsp) is woody perennial legume, which is grown as an annual in eastern Africa by smallholder farmers in Kenya, Tanzania, Uganda, Malawi, Mozambique and in other countries to a lesser extent. It is particularly valued by these farmers because it is drought tolerant and is a source of protein, fire wood, livestock feed and even construction materials. There were no improved varieties in the region up to 1980 (Kimani, 2001). Farmers relied on tall (up to 3m), traditional varieties that took up to 11 months to mature. These landraces were susceptible to Fusarium wilt (*Fusarium udum*), leafspot (*Mycovellosiela cajani*) and insect pests, especially pod borers, pod suckers and pod fly. The first pigeonpea programme in the region was initiated in 1968 at Makerere University in Uganda, to breed short-duration, high yielding grain type cultivars (Khan and Rachie, 1972). The Ugandan programme was disrupted by civil strife between 1973 and 1986. Although no cultivars were released from this programme, some of the materials were used to initiate the breeding programme at the University of Nairobi in 1975. The objectives of the University of Nairobi programme was to develop varieties with improved grain yield, earliness, reduced plant height, resistance to Fusarium wilt, large cream or white seeds, drought tolerance and suitability for intercropping (Kimani, 2001). The early stages of the University of Nairobi programme focused on germplasm collection and evaluation, followed by on-farm testing and participatory selection, and later on hybridization and selection (Kimani, 1990; Kimani, 2001). Earlier attempts to popularize early maturing varieties from ICRISAT, India failed because farmers rejected the varieties, despite their early maturity and short stature, due small seed size and brown or tan seed coat colours. Moreover, the Indian cultivars were not suitable for intercropping, losing up to 80% of their grain yield when intercropped with maize (Onim, 1981). The first early maturing cultivar developed was NPP670, which originated from crosses made in 1977 between early maturing lines from ICRISAT and West Indies, and locally adapted landraces. This variety was disseminated and adopted in Mbeere, Kirinyaga, Embu and Kitui Counties, where is it popularly known as 'Katumani' pigeonpea. Seeds were disseminated through formal channels in early stages, and by informal channels from 1987 (Kimani, 1990; Kimani and Mbatia, 1990). It became very popular with farmers because of its earliness, large cream seeds (19 g per 100 seeds). NPP 670 yields about 1 t ha^{-1}, but requires spraying against insect pests (Kimani, 2001) and reduced height (about 1m tall).

ICRISAT conducted a survey in 1996 to determine the adoption of NPP670 and factors which influenced its rapid diffusion in three sub-locations (Karaba, Riakanau and Wachoro) in Mbeere County, which is in the semi-arid eastern Kenya (Jones *et al.,* 2001). Farmers in this region grow the traditional indeterminate local varieties that mature in about 11 months. NPP670 is determinate and matures in 5 to 6 months, and produces a second harvest about two months later. It was first introduced into this area by the University of Nairobi in 1986. They reported that within a relatively short period of 10 years, virtually all the farmers in the study area knew about NPP 670. More than 75% of those were interviewed had grown the variety. Adoption rates varied from 73% in Karaba to 96% in Wachoro (Jones *et al.,* 2001). They attributed the rapid diffusion and adoption to four factors. First, NPP 670 was easily distinguishable from local pigeopea varieties because of its determinate growth habit, short-stature and bold-white seeds. Secondly, the high market value of the crop due its attractive bold white seeded grain, and its availability before the main pigeonpea harvest; thirdly, the earlier maturity of NPP 670 makes it less susceptible to terminal drought stress in an area where long rain season which occur in March to June are unreliable; and fourthly, the ease with which farmers were able to maintain the seed purity. More than 30 years since NPP 670 was introduced in this region, farmers have continued to maintain the variety, produce and market their seed through an informal seed system. Diffusion has continued to the drought-prone areas of neighbouring Kirinyaga and Muranga counties. Apart from the initial injection of seed by the University of Nairobi Pigeonpea Improvement Programme, which was facilitated by the extension service, neither the formal seed system nor the extension service has played a major role in the diffusion process. Jones *et al.* (2001) noted that other factors that contributed to the rapid diffusion was the willingness of people to pay for the seed and the relatively low planting rate (<15 kg ha^{-1}). NPP 670 was officially released in 1999, more than 10 years after it was first tested with farmers in semi-arid regions of eastern Kenya (Jones *et al.,* 2001).

THE 1990S: PARTICIPATORY PLANT BREEDING. Farmer participatory research, which became prominent in the 1970s and 1980s, was followed by various forms of participatory breeding approaches. Participatory plant breeding was developed as a distinct breeding approach in the 1990s. In its broadest sense, it can be defined as the involvement of farmers and other end-users in the process of developing improved varieties of crop plants. It has also been defined as 'approaches that involve close farmer-researcher collaboration to bring about plant genetic improvement within a species' (Weltizien *et al.,* 2003). Involvement of farmers in crop improvement is neither new nor revolutionary (Ceccareli *et al.,* 2000). Farmers have been selecting improved crop varieties since their wild progenitors were domesticated more than 10,000 years ago, and therefore long

before the science of plant breeding developed as a distinct field of professional studies.
During the last two decades of the 20th century, researchers felt the need to involve farmers and other end users of their products in the research process. This was partly due to failure to make desired changes in improving crop productivity, despite release of many crop varieties. Specifically, adoption rates were generally low, and in some cases, farmers stopped growing some of the recommended varieties altogether and reverted to the old varieties. Initial experiences indicated that involving farmers and other end user may be a useful research strategy because it could enhance understanding of their preferences, improve targeting of germplasm to specific niches and user-needs. In addition, involving farmers could reduce pressure for land in research stations and labour costs, and improve adoption of new varieties. Researchers in public research centres were under pressure to demonstrate results in farmers' fields. The pressure increased as percentage of people living under the poverty line rose, instead of the expected decrease with dissemination of relevant research products. A consensus gradually emerged that empowering farmers through strengthening decision making, skill building and improved access to local and introduced germplasm, could be achieved through their involvement in participatory crop improvement programs. Participatory bean improvement in eastern Africa is an example of such an attempt to empower farmers by involving them during, rather than at the end of the variety development process.

Case of participatory bean improvement in eastern Africa. The overall objective of participatory bean improvement in east and southern Africa was to develop higher yielding, marketable bean varieties with resistance to major biotic and abiotic stresses, and with acceptable organoleptic and cooking characteristics (Kimani *et al.,* 2005). Improved bean varieties should be compatible with major cropping systems, and with broad or specific adaptation to one or more of the major agroecological zones.

Before 1985, breeding activities focused mainly on developing cultivars of dry bush beans with little collaboration between countries. These programmes followed traditional approaches of introduction, mass selection and limited hybridization (notably in Uganda) followed by selection by breeders and on-station testing of promising lines in preliminary, intermediate and national performance trials (Kimani *et al.,* 2005). Best lines compared to landraces were released formally by national variety release committees and their seed multiplied and distributed by publicly owned seed companies or seed projects. In the initial stages, farmers were not involved in the variety design, selection or testing and were expected to grow the officially released varieties as recommended by extension agents. It soon became evident that most farmers failed to adopt the improved varieties and continued to grow their own selections or landraces (Sperling e*t al.,* 1993). In other cases, lines selected from introductions because of excellent resistance to diseases had poor seed and plant characteristics. In all, farmers complained that new varieties were poorly adapted to their growing conditions and did not meet other important requirements including cooking quality, taste, physical appearance and compatibility with cropping systems. Supply of seeds of these new varieties was erratic and did not reach farmers in remote regions, if at all in good time for planting. Indeed, the few successful varieties were selections from the land races, which had retained most of the attributes of their parental populations. The need to involve farmers in the evaluation of the new cultivars was realized and researchers included on-farm tests as part of their cultivar development programmes. However, this feature was incorporated, as the last step prior to release of new varieties, and in most cases was not meticulously followed. It was not a condition for releasing new varieties. The overall result for this period was poor adoption of new cultivars and lack of significant impact, which in turn contributed to frustration among national scientists, extension officers, farmers and policy makers.

Beginning 1985, the International Center for Tropical Agriculture (CIAT) in collaboration with national programmes, while emphasizing the significance of farmer involvement in on-farm trials, started in earnest to experiment with farmer participatory methods in variety development. The first programme started at Rubona in collaboration with the Rwandese Institut des Sciences Agronomiques du Rwanda (ISAR). This programme was initiated to compare the performance of farmer selected cultivars using a system of farmer participatory selection with those selected by breeders under the conventional breeding scheme of on-station and on-farm testing. Evaluation of the two approaches was based on on-farm yields, long-term varietal use, maintenance of genetic diversity and the costs of the screening process (Sperling *et al.,* 1993). The trial was conducted at three ISAR research stations: Rubona (1630m), Rwerere (2300m) and Karama (1400m). Rubona with a bimodal rainfall of about 1170mm, and Rwerere have more fertile soils and adequate moisture for bean production. In contrast, Karama is located in semi-arid region with less fertile sandy soils and frequent droughts. Disease pressure is generally higher at Rubona and Rwerere due to high humidity. The on-station trials were designed not only to screen sets of cultivars for their farmer acceptability, but also to encourage dialogue among breeders, pathologists and farmers, and to determine the correlation between farmers' and breeders selection criteria. The on-farm trials compared performance of farmer-selected cultivars with those selected under the conventional scheme.

Results showed that farmers selected for a range of characteristics. They selected, not only varieties with higher yields, but those in the middle range. Selection was based on preferences of plant aspects they valued, and performance and uses in different and diverse home conditions. Main selection criteria in addition to yield were earliness, grain colour and seed shape. Grain type was important for varieties destined for markets, which preferred uniformity. Performance traits selected for included adaptation to cropping systems, tolerance to poor soils, pod clearance and disease (''rain'') tolerance. Some varieties were judged as appropriate to large areas within a region, while others were appropriate for specific niches. For example, in Karama, farmers selected a variety they believed was drought tolerant, while at Rwerere, the same variety was rejected because of its late maturity (and hence susceptible to terminal moisture stress). This implied a need to decentralize selection early in the screening process to cater for regional variability. Farmers selected 21 bush bean cultivars, which outperformed their local mixtures 64-89% of the time, with average production increases of up to 38%. Although breeders selections could not be compared directly with those of farmers (since few comparable on-farm trials were conducted in the same region and years), comparisons with data from trials conducted in 1987-88, showed that varieties selected by breeders outperformed local mixtures in 34-53% of the time with insignificant yield increases in one region. However, they out yielded local mixtures by up to 8% in 41-51% of on-farm trials countrywide.

Analysis of survival rates three to six seasons after the first on-farm testing, showed that farmers' selections compared favourably with the very best of releases from ISAR's standard programme. Farmers' selections had a 71% chance of being grown compared with a popular bush bean variety ''Kilyumukwe'' in the Central Plateau (Sperling and Loevinsohn, 1993). Longer retention of farmers' selections was attributed to their compatibility with local mixtures (Sperling, 1993). About 32% of the varieties were found in newly constituted mixtures, and 35% had been incorporated into the existing blends. An added benefit of this compatibility is broadening or maintaining the existing genetic diversity. Results also indicated that farmers were indeed aware of genotype x environment (G x E) interactions, a common hurdle in breeding for marginal, low input areas (Ceccareli *et al.,* 2000). They were able to predict, with some accuracy, on-farm performance from what they observe on-station. This program was later expanded to the adjacent bean farmers in eastern region of the Democratic Republic of Congo.

Regional networks. Development of regional networks was another crucial step in institutionalizing and promoting participatory approaches in bean improvement and also in ensuring research benefits were shared across national boundaries (Kimani *et al.,* 2005). Two networks were created in the mid 1980's soon after the arrival of CIAT scientists in the region. These were East African Bean Research Network (EABRN) comprising the national programmes of Uganda, Kenya, Tanzania, Ethiopia, Sudan, Madagascar and Mauritius, and RESAPAC which catered for Rwanda, Burundi and DR Congo. In 1995, RESAPAC and EABRN were replaced by the East and Central Africa Bean Research Network (ECABREN) with a responsibility of nine countries (DR Congo, Uganda, Rwanda, Burundi, Kenya, northern Tanzania, Sudan, Madagascar and Ethiopia). At the same time the Southern Africa Bean Research Network (SABRN) comprising national programmes of Angola, Botswana, Lesotho, Malawi, Mozambique, South Africa, southern Tanzania, Swaziland, Zambia and Zimbabwe was formed. These networks provided forum for exchange of information, materials and technologies. Technologies developed in one country could be used in another country with similar conditions. For example, although climbing bean production technology was originally developed in Rwanda, it spread rapidly to Kenya, Uganda, Congo, Ethiopia, Malawi and Tanzania facilitated by exchange of visits, meetings, publications and germplasm. Regional working groups were created with representation from all member countries. Breeding and constraint nurseries were constituted and made available to all countries. Variety releases increased considerably. However, most of the germplasm originated from CIAT bean programme and later from regional programme in Uganda, which served as the distribution hub for the region. Unfortunately, due to a constant and regular flow of germplasm from CIAT, many national programmes failed to initiate crossing programmes or create new breeding populations.

From 2000: Market-led breeding. Despite the success in developing and releasing new bean cultivars using participatory approaches among the network members, a bean market research study revealed a need to develop cultivars that were more responsive to market demands (Kimani *et al.,* 2005a). This was based on the observation that although most smallholders grew bean for their domestic consumption, sizeable quantities were traded in domestic, regional and international markets. It was evident that increased production was driven not only by need to meet food needs for households, but also to generate income from sale in their localities (neighbours, retail traders, schools and other institutions), larger domestic markets in urban centres, regional and international markets. For example farmers in northern Tanzania, eastern and south western Uganda were producing red mottled bean for sale in Nairobi and other urban centres in Kenya; in Rift valley region of Ethiopia, farmers exported over 90% of navy bean; in Madagascar farmers were producing the large white bean mainly for export; and eastern Congo farmers produced bean for sale to neighbouring Rwanda and Kinshasa. Moreover, preferences for bean types differed with markets, countries, regions and no one variety could be expected to meet the diversity of market needs. Production priorities differed among countries in response to consumption preferences and market demands. To respond to these challenges, a new decentralized breeding strategy was developed in mid 2000 (Kimani *et al.,* 2005b). The overall strategy was to develop breeding programmes for the seven most important market classes following participatory approaches (Table 1). For each programme, breeding objectives and methods were defined; germplasm requirements to meet breeding goals, the expected outputs, lead National Agricultural Research Systems (NARS), collaborating partners and test sites were identified and described (Table 1). Lead NARS were selected on the basis of importance of a particular market class in their country, interest in providing regional leadership and presence of other comparative advantages. Collaboration in each programme was open to all NARS, farmers, non-governmental organizations, seed companies, processors, exporters and other stakeholders. Test sites were selected to represent the major bean growing environments for each market class, which were previously defined and described by Wortmann *et al.* (1998).

The strategy was approved by the ECABREN steering committee in 2001, and subsequently by respective steering committees for southern Africa and West African countries. It has been operational for the last 19 years. The market-led breeding programmes incorporated aspects of participatory approaches and has been adopted by programmes and guided research in more than 28 African bean producing countries. This approach was designed not only to respond to local farmer preferences, but also to meet market demands with potential for production across countries (Kimani *et al.,* 2005). Market led breeding was informed by regional surveys that showed similarities in production conditions and preferences (Wortmann *et al.,* 1998). Lines developed by one country were available for validation and release by other member countries. This contributed to unprecedented release of new varieties in more than 20 bean producing countries in east, central, southern and west Africa from 2001 to the present (Buruchara *et al.,* 2011). However, the level of commercialization has remained low, partly because of the limited attention to client focused variety design, product profiles and performance standards which are critical in refining the breeding goals and objectives, and ultimately influence performance in the market. In addition, although dry bean for household consumption remains the dominant market class in most countries, demand for snap bean and runner bean (*Phaseolus coccineus* L.) for fresh market and processing, canning beans, and niche market grain types such as yellow, speckled sugars is rising in countries where they were previously considered as minor market classes as predicted by Kimani *et al.* (2005a). These types of beans received little attention except at the University of Nairobi where considerable progress has been made in the last decade as described in other sections of this paper.

From 2010 To Date: Towards the demand led approach. A review of breeding approaches in crop improvement in eastern Africa in the last three and a half decades reveals several gaps. First, breeding objectives were largely based on producer preferences with limited attention to other end users such as processors, traders and diverse consumer needs. To some extent this led to skewed goals and objectives. Secondly, participatory approaches often targeted marginal environments where farmers cannot modify their environments. For example, decentralized selection was defined as selection in target environment (Ceccareli and Grando, 2007). However, Witcombe *et al.* (1999) recognized that despite the lower benefits for participation in more productive environments, the range of

Table 1. Decentralized, market-led bean improvement programs in East and Central Africa

Program	Production (ha) (Africa total > 4 million ha)	Priority constraints*	Program Leader	Collaborators**
Programme 1. Red mottled	740,000	ALS, Anth/RR, low N and P, drought, BSM	Uganda	Kenya, DR Congo, Rwanda, Madagascar, Tanzania, Sudan,
Programme 2A. Large red kidneys	350,000	ALS, Anth/RR, low P and N, Bruchids	Tanzania	Ethiopia,Rwanda, Kenya, Madagascar, Uganda, Burundi, Sudan
Programme 2B. Small and medium reds	670,000	Rust, ALS, RR, low P and N	Ethiopia	Rwanda, Burundi, Kenya, Uganda, Tanzania, DR Congo, Madagascar, Burundi
Programme 3. Cream 3 A. Pinto 3 B. Sugars/cranberry 3 C. Carioaca	360,000	Pinto : Rust, CBB Sugar : Rust, CBB, HB, ALS, low N and P, Bruchids	Kenya Congo Ethiopia	Kenya, Ethiopia, Uganda, Madagascar, DR Congo, Rwanda
Programme 4. Climbers	40-100,000(?)	Anth., ALS, Aschochyta, BCMV, RR, HB, low P and N, drought	Rwanda	Burundi, DR Congo, Kenya, Uganda
Programme 5. Snaps 5A. Bush 5B. Climbers 5C. Runner Climbers	?	Rust, RR, ALS, BCMV, Anth,, BSM, thrips and nematodes	5a. Uganda 5b&C: Kenya	Kenya, Uganda, Tanzania, Ethiopia, Madagascar, Burundi
Programme 6A. . Navy	310,000	Rust, CBB, ALS, Anth, drought, low P and N, BSM	Ethiopia	Leader: Ethiopia, Collaborators: Kenya, Sudan, Uganda, Tanzania, DR Congo
Programme 6B. Large white kidney	220,000	Rust, ALS, Anth, low N and P	Madagascar	Leader: Madagascar, Collaborators: Tanzania, DR Congo
Programme 7. IIIa. Yellow IIIb. Brown IIIc. Tan	380,000	ALS, Anth/CBB, RR, rust, HB and low N and P	D R Congo	Angola, Tanzania, Kenya, Madagascar, Sudan
Programme 8 Parental source nurseries		Als, Anth, RR,Rust, Low N, pH and P	University of Nairobi	ALL
§BILFA		Low N, Low P and Low PH	D R Congo	ALL
§BIWADA		Drought and earliness	Tanzania	ALL

*Anth=anthracnose; ALS= angular leaf spot; RR= root rots; P=phosphorus; N= nitrogen; CBB= common bacterial blight; HB=halo blight; BSM= bean stem maggot; A slash (/) between two constraints indicate equal importance; § BILFA, Bean improvement for low soil fertility soils in Africa; BIWADA, Bean improvement for water areas in Africa

Source: Kimani *et al.,* 2005b

client needs was more diverse.

Thirdly, breeding approaches failed to consider needs of all actors in a value chain. These approaches were largely limited to supply side. Fourthly, because the approaches were highly localized and specific, several selection schemes each targeting a different environment are required. Fifthly, the approaches targeted local food security and not processing and commercialization. Sixthly, sustainability beyond the project period was not guaranteed. There was no exit strategy. Most of the breeding projects were and still are supported by external donors with little input from national governments and commercial sector. Consequently, these programmes ended with donor support, which was detrimental because of the long term nature of plant and animal breeding activities. Furthermore, these projects were poorly linked to private sector. Consequently synergy and learning opportunities were lost. Seventh, market research was not used to define the performance standard. Few programmes were aware of the value of market research in defining their objectives, performance standards, diversity of market needs and their implications. Consequently, research products did not match the market demands. This contributed to poor adoption and limited commercialization of these products. The primary focus was productivity and not market demands. Eighth, the regulatory agencies responsible for testing and validation of candidate varieties were not in sync with advances in plant breeding and used productivity as the over-riding release criteria. Thus, varieties identified through participatory plant breeding were not recognized by regulatory agencies despite having unique traits valued by end users such as taste, cooking time, grain type and plant architecture. Finally, many breeding programs did not consider seed supply and tracking adoption as part of their activities (Schnell, 1982; Witcombe *et al.,* 2005). Demand led approach was developed in last three years to address some of these limitations (Kimani, 2017; Parsley and Anthony, 2017).

Demand led plant variety design. This approach was developed between 2014 and 2017 by a consortium of universities with leading education programmes in plant breeding (University of Nairobi, Kenya; Makerere University, Uganda; University of Ghana, Legon, Ghana; University of Kwa-Zulu Natal, South Africa; University of Queensland, Australia); a CGIAR center (CIAT); the Syngenta Foundation for Sustainable Agriculture, Switzerland; ASARECA, Entebbe, Uganda; RUFORUM (Makerere University, Uganda); regional crop improvement programmes (Biosciences for East and Africa (BECA) Nairobi, Kenya; African Center for Crop Improvement (ACCI), Kwa-Zulu Natal, South Africa; West African Centre for Crop Improvement (WACCI), Accra, Ghana, with financial support from the Syngenta Foundation for Sustainable Agriculture, the Crawford Fund (Australia) and Australian Centre for International Agricultural Research (ACIAR) (Parsley and Anthony, 2017; Kimani *et al.,* 2018). Demand led plant variety design follows an innovation system and value chain approaches, with bridging institutions linking plant breeding research with business and enterprise domains. It is designed to develop improved products which enable small scale farmers to access the expanding local and regional markets, which is one of the critical challenges facing policy makers in Africa. However, the participation in local and regional markets requires identification of market demands and development of products with suitable characteristics to meet the market requirements. A more focused approach is required in public and private breeding programs. Decisions on determining the preferred traits which new varieties must have are paramount to success. A demand led variety design based on the needs of customers can undoubtedly add value to breeding programs in Africa. New varieties which do not meet changing customer demands and emerging market opportunities has contributed in a significant way to low adoption rates in Africa compared to other regions.

Demand-led variety design also seeks to build on experiences gained in the last three decades. The following case study on development of new canning beans for processing industry illustrate some of the challenges and key elements of a demand led variety design.

Case study of canning beans for processing industry. Production of canning beans in eastern Africa started in 1937 in Arusha, Tanzania. Varieties with canning characteristics were introduced from United States and other sources, and screened for canning quality based on Heinz standard quality specification (Macartney, 1966; Leakey, 1970). Between 1937 and 1958, production was based on the well known cultivar, Comtesse de Chambord. Production increased rapidly from 252 t in 1949, to 2029 t in 1950, and 2553 t by 1952. Beans were produced by contracted smallholder farmers for export by a company known as Arusha Ltd, because there was no canning industry in the region. However, quality of beans deteriorated in subsequent years due to an increasing number of inexperienced producers and middlemen. Producers were supplying beans of mixed varieties, while the canners were demanding specific varietal characteristics and purity. By 1953, the entire crop was rejected due to poor quality. By 1954, the export market had largely been lost despite the interest in growing the crop. By 1957, production had declined to just 172 t. Michigan pea bean, internationally recognized as ideal for canning, was introduced in an attempt to keep the industry operational. However, it was highly susceptible to East African races of bean rust and was almost totally destroyed by rust. This led to initiation of canning bean research programme in Tanzania lead by Macartney, Joy and others, backed by the Bean Rust Unit at the East African Agricultural and Forestry Research Organization (EAAFRO), the well known regional research organization (Macartney, 1966). The aim of this programme was to develop a high yielding pure white canning bean, resistant to East African races of bean rust for export. Other selection criteria included maturity within 120 days, high soakability, good ground clearance and freedom from hard seed trait.

Between 1955 and 1959, more than 74 introduced canning bean cultivars were introduced and screened for suitability of production under East African conditions and for canning criteria. Of these, 20 satisfied the soakability criteria. Of the 20 varieties, three were discarded because of their seed size. Only three of the remaining 17 cultivars which met the soakability and seed criteria, were also resistant to races A and B of bean rust prevalent in northern Tanzania. These were Mexico 119, Mexico 142 and Criolla from Puerto Rico. Of these three varieties, only Mexico 142 ('Mex 142' for short) had satisfactory yield potential (>1300 kg ha^{-1}). However, it was susceptible to race C. Mexico 142 was subsequently distributed to Kenya and Uganda. However, in Uganda this variety was not considered suitable as food because of its size, colour and shape despite its high yield potential. In Kenya, Mexico 142, popularly referred to as 'Mex 142', was adopted and became the main canning variety for industries from 1960 to 2000. It was introduced in Ethiopia in the early 1970s, where it became the main canning bean to date (Assefa *et al.,* 2007). The rift valley region of Ethiopia led in production of this variety with more than 1000 exporters based in Adama (Nazareth) by end of 2010.

In Kenya, production of Mex 142 to support local canning industries continued up to 2000. By this time, Mex 142 had become susceptible to races of rust prevalent in Kenya, common bacterial blight, bean common mosaic virus, angular leaf spot and anthracnose, root rots and drought stress (Warsame and Kimani, 2014). Yields declined drastically such that in some seasons, yields were below 200 kg ha^{-1}. Farmers abandoned growing the variety because of its susceptibility to drought and diseases. Certified seed was no longer available because the local companies were not willing to grow the variety due to poor seed yields. Local companies resorted to imported grain from Ethiopia to keep the factories running. Unfortunately supplies of canning bean become erratic, and beans supplied were of poor quality (Kimani *et al.,* 2018).

In 2010, the canning companies requested the University of Nairobi Bean programme to develop a better canning bean variety to replace Mex 142. A regional canning bean programme was initiated in 2011 supported by Bioinnovate Network based in Nairobi. This programme brought together a multi-disciplinary team of bean researchers from Kenya, Ethiopia, Tanzania, Rwanda and Burundi, and two bean canning industries. The objective of this programme was to develop high yielding varieties which met canning requirements of the processing industry. The requirements included drought tolerance, resistance to major diseases and canning quality. Between 2011 and 2014, more than 427 lines from University of Nairobi bean programme were systematically evaluated for tolerance to drought stress, diseases and canning quality. These lines were selections from a larger nursery of more than 1400 entries which were previously field tested for drought tolerance under severe early season, mid-season, intermittent and terminal drought stress in 2007, 2008 and 2009 at Kabete and Thika. Of the 445 lines, 73 were red mottled, 57 red kidney, 48 speckled sugars, 44 pintos, cariocas and purples, 144 navy, 42 small reds, and 57 were of mixed colours. The red mottled, red kidneys and speckled sugars are large seeded, and represented the Andean gene pool. The other four market classes are medium or small seeded and represented the Mesoamerican genepool of *Phaseolus vulgaris* L. Although, the small white, also known as navy or the white pea bean, is the major canning bean type, other market classes such as red kidneys, speckled sugars and small red were included because they are important in the regional and global canning bean industry, and will provide future niche markets for local canning factories.

Of the 445 lines evaluated, 295 lines were discarded because they showed susceptibility to drought, one or more diseases, poor vigour and undesirable growth habit. The remaining 150 lines were subjected to farmer participatory selection under drought stressed and no-stress conditions at Mwea and Kabete. Twenty-four navy bean lines which met criteria for drought tolerance, high yield potential, multiple disease resistance and upright growth habit and farmers' additional selection criteria (earliness, marketability, fast cooking, non-shattering and foliage), were tested for canning quality at the Pilot Food processing plant at the Department of Food Science, Technology and Nutrition at Kabete. Laboratory testing for canning quality was a challenge because there were no suitable facilities in the region. Samples had to be sent to Italy or South Africa which made selection more expensive and time consuming. Only a limited number of breeding lines could be tested. Facilities for laboratory testing were installed at the Pilot Plant as part of project activities in 2012.

Results showed that there were significant differences in drought tolerance, yield potential, resistance to disease and 35% reduction in cooking time compared to Mex 142, the industry standard check variety. Drought stress reduced grain yield by 18 to 31%. Several new lines out-yielded local and international drought checks (Tio Canella) by as much as 100% in drought stressed conditions (Fig 1). Grain yield under stress was positively associated with pod partitioning index (r=0.89***), pod harvest index (r=0.40**), and stem biomass reduction (r=0.32**) (Table 2). Fourteen new lines were rated superior to industrial standard check variety Mex 142, for agronomic potential, drought tolerance, combined resistance to angular leaf spot, rust, anthracnose, bean common mosaic virus, culinary and canning characteristics (Tables 3 and 4).

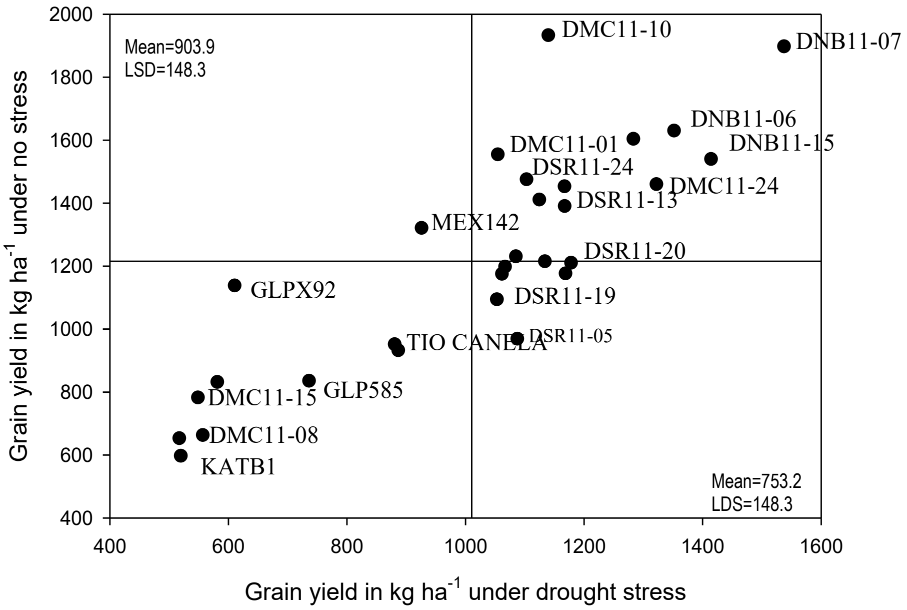

Figure 1. Grain yield of new drought tolerant navy (DNB), small red (DSR) and mixed colour (DMC) bean lines under drought stressed and non-stressed conditions at Kabete and Thika. KAT B1 (yellow), GLP (small red), Tio Canella (small red), GLP 92 (pinto), Mex 142 (navy) were the check varieties

Table 2. Correlation between grain yield with shoot characteristics of small and large seeded bean lines grown under drought stressed and irrigated conditions at Kabete and Thika, Kenya

Plant traits	Irrigated	Rainfed (Moisture Stressed)
Canopy biomass (kg/ha)	0.64***	0.25**
Pod harvest index (%)	0.62** *	0.40***
Pod harvest index (%)	0.62***	0.40***
Grain harvest index (%)	0.50***	0.39***
Pod partitioning index (%)	0.57***	0.89***
Pod wall biomass proportion (%)	0.26**	0.19*
Stem biomass reduction (%)	-0.18*	0.32**
Total chlorophyll content (SPAD)	0.24**	0.18**

*, **, *** Significant at p<0.05, p<0.01 and p<0.001 probability levels respectively

Table 3. Grain yield, reaction to diseases, cooking time and water uptake of the new candidate canning bean lines developed at the University of Nairobi

Candidate variety	Market class	Mean grain yield	Disease reaction				Cooking time (min)#	Water uptake (%)
		(kg ha^{-1})	Root rots	ALS	CBB	Anthracnose		
KCB13-01	Red mottled	2336	2	3	2	3	46.3	104.0
KCB13-02	Red mottled	2529	3	3	3	5	42.8	115.5
KCB13-03	Red kidney	2617	3	3	2	5	31.3	101.1
KCB13-04	Red kidney	2771	2	2	3	5	41.6	115.3
KCB13-05	Speckled sugar	2732	2	2	2	2	36.1	128.8
KCB13-06	Speckled sugar	2934	2	3	2	3	30.1	101.8
KCB13-07	Small red	2398	3	3	2	5	40.8	105.5
KCB13-08	Small red	2278	2	3	3	3	35.1	110.8
KCB13-09	Navy	2663	2	3	2	2	34.6	99.2
KCB13-10	Navy	2752	2	3	2	2	41.3	98.7
KCB13-11	Navy	3071	3	2	2	3	35.3	140.6
KCB13-12	Navy	2902	2	2	3	3	39.2	102.4
Checks								
Mex 142	Navy	2472	7	3	4	2	47.3	89.7
GLP 24	Red kidney	2063	7	5	4	4	70.9	92.8
Miezi Mbili	Speckled sugar	1748	6	5	6	7	67.1	97.3
GLP 585	Small red	1879	8	5	5	7	81.3	75.9
GLP 2	Red mottled	2207	7	4	4	7	67.1	97.3
Trial mean		1106	4	2	4	3	45.5	85.6
$LSD_{0.05}$		296.8	0.5	0.4	0.7	0.6	5.2	11.5
CV(%)		27.5	21.3	15.8	20	24	6.9	6.5

Mexican 142 used as the check. It had a cooking time of 41.6 minutes, and water uptake of 89.7% after 16 hours. CV= coefficient of variation; ALS= angular leaf spot, CBB= common bacterial blight. Disease score based on CIAT (1987)/international scale, where 1-3 =resistant, 4-6=intermediate and 7-9= susceptible

Table 4. Canning characteristics of the new drought tolerant and disease resistant candidate bean varieties developed at the University of Nairobi

Line	Market class	HC	WDWT	PWDWT (%)	Size	Shape	Uniformity	Splits	Clumping	Brine clarity
KCB13-09	Navy	1.92	272.4	66.0	2.33	4.7	6.3	5.7	6.3	7.0
KCB13-10	Navy	1.70	294.4	71.1	2.67	2.7	4.7	2.3	5.7	6.0
KCB11-11	Navy	1.64	267.1	64.8	2.67	5.0	4.7	2.3	5.7	6.0
KCB11-12	Navy	1.78	273.6	67.8	3.67	5.3	5.0	3.3	6.0	6.7
KCB13-08	Small red	1.59	276.6	67.1	2.67	5.7	5.3	2.7	3.7	3.0
KCB13-07	Small red	1.58	269.0	64.8	1.67	6.0	6.0	5.3	4.3	2.3
KCB13-01	Red mottled	1.55	284.0	69.0	5.3	4.0	6.0	5.7	5.7	3.0
KCB13-02	Red mottled	1.49	284.3	69.4	4.7	5.3	5.0	5.0	6.0	3.0
KCB13-03	Red kidney	1.52	279.9	67.6	5.3	5.0	4.0	4.0	5.7	3.7
KCB13-04	Red kidney	1.52	279.1	67.5	6.3	2.0	2.7	3.0	5.7	3.0
KCB13-05	Sugar	1.61	274.3	67.0	5.3	3.0	5.7	3.0	6.0	2.3
KCB13-06	Sugar	1.43	278.7	71.6	5.3	3.0	5.0	4.0	4.3	2.7
Mex142	Navy	1.74	282.8	69.7	2.67	5.0	3.7	3.3	5.3	6.0
Trial mean		1.8	274.2	65.7	2.5	5.0	5.7	4.3	5.2	4.6
$LSD_{0.05}$		0.04	7.6	3.9	1.3	0.7	1.1	1.0	1.3	0.9
CV (%)		1.5	1.7	3.6	23.3	8.8	11.9	13.8	14.9	11.8

HC= Hydration coefficient; WDWT=washed drained weight; PWDWT= per cent washed drained weight
Note: Market classes; navy, small red are small /medium seeded; red mottled, red kidney and sugar are large seeded

Validation for agronomic performance and canning quality. Of the 14 lines, 12 were submitted for validation by regulatory agency for agronomic performance, and for canning quality by the industry. The multi-location national performance trials were conducted in 2014 and 2015 by Kenya Plant Health Inspectorate Service. The new lines showed agronomic superiority compared with Mex 142 and other check varieties. For example, Mex 142 succumbed to bean common mosaic virus at Kabete. KAT B1, another drought tolerant check variety succumbed to severe anthracnose and haloblight attack in a farmer's field in Bahati, Nakuru County. KAT B1 gave a yield of 536 kg ha^{-1} compared to 740 to 3000 kg of the 12 candidate varieties during the prototype, large plot (0.5 to 1 ha) testing in farmers' fields. Industrial testing by two collaborating companies confirmed the laboratory canning tests conducted at the pilot plant in Kabete. Post canning evaluation of canned products was done in partnership with processors. Professional tasters from two companies independently conducted carefully managed sensory analysis for the candidate lines and obtained similar results. All 12 candidates fully met canning and sensory criteria set by the local industry and internationally. The two firms started contracting farmers to produce grain for processing during the 2014 short rain season. In March 2015, the companies purchased the first grain consignment of 3950 kg of the new varieties from the 41 farmers contracted. Five of the candidate varieties were officially released between 2015 and 2018. These were: Kenya Cheupe, Kenstar, Kenya Mamboleo, Kenya Salama and Kenya Red Kidney. Reports indicate that the companies are satisfied with new varieties since they have multiple advantages compared with Mex 142.

CONCLUSION

This paper presents a brief review of the evolution of client oriented breeding in eastern Africa from 1970 to 2000 with emphasis on legume breeding and provides evidence of progress made to date. Case studies of pigeopea, participatory improvement of dry beans, and the development of new canning bean varieties are presented. Adoption of the market led approaches can increase the chances of adoption as demonstrated in the case studies, facilitate access to larger markets, lead to better returns to investment in research, attract partnerships with private sector as demonstrated by development of new canning bean varieties, and make significant and sustainable contributions towards the national and regional goals of food and nutrition security.

ACKNOWLEDGEMENT

We acknowledge the support provided by the Government of Kenya, Bioinnovate Network, Swiss Development Corporation (SDC), Pan-African Bean Research Alliance and the University of Nairobi for the research reported in this paper.

STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

REFERENCES

African Development Bank. 2018. African Economic Outlook, 200pp. (ISBN9789938-882-438).

Assefa, T., Assefa, H. and Kimani, P.M. 2007. Development of improved haricot bean germplasm for mid- and low altitude sub-humid ecologies of Ethiopia, pp. 87-94. In: Food and Forage Legume of Ethiopia: Progress and Prospects. ICARDA, Allepo, Syria.

Arnold, M.H. 1970. Cotton improvement in East Africa. pp.178-208. In: Leakey, C.L.A (Ed.). Crop improvement in East Africa. Commonwealth Agricultural Bureaux, Farnham Royal, England.

Cercarelli, S., Grando, S., Tutwiler, R., Baha, J., Martini, A.M., Salahieh, H., Goodchild, A., and Michael, M. 2000. A methodological study on participatory barley breeding I. Selection phase. *Euphytica* 111:91-104.

Cercarelli, S. and Grando, S. 1997. Increasing the efficiency of breeding through farmer participation. pp. 116-121. In: Ethics and equity in conservation and use of genetic resources for sustainable food security. Proceedings of a workshop to develop guidelines for CGIAR, 21-25 April 1997, Foz de Iguacu, Brazil. IPIGRI, Rome, Italy.

Harrison, M.N. 1970. Maize improvement in East Africa. pp. 21-59. In: Leakey, C.L. A. (Ed.). Crop improvement in East Africa. Commonwealth Agricultural Bureaux, Farnham Royal, England.

Government of Kenya (GOK). 2010. Agricultural Sector Development Strategy 2010-2020. Republic of Kenya, Nairobi, Kenya.

Guthrie, E. J. and Pinto, F. F. 1970. Wheat improvement in East Africa. pp. 88-98. In: Leakey, C.L.A. (Ed.). Crop improvement in East Africa. Commonwealth Agricultural Bureaux, Farnham Royal, England.

Dogget, H. 1970. Sorghum improvement in East Africa. pp. 60-87. In: Leakey, C.L.A (Ed.). Crop improvement in East Africa. Commonwealth Agricultural Bureaux, Farnham Royal, England.

Kimani, P.M. 1990. Pigeonpea improvement research in Kenya; an overview. pp. 108-117. In: Singh, L., Silim, S.N., Ariyanayagam, R.P. and Reddy, M.V. (Eds.). Proceedings of the First Eastern and Southern Africa Regional Legumes Workshop, Nairobi, Kenya, 25-27 June 1990. Eastern Africa Regional Cereals and Legume (EARCAL) Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Kimani, P.M. 2001. Pigeonpea breeding: Objectives, experiences and strategies for Eastern Africa. pp. 21-32. In: Silim, S.N., Mergeai, G. and Kimani, P.Mi (Eds.), Status and potential of pigeonpea in Eastern and Southern Africa: Proceedings of a regional workshop, Nairobi, Kenya. 12-15 Sep 2000. B-5030 Gembloux, Belgium Agricultural University and Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Kimani, P.M. and Mbatia, O.L.E. 1990. Seed production and distribution mechanism: Case study of pigeonpeas in Kenya. Ottawa, Canada: International Development Research Centre. 84pp.

Kimani, P.M., Anthony, V.M., Chirwa, R., Danquah, A., Danquah, E., Edema, R., Gibson, P., Hussein, S., Mignouna, J., Persley, G.J., Rubyogo, J.C., Tongoona, P. and Yao, N. 2018. Improved crops for Africa: Leadership in demand-led breeding, education and catalyzing policy development. RUFORUM Biennial Conference, Nairobi, Kenya 22-26 October 2018. Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), Kampala, Uganda.

Kimani, P. M., Warsame, A., Njau, S. N., Njiru, M., Waidhima, P. and Omondi, S. 2018. Development and release of new stress tolerant canning beans for smallholder farmers in eastern Africa. pp. 83-90. In: Ogot, M. (Ed.). Proceedings of the 2nd Innovation Research Symposium, 6th March, Nairobi. http://uonresearch.org/irs

Khan, T.N. 1973. A new approach to breeding of pigeonpea (*Cajanus cajan* (L) Millsp): Formation of composites. *Euphytica* 22: 373-377.

Khan, T.N. and Rachie, K.O. 1972. Preliminary evaluation and utilization of pigeonpea germplasm in Uganda. *East African Agricultural and Forestry Journal* 38: 78-82.

Jones, R. B., Audi, P. A. and Tripp, R. 2001. Role of informal seed systems in dissemination of modern varieties. The example of pigeonpea from a semi-arid area of Kenya.

Experimental Agriculture 37: 539-548.

Leakey, C.L.A. 1970. The improvement of beans (*Phaseolus vulgaris* L.) in East Africa. pp. 99-129. In: Leakey, C.L.A (Ed.). Crop improvement in East Africa. Commonwealth Agricultural Bureaux, Farnham Royal, England.

Onim, J.F.M. 1981. Pigeonpea improvement research in Kenya. pp. 15-19. In: Proceedings of the International Workshop on pigeonpeas, Patancheru, Andhra Pradesh 502324, India, 15-19 December 1980. International Crops Research Institute for the Semi-Arid Tropics.

Onim, J.F.M. 1984. On-farm testing of improved pigeonpea (*Cajanus cajan* (L) Millsp) cultivars in Kenya. pp. 65-72. In: Kirkby, R.A. (Ed.) Crop Improvement in Eastern and Southern Africa: Research Objectives and on-farm research. Proceedings of regional workshop, Nairobi, Kenya. 20-22 July 1983. Ottawa, Canada, IDRC.

Sperling, L., Loevinsohn, M.E. and Natvombura, B. 1993. Rethinking the farmer's role in plant breeding: Local bean experts and on-station selection in Rwanda. *Experimental Agriculture* 29: 509-519. DOI: 10.1017/S0014479700021219

Warsame, A. and Kimani, P.M. 2014. Canning quality of new drought-tolerant dry bean (*Phaseolus vulgaris* L.) lines. *American Journal of Food Technology* 9: 311-317 (DOI: 10.3923/ajft.2014.311.317).

Witcombe, J. and Joshi, A. 1996. Farmer's participatory approaches for varietal breeding and selection and linkages to the formal seed sector. pp 57-65. In: Eyzaguirre, P. and Iwanaga, M. (Eds.). Participatory plant breeding: Proceedings of a workshop on participatory plant breeding, 26-29 July 1995, Wageningen, The Netherlands. IPIGRI, Rome, Italy.

Wortmann, C.S., Kirkby, R. A., Eledu, C.A. and Allen, D. J. 1998. Atlas of common bean (*Phaseolus vulgaris* L.) production in Africa. CIAT, Cali, Colombia, CIAT, 1998. 133pp.