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Breeding and Deploying Multiple Stress-Tolerant Maize Varieties in the Tropics

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Abstract

Maize is the key crop for food, feed, and nutritional security of millions of smallholder farmers and consumers in the developing world, especially in sub-Saharan Africa (SSA), Asia, and Latin America. CIMMYT and partners have adopted innovative approaches over the last one decade to develop, evaluate, and deliver elite stress-resilient and nutritionally enriched maize varieties with relevant client-preferred traits, especially in the stress-prone tropics. Effective integration of modern breeding tools/strategies, including high-throughput and precision phenotyping, doubled haploid (DH) technology, and genomics-assisted breeding, are integral part of these efforts leading to impressive genetic gains, while enhancing the pace, precision, and efficiency of breeding pipelines. Through extensive public-private partnerships, CGIAR-derived climate-resilient and multiple stress-tolerant improved maize varieties are being deployed in over 13 countries in SSA, four countries in South Asia, and several countries across Latin America. Certified seed production of CGIAR-derived improved stress-tolerant maize varieties was estimated to cover approximately 7.2 million hectares in SSA in 2022, reaching an estimated 7.2 million households, and benefitting ~44 million people. In the past five years, a total 20 high-yielding drought + heat stress-tolerant maize hybrids were released in South Asia, including four new hybrids in 2022 – BWMRI-2 in Bangladesh; Rampur Hybrid-12 in Nepal; and IMH-222 and IMH-223 in India. In collaboration with seed company partners, certified seed production of climate-resilient maize hybrids scaled-up from a baseline of just 70 MT in 2018-19 to 1026 MT in 2021-22, and deployed in about 50,000 hectares in various stress-vulnerable targeted ecologies in Bangladesh, India, Nepal and Pakistan, reaching ~128,200 farm families. Experiences of CIMMYT strongly indicate that besides strengthening the seed sector, adoption of progressive seed laws and regulations, are vital for improving smallholder farmers' access to climate-resilient improved seed. Policy support and institutional innovations are also required for overcoming key bottlenecks affecting maize seed value chain.

Keywords: Climate resilience, Multiple Stress, Maize, Tropics, Variety, Modern tools

Introduction

Achieving sustainable food and nutritional security, i.e., the basic right of the people to produce and/or purchase the nutritionally balanced food they need, without harming the social and biophysical environment, has to be the funademental goal of any nation. Over the last seven decades, India made immense progress towards food security of the population. Since 1950, the population almost tripled, but food grain production had more than quadrupled. India is now among the largest producers of rice, wheat, pulses, fruits, vegetables, milk, cotton, horticultural crops, dairy and poultry, aquaculture, and spices. Agricultural production in India is valued at US$ 401 billion in 2017, which is more than that of the USA (US$ 279 billion).

Despite this impressive progress, there is no scope for complacency. It is estimated that by 2030, India's population would be 1.52 billion; by 2050, it would be approximately 1.7 billion, which will be the highest in the world and about 400 million more than China, the most populous nation today (Singh, 2019). By 2050, India needs to step up production of all agricultural commodities by around 30 per cent in food grains and to more than 300 percent in vegetable oils to meet the needs of increased population and rising living standards (Singh, 2019). Also, by 2050, to meet the diverse demands of the population, it has been estimated that land productivity has to be increased by 4 times, water productivity by 3 times, and labour productivity by 6 times (Chand, 2012). All this has to be achieved in the context of changing climates, more fargile natural resources, and by staying within the planetary boundaries i.e., without major environmental and ecological footprints.

Climate change is for real, and certainly not fiction, as is unfortunately still believed by some in the world! The negative impacts of frequently occuring climatic extremes/ variabilities on agricultural production are most often felt by the resource-constrained smallholders in the tropics, be it in Africa, Asia or Latin America. Abiotic stresses, especially drought, heat, flooding/waterlogging, soil acidity, and combinations of various abiotic stresses have a huge negative impact on the rainfed crop yields. For instance, in South and South East Asia, more than 80 percent of the maize-growing area is rainfed and prone to various climatic extremes/variabilities. While we tend to focus mostly on abiotic stresses in the context of climate change, it is equally important to consider the changing spectrum of pathogens and insect-pests, due to increase in temperature (Deutsch *et al.,* 2018; IPPC Secretariat, 2021; Skendžic *et al.,* 2021).

Building climate resilience in the smallholder farming systems, therefore, requires implementation of an intenisve multi-disciplinary and multi-institutional strategy. This should include extensive awareness creation and widespread adoption of climate-resilient crop varieties and climate-smart agronomic management practices, strengthening of local capacities, and much stronger focus on sustainability. An array of agricultural production technologies and practices, including stress-tolerant improved crop varieties, conservation agriculture practices, and agroforestry systems, that aim to mitigate climate-induced risks and foster resilience have been developed through national and international AR4D initiatives over the past two decades. In addition, institutional interventions that seek to mitigate risk and build resilience through other mechanisms could play a complementary role to climate-smart agricultural production technologies/practices (Hansen *et al.,* 2019).

Breeding Multiple Stress-tolerant Improved Maize Varieties for the Tropics

The International Maize and Wheat Improvement Center (CIMMYT) and partners in Africa, Latin America and Asia are intensively engaged in developing and deploying climate-resilient improved maize varieties adapted to the tropics (Cairns and Prasanna, 2018; Prasanna *et al.,* 2021; Chivasa *et al.,* 2021). CIMMYT has used two major approaches for developing sources of abiotic stress tolerance that have been widely used in maize breeding programs in SSA, Asia and Latin America. The first was constitution of drought-tolerant populations for undertaking recurrent selections and derivation of elite inbred lines. The DTP-Y, DTP-W, and La Posta Sequia are examples of such populations. The second approach was full-sib recurrent selection under managed drought stress within elite populations to increase the frequency of drought tolerance alleles in germplasm already adapted to the lowland tropics (e.g., Edmeades *et al.,* 1999; Prasanna *et al.,* 2021a). Both approaches have generated several inbred lines that have become important sources of drought and heat tolerance in maize, especially in the tropics (Cairns *et al.,* 2012). Thus, population formation and improvement have resulted in an increase in the frequency of drought-adaptive alleles and identification of superior sources of drought tolerance (Edmeades *et al.,* 2017).

Besides constitution of appropriate maize populations for implementing recurrent section for improving drought stress tolerance, CIMMYT also has established an extensive phenotyping network for maize breeding in the tropics along with managed stress screening protocols (Prasanna *et al.,* 2021a); identified and used suitable secondary traits (e.g., anthesis-silking interval or ASI); and implemented focused breeding programs to continuously develop products (inbred lines, improved OPVs, and hybrids) that can perform well under both optimal and stressed environments (Cairns and Prasanna, 2018; Prasanna *et al.,* 2021a). CIMMYT's maize product advancement process typically includes not only regional on-station trials of promising pre-commercial hybrids coming out of the breeding pipeline vis-à-vis internal genetic gain checks and commercial checks but also extensive regional on-farm varietal trials to ascertain the performance of the promising pre-commercial hybrids under farmer-managed conditions. This also provides opportunity for the socioeconomics team to assess farmers' product as well as their trait preferences. The best entries coming out of this rigorous process are then announced on the CIMMYT website, and further allocated to interested public/private sector partners for varietal registration, scale-up, and delivery in the target geographies.

Accelerating Improved Varietal Development using Modern Tools/Technologies

CIMMYT-Maize Teams in Africa, Asia and Latin America use an array of modern tools/technologies for accelerating improved varietal development and for increasing genetic gain for grain yield in stress-prone tropical environments (Prasanna *et al.,* 2021a). These tools include the doubled haploid (DH) technology (Prasanna *et al.,* 2012; Chaikam *et al.,* 2019), low-cost and high-throughput phenotyping using proximal and remote sensors (e.g., Makanza *et al.,* 2018a,b), genomics-assisted breeding (e.g., Nair *et al.,* 2018), and breeding information management system, including decision-making tools. With the rapid reduction in genotyping costs, new genomic selection technologies have become available in several crops that allow the crop breeding cycle to be greatly reduced, facilitating inclusion of information on genetic effects for multiple stresses in selection decisions (Xu *et al.,* 2017).

Through dedicated maize DH facilities in Kenya and Mexico, CIMMYT Global Maize Program produces annually over 100,000 DH lines (up from less than 5000 in 2011) and selects the best out of these lines in breeding pipelines. CIMMYT team has also developed and deployed superior second-generation haploid inducers for tropics using marker-assisted breeding (Chaikam *et al.,* 2018). In December 2021, CIMMYT has established a Maize Doubled Haploid Facility at ARS-Kunigal in Karnataka, India, in partnership with UAS-Bangalore. This facility will provide DH development service not only to CIMMYT maize breeders, but also to those from the NARS and small- and medium-enterprise (SME) seed companies in South Asia.

Deploying Climate-resilient Maize Varieties in the Tropics

An array of elite maize varieties with drought tolerance, disease resistance and other farmer-preferred traits have been developed by CIMMYT and deployed by seed companies across sub-Saharan Africa (SSA), Asia and Latin America. Between 2007 and 2021, CIMMYT and partners in SSA released more than 300 climate-resilient maize varieties in 13 African countries. In 2021, more than 171,000 tons of certified seed of CGIAR-dericed multiple stress-tolerant maize varieties were produced and commercialized by over 100 small- and medium-enterprise seed company partners across SSA, covering an estimated 7.2 million hectares, and benefiting about 7 million farm households.

Tesfaye *et al.,* (2017, 2018) highlighted the potential benefits of incorporating drought, heat and combined drought and heat tolerance into improved maize varieties in the climate-vulnerable tropical environments. Asia is now beginning to emulate the success story from Africa in terms of extensive deployment of drought-tolerant and drought + Heat-tolerant improved maize varieties through intensive public-private partnerships. Through the USAID-funded Heat Tolerant Maize for Asia (HTMA) project, a large heat-stress phenotyping network, comprising 23 sites in four Asian countries (India, Bangladesh, Nepal and Pakistan) has been established. Several CIMMYT-derived drought-tolerant and heat-tolerant CIMMYT-derived elite maize varieties have been released during 2016-2018 through public and private sector partners in South Asia, and several more are in pipeline.

For new climate-resilient crop varieties to contribute towards smallholders' adaptation to climate variability, it is important to further strengthen the seed systems. Delivering low-cost improved seed to smallholder farmers with limited purchasing capacity and market access requires stronger public-private partnerships, and enhanced support to the committed local seed companies, especially in terms of information on access to new products, adequate and reliable supplies of early-generation (breeder and foundation) seed, and training on quality seed production, quality assurance/quality control (QA/QC), and seed business management. Proactive management of product life cycles by seed companies benefits both the farmers and businesses alike, contributing to improved food security and adaptation to the changing climate (Chivasa *et al.,* 2021).

Protecting Agri-food Systems from Devastating Pathogens and Insect-Pests

Pathogens and insect-pests have severe and cross-cutting negative impacts, particularly affecting farmers' incomes, and livelihoods. Their capacity to rapidly evolve and proliferate pose a huge challenge. There is a significant need for implementation of development and implementation of multi-disciplinary, multi-institutional, and sustainable strategies for devastating crop diseases and pests, to counter the threat to food and nutritional security, and the livelihoods of populations (Prasanna *et al.,* 2022b).

Two most recent examples of transboundary pests/ pathogens severely affecting maize smallholders are the maize lethal necrosis (MLN) in Africa, and the fall armyworm (*Spodoptera frugiperda*) in Africa and Asia. MLN is a complex viral disease, emerging as a serious threat to maize production and the livelihoods of smallholders in eastern Africa since 2011, primarily due to the introduction of maize chlorotic mottle virus (MCMV). CIMMYT, in close partnership with national and international partners, implemented a multi-disciplinary and multi-institutional strategy to curb the spread of MLN in sub-Saharan Africa, and mitigate the impact of the disease (Prasanna *et al.,* 2020; Prasanna, 2021).

Fall armyworm (FAW) has been prevalent in the Americas for several decades but was reported for the first time in West Africa in 2016. Within two years, FAW incidence had already been reported in more than 40 countries across Africa, and over 15 countries across the Asia-Pacific (Prasanna *et al.,* 2021b). The pest was reported for the first time in India in mid-2018, and subsequently reported in several other Asian countries. FAW attacks primarily the maize crop and has potential to feed on more than 80 other crops, including sorghum and sugarcane. Indiscriminate and unguided use of toxic synthetic pesticides is reported across Africa and Asia for FAW control, which poses serious threat to environment, animal and human health, besides affecting the natural enemies of the pest. Therefore, it is extremely important to develop, test, and urgently deploy science-based, integrated pest management (IPM) technologies/management practices, including host plant resistance (both native genetic resistance and transgene-based resistance) to FAW (Prasanna *et al.,* 2022), environmentally safer synthetic pesticides, biopesticides and botanicals, besides low-cost cultural control and agro-ecological approaches (Prasanna *et al.,* 2018, 2021b). A set of three first-generation FAW-tolerant CIMMYT maize hybrids have been announced in 2021 for Africa (https://maize.org/cimmyt-announces-fall-armyworm-tolerant-elite-maize-hybrids-for-africa/). South Sudan and Zambia have recently released these three hybrids, while several more countries are expected to release the FAW-tolerant maize hybrids in 2022-2023. Breeding for native genetic resistance to FAW has also been initiated by CIMMYT and partners in South Asia.

Conclusions

We need to collectively address an array of challenges, including adaptation to the changing climates, alleviating extensive malnutrition, improving soil health, and protecting agrifood systems from devastating diseases and insect-pests. Intensive multi-institutional and multi-disciplinary efforts are required to cocreate and deploy innovative and sustainable technologies that can improve crop productivity, reduce production costs, and improve the incomes and livelihoods of smallholder farmers. Building climate resilience warrants effective integration of climate-resilient crop varieties, climate-smart agronomic management practices, and effective implementation of policies to help reduce environmental and ecological footprints of agricultural practices.

Scientific institutions must enhance the the pace, precision and efficiency of breeding programs through judicious and effective integration of modern tools/strategies, including high-density genotyping, high throughput and precision phenotyping, speed breeding, molecular marker-assisted and genomic selection-based breeding, and knowledge-led decision-support systems. Seed systems need to be further strengthened to become more market-oriented and dynamic, and for providing smallholders with greater access to affordable climate-resilient and nutritionally enriched improved seed. Understanding the smallholder farmers' constraints for adoption of modern technologies, enhancing affordability and access to quality agricultural inputs, and improving their linkages to the input and output markets should be accorded top priority.

Technologically, we are living in exciting times. Genomics-assisted breeding, genome editing, speed breeding, remote sensors, satellite imagery, drones, artificial intelligence, machine learning, decision support tools, and information and communication technologies, are only a few of the innovations that one can mention that are impacting various spheres of life, including agriculture. Breeding programs should be constantly appraised and revised by incorporating new innovations. Furthermore, the efficiency and effectiveness of the breeding programs should be monitored by employing metrics designed to measure the impacts of breeding outcomes (= improved varieties) on the ultimate users – the farmers.

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