3. Stress tolerant varieties to counter climate change

Climate change affects the yield of crops through increased exposure to high temperature, water, salinity and flooding stresses. The CGIAR has produced rice, maize, wheat, sweetpotato and potato varieties that have increased tolerance to climatic stresses and these have been rolled out in Africa and Asia to increase smallholder resilience to climate change. These benefits came about by either increasing the physiological resilience to climatic extremes or the use of early-maturing varieties that allow cropping calendars to be adjusted to cope with seasonally unfavourable conditions (Wassmann et al. 2009a). Strengthened breeding systems, using the latest technologies, together with more open international exchange of germplasm, and rapid change in varieties are fundamental components of this adaptation strategy (Reynolds et al. 2016; Atlin et al. 2017; Grüneberg et al. 2015).

Case study 3: Drought tolerant maize for Africa

For the past decade the Bill & Melinda Gates Foundation and USAID have invested in stress tolerant maize for Africa. Investments have focused on three main areas: improving breeding, strengthening the seed sector and reducing bottlenecks associated with adoption. To date, over 200 varieties have been released across 13 countries in sub-Saharan Africa, which has the potential to generate between USD 362 million to USD 590 million over a 7-year period, through both yield gains and reduced yield variability (Kostandini et al. 2013). Most importantly, breeding for stress tolerance has not been at the expense of yield. Stress tolerant maize yielded approximately 20% more under stress prone conditions, with no yield penalty in favourable years/environments leading to a reduction in year-to-year yield variability (Setimela et al. 2017a). More than 52,000 metric tonnes of certified improved seed was produced, enough to plant 2 million hectares by 5.2 million households and impacting as many as 41 million people. Yield gains in stress prone environments significantly increased household income and food security (Lunduka et al. 2017).

Adaptation benefits

- **Maize** - on-farm trials show climate resilient maize varieties yield 20% more than current commercial varieties in low yielding environments, and double in severe stress environments, such as the El Niño event of 2015/16 (Setimela et al. 2017a and b). In drought prone regions of Zimbabwe increased yields of climate resilient maize translated to USD 240 ha^{-1} income or nine months of extra food (Lunduka et al. 2017).
- **Sweetpotato** – Fifteen pro-vitamin A rich, drought tolerant orange-fleshed sweetpotato (OFSP) varieties were released in Mozambique in 2011 (Andrade et al.

2016), with an additional four varieties in 2016 (Andrade et al. 2017), using the accelerated breeding scheme approach. These varieties now account for one-third of the sweetpotato produced in Mozambique. Yield has improved concurrently, with an average yield gain of 0.3 t ha^{-1} yr^{-1}.

- **Rice** - an estimated 700,000 farmers in India and Bangladesh have adopted improved stress tolerant rice varieties. Farmers in Odisha State, India, who adopted the flood-tolerant Swarna-Sub1 variety, obtained an average yield benefit of 232 kg ha^{-1} (11%), with a maximum of 718 kg ha^{-1} (66%) when floods lasted up to 13 days (GRiSP 2013). In Uttar Pradesh, India, the average yield of the drought-tolerant variety Sahbhagi Dhan in the severe drought year 2015 was 1.0-3.9 t ha^{-1} higher than that of other varieties (GRiSP 2015). In SSA, around 2010, NERICA rice varieties occupied about 8% of the cultivated rice area of 6.8 million ha across 13 rice-growing countries (Diagne et al. 2015). By 2013, adoption had spread to 16 countries, which increased rice yields by 319 kg ha^{-1} and helped lift about 8 million people out of poverty.
- **Wheat** – continual yield gains for both heat and drought tolerance have been demonstrated through extensive trials worldwide (Manes et al. 2012; Gourdji et al. 2012). The benefits are seen in most wheat growing countries and especially in less developed countries (see also Lantican et al. 2016) with yield gains varying by region but are typically between 0.5 and 1% yr^{-1}.
- **Potato –** potato varieties tolerant to drought, heat and salinity have been developed and tested. These include the Tacna, Unica and Maria Bonita varieties in Peru, Kinga, Meva, Kinigi varieties in Africa and the Raniag variety in the Philippines. Tacna was also introduced to China under the name Jizhangshu 8 and by 2008 covered over 20,000 ha. Another example is the variety Sarnav, released in Central Asia (Uzbekistan and Tajikistan) with tolerance to soil salinity and drought.

Co-benefits

Nutrition: Stress tolerant varieties have the ability to deliver co-benefits for nutrition, by combining traits associated with climate variability (e.g. drought and heat stress) and nutrition (pro-vitamin A, iron, zinc or quality protein maize). Vitamin A rich orange-fleshed sweetpotato varieties are being disseminated in 14 SSA countries and have reached over 3 million households (Low et al. 2017). In Malawi, Zambia and Zimbabwe maize varieties are now on the market with both drought tolerance and high pro-vitamin A content. Research is currently underway to develop drought and heat tolerant, nutritionally enhanced maize rich in pro-vitamin A and zinc.

Pest and disease tolerance: An indirect benefit of investing in breeding for climate-related stresses is that strengthened breeding pipelines are able to quickly and efficiently incorporate tolerance to other emerging threats such as pests and diseases.

Salinized land reclamation: The growing of salt-tolerant rice has huge opportunities to reclaim and restore salt-salinized lands. Increased yields and income will contribute to overall increased farmers' livelihoods, food and nutrition security and welfare.

Low carbon development: Rice environments affected by salinity and droughts are inherently associated with low methane emissions, hence, the propagation of salinity-tolerant and drought-tolerant rice varieties present pathways of low carbon development. Likewise, the replacement of traditional varieties grown by short-maturity varieties has reduced flooding periods and thus, the amount of methane emitted per season.

Costs and benefits

The adoption of climate-smart maize across 13 African countries has the potential to generate between USD 362 million to USD 590 million over a 7-year period, through both yield gains and an increase in yield stability (Kostandini et al. 2013).

Drought-tolerant Sahel rice varieties introduced by AfricaRice in 1994/95 have helped adopters in Senegal to significantly increase yields and incomes by an average of 872 kg ha^{-1} and USD 227.65 per cropping season respectively (Basse et al. 2015). The internal rate of return and the economic internal rate of return are evaluated at 81% and 72%, respectively. The net present value (NPV) of benefits was estimated at USD 24.6 million.

Increased yield from improved wheat varieties, including increased heat and drought tolerance, has resulted in an increase in annual revenue of between USD 2-3 billion and mainly for farmers and resource poor consumers in the developing world, demonstrating a staggering return on investment of 100:1 (Lantican et al. 2016). Direct benefits to smallholder farmers and poor consumers are supported by studies like Shiferaw et al. (2014) in Ethiopia and in other studies (see Reynolds et al. (2017). Gourdji et al. (2012) showed that improved varieties are already delivering climate resilience, and more recent analysis have demonstrated the potential for further impacts under heat and drought stress (see Reynolds and Langridge, 2016).

Geographies

The breeding for and distribution of improved stress tolerant varieties is never a completed task given the continual changing climate that breeders need to target as well as ever evolving threats from pests and diseases. Whilst efforts have concentrated largely on sub-Saharan Africa and South Asia, the potential target areas are huge.

Drought Tolerant Maize for Africa (DTMA) and High Temperature Maize for Asia (HTMA) have been crucial in terms of breeding for and distribution of improved stress tolerant varieties of maize. DTMA has catalysed the release of more than 230 maize varieties in eastern Africa (Ethiopia, Kenya, Tanzania, and Uganda); southern Africa (Angola, Malawi, Mozambique, Zambia, and Zimbabwe); and in West Africa (Benin, Ghana, Mali, and Nigeria) between 2007 and 2015. HTMA has seen the licensing of 18 precommercial heat tolerant maize hybrids; 6 have broad adaptation across agro-ecological zones in South Asia (suggesting they likely possess both heat and drought tolerance) and 12 hybrids had good adaptation to specific mega-environments in Bangladesh, Bhutan, India, Nepal and Pakistan.

With regard to wheat, CGIAR-related improved varieties covered about 64% of the 165.7 million hectares sown in 2014 (Lantican et al. 2016), representing three-quarters of the world's wheat area (222 million hectares). In South Asia where over 100 million tonnes of wheat is consumed each year, 92% of the varieties released contained CGIAR breeding contributions.

Recognizing the importance of breeding for locally adapted varieties that concurrently meet taste preferences of different communities, a major investment was made to increase sweetpotato-breeding capacity in SSA. Varieties from the nutrition-smart and climate-smart program have now been provided to 13 countries in sub-Saharan Africa (SSA). Some of the drought-tolerant OFSP varieties have now been released in Madagascar, Ivory Coast, and Abu Dhabi, and included as parents in other SSA breeding programs. In addition, since 2009, 14 SSA countries have released 40 early-maturing varieties (mature in 90-120 days after planting) that are ideal for shortening rainy seasons.

Distribution of drought, flood, and salinity tolerant rice varieties have concentrated so far on SSA and South Asia, especially Bangladesh and India where an estimated 700,000 farmers have adopted improved stress tolerant rice varieties to date. Potential targets areas are huge (http://strasa.irri.org/stresses/): drought regularly affects 23 million hectares of rainfed rice in South and Southeast Asia; flooding afflicts some 20 million hectares in Asia, whereas as much as one-third of the rainfed lowland areas in sub-Saharan Africa are thought to be affected by submergence; in India and Bangladesh alone, productivity of more than 7 million hectares of rice land – predominantly inhabited by impoverished communities with fewer opportunities for food security and livelihood options – is adversely affected by salt stress.

Timeframes for implementation

The use of off-season nurseries, multi-location testing networks and new breeding technology has the potential to drastically reduce breeding cycle times by almost two-thirds (Atlin et al. 2017). New varieties can now be developed and released within 5-7 years. Whilst such advances in breeding technologies and registration policies have significantly reduced the time taken to develop and commercialize stress-tolerant varieties (e.g. Reynolds and Langridge 2016; Grüneberg et al. 2015) in country policies also need to be addressed to accelerate adoption of new technologies where needed.

Monitoring and evaluation

The benefits of stress tolerant varieties impact positively on the adaptation (increasing resilience) pillar of the global stocktake. Process indicators (e.g. # of beneficiaries accessing/adopting improved varieties) can be measured using household level surveys, especially nationally representative sample surveys for agriculture. Outcome indicators (e.g. positive changes in households food and livelihoods security, income diversification, ability to recover from/buffer against climate-related shock, or increases in household saving/investment capacities) can also be measured using household-level surveys, and will enable the assessment of adaptation benefits in terms of decreased vulnerability/increased stability and/or improved adaptive capacity. At a more fine-tuned level, adaptation co-benefits at the farm level can be evaluated using more technical quantitative indicators to measure improved productivity, positive changes in soil characteristics and resource use efficiency (e.g. water, fertilizers) as well as potential co-benefits in GHG emissions reductions and/or carbon sequestration per hectare covered (e.g. improved pastures).

Challenges

Two of the main challenges of implementing this intervention have been related to slow varietal replacement, particularly in SSA. Although the time taken to register new varieties has reduced in many countries, older varieties remain available on the market for many years. In the USA varieties are available to farmers for 4-5 years before they are replaced by superior ones (Magnier et al. 2010). By sharp contrast, in SSA, maize varieties are often 20-

30 years old meaning they were developed in significantly different climate (Atlin et al. 2017).

Another challenge is the massive range of farm environments that exist, and the need to be able to tailor not only new varieties but also the seed systems and crop management practices that complement them. One solution is to develop better global networks in collaboration with national programs and other entities so that data and other resources can be shared, and lessons learned in one environment or cropping system can be applied to others (Reynolds et al. 2017). If at the same time, the political and institutional bottlenecks – including restrictive seed policies, limited number of seed producers, poor marketing and distribution - that restrict smallholder farmer access to new seed can be addressed then the challenges of crop improvement could be tackled more systematically.

Key resources

Maize variety options of 13 African countries:

Abate T. 2016. *Maize Variety Options for Africa*. Nairobi: Drought Tolerant Maize for Africa. Available online at: http://repository.cimmyt.org/xmlui/bitstream/handle/10883/16772/58500.pdf

Global use of improved wheat varieties:

Lantican MA, Payne TS, Sonder K, Singh R, van Ginkel M, Baum M, Braun HJ, Erenstein O. 2016. Impacts of International Wheat Improvement Research in the World 1994-2014. Mexico City, Mexico: International Maize and Wheat Improvement Center. Available online at: http://wheat.org/wheat-global-impacts-1994-2014-published-report-available/

CIMMYT MR
International Maize and Wheat Improvement Center

CIP
INTERNATIONAL POTATO CENTER
A CGIAR RESEARCH CENTER

IRRI
International Rice Research Institute

CGIAR RESEARCH PROGRAM ON Rice

CGIAR RESEARCH PROGRAM ON Wheat

CGIAR RESEARCH PROGRAM ON Maize

10 best bet innovations for adaptation in agriculture:

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Abstract

Faced with the triple challenges of achieving food security, adapting to the impacts of climate change, and reducing emissions, agriculture has been prioritized by countries as a sector for climate action. The national process of formulating and implementing National Adaptation Plans, which gives effect to the ambitions set out in the Intended Nationally Determined Contributions of countries, is a key instrument that will not only facilitate access to resources, but also advance best practice and implementation of proven and effective adaptation actions. In order to support countries in the elaboration of their National Adaptation Plans, this paper aims to tap into agricultural research for development conducted by CGIAR Centers and research programs, to identify best bet innovations for adaptation in agriculture, which can help achieve food security under a changing climate, while also delivering co-benefits for environmental sustainability, nutrition and livelihoods.

Keywords

Adaptation; agriculture; climate change