2 New high-yielding, stress-resilient, and nutritious crop varieties

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Introduction

The Africa RISING research for development agenda is guided by the principles of sustainable intensification (SI) and farming systems. SI refers to efficient use of resources for agriculture that results in increased productivity on the same amount of land (Pretty, 1997; Reardon *et al.*, 1996). A farming system refers to a population of individual farm systems that may have widely different resource bases, enterprise patterns, household livelihoods, and constraints (Giller, 2013). Africa RISING focuses on efficient use of resources for agriculture, to produce more food on the same amount of land, but with reduced negative environmental or social impacts. This approach is necessary given the diverse farming systems of East and Southern Africa (ESA), which are predominantly smallholder-based.

This chapter describes the contribution of new resilient and nutrient-dense crop varieties to SI. The technology validation research on these varieties was done in partnership with several stakeholders in three areas:

- The semi-arid zones of Tanzania, which have a single rainy season (500–800 mm) and short growing season (70–180 days).
- The sub-humid zones of Malawi: two main areas with annual rainfall of 800–1,200 mm and 600–800 mm, and two cropping seasons (180–270 growing days).
- The mid-altitude sub-humid zone of Zambia (annual rainfall 800–1000 mm) and a growing season of 100–140 days.

These agroecosystems (farming systems and environmental conditions) are highly dependent on rainfed agriculture. Farmers are therefore vulnerable to food shortages due to increasingly erratic weather caused by climate change. At the same time, increasing rural populations mean farmers need to grow food on smaller plots, and rising urban populations are demanding additional agricultural products. The main staple crops in ESA are maize and legumes, with tomato being the most widely grown and traded horticultural crop. However, productivity of these important sources of dietary calories and nutrients remains low, due in large part to a lack of adequate rainfall. Many farmers also produce crops from poorly adapted varieties that are not resilient to emerging production threats. As a result, many rural communities cannot access a sufficient quantity of nutritious food, leading to high levels of undernutrition, poor health, and low household incomes.

Research on genetic intensification (Montpellier report, 2013) – a component of the Africa RISING SI approach – has led to the deployment of resilient, high-yielding, and

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nutritious crop varieties that are suitable for the agroecosystems described above, and with scope for scaling out within ESA. These new varieties will provide food, nutrition, and income security for farming communities across ESA. The following varieties are described in this chapter.

- Drought-tolerant quality protein maize: Three high-yielding varieties developed for semi-arid and sub-humid agroecosystems, with good resistance to stresses.
- Tanzanut 2016: A high-yielding, disease-resistant groundnut bred for semi-arid agroecosystems.
- SER83 and SEN43: Two high-yielding, drought-tolerant varieties of common bean, adapted for the sole crop and intercropping conditions common in ESA.
- Ilonga 14 M1 and Ilonga 14 M2: Medium-duration maturity, high-yielding pigeonpea, resistant to Fusarium wilt, the most important disease in ESA.
- Tengeru 2010: A resilient variety of tomato, which can be coupled with improved agronomic practices to boost productivity and incomes.

The Africa RISING teams used two research strategies to evaluate these varieties: a) to validate and commercialize new, improved crop varieties and their agronomy in agroecosystems where they have not been tested before; and b) to validate and promote new commercialized crop varieties where they have yet to be adopted on a large scale. Both strategies employed participatory methods to capture production requirements, especially for smallholder farming, to ensure the new varieties were relevant to and would be adopted by farmers and other stakeholders.

Drought-tolerant quality protein maize

Background

Maize (*Zea mays* L.) is the most important staple food grain in ESA, contributing up to 60% of people's daily calorie requirements in Tanzania (Minot, 2010), and 86% of daily calorie requirements in Zambia (FAO, 2009). The demand for maize in Tanzania has been projected to increase annually by 2.4% up to 2025 (Msangi and You, 2010). However, maize productivity remains low compared with grain yields obtained under experimental conditions, due partly to limited adoption of highly productive and resilient crop varieties. Traditional maize also has poor protein quality, being deficient in essential amino acids such as tryptophan and lysine, which cannot be synthesized by the body (Gibbon and Larkins, 2005).

Quality protein maize (QPM) is biofortified with lysine and tryptophan, and is an attractive option to improve human dietary quality. However, despite its significant nutritional benefits for humans and livestock, widespread adoption remains low, even in ESA, where it was promoted by the Association for Strengthening Agricultural Research in Eastern and Southern Africa (ASARECA) in the mid-2000s (Kimenye and McEwan, 2014). One factor limiting the widespread adoption of QPM is the poor adaptability of commercially available varieties to different agroecosystems. The high-yielding and stress-resilient QPM hybrids presented here (CZH132019Q, CZH132003Q, and CZH132015Q) have been tested by Africa RISING for their suitability in the target zones and for scaling out to farmers throughout ESA.

Description of the QPM hybrids

The key features of the three hybrids adapted for the semi-arid and semi-humid agroecosystems of ESA are outlined in Table 2.1. These new QPM hybrids produce good yields even in drought-prone environments. They are relatively nutrient dense, containing about 0.08% tryptophan and 4% lysine and are therefore classified as biofortified because they contain up to 90% of the nutritional value of milk protein (compared with 40% in non-QPM maize). The new hybrids are tolerant to drought and resistant to major diseases of maize, such as grey leaf spot (*Cercospora zeina* and *C. zeae-maydis*) and maize streak virus disease, which are among the most significant causes of low grain yield in traditional varieties.

Table 2.1. Key features of the new QPM hybrids

1. Administrative information			
Attribute	Go-to information and sources for Tanzania		
Target agroecosystems	Most agroecosystems between 700 and 1,500 m above sea level		
Seed source	Certified seed: Supplied by private sector		
2. Distinguishing characteristics and benefits			
Attribute	CZH132015Q	CZH132003Q	CZH132019Q
Hybrid	Three way	Same[1]	Same
Color	White	Same	Same
Maturity	Intermediate maturity	Same	Same
Yield potential	7,000–8,000 kg/ha	Same	Same
Tolerance to pests and diseases	Maize streak virus, grey leaf spot, blights, ear-rots	Same	Same
Tolerance to drought	Tolerant	Tolerant	Highly tolerant
Texture	Semi-flint grain texture with excellent poundability[2]	Same	Same
Tip cover	Good husk tip cover	Same	Same
Ecology of validation	ESA agroecoeystems 700–1,500 m above sea level	Semi-humid and semi-arid zones of Zambia	Same

[1]Same characteristics as for CZH132015Q.
[2]Poundability is an important trait for post-harvest grain processing into flour.

Benefits of the new QPM hybrids

The new QPM hybrids produce higher grain yields than the most recently registered and commercially available QPM variety (LISHE 2), with a yield gain of up to 31% under optimal growing conditions. Under conditions of random drought stress, they have a yield advantage of 22, 15–31 and 4% over LISHE 2, for CZH132019Q, CZH132003Q, and CZH132015Q, respectively (Figure 2.1).

The new QPM hybrids are biofortified and more nutritionally dense than the widely adopted non-QPM varieties and hybrids (e.g., PAN 53) due to their relatively higher lysine and tryptophan content (Table 2.2). Under the same management conditions and production costs, the new hybrids produce higher grain yield and generate a higher return on investment than traditional varieties (Table 2.3).

Farmers' responses to the new varieties

The adaptability trials included on-farm participatory selection to identify varieties preferred by farmers and consumers. The three new QPM varieties were very well received. The hybrid CZH132003Q was ranked first by both women and men in all test sites. The variety ranked second, varied between test sites and gender, but in general, all new QPM varieties were preferred by farmers over the older LISHE 2 and Kilima maize. Farmers preferred the new varieties because they are tolerant to drought and endemic diseases, and have a suitable grain texture (semi-flint) for dehulling before milling into flour.

How to get started

Farmers wishing to grow these hybrids must acquire quality seeds from authorized seed companies. In Tanzania, for example, varieties CZH132003Q and CZH132019Q are produced and supplied by Meru Agro Tours and Consultants through various retail outlets. In Zambia, the hybrid CZH132015Q is produced and supplied by Kamano Seeds Company. Companies and development partners seeking to scale out these materials in other countries may contact the International Maize and Wheat Improvement Center (see 'References' below) for guidance. Additionally,

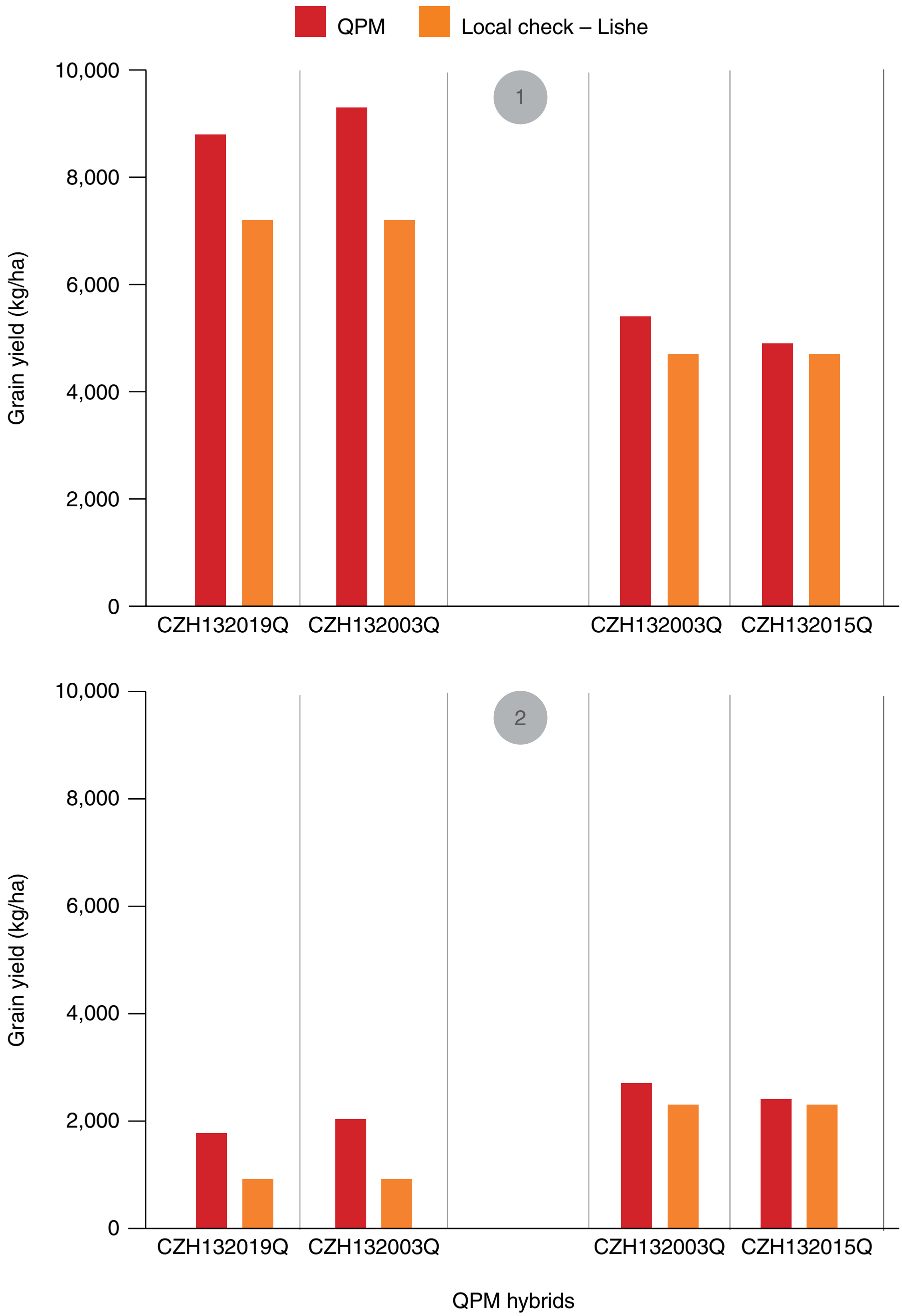

Figure 2.1. Productivity of the new QPM hybrids (average yields). Top (1): Field conditions under good agronomic management and favorable soil moisture conditions. Bottom (2): Field conditions when water availability, especially from rain, varies randomly, i.e., demonstrating tolerance to drought.

Table 2.2. Nutritional qualities of the new QPM varieties

Hybrid	QPM	Non-QPM (PAN 53)	Indicator change (%)	QPM	Non-QPM (PAN 53)	Indicator change (%)
	Lysine (%)			Tryptophan (%)		
CZH132019Q	0.39	0.24	0.15	0.30	0.04	0.26
CZH132003Q	0.33	0.24	0.09	0.09	0.04	0.05

Table 2.3. Economic benefits of the new varieties

Hybrid	Total production (kg)	Value of sales (US$)	Quantity sold (kg)	Gross margin (US$/ha)[1]	Cost–benefit ratio[2]
Tanzania					
CZH132019Q	1,770	244.3	1,062	53.0	3.47
CZH132003Q	2,030	280.2	1,218	72.3	3.64
Local (PAN 53)	500	69.0	300	5.0	2.84
Zambia					
CZH132003Q	2,700	372.6	1,620	90.3	3.05
CZH132015Q	2,400	331.2	1,440	67.3	2.77
Local (ZS261)	2,300	317.4	1,380	59.7	2.66

[1]Gross margins were calculated from own data according to the USAID *Feed the Future Agricultural Indicators Guide* (Nelson and Swindale, 2013).
[2]Calculated according to ELD Initiative (2019).

seed companies may exploit the Common Market for Eastern and Southern Africa (COMESA) seed trade harmonization regulations and other regional economic community protocols that allow for inter-country seed trade.

Once seed is available, the crop may be produced through conventional tillage or conservation agriculture, as detailed in Chapters 3–6 of this book. In general, the crop can be established by planting in rows when soil moisture is adequate, at 75 cm between rows, one seed per hill placed at 25 cm between planting stations. Good agricultural practices should be applied (as with other maize varieties), with basal fertilizer applied at planting, followed by top dressing at two and a half weeks after emergence using recommended rates. Type of fertilizer and application rate should be informed by the soil type and fertility (see Chapter 4). Detailed information on recommended fertilizers for target areas can be obtained from local agricultural extension officers. Weed control must be conducted at the right time (first weeding at two to three weeks, and second weeding at six to seven weeks).

Opportunities for adopting the new maize varieties

The QPM maize varieties have good potential, since they have high grain yields, are resilient to endemic environmental stresses, and have nutritional benefits. If these varieties are promoted, farmers will accrue improved returns on their investments, and nutrition security will be promoted. The QPM varieties were found to be acceptable by rural consumers in the test countries. Given that the food system in urban centers of ESA countries is similar to that in rural areas, the acceptability of products (especially flour) from these new hybrids by urban dwellers is assumed to be equally good, thus providing a ready market for farmers' produce.

Tanzanut 2016: Stress-resilient and highly productive groundnut

Background

Groundnut (*Arachis hypogea* L.) is an important legume for the livelihoods of smallholder farmers in the semi-arid tropics. In the focus agroecosystems of Africa RISING (semi-arid and mid-altitude sub-humid), groundnut productivity is low. The yield potential for groundnut is estimated at over 2,500 kg/ha, but the average productivity in Zambia is only 500–600 kg/ha. In Tanzania, it is slightly better at 800 kg/ha, and in Malawi it is 914 kg/ha. Several factors contribute to this low grain productivity, with limited access to quality seed being the major factor. In many ESA cropping systems where groundnut is grown, dissemination of improved crop varieties is limited. For example, in the central semi-arid zone of Tanzania, only around 6% of farmers plant improved groundnut varieties. Instead, many recycle their own seeds, perpetuating the use of obsolete varieties, many of which are susceptible to diseases. Most groundnut landraces are susceptible to groundnut rosette disease (Figure 2.2), a highly destructive disease that can cause complete yield loss (Sirongo *et al*., 2018).

In semi-arid agroecosystems, improved access to resilient groundnut varieties could unlock opportunities for farmers to produce nutritious legumes and generate income from sales of excess grain. This is particularly important where groundnut is grown as a cash and a food crop to meet household needs for protein and micronutrients (Sirongo *et al*., 2018). Groundnut is also an important oil crop, accounting for 40% of vegetable oil demand in Tanzania (CEPA, 2016). It is suitable for multiple cropping systems (see Chapters 3 and 6) and contributes to soil health through fixation of nitrogen (30–50 kg/ha) as net nitrogen added after harvest, according to ongoing work by Africa RISING in central Malawi.

Figure 2.2. A groundnut plant infected by groundnut rosette disease. (Photo courtesy of Patrick Okori, 2017).

Description of Tanzanut 2016

The new groundnut variety was approved for release in Tanzania in 2015 and subsequently released as Tanzanut 2016 in 2018. It belongs to the Spanish botanical group, which has a short-duration maturity period (90–110 days), is tolerant to groundnut rosette disease, and has a yield potential of 2,000 kg/ha (up to 64% yield advantage over commercial varieties available in Tanzania). Tanzanut 2016 is tolerant to other diseases, has an acceptable kernel size (45–50 g per 100 seeds), and is suitable for local and export trade. Table 2.4 summarizes the key features.

Benefits of Tanzanut 2016

During its development, the performance of Tanzanut 2016 was compared with commercial varieties and local landraces commonly grown by farmers. Two commercial groundnut varieties, Mangaka (Spanish group) and Mnanje (Virginia group), which are known and widely adopted in ESA, were used as local checks. Under the same crop management, Tanzanut 2016 average grain yield was found to be significantly higher than that of the commercially available varieties and local landraces (Table 2.5). Under optimal conditions (minimum of 800 to 1,000 mm of rainfall annually), Tanzanut 2016 can yield 2,000 kg/ha of grain if production is complemented with appropriate agronomy. Maximum yields were obtained in Malawi under optimal production conditions. Yields were lower under sub-optimal conditions in Tanzania, due primarily to differences in agronomic practices and rainfall.

Based on data generated in Tanzania, the gross margin for Tanzanut 2016 is higher than that for the local material and for the old commercial varieties, Mangaka and Mnanje, which are commonly grown in Tanzania (Table 2.5). The cost–benefit analysis confirms a superior profitability for Tanzanut 2016. However, it should be noted that the cost of new variety seed

Table 2.4. Key features of Tanzanut 2016

1. Administrative information	
Attribute	**Go-to information and sources for Tanzania**
Target agroecosystems[1]	Low-altitude: 200–1,500 m above sea level
Seed source	Early generation seed (breeder, foundation): Tanzania Agricultural Research Institute (TARI) Certified seed: Private sector and/or quality declared seed from selected trained and/or registered communities and seed producer associations (Contact TARI)
2. Distinguishing characteristics and benefits	
Attribute	**Detailed information**
Days to 75% flowering	35–40
Days to maturity	90–110
Pod size	Medium
Number of kernels per pod	2
Seed color	Red
Seed dormancy	Present
100 seed weight (g)	45–50
Tolerance to diseases	Tolerant to groundnut rosette disease and leaf spots
Grain yield	Up to 2,000 kg/ha

[1]Groundnut is well adapted to semi-arid and sub-humid environments that receive at least 500 mm of rainfall annually.

can be higher than that of existing varieties, but this is offset by the higher grain yield.

While the research did not profile the new variety for nutrients, groundnut is generally rich in essential fatty acids, protein, and other micronutrients, including vitamins and minerals. The validation studies show that 60% of households in semi-arid agroecosytems experience food deficits for between one and nine months of the year. Thus, by significantly increasing groundnut yields, Tanzanut 2016 increases grain supply for domestic consumption by up to 70%. This increases access to protein, calories, essential fatty acids, and several micronutrients.

Farmers' responses to Tanzanut 2016

During participatory variety selection conducted as part of the technology development phase, 655 men and women farmers were asked to rank seven attributes for importance (Table 2.6). Yield, drought tolerance, and earliness were ranked as the most important traits. The preferences of men and women differed only on taste and earliness (a proxy indicator for drought tolerance).

How to get started

As with all improved crop varieties, successful production starts with good land preparation. In general, early and deep ploughing (to a depth of 20–30 cm) is needed for a good pod setting, since groundnut produces and ripens its fruits below the ground. Seed may be planted on the flat or on ridges, according to the farmer's preference. Planting under conservation agriculture conditions is described in Chapter 6 of this book. Key issues to be considered when planning to produce groundnut include the following.

- Good site selection. Soil should preferably be sandy loam with a pH of 5.0–6.2 to aid pod development. The crop does not perform well in virgin soils, due primarily to limited rhizobia bacteria needed for nitrogen fixation. Inoculation of the seed with a commercial rhizobium inoculant will increase the bacterial population.
- Good quality seed with a high germination percentage should be used. Groundnut pods intended for sowing should be machine- and/or hand-shelled no earlier than

Table 2.5. Productivity, cost–benefit ratio, gross margins, and food production for Tanzanut 2016, commercial varieties, and local landraces

Variety	Average grain yield (kg/ha)	Cost–benefit ratio[1]	Gross margin (US$/ha)[1]	Food production (kcal/ha/year)[2]
Optimal conditions[3]				
Tanzania				
Local material	945	n/a[4]	n/a	7,995
Tanzanut 2016	1,575	3.17	703	14,912
Mangaka	1,450	2.92	765	12,361
Mnanje	1,346	2.71	692	11,453
Malawi				
Local material	768	n/a	n/a	10,886
Tanzanut 2016	2,028	2.47	1,020	28,747
Mangaka	1,162	1.41	563	16,500
Mnanje	2,325	2.83	1,378	32,943
Suboptimal conditions[5]				
Tanzania				
Local material	530	1.07	n/a	7,541
Tanzanut 2016	1,431	2.88	602	12,191
Mangaka	730	1.47	411	6,237
Mnanje	870	1.75	539	11,453
Malawi				
Local	327	n/a	n/a	2,778
Tanzanut 2016	808	0.98	160	11,340
Mangaka	451	0.55	66	6,407
Mnanje	584	0.71	159	8,278

[1]Calculated as described in Table 2.3. Gross margins cross-referenced data from Mangasini *et al*. (2014).
[2]Calculated according to Musumba *et al*. (2017).
[3]Validation was conducted at Chitedze Research Station, Malawi (annual rainfall <1,000 mm) and Tanzania Agricultural Research Institute, Naliendele (annual rainfall <800 mm).
[4]n/a = not applicable.
[5]Validation was conducted at Ngabu Research Station, Malawi (annual rainfall <600 mm), and at Tanzania Agricultural Research Institute, Hombolo (annual rainfall <600 mm).

Table 2.6. Farmer preferred traits for Tanzanut 2016

Trait	Number of farmers scoring trait as most important (mode)	Rank assigned by women	Rank assigned by men
Yield	655	1	1
Drought tolerance	572	2	2
Kernel taste	420	3	4
Earliness (maturity)	534	4	3
Seed size	173	5	5
Tolerance to disease	109	6	6
Seed color	97	7	7

one to two weeks before sowing. Groundnut germination rates decline faster when the seed has been poorly stored. In general, viability may reduce by up to 25% every six months under hot and humid storage conditions.

- The crop can benefit from residual soil fertility, especially when included in crop rotations. Calcium may be required for good pod development and seed setting. Calcium is applied as commercial gypsum at a rate of 200 kg/ha.

- Seed may be treated with an appropriate seed dressing fungicide such as thiram (commercially available as thiuram disulfide) at a rate of 120 g per 100 kg of seed.
- Tanzanut 2016 should be planted at a depth of 5 cm, at a plant spacing of 60 cm between rows and 10 cm within rows, giving an optimum plant population of 166,000 plants per hectare. Between 80 and 100 kg of seed are required per hectare.
- Weeds can cause up to 30% yield loss and losses of up 80% may occur with poor weed management. The crop should thus be weeded, especially early in the growth cycle (three to six weeks after sowing), together with earthing up plants to support flower peg penetration into the ground.

Opportunities for adoption

In addition to providing protein-rich nutrition, groundnut has potential to become an important cash crop. Tanzanut 2016 has large seeds, an important trait for domestic and international confectionery markets, and is strongly recommended for commercial production by smallholders. Being adaptable to stressful production environments, Tanzanut 2016 could be scaled out to other regions in Tanzania and Malawi, and to additional ESA countries with similar agroecosystems. The market for groundnut is extensive, with key importing countries in Africa including Burundi, the Democratic Republic of Congo, Kenya, and South Africa, and additional markets in Belgium, Malaysia, Mauritius, and Mexico.

SER83 and SEN43: Drought-tolerant beans

Background

Common bean (*Phaseolus vulgaris* L.) is a grain legume that contributes to the food, nutrition, and income security of many communities in Africa. It is particularly popular among smallholder farmers in ESA, due to its short growth cycle of 65–110 days (Buruchara *et al.*, 2011). Common bean provides an ideal source of food and cash early in the cropping season (Mukankusi *et al.*, 2019). For both urban and rural populations, beans provide a good source of calories, protein, fiber, minerals (iron, zinc, potassium, selenium, and molybdenum), and vitamins (thiamine, vitamin B6, and folate) (Mukankusi *et al.*, 2019). Eastern Africa has the world's highest per capita consumption of common bean (40–60 kg per year).

Common bean is suited for production in a range of smallholder farming systems, including the mixed cropping systems that are common in ESA. It is appropriate for farmers with limited land holdings and those living in densely populated countries. Common bean is generally sown after staple cereals such as maize. Farmers are aware of the dangers of high precipitation and humidity, which encourage the spread of leaf and pod diseases. Farmers address this risk by planting beans late in the rainy season. However, this may result in the crop facing water stress, especially when rainfall ceases in the middle or toward the end of the growing season (terminal drought). Another strategy is to grow common bean outside of the main cropping season, either as a follow-on crop in wetlands (as in Malawi) or under irrigation. Water stress in common bean production has been studied extensively, confirming its sensitivity to heat, drought, and excess rainfall (Mukankusi *et al.*, 2019). Developing varieties that are tolerant to water stress is therefore an appropriate strategy to sustain and increase the mostly smallholder production of common bean. Commercialization of drought-tolerant common bean varieties will reinforce livelihood strategies, sustain food and nutrition security, and generate incomes.

Description of SER83 and SEN43

The Africa RISING research team has validated and promoted two new drought-tolerant bean varieties (SER83 and SEN43). These have determinate bush growth habits and can be grown as a pure stand or an intercrop. Both varieties are small-seeded and SER83 has a red seed coat, while SEN43 has a black seed coat (Figure 2.3). Both varieties take about 42 days to flower and 73 days to reach physiological maturity. They are resistant to common bean diseases endemic to ESA, including anthracnose (*Colletotrichum lindemuthiunum*), common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli)*, rust (*Uromyces appendiculatus*), and bean common mosaic virus (Table 2.7). Their good resistance makes them popular with farmers since it reduces the need for costly pesticides.

Benefits of the new bean varieties

When compared with an old commercial variety of common bean (Napilira), the new drought-tolerant beans were found to produce higher grain yields, with an advantage of 48% for SER83 and 28% for SEN43. Trials were conducted

Figure 2.3. New drought-tolerant bean varieties released in Malawi. (Photo courtesy of Wilson Nkhata, 2021.)

Table 2.7. Key features of common beans SER83 and SEN43

1. Administrative information		
Variety	SER83	SEN43
Attribute	Go-to information and sources for Malawi	
Target agroecosystems	Bean production agroecosystems in Malawi experiencing drought	All bean production agroecosystems in Malawi
Seed source	Early generation seed (breeder): International Center for Tropical Agriculture and Chitedze Research Station Basic seed: Private sector seed companies Certified seed: Private sector seed companies	
2. Distinguishing characteristics and benefits		
Grain color	Red seed coat	Black seed coat
Plant height	50–55 cm	45–50 cm
Days to flower	42	42
Growth habit	Bush erect	Bush erect
Tolerance to diseases	Anthracnose, common bacterial blight, rust, and bean common mosaic virus	As for SER83
Tolerance to drought	Yes	Yes
Days to maturity	73	73
Seed size (100 seed weight in grams)	23	22
Potential yield (kg/ha)	2,800	2,500

under irrigation, with soil moisture levels controlled to simulate terminal drought and non-drought conditions. The new varieties also performed well under rainfed conditions at four locations in Malawi. Under non-optimal and optimal production conditions, the gross margins and cost–benefit ratios for SER83 and SEN43 were also improved (Table 2.8).

Farmers' responses

Participatory variety selection was conducted at the two sites where the beans were evaluated for drought in farmers' fields. A total of 402 farmers (115 male and 287 females) were involved (Table 2.9), with each farmer asked to select the bean variety they preferred and give their reasons. More farmers voted for SER83 (221) than SEN43 (181). Both varieties received mostly positive comments, with selection criteria including high yield, tolerance to drought and diseases, fast to cook, good aroma, and palatable leaves. Some negative traits mentioned included small seed size, limited market, black seed color for SEN43, and low market price.

How to get started

- To establish a healthy and productive crop, farmers should plant certified or quality declared seeds obtained from reputable sources. The seed should be planted on well-tilled land to allow for good root development.
- When producing the crop as a pure stand, seed should be planted at intervals of 50–60 cm between rows and 10 cm within rows. The seed rate for SER 83 is 50 kg/ha and for SEN43 it is 40 kg/ha.
- In a maize–bean intercrop system, an inter-row spacing of 75 cm is recommended. Maize should be planted first at 60 cm within the row. Two weeks after germination of the maize, the bean crop should be

Table 2.8. Performance of drought-tolerant bean varieties under drought and non-drought stress production environments

Variety	Average grain yield (kg/ha)	Cost–benefit ratio	Gross margin (US$/ha)[1]	Food production (kcal/ha/year)[2,3]
Optimal conditions[4]				
Napilira	2,156	2.76	597	14,352
SER83	3,228	4. 13	1,713	21,412
SEN43	2,665	3.41	1,310	17,749
Suboptimal conditions[5]				
Napilira	1,875	2.39	477	12,488
SER83	2,745	3. 51	1,572	18,282
SEN43	2,488	3.18	1,392	16,583

[1]Calculated as described in Table 2.3.
[2]Calculated according to Musumba *et al*. (2017).
[3]Households are estimated to consume about 20–30% of their produce, including both fresh and dry grain.
[4]Validation was conducted at Chitedze Research Station, Lilongwe, Malawi (annual rainfall <1,000 mm).
[5]Validation was conducted as irrigated crops with controlled water administration to simulate drought conditions.

Table 2.9. Results of participatory variety selection for drought-tolerant bean varieties in Malawi

	Positive votes		Negative votes		Total votes	
Variety	Men	Women	Men	Women	Positive	Negative
SEN43	39	79	24	39	118	63
SER 83	42	153	10	16	195	26
Total	81	232	34	55	313	89

sown at 15 cm intervals, starting 15 cm away from each maize plant. This will provide three bean plants between the maize plants.
- Inorganic fertilizers may be applied at rates of 40 kg/ha for nitrogen and 40 kg/ha for phosphorus.
- The crop should be kept weed free up to the post-flowering stage to minimize competition for nutrients and other resources. Mechanized weeding during flowering is not recommended because it can cause flower shedding and therefore reduce yields.
- The bean crop is ready for harvest when all the pods are dry. Harvesting can be done by hand, by uprooting the mature plants from the ground. Harvesting should be done early in the day, preferably when the pods are crispy and dry, to minimize shattering. The uprooted plants can then be tied into bundles for ease of transportation to threshing points.
- Further pre-processing requires sun-drying of the harvest before threshing and winnowing to obtain clean grain. The clean grain should be stored in hermetic storage bags or sealable containers to avoid insect infestation (see Chapter 7 of this book).

Opportunities for adoption

The new bean varieties are drought tolerant and perform well in a wide range of bean-producing agroecosystems. Common bean is a relatively cheap source of protein, and early-maturing varieties support better food, nutrition, and income security among smallholder farmers. Legumes also contribute valuable nitrogen and carbon to the soil. There are therefore broad opportunities to disseminate these varieties beyond the validation sites in Malawi.

Ilonga 14 M1 and M2: Stress-resilient and highly productive pigeonpea

Background

Pigeonpea (*Cajanus cajan* [L.] Millspaugh) is a widely adapted perennial leguminous shrub, grown in most agroecosystems of ESA. The crop is cultivated in Kenya, Malawi, Mozambique, Tanzania, Uganda, and Zambia, mostly as an intercrop due to its wide suitability for mixed cropping systems (Snapp *et al*., 2010). Productivity is influenced by photoperiod, with flowering induced by long days (Ellis *et al*., 1998). ESA is Africa's leading producer of pigeonpea, accounting for 13.4% of the world's production (FAOSTAT, 2020). Three types of pigeonpea are grown in ESA, classified according to their phenology: short duration (90–100 days to flowering), medium duration (110–160 days to flowering), and long duration (over 160 days to flowering). Various pigeonpea varieties have been developed and commercialized, guided by adaptation, phenology, market preferences, and pathogen specificity. The most widely grown varieties of pigeonpea in ESA are medium- and long-duration types because they are most adaptable to the diverse cropping systems of the region.

Pigeonpea is a versatile crop that could benefit farmers and the economy to a greater extent. Traditionally, farmers in the Kiteto and Kongwa districts of Tanzania have grown long-duration landraces (up to 240 days to maturity). However, with increasing rainfall variability, the introduction of medium-duration varieties that are not susceptible to end-of-season drought present alternative varieties to build greater resilience against weather-related losses, particularly in the face of climate change (Silim *et al*., 2006).

Description of Ilonga 14 M1 and M2

The two pigeonpea varieties were released in Tanzania in 2014. These varieties have a medium-duration maturity period, are tolerant to fusarium wilt (*Fusarium udum*), are high-yielding, and have good market qualities (Table 2.10). Pigeonpea grows well in most soils, and is able to mobilize iron-bound phosphorus using its root exudates, minimizing the need for phosphate fertilizer application, while improving soil fertility (Ae *et al*., 1990).

Benefits of the new varieties

In terms of productivity, these medium-duration varieties give better yields than the local long-duration landraces. Grain yield is less than that reported under optimal environments but better than the local landraces, under both optimal and sub-optimal production environments. The new varieties are nutritionally rich, comprising 22–24% highly digestible protein, 110 mg/100 g calcium, 120 mg/100 g magnesium, and 777 mg/100 g potassium.

The gross margins for the new varieties show they are profitable even in semi-arid areas. Elsewhere, variety release data show a two-fold increase in incomes generated from these varieties (Lyimo *et al.*, 2012). The cost–benefit analysis on producing the new varieties as an intercrop (common practice) and sole crop confirm their profitability (Table 2.11).

Studies by Africa RISING in the Kiteto and Kongwa districts of Tanzania show that 60% of households do not grow sufficient food to last the whole year, with 28% of the population exchanging labor for food, and 62% buying food from local vendors. In general, farmers in these districts sell about 75% of the crop harvested, leaving about 25% for domestic consumption. These new varieties, have the potential to increase food security and incomes, by providing more grain for trading and home consumption.

The new pigeonpea varieties also offer options for improving soil health by fixing soil nitrogen and improving soil carbon. Long-duration varieties such as Mali (ICEAP 0040) can fix between 30 and 118 kg/ha of nitrogen, depending on weather and soil conditions (Mhango *et al.*, 2020). Medium-duration varieties may fix similar amounts, especially in the second year as a ratoon crop, but this awaits experimental validation. Pigeonpea can be grown as an intercrop with maize or with another legume crop, as in the Africa RISING "doubled-up legume" technology (see Chapter 3 of this book).

Farmers' responses

On-farm evaluations were conducted over three years (2012–2015) in semi-arid agroecosystems in Tanzania's central zone, coupled with participatory variety selection. Ilonga 14 M1 and M2 were preferred by farmers and considered to be better adapted than the long-duration local check (Mali). The most desirable trait was the earlier maturity period of the two new pigeonpea varieties.

How to get started

- Farmers should plant only good-quality seed with a high germination percentage. Seed may be treated with an appropriate seed

Table 2.10. Key features of new pigeonpea varieties Ilonga 14 M1 and M2

1. Administrative information	
Attribute	Go-to information and sources for Tanzania
Target agroecosystems	Southern zone (Lindi and Mtwara); northern zone (Arusha, Kilimanjaro, and Manyara); eastern zone (Coast, Dar es Salaam, Morogoro, and Tanga).
Seed source	Early generation: TARI–Selian Certified seed: Private sector Quality declared seed: Selected trained and registered communities

2. Distinguishing characteristics and benefits		
Attribute	Ilonga 14 M1	Ilonga 14 M2
Days to 50% flowering	90–110	90–110
Days to 75% maturity	152	150
Seed color	Cream	Cream to yellowish
Tolerance to diseases	Fusarium wilt	Fusarium wilt
Potential grain yield (kg/ha)	1,500	2,000

Table 2.11. Performance of new pigeonpea varieties under drought and non-drought conditions in Central Tanzania

Variety	Average grain yield (kg/ha)	Cost–benefit ratio	Gross margin[1] (US$/ha)	Food production (kcal/ha/year)[2,4]
Optimal farmer production conditions[3]				
Local variety	250	n/a[5]	n/a	1,265
Ilonga 14 M1	700	1.51	58	3,497
Ilonga 14 M2	950	2.24	208	4,762
Researcher-managed optimal conditions[6]				
Ilonga 14 M1	1,700	2.06	470	8,492
Ilonga 14 M2	2,500	2.79	950	12,488
Suboptimal conditions[7]				
Local variety	100	n/a	n/a	500
Ilonga 14 M1	679	1.43	45	3,397
Ilonga 14 M2	745	1.67	85	3,730

[1]Calculated as described in Table 2.3.
[2]Calculated according to Musumba *et al*. (2017).
[3]Validation was conducted in Central Tanzania at TARI Hombolo with optimal management.
[4]Households are estimated to consume about 20% to a maximum of 30% of their produce, including both fresh and dry grain.
[5]n/a = not applicable.
[6]With extra inputs compared with farmer optimal management.
[7]Validation was conducted in dryer villages of Kongwa that receive a maximum of 600 mm annually.

dressing fungicide such as thiram, applied at a rate of 120 g per 100 kg of seed, to protect against soil-borne diseases, especially *Fusarium* wilt, which can cause a problem under poor rotation systems. Otherwise, it is important to grow pigeonpea in rotation with a cereal to minimize the build-up of soil-borne diseases such as *Fusarium* wilt.

- The crop should be grown in deep sandy loam soils with a pH of 5.0–6.2 to support good tap root system development. Although pigeonpea has a robust nitrogen fixation system, inoculation with the right rhizobia may boost grain yields by up to 30%, especially on sites where the crop is being planted for the first time. The new varieties should be planted at a spacing of 100 cm between rows and 30 cm within rows. The seed rate for both varieties is 15 kg/ha. Farmers interested in intercropping may use a spacing of 100 cm between rows and 50 cm within rows, generating a population of 20,000 plants per hectare (see Chapter 3 of this book for more details).
- Pesticide application should be timed to control pests at the flowering and grain filling stages. Two to three applications during these stages is generally effective.
- Weeds can account for up to 30% yield loss, but with poor management, losses can reach 80%. Weeding should be done intensively about three times during the first three to six weeks after planting. Weeding also helps to minimize the build-up of pest populations.

Opportunities for adoption

The market for pigeonpea grain is driven largely by demand from India, with bilateral trade deals designed to smooth exports from ESA to India. The new varieties could therefore unlock a significant market opportunity for farmers in the semi-arid regions of ESA. National governments in ESA are offering policy support toward this goal. For example, Tanzania's Agriculture Sector Development Programme, now in its second phase, prioritizes legumes as a means to stimulate agricultural and economic growth. There is also considerable scope to increase the scale of production of pigeonpea in Tanzania, with evaluations in the semi-arid zones demonstrating a two-fold increase in productivity.

There are also untapped opportunities to increase domestic consumption of pigeonpea in

ESA countries, as growing urban populations increase their consumption of a more diverse range of foods. Establishing de-hulling facilities will support this trend by producing faster-cooking grain.

Pigeonpea is being promoted increasingly as a key component of SI in crop–livestock systems in semi-arid agroecosystems. The new varieties Ilonga 14 M1 and M2 have been released in Kenya, Malawi, and Mozambique, in addition to Tanzania. Wider dissemination and use create pressure for seed companies to develop existing regional seed trade protocols, e.g., the COMESA Seed Harmonization and Implementation Plan, to facilitate regional movement of improved seed. It will also stimulate the formation of regional partnerships for the production of quality pigeonpea for domestic and export markets, with an increased scale of production across more months of the year benefiting both farmers and the broader economy.

Tengeru 2010: New tomato variety plus good agricultural practices to boost productivity

Background

Tomato (*Solanum lycopersicum* L.) is an important food and cash crop right across the world, and among the most commonly traded fruit and vegetable commodities. The crop is mostly grown by women on small plots as a source of income and nutrition security. Tomato fruits mature at different times during a crop cycle, permitting piecemeal harvests, and this fits well with the labor and utilization requirements of smallholder households. Tomato, particularly Tengeru 2010, is therefore well suited to provide a regular income and nutritious food for farm households. However, despite apparent market and household opportunities, the productivity of tomato across ESA remains low. For example, farmers in Tanzania produce around 12,200 kg/ha, while the global average is around 37,000 kg/ha (FAOSTAT, 2020).

Introducing new tomato varieties coupled with good agronomic practices has great potential to address the current productivity challenges and support more stable tomato supply chains. Africa RISING has therefore supported the validation of a new tomato variety, Tengeru 2010, produced using good agronomic practices. This work was accomplished in the Babati district of Tanzania.

Description of Tengeru 2010

The improved tomato variety, Tengeru 2010 (Figure 2.4) is early maturing and tolerant to late blight (*Phytophthora infestans* [Mont] de Bary), which is a major threat to tomato production worldwide. Tengeru 2010 has a high yield potential of up to 90,000 kg/ha (Table 2.12). For tomato farmers to fully benefit from this new variety, they need to apply good agronomic practices, which include using healthy seedlings, proper spacing, crop rotation, mulching, timely weeding, pruning, integrated pest management, and soil fertility augmentation with organic and inorganic fertilizers.

Benefits of growing Tengeru 2010

The performance of Tengeru 2010 was validated in four villages in Babati district, Tanzania. Fruit yield was five times higher than the national average of 12,200 kg/ha and within the potential fruit yield for tomato of 40,000–90,000 kg/ha. Sole use of healthy seedlings increased fruit yield by 28% and, when combined with good agricultural practice, yield increased by 128% (Table 2.13). Integrated pest management practices reduced pesticide use by 73%, which is of benefit to the environment and the consumer. Economic analysis shows the new technologies combined with good agricultural practices can deliver more than twice the gross margins of conventional farmer practices. The cost–benefit analysis revealed similar results with cost–benefit ratios higher than for farmer practice.

Tengeru 2010 and other varieties tested in Africa RISING sites are open-pollinated and can therefore be re-sown by farmers up to five times without significant yield reduction. This makes them viable for scaling up by smallholder farmers who might not easily access the improved seed.

Figure 2.4. A group of farmers admire the fruits of the new tomato variety Tengeru 2010 in Songambele village, Kongwa, Tanzania. (Photo courtesy of Hassan Mndiga, 2015.)

Table 2.12. Key features of Tengeru 2010

1. Administrative information	
Attribute	Go-to information and sources for Tanzania
Botanical name	*Solanum lycopersicum* L., Synonym: *Lycopersicon esculentum* Mill.
Target agroecosystems	All tomato-producing ecologies in ESA at between 500 and 1,700 m above sea level
Seed source	Early generation (breeder seed): World Vegetable Center Foundation seed: Horticultural Research and Training Institute, Tengeru Certified seed: Private sector Quality declared seed: Selected trained and registered farm communities
2. Distinguishing characteristics and benefits	
Days to flowering	35–40 days
Days to maturity	85–100 days
Fruit weight	125–200 g under moderate management; up to 400 g under optimum management
Tolerance to diseases	Late blight disease
Fruit yield potential	40,000–90,000 kg/ha
Utilization	Salad and industrial

Farmers' responses

On-farm performance evaluations of Tengeru 2010 under different production management regimes was conducted in Babati district of Tanzania. Growing Tengeru 2010 combined with good agricultural practices more than doubled the fruit yields and gross margins compared with conventional

Table 2.13. Performance of Tengeru 2010 under different management options

Management options	Fruit yield		Gross margin		Cost–benefit ratio[1]		Pesticide use[2]	
	t/ha	% increase	US$/ha	% increase	Ratio	% change	g/ha	% decrease
Farmer practice[3]	28.3	n/a[4]	7,916	n/a	11.9	n/a	45	n/a
Healthy seedlings[5]	36.5	28	9,664	22	14.3	20	35	22
Good agricultural practices[6]	64.7	128	18,307	131	20.4	74	12	73

[1]Calculated as described in Table 2.3.
[2]The most common pesticide is Dithane M45, used from the start of fruiting to maturity to control late blight. Common insecticides are based on cypermethrin and dimethoate.
[3]Refers to commonly used production systems including poorly adapted varieties and limited improved crop management practices.
[4]n/a = not applicable.
[5]Healthy seedlings of Tengeru 2010 without application of other good agricultural practices.
[6]Includes the use of healthy seedlings combined with good agronomic practices, including integrated pest management.

farming practices (Table 2.13). This contributed to farmers' increased adoption of good agricultural practices. Dissemination activities should ensure the inclusion of women (see Box 2.1).

How to get started

The crop is best grown from seedlings raised in a nursery. This enables the farmer to have greater control over stresses affecting young seedlings.

Box 2.1. Ensuring the inclusion of women in extension activities

Before following the instructions on how to get started, it is important to consider how a diverse group of farmers can be invited to extension activities. A woman extension officer from Babati, Tanzania, interviewed in a vegetable study, explained: "Many times when there are agricultural trainings, from the community it is mainly men who turn up. There is a local group here; according to them, women should not get involved in activities outside the home. This prevents women from taking part. These days I tell men, I do not only want to see you, but I would also like to see your wife. I am now experiencing some changes."

Practitioners should reflect upon challenges for women's participation in extension activities and address them (see team exercise outlined in Chapter 1 of this book). Part of this is the assessment of invitation channels: Through which invitation channels can women farmers be reached best?

See Fischer *et al*. (2020) for more information.

Field identification

Tomato can be grown under a wide range of agroecological conditions if the site is well drained. Good soil drainage minimizes the development of fungal diseases, commonly called 'damping off'. Fields should be sheltered from strong winds to avoid damage to tomato vines, but airflow should be permitted to prevent the build-up of humidity, which favors the growth of fungal diseases. Young plants have a particularly high demand for water.

The tomato crop should not be grown in a field with a recent history (less than three months) of growing other Solanaceae crops such as potato (*Solanum tubersorum* L.), eggplants (*Solanum melongena* L.), bell pepper (*Capsicum annum* L.) and other capsicum species. This will reduce early infections by soil-borne diseases, especially bacterial wilt (*Ralstonia solanacearum* (Smith)) and fusarium wilt (*Fusarium oxysporum* f.sp. *lycopersici*).

Nursery management

Nursery beds should be laid horizontally, 1 m wide and 6–7 m long, for easy access during weeding. Beds should be raised 15 cm above the ground to improve drainage, especially during rainy seasons. The bed should be established away from any permanent shade (cast by trees or buildings) during rainy seasons as this limits evapotranspiration and may lead to infection of young seedlings through 'damping off'. Soil should be mixed with composted manure at a rate of 2–5 kg/m^2 if the soil is generally infertile.

Tomato seed should be obtained from authorized dealers and seed mixed with sand in a ratio of 1:4 for even sowing. Sow seed directly into the nursery bed, in furrows at a depth of 0.5–1.0 cm, and at a spacing of 1 cm within furrows and 15–20 cm between furrows. Cover lightly with soil and water. Water twice a day, in the morning and evening, during dry seasons, and once a day during rainy seasons, if necessary. Thin seedlings after two to three weeks, when seedlings have three of four leaves. Keep the seedbed weed-free.

Common disease vectors such as whiteflies (*Aleurodicus dispersus, Bemisia tabaci*), aphids (*Macrosiphum euphorbiae* and other species), and thrips (*Frankliniella occidentali*) should be controlled using environmentally friendly systemic pesticides to kill plant-sucking insect pests. Recommended pesticides should be sought from local extension staff.

Seedlings may alternatively be raised in trays filled with a healthy soil medium at a maximum sowing rate of two seeds per hole and a depth of 0.5 cm. The seedbed should be kept moist, and seedlings thinned to avoid damping off after three weeks when the first true leaves have appeared. To improve initial seedling growth, starter nutrient solutions (usually high phosphorus fertilizers) should be applied at a rate of 103 g/10–15 liters of water between days 9 and 11 after germination. This should be followed by a daily water application at a rate of 7.5–10 ml per hole. Nitrogen, phosphate, and potassium (NPK) foliar fertilizer (15:10:15 + 2 magnesium oxide) should be applied twice between 11 and 21 days at a rate of 5 ml per seedling before transplanting. Watering should continue until transplanting. Seedlings will by then have hardened before being transplanted in week four.

Transplanting and crop management

Seedlings should be transplanted after four to six weeks of growth at a spacing of 50 cm within rows and 60 cm between rows, when plants have between four and seven true leaves. During transplanting, apply organic manure at a rate of 0.2–0.5 kg per hole. Inorganic fertilizers such as NPK (16:16:16) may be applied one week after transplanting at a rate of 200 kg/ha. Urea (46% nitrogen), may be used at a rate of 120 kg/ha in two split applications, the first application one week after transplanting and the second application during the flowering stage. Tengeru 2010 has an indeterminate growth habit and therefore generally grows upright and should be staked at two to four weeks after planting. Good agronomic practices such as weeding, erosion control and mulching between rows (or use of thin polyethylene plastic sheets) will support healthy growth. Mulching using organic material adds organic matter to the soil during and after the cropping season. The crop is ready for harvesting two months after transplanting and harvesting may continue for six to eight weeks.

Plant protection

To control pests and diseases during crop growth, farmers are recommended to follow integrated pest management guidelines (Higley and Pedigo, 1996), involving integrated use of cultural methods (crop rotation, proper soil tillage, and trap crops to reduce pathogen load, especially soil-borne pathogens); biological control (beneficial microbes to out-compete and/or control pests and/or pathogens, these may be applied as biorational pesticides such as *Bacillus thuringiensis, Trichoderma* species, and/or by applying predators and parasitoids to control insect pests); and, as a last measure, chemical control. In general, pesticides should only be applied when pest pressure reaches the economic injury level (the point in pest management where costs associated with pest management such as the use of pesticides equals the benefits from the pest management actions). Pest management should be used judiciously to balance maximum productivity, environmental protection, and food safety for consumers.

Opportunities for adoption

Market demand for tomatoes continues to grow steadily in ESA and beyond. Production in Tanzania increased from about 520,000 tons in 2016 to 628,000 tons in 2019. Most of the tomatoes were consumed by the domestic market, with exports amounting to less than 900 tons annually between 2016 and 2019 (FAOSTAT, 2020). Tomato has potential for export as processed products, including tinned tomatoes and tomato paste, but this is yet to be exploited. The strategic partnership established among diverse stakeholders through the Southern Agricultural Growth Corridor of Tanzania aims to expand the tomato value chain by linking more than 10,000 smallholder farmers in Iringa and Njombe regions with broader markets.

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