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Review

Pigeonpea breeding in eastern and southern Africa: challenges and opportunities

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Abstract

Pigeonpea (*Cajanus cajan* [L.] Millspaugh) is an important multipurpose grain legume crop primarily grown in tropical and subtropical areas of Asia, Africa and Latin America. In Africa, the crop is grown for several purposes including food security, income generation, livestock feed and in agroforestry. Production in Eastern and Southern Africa (ESA) is however faced with many challenges including limited use of high-yielding cultivars, diseases and pests, drought, under-investment in research and lack of scientific expertise. The aim of this review is to highlight the challenges facing pigeonpea breeding research in ESA and the existing opportunities for improving the overall pigeonpea subsector in the region. We discuss the potential of the recently available pigeonpea genomic resources for accelerated molecular breeding, the prospects for conventional breeding and commercial hybrid pigeonpea, and the relevant seed policies, among others, which are viewed as opportunities to enhance pigeonpea productivity.

Key words: Africa — *Cajanus cajan* — climate change — food security

Climate change and nutritional food security have attracted global concerns in the recent years (Dyal et al. 2009). Generally, the poorer developing countries are more vulnerable to climate change because of their geographic exposure, low incomes and dependence on climate sensitive sectors such as agriculture (IPCC 2007). Although economic growth in most African countries has experienced an upward trend over the last 5 years, the continent is still considered most susceptible to climate change due to its vulnerability and inability to cope with the physical, human and socio-economic consequences of climate extremes (Kabasa and Sage 2009). Furthermore, an estimated 30% of children under the age of five in sub-Saharan Africa (SSA) are underweight, mainly due to malnutrition (Mula and Saxena 2010). Sustainable solutions to agriculture and food security in Africa must consider more focused research efforts on locally adapted, highly nutritious and stress-tolerant crops alongside sustainable government support to agricultural research and development. One such crop with potential to cope with climate change and provide nutritional food security is pigeonpea (*Cajanus cajan* [L.] Millspaugh).

Pigeonpea, a diploid legume crop species ($2n = 2x = 22$), belongs to *Cajaninae* subtribe of the economically most important leguminous tribe Phaseoleae (Van der Maesen 1990). The crop derives its name from Barbados, where the seeds were once used to feed pigeons (Van der Maesen 1990). It is generally grown under risk-prone marginal lands with low inputs (Mula and Saxena 2010). Pigeonpea is increasingly gaining importance in Africa, especially in ESA, where it occupies an area of about 990 000 ha (TIA/IAI 2012; FAO 2013) (Table 1).

Both local and export demand for this multipurpose legume crop continue to rise, presenting an opportunity for faster productivity enhancement and strengthening of seed delivery systems, as well as improvement of existing value chains. Pigeonpea is likely to become a major player in ESA's agriculture, especially with increased research investment. The aim of this review is to highlight the challenges facing pigeonpea production and improvement and the existing opportunities for improving pigeonpea research and overall subsector in ESA.

Historical perspectives of pigeonpea genetic diversity and breeding in Africa

The centre of origin of pigeonpea has been a subject of discussions in the past. For instance, some studies (Leslie 1976, Purseglove 1976, Singh et al. 2001) favoured the origin of pigeonpea in Africa. Many other studies (Van der Maesen 1990, Fuller and Harvey 2006, Saxena et al. 2014) suggest India as the origin of the crop. The presence of several wild relatives, the diverse genepool of the crop in the Indian subcontinent and some recent molecular studies provide a stronger evidence of the latter group. Africa harbours only two wild species of pigeonpea: C. *kerstingii* Harms and *C. scarabaeiodes* (L.) Thouars (Van der Maesen 1990). It is most likely that pigeonpea was introduced by immigrants in the 19th century who moved to Africa to become railway workers and storekeepers (see Odeny 2007). From eastern Africa, pigeonpea spread over the African continent, albeit without acquiring a prominent position. In Africa and the Far East, pigeonpea has been grown for at least 4000 years (Van der Maesen 1980) and therefore considerable agro-ecological adaptation has been obtained locally.

The traditional African pigeonpea genotypes are long-duration, cream- and large-seeded (Remanandan 1990). In Uganda, medium-duration, cream to mottle small-medium seeded type (Manyasa et al. 2009) have been part of the traditional cropping system (Silim et al. 1991, Kimani 2001). Uganda was the first country in ESA to implement a pigeonpea breeding programme in 1968 at Makerere University (Saxena 2008). However, there is a scope to expand further under sustainable intensification of

Table 1: Area, yield and production of pigeonpea in five countries from 1990 to 2011

Country	Area ('000 ha)			Yield (kg/ha)			Production ('000 t)		
	1990–92	2000–02	2011	1990–92	2000–02	2011	1990–92	2000–02	2011
Kenya	159.8	166.7	182.3	409	465.4	607.9	65.2	77.4	110.8
Malawi	142.3	137.4	233.9	683.8	752.9	1102.8	97.3	103.4	216.7
Mozambique	–	68.8	193.2	–	465.1	504.3	–	32.0	97.4
Tanzania	56.0	134.0	288.1	673.2	650	946	37.7	87.1	272.6
Uganda	61.3	80.0	92.5	827.1	1000	1024.8	50.7	80.0	94.8
Total	419.4	586.9	990.0	598.2	647.3	831.7	250.9	379.9	792.3

cropping systems with pigeonpea as one of the component crops.

Challenges Facing Pigeonpea Production and Improvement

Challenges facing pigeonpea production and improvement in ESA are divided into two main categories, namely technical and institutional challenges.

Technical challenges

Limited use of high-yielding varieties

Low realized productivity in pigeonpea remains one of the major constraints despite past and ongoing breeding efforts. In ESA, the yield of green pods varies from 1000 to 9000 kg/ha and that of dry grain may reach 2500 kg/ha in pure stands with modern cultivars. Present regional yields are about 800 kg/ha under intercropping systems which is much lower than the realizable yield potential. Malawi is the major producer of pigeonpea in the region with productivity of about 1327 kg/ha at present (FAO 2013). Although several improved varieties are now available, adoption is limited and most farmers grow traditional landraces that are prone to soilborne fungal diseases and grain yields are of low quality (Høgh-Jensen et al. 2007).

Alternatively short-duration varieties are much more susceptible to insect pest attack, necessitating the use of insecticides, which most ESA farmers cannot afford, therefore opting to grow traditional long-duration types (Jones et al. 2002). However, recent trend was on cultivation of medium-duration varieties that can fit very well into existing cropping systems. More breeding efforts are needed to focus on developing farmer- and market-preferred genotypes with high yield, fusarium wilt resistance and pest tolerance.

Biotic stresses

Biotic stresses significantly reduce the pigeonpea yield in ESA (Reddy et al. 1990). The most important fungal diseases of pigeonpea in ESA are *Fusarium* wilt, Cercospora leaf spot and powdery mildew (Brink et al. 2006). *Fusarium* wilt is the most serious disease in all major pigeonpea-producing countries in the region (Silim et al. 1995). Surveys carried out in 1980 estimated wilt incidences to be 60% in Kenya, 36% in Malawi and 24% in Tanzania with annual losses of US$ 5 million in each of these countries (Kannaiyan et al. 1984). Accessions with less wilt incidences and high yield, which are potential donors in resistance breeding, have been identified, such as ICEAP 00926, ICEAP 00576-1, ICEAP 00933, ICEAP 00040 and ICP 9145 (Rao 2012). They have been identified as potential in terms of yield and resistance traits.

Insects that are serious, widely distributed and cause heavy economic losses in pigeonpea in ESA are pod and seed boring Lepidoptera (*Helicoverpa armigera* Hübner, *Maruca vitrata (=testulalis)* Geyer, *Etiella zinkenella* Treitschke), and pod fly (*Melanagromyza chalcosoma* Spencer) (Johansen et al. 1993, Minja et al. 1999). *H. armigera* is the major biotic constraint to pigeonpea production (Lateef and Reed 1990), with yield loss estimated at 42% (Abate and Orr 2012). Reports on the seed damage due to pod-sucking bugs in Kenya, Malawi, Tanzania and Uganda have shown it ranges from 3 to 32% and varies among locations within and between countries (Minja 1997).

Pigeonpea lines with resistance to *H. armigera* have been reported, but little progress has been made in incorporating resistance in cultivars that are acceptable to farmers (Shanower et al. 1999). The development of insect-resistant and/or -tolerant pigeonpea cultivars has been a high priority in the research programmes, but the progress is hindered by high variation in pest populations (within and across seasons) and the high degree of out-crossing in pigeonpea (Shanower et al. 1999).

Abiotic stresses

In ESA, pigeonpea is grown purely under rainfed conditions with varying temperatures, altitudes and latitudes (Silim et al. 2006). Pigeonpea encounters various abiotic stresses during its life cycle such as moisture stress (drought), temperature, photoperiod and mineral (salinity/acidity) stress (Choudhary et al. 2011). Among these stresses, moisture stress is most prevalent (Silim and Omanga 2001). The medium and long-duration genotypes that are commonly grown in ESA depend on residual moisture for the reproductive phase development. In some cases, this leads to terminal drought stress which is causing substantial yield reduction (Kimani 2001). In a study concerned with field evaluation of pigeonpea germplasm, a high (>50%) yield loss was attributed to a combination of a severe mid-season drought and high temperatures (Gwata 2010). Through multilocational and multiyear evaluations, medium-duration genotypes such as ICEAP 00673, ICEAP 01170 and ICEAP 01179, as well as long-duration genotypes such as ICEAP 01423 and ICEAP 01202 possessing drought tolerance coupled with high yield have been identified (Rao 2012).

Institutional challenges

Shortage of improved seed

Access to improved seeds and markets is particularly limited in sub-Saharan Africa (ICRISAT 2009). Inadequate supply of the breeder seeds by the public sector (Rao 2012), limited involvement of the private sector (Jones et al. 2002) and non-existence of the commercial pigeonpea seed markets (Tripp 2000) are the major challenges facing the pigeonpea seed industry in ESA. In addition, lack of access to quality seeds (Abate and Orr 2012) and poor extension services (Abate et al. 2012) significantly contribute to the poor adoption of the improved pigeonpea seeds in ESA.

Under-investment in research

Most of the research on pigeonpea in ESA to date has been through donor funding to the National Agricultural Research Systems (NARS) and ICRISAT (Jones et al. 2001). Despite positive growth in the 1980s, public investment in agricultural research and development (AR&D) in ESA has declined (Beintema and Stads 2010). For instance, in Malawi, the major pigeonpea producer in ESA, the government currently invests only 4% of the agricultural budget in research (Phiri et al. 2012). In Tanzania, for the past decade, the government budget approved for the Department of Research and Training has been in the average of 24% of the total actual budget requirement for all agricultural crops (ESAFF 2013).

Lack of human resource capacity

In ESA, all major producers of pigeonpea have limited capacity to carry out effective research and development on pigeonpea, which have traditionally received less attention than cereals and cash crops (Abate and Orr 2012).

Information from the Uganda National Agricultural Research Organization (NARO) revealed that is within the national programme, currently there is only one scientist who is actively involved in pigeonpea breeding (Valentino Obong personal communication, 2015). The same applies to Malawi where only one pigeonpea breeder and one agronomist within the national programme are working (Esnart Nyirenda Personal communication, 2015).

There is also still a huge gap in scientific capacity left by retired scientists, due to failure by the national governments to continue hiring and support agricultural scientists for a long time (Beintema and Stads 2006). For instance, in Tanzania, the situation is most extreme at Ilonga Agricultural Research Institute, a country pigeonpea mandate, where most of the posts for senior research officers are vacant (Coulson and Diyamett 2012).

Opportunities for Pigeonpea Production and Breeding in ESA

Increased adoption for pigeonpea production as a strategy in climate smart agriculture

The agricultural system in ESA is characterized by low productivity, low use of external inputs, traditional management practices and limited capacity to respond to environmental shocks (Tabo et al. 2007). Pigeonpea has a huge untapped potential for improvement both in quantity and in quality of production in ESA (see Odeny 2007). Besides its ability to tolerate droughts and availing water and soil mineral nutrients (Valenzuela and Smith 2002, Mathews and Saxena 2005, Adu-Gyamfi et al. 2007), pigeonpea is also a multipurpose crop (Boehringer and Caldwell 1989, Kimani 2001, Snapp et al. 2003, Saxena et al. 2010). Unreliable rainfall received in many parts of the sub-Saharan Africa has reduced cereal production especially maize and wheat, and made farmers to shift to legumes production especially pigeonpea which is drought tolerant, and in most cases intercropped with cereals mainly maize or sorghum. The drought-tolerant pigeonpea has a unique role in meeting food security needs of subsistence farmers in climatic risky regions of ESA (Snapp et al. 2003). With the regional breeding approach in place, the crop can now be grown in more targeted areas and breed for a wide range of uses.

Increased market demand for pigeonpea

Both local and export demand for pigeonpea exist in Africa, especially in ESA. Some studies indicate that a vibrant domestic, regional and export trade of dry grain and an emerging market for vegetable pigeonpea exist in ESA (Shiferaw et al. 2008b). ESA countries export about 200 000 t grain annually to India. In ESA, Kenya and Malawi are the two biggest producers of pigeonpea. In Kenya, 45% of the crop is sold, while in Malawi, the share is 35% (Shiferaw et al. 2008a, Abate and Orr 2012). During recent years, Tanzania and Mozambique have increased area under cultivation and contributing to large quantities of grain export.

Although informally traded, cross-border trade of pigeonpea between ESA countries do exist, for instance, between the northern Tanzania and Kenya (Brink et al. 2006). In addition, the large Indian and Afro-Caribbean communities in Europe and North America offer new potential markets that can be accessed through the application of improved processing technologies such as freezing (Jones et al. 2006).

Improved seed access and policy support

One of the key factors for stimulating technology uptake and increasing agricultural productivity in smallholder agriculture is access to quality seed of improved varieties (Shiferaw et al. 2008a).

Many countries in ESA have regulations that only permit the sale of certified seed (Abate and Orr 2012). Community-based seed production and marketing systems like quality declared seed, which is tested in Tanzania for dissemination of truthfully labelled seed of high quality, could be one strategy for easing the seed shortage problem, especially for open-pollinated cereals or self-pollinated legumes like pigeonpea (Abate et al. 2012). For an efficient seed system to operate, the public sector must play a bigger role in plant breeding and some aspects of quality control, while the private sector has better incentives in the area of seed multiplication, processing and distribution (Minot et al. 2007). The ongoing seed policy reforms in the region have facilitated more participation of the private sector within pigeonpea seed systems. For instance, right now in Tanzania, there are more than 10 big companies/estates producing quality seeds and grain for sale excluding community-based organizations, NGOs, PMGs, farmers groups and contract farmers (Rao et al. 2014). The move towards formation of strategic partnership with different stakeholders has accelerated the release of pigeonpea seeds as well as increasing the quantity of seeds produce in the region. Commercial seed companies are also expected to develop interest in pigeonpea, due to ever growing demand for pigeonpea exports. ESA countries export about 200 000 t of pigeonpea grain to India on annual basis.

Improved varieties and potential for hybrid pigeonpea

Breeding activities supported by ICRISAT over the years developed several region-specific genotypes through intensive genetic enhancement programme. In close collaboration with national programmes, 32 high-yielding varieties were released as follows; Malawi (7), Kenya (7), Tanzania (7), Mozambique (5), Uganda (2), Zambia (2), Ethiopia (1) and Sudan (1). Further, 10 varieties (4-Ethiopia, 2-Zambia, 4-Uganda) are being processed for

Table 2: List of popular pigeonpea varieties grown in ESA

Country	Variety	Year of release	Special varietal attributes
Kenya	KARI Mbaazi2 (ICEAP 00040)	1995	Long duration,large cream seed and Fusarium wilt resistant
	Katumani 60/8 (Kat 60/8)	1998	
	Karai (ICEAP 00936)	2011	
	Peacock (ICEAP 00850)	2011	Medium duration
Malawi	Sauma(ICP 9145)	1987	Long duration, fusarium wilt resistant
	Kachangu(ICEAP 00040)	2000	Long duration,large seeded, fusarium wilt resistant
	Mwaiwathualimi(ICEAP 00557)	2010	Medium duration
	Chitedze pigeonpea 1 (ICEAP 01514/15)	2011	Medium duration and high pod load
Mozambique	ICEAP 00040	2011	Long duration
	ICEAP 00020	2011	Long duration
Tanzania	Komboa (ICPL 87091)	1999	Short duration (110–120 days)
	Mali (ICEAP 00040)	2002	Long duration (180–270 days)
	Tumia (ICEAP 00068)	2003	Medium duration (140–180 days)
	Kiboko (ICEAP 00053)	2015	Long duration and erect plant type
	Karatu 1(ICEAP 00932)	2015	Long duration
	Ilonga 14-M1(ICEAP 00554)	2015	Medium duration
	Ilonga 14-M2 (ICEAP 00557)	2015	Medium duration
Uganda	Sepi I (Kat 60/8)	1999	Medium maturity
	Sepi II (ICPL 87091)	1999	Short duration, multiple cropping

Table 3: Geographical positions and weather information of the location (study sites in Kenya)

		Location									
Latitude/Altitude(m)	Temp (°C)	Kabete		Katumani		Kiboko		Mtwapa		Muguga	
1° 15′(1825)	Max	24.6[1]	22.1[2]								
	Min	12.9[1]	12.2[2]								
	Mean	18.7[1]	17.1[2]								
1° 35′(1560)	Max			25.6[1]	23.6[2]						
	Min			14.4[1]	12.9[2]						
	Mean			20[1]	18.7[2]						
4° 25′(900)	Max					29.4[1]	27.8[2]				
	Min					17.7[1]	15.5[2]				
	Mean					23.5[1]	21.6[2]				
4° 25′(–)	Max							31.4[1]	28.9[2]		
	Min							23.2[1]	21.5[2]		
	Mean							27.3[1]	25.2[2]		
1° 15′(2110)	Max									22[1]	19.4[2]
	Min									11.5[1]	10.2[2]
	Mean									16.8[1]	14.9[2]

Rainfall duration = [1]Short, [2]Long.

release. Most of these varieties were developed from local germplasm with region-specific breeding priorities such as high grain yield, intercropping compatibility, photoperiod insensitivity, consumer-preferred grain quality, resistance/tolerance to *Fusarium* wilt, Helicoverpa pod borer and resilience to climate change. List of popular pigeonpea varieties released in ESA is given in Table 2.

Table 4: Days to flowering of the selected pigeonpea genotypes tested under natural daylength at the selected study sites in Kenya

		Location				
Genotype	Maturity	Kabete	Katumani	Kiboko	Mtwapa	Muguga
ICEAP 00040	Long	149	178	227	300	156
T-7	Long	150	185	164	–	170
ICP 6927	Medium	123	105	121	119	160
ICP 7035	Medium	119	94	125	122	–
ICPL 87091	Short	91	81	74	84	–
ICPL 9001	Extra short	80	78	64	79	–

'–', Missing data.

A key to today's success in pigeonpea breeding in ESA was the adoption of the breeding strategy for the establishment of the regional approach taking into consideration the key factors such as adaptation, crop phenology, market preference and pathogen specificity (Silim et al. 1995, 2006, Silim and Omanga 2001). Kenya transect considered as an open laboratory (Table 3) was used. It varied from 50 to 2500 m above sea level and where temperature decreases with increase in altitude. It was the basis for understanding the adaptation for developing and targeting varieties (Table 4). In addition, sources of resistance in the medium- and long-duration background were also identified. Efforts are under way to increase the adoption of these varieties in farmers' fields.

ICRISAT in Asia has developed a number of hybrids that have been released by NARS and commercial seed companies. The hybrid variety has a 20–40% yield advantage over the open-pollinated varieties (Shiferaw et al. 2008b). ICRISAT-ESA would like to develop region-specific hybrids that meet consumer preference and cropping systems adaptability. Efforts are underway to identify stable CMS lines that are adaptable to ESA, maintainers in local germplasm and heterotic parental combinations as hybrid vigour is associated with genetic diversity, crosses between the genetically diverse African and Asian gene pools could result in considerable yield improvement and create greater incentive for adoption of such varieties (Kimani 1991).

Availability of genomic resources for pigeonpea genetic enhancement and breeding

To meet the growing demand for pigeonpea in ESA, conventional breeding on its own will not be sufficient in developing superior genotypes. Pigeonpea genome has now been sequenced, availing more genomic resources for exploitation to speed up the ongoing conventional breeding activities (Bohra et al. 2011, Varshney et al. 2011, 2012). Availability of DNA markers for pest and disease resistance will be of utmost importance, as it will be easier to conduct resistance breeding to achieve both stability and productivity of the crop which is top priority in the genetic enhancement of this pulse in ESA (Crouch and Ortiz 2004).

Conclusions

This paper has shown that pigeonpea breeding research in ESA has moved knowledge forward and has resulted in impacts on the ground over a very short period, moving the crop from an orphan crop to where both national governments and development partners are now paying attention to it. In addition, the review has shown that much needs still to be performed to unlock the opportunities that exist in this crop. This will require a multifaceted approach from science-based solutions, policies to market requirements.

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