International research on vegetable improvement in East and Southern Africa: Adoption, impact and returns

Pepijn Schreinemachers ¹, Teresa Sequeros ², Philipo Joseph Lukumay ³

¹ World Vegetable Center, P.O. Box 42, Shanhua, Tainan 74199, Taiwan. Email: pepijn.schreinemachers@worldveg.org

² Independent consultant, P.O. Box 11969, Arusha, Tanzania. Email: tsequeros@a4dev.com

³ World Vegetable Center, Eastern and Southern Africa, P.O. Box 10, Duluti, Arusha, Tanzania. Email: philipo.joseph@worldveg.org

This is the original version of a paper submitted to Agricultural Economics (January 2016). The published version is an improved and shortened version of this paper, but the results are identical. Please cite this paper as: Schreinemachers, P., T. Sequeros, P.J. Lukumay. 2017. International research on vegetable improvement in East and Southern Africa: Adoption, impact and returns. Agricultural Economics. http://dx.doi.org/10.1111/agec.12368.
Abstract

This study analyzes the adoption of tomato (*Solanum lycopersicum*) and African eggplant (*Solanum aethiopicum*) varieties developed through international agricultural research, released by national agricultural research and extension systems (NARES) and supplied to farmers by private seed companies in East and Southern Africa from 1990 to 2015. It quantifies the economic impact and returns to investment of these varieties for Tanzania. We found that 50% of tomato and 98% of African eggplant commercial seed production in the region were varieties developed by the World Vegetable Center. WorldVeg and NARES invested US$ 6.9 million in research, extension, and promotion of these two crops. This generated economic gains of US$ 254 million for tomato and US$ 5 million for African eggplant in Tanzania up to 2014. The internal rate of return is 29.3% for tomato and 12.3% for African eggplant, though we project the latter to increase to 26.0% by 2024 as adoption only started in 2007. These results indicate international research into vegetable improvement to give returns to investment that are as high as those previously reported for some staple crops. With vegetables increasingly recognized for their importance to human health as well as to farm household income, the time seems ripe for much greater investment in vegetables.

*Keywords*: African eggplant, tomato, economic surplus model, impact evaluation, technology adoption, Tanzania
1 Introduction

Plant breeding research in sub-Saharan Africa continues to lack capacity and resources (Lynam 2011). Public sector plant breeders, if present, tend to work on food staples rather than vegetables; vegetable breeding is usually left to the private sector. However, very few private seed companies in sub-Saharan Africa have capacity in plant breeding, as most of them trade rather than produce vegetable seed (Fufa et al. 2011; Afari-Sefa et al. 2012).

Lacking capacity to develop their own varieties, public access to improved germplasm from international agricultural research centers is vital for crop improvement programs in sub-Saharan Africa (Lynam 2011). For vegetables, the World Vegetable Center (WorldVeg) is the only international nonprofit organization that makes improved breeding lines and genebank accessions publicly available. Yet there is no robust evidence for adoption and impact of open-pollinated vegetable varieties developed and disseminated by WorldVeg and its partners.

In contrast, several previous studies have documented the adoption and impact of improved varieties of the world's main food staples developed by the Consultative Group for International Agricultural Research (CGIAR) and its national partners (e.g. Morris 2002; Alene et al. 2009 for maize, Morris et al. 1994; Lantican et al. 2005 for wheat, Brennan and Malabayabas 2011 for rice, Thiele et al. 2006 for potato and Alene et al. 2013; Robinson and Srinivasan 2013 for cassava). These studies generally have shown very attractive returns to investment into food staple research by international agricultural research centers.

With growing recognition of the importance of vegetables for human nutrition and health and for agricultural sustainability through crop diversification, it is imperative to understand the role and impact of vegetable variety improvement by international and national research organizations. Therefore, the objectives of this study are twofold. The first is to quantify variety release and adoption of vegetable crops developed from public germplasm material originating
from international research in East and Southern Africa. The second is to quantify the economic impact and returns of this germplasm material for Tanzania.

Vegetables are an extremely diverse group of crop species—there are 439 species available in the WorldVeg genebank in Taiwan. To narrow down the scope of the study we chose tomato (*Solanum lycopersicum*) and African eggplant (*Solanum aethiopicum*) as two similar yet contrasting crops. Tomato is the world's most popular vegetable and the world's fifth most important crop by value after rice, wheat, maize, and potato (FAO 2015). WorldVeg has worked on tomato for more than 40 years and all major vegetable seed companies in the world are engaged in tomato breeding. On the other hand, African eggplant (also known as garden egg or mock tomato) is a traditional African vegetable that is little known outside Africa, and until very recently, was completely ignored by the major vegetable seed companies. WorldVeg has worked on African eggplant for 12 years on germplasm collection, selection, purification and promotion, but breeding was initiated only recently. The contrast is therefore helpful to compare the relative merits of research in ‘global’ versus ‘local’ vegetables, of ‘major’ versus ‘minor’ vegetables, and of efforts in crop ‘breeding’ versus ‘selection’.

We further narrowed the scope of our study to ten countries in East and Southern Africa that received seed shipments from WorldVeg since the early 1990s: Burundi, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Tanzania, Uganda, and Zimbabwe. For the in-depth analysis of impact and impact pathways, we focused on Tanzania because it is the center of vegetable seed production in East and Southern Africa.

The paper starts by providing relevant background information about the impact pathway of WorldVeg's research on tomato and African eggplant. We then explain our method of quantifying adoption rates from seed company data and of quantifying impact using the economic surplus method. After presenting the results, we put our findings into the wider
context of vegetable improvement research in East and Southern Africa and make the shortcomings of our study explicit. The paper ends with a conclusion.

2 Impact pathway of new tomato and African eggplant varieties in Tanzania

WorldVeg produces improved open-pollinated vegetable lines suitable for tropical and subtropical conditions.\(^1\) It does not directly release varieties, but gives private and public sector breeding programs and seed producers worldwide access to its improved breeding lines and genebank accessions to use as parental material in their own crop improvement programs, or more commonly in sub-Saharan Africa, to simply test advanced vegetable lines and release the best ones to farmers. The adoption of varieties by farmers is therefore the result of a collaborative effort between WorldVeg, national agricultural research and extension systems (NARES) including national seed agencies, and seed companies. Since 1978, WorldVeg-developed material is known to have been incorporated in at least 169 tomato varieties released in 40 countries (Ebert 2012).

Tomato is originally a subtropical crop from South and Central America, but centuries of selection and breeding have changed the genetic structure of cultivated tomato into a mostly temperate crop that performs poorly under hot and humid conditions. Since 1973, WorldVeg scientists, in collaboration with scientists worldwide, have developed improved breeding lines for cultivation in the tropics with traits such as heat tolerance and resistance to plant diseases as well as fruit characteristics such as high beta carotene, long shelf-life, and improved color, size, and taste.\(^2\)

\(^1\) The word \textit{accession} refers to germplasm material identified and stored in a genebank; \textit{line} refers to improved germplasm material, developed through crop breeding or selection, which has not, or not yet, been released to farmers; a \textit{variety} here refers to a cultivar, which is a cultivated crop species that has been intentionally bred or selected for use by farmers. WorldVeg distributes accessions and develops lines, but does not release varieties.

\(^2\) Resistance to tomato diseases which include late blight, early blight, root-knot nematode, Fusarium wilt, bacterial wilt, gray leaf spot, \textit{Tomato mosaic virus}, and begomoviruses that cause tomato yellow leaf curl disease.
The original focus of WorldVeg was on Asia and it was only in 1992 that WorldVeg established its first Africa office at the premises of the Horticultural Research and Training Institute (HORTI-Tengeru), which at the time was the only entity in Tanzania with capacity in vegetable breeding. The arrival was timely because the government of Tanzania had in part liberalized seed production in 1991. The state-owned Tanzania Seed Company Ltd (TANSEED) previously held a monopoly over the production, import and distribution of certified seed. Vegetable seed was expensive, varieties were not adapted, seed quality was poor, and TANSEED was unable to distribute seed to most rural areas (Afari-Sefa et al. 2013).

The collaboration between WorldVeg and HORTI-Tengeru focused on the development and release of new vegetable varieties, particularly tomato, as this was the most popular vegetable in Tanzania. At that time, old tomato varieties such as Marglobe (released in 1917), Money Maker, and Roma (released in the 1970s) dominated the market. These varieties had been introduced from Europe or the USA and were poorly adapted to tropical conditions. They were susceptible to disease and had a soft flesh type unsuitable for unrefrigerated transport over long distances on bumpy roads.

A range of advanced tomato breeding lines developed at WorldVeg in Taiwan were evaluated in four regions of Tanzania in 1993 and two open-pollinated lines were eventually selected for release. The first variety was Tanya—a determinate variety (has a compact height) with medium-sized fruit, high yield potential, high solids content, and thick flesh, which gives it a long shelf-life and makes it suitable for transport under poor road conditions. The second variety was Tengeru-97—an indeterminate variety with a slightly larger fruit size than Tanya, high yield potential, high solids content, thick flesh, and resistance to root-knot nematode, gray leafspot, and Fusarium wilt.
The new varieties were tested for 3 years (1994-1996) and officially released in 1997, though some seed companies had started selling them as early as 1995. HORTI-Tengeru and WorldVeg produced and made available foundation seed of these varieties and promoted the varieties among farmers and seed companies. The Agriculture Seed Agency (ASA) played a critical role in this process as the main intermediary between the research institutions and private seed companies as its mandate is to supply foundation seed to local seed producers.

Alpha Seed was the first private seed company in Tanzania, established in 1994. The company owners recognized the superior qualities of the new tomato varieties and promoted them to farmers in Tanzania. The new varieties were popular with farmers because of lower yield losses from pests and diseases (giving a higher average yield) and the possibility of transporting the tomatoes over long distances. Fruit of both varieties was popular with consumers for its long shelf-life and suitability for eating fresh or cooked. Alpha Seed then won a bid from the Food and Agriculture Organization (FAO) to distribute Tanya and Tengeru-97 to Burundi, the Democratic Republic of Congo, Uganda, and Zambia. This prompted other seed companies in Tanzania and elsewhere to add the same varieties to their portfolio. Lyimo et al. (2006) estimated that 69% of Tanzania tomato farmers had adopted these new tomato varieties in 2003.

From the mid-1990s, WorldVeg and HORTI-Tengeru started collaboration on a range of African traditional vegetables, including African eggplant. Existing varieties of African eggplant had been improved by farmers through centuries of seed selection. Cultivation was mainly in home gardens as the crop had little commercial value. WorldVeg and HORTI-Tengeru worked together to collect and characterize germplasm, purify lines, conduct multilocation trials, and produce foundation seed. The first best-performing variety was named Tengeru White, later followed by a second variety DB3. These varieties had better resistance to pests and diseases, and had a long fruit production season, but the most important quality
was reduced bitterness of the fruit, as other varieties had been very bitter tasting (Keding et al. 2007).

Building on the success of the new tomato varieties, Alpha Seed was the first company to start production of Tengeru White and DB3 in 2000. Consumer demand was stimulated by WorldVeg and HORTI-Tengeru through coordinated campaigns to raise awareness about the nutritional value of traditional vegetables. African eggplant has since changed from a subsistence crop into a commercial crop that is nowadays widely available, even in supermarkets (Ojiewo et al. 2010a).

3 Material and methods

3.1 Estimating adoption

Adoption rates were estimated from data collected from private seed companies through a survey eliciting information on seed production of tomato and African eggplant varieties released since 1990. The method was the same as that of previous studies (e.g. Morris 2002; Thiele et al. 2006). However, whereas public sector organizations dominate the seed sales of staple crops, the private sector dominates vegetable seed sales. This makes data collection more difficult because companies are more hesitant to disclose data. Each company was therefore visited in person to explain the purpose of the study and ensure data confidentiality.

For each variety, respondents were asked if: (1) it is an unmodified WorldVeg line; (2) it is a cross of two WorldVeg lines; (3) one of the parents is an WorldVeg line; (4) some WorldVeg material is in the pedigree, but more distant than a parent; or (5) it is a variety unrelated to WorldVeg. Respondents were asked the year the variety had been introduced and the amount of seed produced in the two most recent crop years. From these data we estimated the number of released varieties and the quantity of seed containing WorldVeg-developed material.
3.2 Economic impact

The economic surplus method is the most widely used and generally accepted approach to quantify the impact of crop improvement research (see Alston et al. 1995; Masters et al. 1996; Morris and Heisey 2003 for a description of the method; Brennan and Malabayabas 2011; Robinson and Srinivasan 2013 for recent applications). Economic surplus is the monetary value of production and consumption, which is defined as the area between the supply and demand curves up to the point of market equilibrium (where demand equals supply). The introduction of an improved variety is assumed to shift the supply curve down and to the right, thereby increasing the area between the supply and demand curves and thus creating economic benefit. The shaded area in Figure 1 illustrates this change in economic surplus, also called social gain or welfare effect. This social gain stems from increased crop yields and reduced production costs for producers and a decreased purchase price and increased consumption for consumers.

Estimating the social gain requires careful construction of the supply curve in the absence of the technology, which is the counterfactual for the impact assessment. The supply curve without the technology is unobserved in an ex-post impact assessment, as the technology already has been adopted. It requires the estimation of yield increases and cost reductions while making adjustments for price changes. The strength of the economic surplus method is that it considers the effect on producers as well as consumers. The method requires few data, but makes strong assumptions of market equilibrium, about the shape of supply and demand curves, and the nature of the supply shift.
Economic surplus was estimated in four steps following Alston *et al.* (1995) for a basic closed economy:

1. *Adoption profiles.* Variety-specific adoption profiles were estimated by assuming an S-shaped adoption curve, similar to that used in previous studies (e.g. Alene *et al.* 2013; Robinson and Srinivasan 2013). This suggests that adoption begins slowly, followed by a period of steep growth, and then reaches a plateau:

   \[ A_t = \frac{U}{1 + e^{-(a+bt)}} \] (1)

   where \( A_t \) is the total area planted to the crop variety in year \( t \), \( U \) is the upper limit on adoption, \( b \) is the slope coefficient measuring the rate of variety acceptance and \( a \) is the intercept reflecting aggregate adoption at the start of the period. Equation (1) can be transformed into the linear form:

   \[ \ln \left[ \frac{A_t}{(U-A_t)} \right] = a + bt \] (2)

   The parameters \( a \) and \( b \) can be estimated using an ordinary least squares (OLS) regression with two observations for \( A_t \) and assuming a value for \( U \). To get the first observation, we assumed that adoption reached 1% of the planted area in the first year that the new varieties became
available to farmers. The second observation reflected 2014 adoption rates and were estimated from the quantity of seed (S) sold in the domestic market:

\[ A = (S \times 10^6) \times r^{-1} \times p^{-1} \]  

in which \( r \) is the seed rate (in grams/ha) and \( p \) is the seed replacement rate, which is the proportion of farmers buying new seed in a given year. The adoption rate of variety was then calculated as its share in the total planted area under all varieties.

2. Changes in yield and production costs. Alston et al. (1995) used the concept of ‘K-shift’ to represent the shift in the supply function resulting from adoption of the new technology. \( K_t \) is per unit and per period cost reduction due to technological change:

\[ K_t = A_t \left[ \frac{(\Delta Y/Y_t)/\varepsilon + (\Delta C/Y_tP_t)}{\eta + \varepsilon} \right] \]  

where \( \Delta Y \) is the yield gain attributable to the new variety, which is assumed constant over the project period, \( Y_t \) is the average national yield in year \( t \) (both in t/ha), \( \varepsilon \) is the price elasticity of supply for the crop (that is, the percentage increase in production for every one percent increase in market price), \( \Delta C \) is the difference in production cost between the new variety and the dominant variety that was replaced (US$/ha), and \( P_t \) is the crop's market price at year \( t \) (US$/ton).

3. Changes in prices. A reduction in the cost of production can be expected to increase total supply as profits are higher and farmers expand their planted area in response. This might create a downward pressure on the market price. The anticipated price effect \( Z_t \) is given by:

\[ Z_t = K_t \varepsilon / (\eta + \varepsilon) \]  

where \( \eta \) is the price elasticity of demand in absolute value terms.

4. Economic surplus. By combining the supply shift \( K_t \) and the price effect \( Z_t \), the total welfare effect, social gain or economic surplus, \( (\Delta TS \text{ in US$}) \) was calculated as:

\[ \Delta TS_t = P_tQ_t(1-s)K_t(1-0.5Z_t\eta) \]
where the $Q_t$ is the marketable output (in tons) and $s$ is the proportion of output that is recycled as seed for the next planting season. The economic surplus can be disaggregated into a consumer surplus ($\Delta CS$) and a producer surplus ($\Delta PS$) as:

$$\Delta CS_t = P_t Q_t (1-s) Z_t (1-0.5Z_t \eta)$$  \hspace{1cm} (7)$$

$$\Delta PS_t = P_t Q_t (1-s) (K_t - Z_t) (1-0.5Z_t \eta)$$  \hspace{1cm} (8)$$

3.3 Data for estimating economic impact

*Adoption of improved varieties*

Domestic seed use was calculated by deducting formal and informal seed exports from the quantity of seed produced in Tanzania as obtained from the seed companies. Informal seed exports were estimated from expert opinion of seed company managers and agricultural input dealers. A rapid questionnaire-based survey was conducted among 300 tomato and 200 African eggplant farmers in five regions of Tanzania in June 2015 to estimate seed rates and seed replacement rates. This survey targeted the main production areas for tomato and African eggplant. Plausible adoption ceilings were set in consultation with seed companies, agrodealers, and local experts from HORTI-Tengeru and the Tanzania Official Seed Certification Institute (TOSCI).

*Area and production data*

Tomato area and production data were taken from FAO (2015) for the period 1995-2014. Data for African eggplant were available only for 2007-08 from the National Sample Census of Agriculture, which showed a total area of 3,208 ha (MAFSC 2012). Seed companies confirmed rapid growth in the seed sales of African eggplant and crop experts at WorldVeg and HORTI-Tengeru also believed there has been rapid area expansion. Without data to build on, we assumed an area expansion at same rate as tomato over the period 2007-2014, which implies an expansion of about 300 ha per year. However, for yield we used a more conservative assumption of constant yields at 2007-08 levels as we had no reliable data on yield trends.
From interviews at ASA, we estimated that farmers set aside 0.01% of their tomato and 0.08% of their African eggplant production to produce seed.

**Price data**

National average retail prices for tomato were available for 2002-2014, and for African eggplant for 2010-2014 (pers. comm. National Bureau of Statistics (NBS), February 2015). Retail margins were deducted from the retail prices to reflect wholesale selling prices. Yearly average wholesale prices from the main rural and peri-urban markets best reflect marginal prices, which are required for the analysis (Masters *et al.* 1996). To obtain wholesale prices, we subtracted a retail margin from the retail prices. Weinberger and Pichop (2009) estimated the retail margin for African eggplant to be 34% while NBS estimated it to be 16% for tomato in Tanzania. Tomato prices for 1995-2001 were estimated using linear extrapolation of available prices for 2002-2014. This method could not be used for African eggplant because of few data points and a poor fit. Yet tomato and African eggplant prices are strongly correlated (correlation coefficient=0.97, p<0.01) and this was used to impute African eggplant prices for the period 2007-2010. All prices were converted into US dollars using the official exchange rate and expressed in constant 2014 US$ using the consumer price index for Tanzania (pers. comm. NBS; IMF 2000).

**Yield advantage of improved varieties**

Tomato yield data were taken from on-station yield trials conducted in four locations across Tanzania in 1994-1997 (Nmdiagi *et al.* 1997). The average yield of Tanya was 53.3 t/ha and 6.6% above the yield of the local check, Roma VF, which was the dominant determinate tomato variety at the time. The average yield of Tengeru-97 was 57.8 t/ha and 16.9% above the yield of the local checks Marglobe and Money Maker, which were the dominant indeterminate varieties at the time. Had the WorldVeg-developed varieties not been introduced to Tanzania, then it is likely that farmers would have continued using the varieties they were familiar with,
as there were few alternative sources of open-pollinated tomato varieties; the yields of these older varieties are therefore a valid counterfactual for the analysis.

These trial data are, however, unrepresentative of average tomato yields in Tanzania, which were only around 7.5 t/ha in 1997 (FAO 2015). However, local experts and farmers confirmed that the relative yield premium of 6.6% for Tanya and 16.9% for Tengeru-97 as estimated from the trials were realistic. Farmers interviewed during the rapid assessment in mid-2015 estimated these premiums to be higher at 21% for Tanya and 39% for Tengeru-97. In addition, Lyimo et al. (2006) estimated the yield of Tanya and Tengeru-97 to be 36% higher than that of the older tomato varieties. The increase in average tomato yield in Tanzania from 7.5 t/ha in 1997 to 12.2 t/ha in 2012 (FAO 2015) also suggests the existence of a yield premium associated with the adoption of improved varieties. We therefore judged that the relative gains achieved in on-farm trials were representative, and likely to be a conservative estimate, of the relative gains achieved by farmers. Previous studies have made the same assumption (e.g. Alene et al. 2009 and also discussed in Morris and Heisey 2003).

Yield data for African eggplant varieties DB3 and Tengeru White were available from on-farm experiments conducted in four locations in 2010 (TOSCI 2010). At 24.7 t/ha, the average yield of DB3 was 10.4% higher than the average yield of four other existing varieties (Manyire Green, RW-AE-7, TZSMN 75-7 and Tengeru White). Farmers interviewed for this study thought that the yield premium was much higher, at around 40%, but we conservatively set it at 10% as based on the opinion of local researchers at HORTI-Tengeru (interviewed in October 2015). The trial data did not show a yield advantage for Tengeru White, despite the fact that the variety has been widely adopted. It must, however, be kept in mind that the main advantage of DB3 and Tengeru White is their non-bitter taste, rather than higher yield. However, the economic surplus method relies on quantitative shifts in supply and demand, and we therefore dropped the case of Tengeru White and focus on DB3 in the remainder of the analysis.
Production costs of the improved varieties

Farmers interviewed for this study estimated that production costs of Tanya were 4% below that of the older varieties, while the production cost of Tengeru-97 was about 6% lower. Lyimo et al. (2006) also estimated a 2% reduction in variable input costs for Tanya and Tengeru-97. We conservatively assumed a zero difference in variable input costs between the new and the old tomato varieties. The correctness of this assumption was confirmed with seed company managers and local experts interviewed for this study (from TOSCI, WorldVeg and HORTI-Tengeru, interviewed in November 2014). Farmers believed African eggplant variety DB3 had lowered their production costs on average by 2%. There are no other studies on the production cost of African eggplant. As local experts from TOSCI, WorldVeg and HORTI-Tengeru also thought there was no difference in production costs between DB3 and other varieties, we assumed a zero cost difference.

Supply and demand elasticity

The supply elasticity ($\varepsilon$) was set at 0.35 as based on Mackay et al. (2004). This connotes a crop that is traded on local rather than international markets. This might underestimate the true supply elasticity because historical tomato area and real prices have shown an upward trend, particularly since 2005. We therefore tested the sensitivity of the results for higher values of the supply elasticity. The demand elasticity ($\eta$) was set at 0.96 as based on Chongela et al. (2013) and Leyaro (2009) and we tested sensitivity for this parameter as well.

3.4 Returns to investment

Returns to investment were estimated by comparing the economic gains to the cost of developing, promoting, disseminating and maintaining the improved varieties by WorldVeg and NARES. Streams of benefits and costs were converted into net present values by compounding historical values and discounting future values at a real discount rate of 5% per
annum. This rate has been used by nearly all comparable studies (e.g. Alene et al. 2009; Brennan and Malabayabas 2011; Robinson and Srinivasan 2013).

The starting year for the cost calculation is a critical assumption in costing studies. Setting the starting year close to the year of release (when benefits start to materialize) is likely to give higher returns to investment. For tomato, we conservatively set the starting year to 1987, which is 10 years before the official variety release. This is the year in which existing WorldVeg breeding lines, which in themselves were the result of a long-term tomato breeding program, were crossed to create new breeding lines that were named Tanya and Tengeru-97. We note that these varieties originally were developed for Asia rather than Africa and could be considered as spillover effects of research in Asia. We return to this in the discussion.

Following the suggestion by Masters et al. (1996), we approximated the investment cost of tomato variety development for 1987-1997 by multiplying the total annual budget of WorldVeg by the proportion of senior scientists involved in tomato breeding (including the tomato breeder as full-time and the pathologist, virologist and nutritionist as part-time) in the total number of senior scientists (excluding administrative and management staff).

Not all of this investment can be allocated to Tanzania because vegetable breeding at WorldVeg has a global mandate. Despite widespread use, we suspect that tomato breeding had the greatest impact in four countries where WorldVeg has had a long-term presence: India, Taiwan, Tanzania, and Thailand. Treating all other countries as one, we allocated one-fifth of the total investment cost to Tanzania. We expect that this will give a fair estimate of the cost of and returns to tomato breeding at WorldVeg. For 1993-2014 we added the cost of field trials.

---

3 Previous studies have not been entirely consistent in their choice of starting year. Brennan and Malabayabas (2011) included investment costs 7 years before the release of a new rice variety, Alene et al. (2013) included cost data for 3 years before the release of a cassava variety in Malawi and Zambia, while Robinson and Srinivasan (2013) included cost data for only 1 year prior to official variety release of a cassava variety in Thailand.
demonstration, promotion, and maintenance breeding done by WorldVeg and HORTI-Tengeru. Much of the variety testing and promotion was project-funded by the Federal Ministry for Economic Cooperation and Development (BMZ) of Germany from 1996 to 1998. The project budget was included in the costs.

Development, dissemination and promotion of African eggplant variety DB3 was done within the context of two BMZ-funded projects (2003-2009) and one project funded by the Bill & Melinda Gates Foundation (BMGF, 2007-2009). These projects operated in Tanzania and three further countries and worked on African eggplant as well as nine other traditional African vegetables. The BMGF project also worked on non-traditional vegetables. To approximate the investment in traditional vegetables in Tanzania we divided the budget of the BMZ projects by four (as there were four project countries) and the budget of the BMGF project by eight (as there were four project countries and two broad groups of crops).

These projects led to the official release of seven varieties of traditional vegetables in Tanzania (Dinssa et al. 2015). However, DB3 is perhaps the variety that has been most widely adopted. Because the project objective was the improvement and promotion of traditional African vegetables in general, rather than the development of one particular variety of African eggplant, we did not try to calculate the cost per variety released but conservatively included the costs of developing all varieties. Again, this is a very conservative assumption that is more likely to overestimate than to underestimate the true cost. For 2010-2014, when the three projects had been completed, WorldVeg and HORTI-Tengeru continued basic work on African eggplant, including variety maintenance and promotion.

---

4 The project was titled "Tomato germplasm improvement programme for Africa" (1996-1998).

5 The projects were "Promotion of neglected indigenous vegetable crops for nutritional health in Eastern and Southern Africa" (phase I and II, 2003-2009) funded by BMZ and "Vegetable Breeding and Seed Systems for Poverty Reduction in Africa" funded by the Bill & Melinda Gates Foundation (2008-2010).
We used three standard financial indicators of return to investment: net present value of the benefit and cost cash flow, benefit-cost ratio, and internal rate of return. Although the project period was set to 1987-2014 for tomato and 2003-2014 for African eggplant, we also estimated returns on investment for a longer period until 2024, which is justifiable because adoption of all improved varieties is still ongoing and benefits have been realized only partially.

4 Results

4.1 Adoption rates for East and Southern Africa

The survey recorded information from 87 seed companies and public sector organizations across ten study countries in East and Southern Africa. We found that 25 of these were involved in commercial seed production while all others were only trading seed. Of these 25 producers, 9 did breeding research, of which 4 were companies and 5 were government research organizations. There was no seed production of tomato or African eggplant in Mozambique or Rwanda.

We found that seed of 60 tomato varieties had been commercially produced in the region from 1990 to 2014 (Table 1). Of these, 12 varieties were unmodified WorldVeg lines while 5 others had some WorldVeg-developed material in their pedigree. For African eggplant, seed of 9 varieties had been produced since 1990 and 6 of these were unmodified WorldVeg lines.

The number of tomato varieties with WorldVeg-developed material in their pedigree shows continuous growth (Figure 2). Growth in variety releases has been particularly rapid since 2004, when private seed companies emerged. Tomato hybrids account for the majority of new releases in recent years but open-pollinated varieties still accounted for 97% of the tomato seed production in 2013/14. For African eggplant, there are currently only open-pollinated varieties, no hybrids.
Table 1 Number of tomato and African eggplant varieties produced in East and Southern Africa, 1990-2014 and 2012-2014.

<table>
<thead>
<tr>
<th>Crop and country (number of seed producers)</th>
<th>1990-2014</th>
<th>2012-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unique varieties ¹</td>
<td>Unmodified WorldVeg lines</td>
</tr>
<tr>
<td>Tomato (24)</td>
<td>60</td>
<td>12</td>
</tr>
<tr>
<td>Burundi (1)</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Ethiopia (2)</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>Kenya (2)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Madagascar (2)</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Malawi (1)</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Tanzania (9)</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>Uganda (5)</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>Zimbabwe (2)</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>African eggplant (16)</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Burundi (1)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Kenya (1)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Madagascar (3)</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Tanzania (8)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Uganda (3)</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Notes: ¹ Corrections were made if the same variety was released under different trade names and if the seed company could tell us the original name. This was not always possible; thus there might be some double-counting in the regional total.

Figure 2 Adoption of tomato varieties by seed producers in East and Southern Africa, with and without WorldVeg-developed material, 1990-2015

Notes: If the same variety is adopted by seed companies in two countries then it shows twice in the figure. The seed company data recorded seed sales for 60 varieties from 1990 to 2014, but only for 54 varieties was the year of adoption known.
We estimated annual production of tomato seed to be 54 t in 2013/14. Of this, 79% was produced in Kenya and Tanzania (Table 2). Unmodified WorldVeg lines accounted for 50% of total tomato seed production in the region, though most of this was produced in Tanzania and Uganda with small amounts produced in Madagascar and Malawi. Seed production of African eggplant was estimated to be 3.7 t/year, based on data reported by 15 seed producers. Nearly all of this was produced in Tanzania, with small amounts produced in Kenya and Madagascar; 98% was unmodified WorldVeg material.

Table 2 WorldVeg germplasm and lines in seed production of tomato and African eggplant in 10 East and Southern African countries, 2013/14

<table>
<thead>
<tr>
<th>Crop and country (number of seed producers)</th>
<th>Total seed production (t/year)</th>
<th>By WorldVeg contribution¹</th>
<th>Non WorldVeg germplasm (t/year)</th>
<th>Unmodified WorldVeg lines t/year</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total tomato (23)</td>
<td>54.13</td>
<td></td>
<td>26.95</td>
<td>27.17</td>
<td>50</td>
</tr>
<tr>
<td>Burundi (1)</td>
<td>0.26</td>
<td></td>
<td>0.25</td>
<td>0.01</td>
<td>4</td>
</tr>
<tr>
<td>Ethiopia (2)</td>
<td>0.04</td>
<td></td>
<td>0.04</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Kenya (2)</td>
<td>13.19</td>
<td></td>
<td>13.19</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Madagascar (2)</td>
<td>0.28</td>
<td></td>
<td>0.19</td>
<td>0.09</td>
<td>32</td>
</tr>
<tr>
<td>Malawi (1)</td>
<td>0.19</td>
<td></td>
<td>-</td>
<td>0.19</td>
<td>100</td>
</tr>
<tr>
<td>Tanzania (9)</td>
<td>29.60</td>
<td></td>
<td>3.95</td>
<td>25.65</td>
<td>87</td>
</tr>
<tr>
<td>Uganda (4)</td>
<td>9.59</td>
<td></td>
<td>8.36</td>
<td>1.23</td>
<td>13</td>
</tr>
<tr>
<td>Zimbabwe (2)</td>
<td>0.98</td>
<td></td>
<td>0.98</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Total African eggplant (15)²</td>
<td>3.79</td>
<td></td>
<td>0.08</td>
<td>3.72</td>
<td>98</td>
</tr>
<tr>
<td>Burundi (1)</td>
<td>0.02</td>
<td></td>
<td>-</td>
<td>0.02</td>
<td>100</td>
</tr>
<tr>
<td>Kenya (1)</td>
<td>0.12</td>
<td></td>
<td>-</td>
<td>0.12</td>
<td>100</td>
</tr>
<tr>
<td>Madagascar (3)</td>
<td>0.28</td>
<td></td>
<td>0.07</td>
<td>0.21</td>
<td>74</td>
</tr>
<tr>
<td>Tanzania (8)</td>
<td>3.38</td>
<td></td>
<td>-</td>
<td>3.38</td>
<td>100</td>
</tr>
<tr>
<td>Uganda (2)</td>
<td>&lt;0.01</td>
<td></td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>40</td>
</tr>
</tbody>
</table>

Note: ¹ There were no tomato varieties with partial WorldVeg parentage in 2013/14. ² African eggplant was not produced in the other countries.

WorldVeg-developed tomato varieties Tanya and Tengeru-97 accounted for 49.8% of regional seed production and for 86.7% of tomato seed production in Tanzania (57.1% for Tanya and 29.6% for Tengeru-97). WorldVeg-developed African eggplant varieties DB3 and Tengeru White accounted for 98% of commercial seed production in the region and for 100% of seed
production in Tanzania (78.0% for DB3 and 22.0% for Tengeru White). WorldVeg-developed varieties therefore clearly dominate the seed market.

4.2 Economic impact for Tanzania

Based on the assumption that 33% of seed production is exported, an average seed rate of 273 g/ha and an average seed replacement rate of 85% per year, we estimated a planted area of 88,000 ha, which is more than double the 35,000 ha reported by FAO (2015). However, this discrepancy does not affect our analysis, as we estimate adoption profiles based on the share of the new varieties in total seed sales.

The left panel of Figure 3 shows the adoption curve for improved WorldVeg-developed tomato varieties. We estimated that 66% of the planted tomato area in Tanzania in 2014 was planted to Tanya and 16% to Tengeru-97 with other varieties accounting for the other 18%. Three-quarters of seed producers indicated increasing sales of Tanya. Therefore, we assumed that the current level of 66% could increase up to 70%. We expect Tanya to reach its adoption ceiling in 2017, and assume that its share will decline symmetrically following a bell-shaped curve as shown in Figure 3. We expect that Tengeru-97 has already reached its ceiling and its share will decline following a bell-shaped curve.

The right panel of Figure 3 shows the adoption curve for WorldVeg-developed African eggplant DB3. We estimated that it occupied 60% of the planted area under African eggplant in 2014 based on expert opinion. After discussion with local experts, we set the adoption ceiling for DB3 at 63% of the planted area. We did not assume a decline of DB3 because this variety is very popular with consumers and no other African eggplant variety has been released thus far.

Entering the above adoption profiles in the economic surplus model, we find that tomato research and extension has generated social gains of US$ 254.5 million up to 2014 while
African eggplant (DB3) has generated social gains of US$ 4.9 million (Table 3). Yearly gains have increased over time in line with increasing adoption rates (Figure 4). When extending our analysis 10 years into the future, we find social gains of US$ 639.1 million for tomato and US$ 27.4 million for African eggplant.

Figure 3 Adoption profiles of WorldVeg-developed varieties of tomato (left) and African eggplant (right) in Tanzania, 1994-2024
Note: Projected values for 2015-2024

Figure 4 Annual social gains of WorldVeg-developed tomato (left) and African eggplant (right) varieties in Tanzania, 1994-2024, in constant 2014 US$
Note: Projected values for 2015-2024
4.3 Returns to investment

Figure 5 shows the present values of the social gains and cost of research, extension and promotion in 2014 dollar values. It shows a wide gap between the benefits to society and the cost of research and extension to WorldVeg and NARES. For tomato, the total investment into research and extension for Tanzania was US$ 10.1 million against benefits of US$ 254.5 million up to 2014. The net present value of the project was US$ 314.0 and the internal rate of return was 26.2%. Each dollar invested into tomato research and development gave 12.5 dollars in economic return to producers and consumers. From society's economic perspective, investments into tomato research and extension gave high returns to investment. The returns are greater if extending the project period up to 2024 (Table 3).

![Graph showing present value of costs and benefits of research into tomato, 1987-2024 (left) and African eggplant, 2003-2014 (right) for Tanzania, in present US$ values](image)

**Figure 5** Present value of costs and benefits of research into tomato, 1987-2024 (left) and African eggplant, 2003-2014 (right) for Tanzania, in present US$ values


The total investment into African eggplant research for Tanzania was US$ 2.5 million against benefits of US$ 4.9 million up to 2014. The net present value of the project was US$ 1.8, the internal rate of return was 12.3%, and the benefit-cost ratio was 1.5. Most benefits of DB3 have
yet to be realized, as the variety was only introduced in 2006. Returns to investment are therefore much higher if extending the project period to 2024. Then, the benefit-cost ratio would be 5.9 and the internal rate of return would be 26.0%. As a word of caution, returns to investment cannot be compared between projects that differ in length and starting year.

Table 3 Returns to investment in research on tomato (1987-2014) and African eggplant (2003-2014) in Tanzania

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Social gain in 2014 dollars (US$ million)</td>
<td>254.5</td>
<td>639.1</td>
<td>4.9</td>
<td>27.4</td>
</tr>
<tr>
<td>Cost of research, extension and promotion in 2014 dollars (US$ million)</td>
<td>10.1</td>
<td>10.1</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Internal rate of return (%)</td>
<td>26.2</td>
<td>27.1</td>
<td>12.3</td>
<td>26.0</td>
</tr>
<tr>
<td>Net present value using 1987/2003 as base year in year 2014 dollars (US$ million)</td>
<td>314.0</td>
<td>595.8</td>
<td>1.8</td>
<td>18.1</td>
</tr>
<tr>
<td>Benefit-cost ratio¹</td>
<td>12.5</td>
<td>22.8</td>
<td>1.5</td>
<td>5.9</td>
</tr>
</tbody>
</table>

Note: ¹ Applies a 5% discount rate to benefits and costs.

4.4 Sensitivity testing

Where there was uncertainty about parameter values or data were missing, we have used conservative assumptions about actual values throughout the analysis. For instance, we assumed constant yields for African eggplant, a zero costs difference between new and old varieties, we included research and development costs for all traditional African vegetables rather than only for African eggplant, and we used a 10-year lag between initial investment and official release for tomato breeding. Our analysis is therefore more likely to underestimate than to overestimate the economic impact of research into tomato and African eggplant.

To gain further confidence in the results, we evaluated how sensitive the economic indicators are to variations in key baseline parameters including the yield gains of the new varieties, the supply and demand elasticity, and discount rate. The economic surplus method is based on a
parallel shift in the supply function. The supply elasticity, which affects the slope of the supply curve, and the yield gain, which determines the magnitude of the supply shift, are therefore influential on the results and the results in Table 4 confirm this.

Table 4 Sensitivity of estimated returns to tomato (1987-2014) and African eggplant (2003-2014) improvement in Tanzania to changes in key parameters

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Social gain (US$ million)*</td>
<td>NPV (US$ million)*</td>
</tr>
<tr>
<td>Baseline</td>
<td>254.5</td>
<td>314.0</td>
</tr>
<tr>
<td>Yield gains (**):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-50%</td>
<td>127.8</td>
<td>144.0</td>
</tr>
<tr>
<td>+50%</td>
<td>380.3</td>
<td>482.6</td>
</tr>
<tr>
<td>Supply elasticity (0.35):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.20</td>
<td>444.9</td>
<td>569.3</td>
</tr>
<tr>
<td>0.40</td>
<td>222.8</td>
<td>271.4</td>
</tr>
<tr>
<td>0.60</td>
<td>148.7</td>
<td>172.0</td>
</tr>
<tr>
<td>Demand elasticity (0.96):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>254.2</td>
<td>313.5</td>
</tr>
<tr>
<td>4.00</td>
<td>254.0</td>
<td>313.3</td>
</tr>
<tr>
<td>6.00</td>
<td>253.9</td>
<td>313.2</td>
</tr>
<tr>
<td>Discount rate (5.0%):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0%</td>
<td>254.5</td>
<td>284.3</td>
</tr>
<tr>
<td>10.0%</td>
<td>254.5</td>
<td>395.9</td>
</tr>
</tbody>
</table>

Notes: * Converted to 2014 dollars. ** Baseline yield gains over pre-adoption average yields are 3.2 t/ha (6.6%) for Tanya, 8.4 t/ha (16.9%) for Tengeru-97, and 2.3 t/ha (10.4%) for DB3. NPV=Net Present Value (2014), IRR=Internal Rate of Return, B:C=Benefit-cost ratio.

If assuming 50% lower yield gains, then the social gains from tomato research would decrease from US$ 255 to US$ 128 million, but the IRR would still be 20% (Table 4). However, if assuming 50% higher yield gains, then the social gains would be US$ 380 million and the IRR would be 30%. As for the supply elasticity, lower values indicate little expansion potential while higher values can be used for crops that have potential to expand. We initially assumed a value of 0.35 but higher values might be justified because there has been an expansion of the area under tomato, and presumably also under African eggplant. The results show that setting
the supply elasticity to 0.60 would reduce the social gains to US$ 149 million and the benefit-cost ratio to 7.3, but has little effect on the IRR, which would still be 21.2%. On the other hand, the results do appear much less sensitive to the demand elasticity or the discount rate.

5 Discussion

The global value of tomato production was US$126 billion in 2013, as compared to US$150 billion for potatoes, US$242 billion for wheat, US$382 billion for maize, and US$429 billion for rice (FAO 2015). Despite being the world’s fifth most important crop by value, public investment in tomato breeding, and vegetable breeding in general, is very low. This is largely because agricultural research, development and policy continues to focus on increasing staple crop production (Pingali 2015). For instance, international agricultural research centers and their national partners invested US$308 million in maize research over the period 1971-2005 in Western and Central Africa (Alene et al. 2009), compared to the US$ 12.6 million that WorldVeg and its national partner HORTI-Tengeru spent on tomato and African eggplant improvement for Tanzania. More worryingly, there is a declining trend in international and national investments in vegetable breeding research for sub-Saharan Africa (Afari-Sefa et al. 2012).

Our study, which is the first to estimate the returns to investment in international vegetable breeding, shows that despite a relatively small area under tomato or African eggplant, the rates of return to research on their improvement is high. The benefit-cost ratios and internal rate of return are as high as those previously reported by impact studies for staple food crops (e.g. Thiele et al. 2006; Alene et al. 2013). Tripp and Rohrbach (2001) wrote that there are few success stories of commercial seed production in Africa, apart from hybrid maize in some countries; yet, our study shows that tomato and African eggplant in Tanzania can be added to this list.
It is probable that we have underestimated the true social gains from tomato and African eggplant research for several reasons. First, at least one-third and probably closer to half of tomato and African eggplant seed produced in Tanzania is exported to other countries in East and Southern Africa. This could potentially double the economic gains generated. Second, home garden production for own household use accounts for a substantial part of vegetable seed use and vegetable production in Tanzania, but currently is not captured in national statistics. Third, quality attributes such as shelf-life and taste are perhaps more important attributes for vegetables than for staple crops, but improvements in these aspects are not fully captured in the analysis. There is a need to develop the methodology further to take into account product quality aspects that are not reflected in yields and prices (cf. Morris and Heisey 2003).

Fifth, vegetables, and particularly traditional African vegetables, are a key source of vitamins and minerals that can address micronutrient deficiencies, yet the nutritional benefit of increased vegetable consumption is not reflected in the analysis. Finally, the improved tomato varieties have promoted the development of a local vegetable seed industry and a local tomato processing industry, which also were not captured in our analysis.

We expect that returns to investment will continue to be attractive because of a large unexploited potential in vegetable production. For example, average farm-level tomato yields in Tanzania are just 12 t/ha while average on-station yields are 50 t/ha in Tanzania and around 80 t/ha in Taiwan. The adoption of newer varieties with better resistance to pests and diseases in combination with better production practices can lead to large social gains in the future.

Widespread adoption of improved varieties of staple crops is often limited by lack of private sector involvement because of low profit margins in seed production, subsistence-oriented production systems, and marginal agro-ecological conditions (Byerlee and Heisey 1996; Lynam 2011). However, these constraints do not equally apply to vegetables, where the private sector is actively involved in seed production, it is commercial rather than subsistence-oriented,
and production is typically concentrated in favorable rather than marginal environments. Against this background, WorldVeg breeding lines developed for tropical Asia were successfully introduced to sub-Saharan Africa with minimal local adaptation apart from selection trials. This stands in strong contrast to research on staple crops, which requires intensive local adaptation. Yet little of this potential to benefit from research in Asia has actually been realized in sub-Saharan Africa because governments and donors have given little importance to vegetable research.

The fact that single varieties of tomato and African eggplant account for 60% of the planted areas of these crops points to continued weaknesses in the vegetable seed sector. The tomato varieties Tanya, and to a lesser extent Tengeru-97, are somewhat susceptible to pests and diseases. In fact, WorldVeg's tomato breeding program in Taiwan uses Tanya as its susceptible check to test the performance of new breeding lines. Superior WorldVeg lines with much better pest and disease resistance are readily available (see Ojiewo et al. 2010b). Increasing the diversity of newer varieties, which would in time replace Tanya and Tengeru-97, would minimize risks to production from biotic factors to ensure the sustainability of tomato production in Tanzania.

Seed companies and farmers have not adopted these newer varieties, presumably because of lack of investment in the promotion of these varieties. The vegetable seed market is competitive and the benefits of promoting new open-pollinated varieties would accrue to all companies. This is different from hybrid varieties for which a company can have at least a short-term monopoly, but tomato hybrids accounted for less than 2% of the tomato seed market in Tanzania in 2014. The public sector therefore has an important role in testing and promoting new vegetable varieties with superior characteristics. Our study shows that such investment by national governments and international donors produces very attractive returns.
6 Conclusion

This study finds that international research into vegetable improvement has resulted in high rates of adoption for East and Southern Africa. In 2013/14, WorldVeg-developed varieties accounted for 50% of tomato seed production in East and Southern Africa while WorldVeg-developed African eggplant varieties accounted for 98% of commercial seed production in the region. For Tanzania, investments by WorldVeg and NARES generated economic gains of US$ 254 million for tomato and US$ 5 million for African eggplant up to 2014. The internal rate of return is 26% for tomato and 12% for African eggplant, though we project the latter to increase to 26% by 2024. International research on vegetable improvement thus gives high returns to investment.

Acknowledgment

We thank Deonice Mshida (ASA), Victor Afari-Sefa, Fekadu Dinssa, Thomas Dubois, Peter Hanson, Jackie Hughes, Maureen Mecozzi, Hassan Mndiga, Srinivasulu Rajendran, Tsvetelina Stoiilova (WorldVeg), Cornel Massawe (HORTI-Tengeru), Hashim Njowele and Fredi Mtola (National Bureau of Statistics) for their contributions to this study. We acknowledge the work of Ildephonse Nahimana, Yared Sertse, Samuel Kabiru Kariuki, Rabenasolo Paul Imboasalamaniaina Andriampenomanana, Charles Malidadi, Alcides Lampaio, Celestin Hakizamungu, Mable Charity Namala, and Takemore Chagomoka in collecting data from seed companies. This work was supported by core donors to the World Vegetable Center: Republic of China (Taiwan), UK aid, United States Agency for International Development (USAID), Australian Centre for International Agricultural Research (ACIAR), Germany, Thailand, Philippines, Korea, and Japan.
References


Masters WA, Coulibaly B, Sanogo D, Sidibé M, Williams A (1996) *The economic impact of agricultural research: a practical guide*, Department of Agricultural Economics, Purdue University, W. Lafayette, IN.


Robinson J, Srinivasan CS (2013) *Case-studies on the impact of germplasm collection, conservation, characterization and evaluation (GCCCE) in the CGIAR*, CGIAR Standing Panel on Impact Assessment


