Breakthroughs in maize breeding

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Extra-early maize inbreds and hybrids that are resistant to *Striga*, tolerant of low nitrogen (N) and drought at flowering and grain filling periods, and that combine tolerance for these three stresses are now available in sub-Saharan Africa as a result of the painstaking research under the Maize Improvement Program at IITA.

Maize is the most important cereal crop after rice in West and Central Africa. However, during the last two decades, its production and productivity have lagged behind population growth for several reasons. These include low soil fertility, little or no use of improved seeds, herbicides, and fertilizers, inadequate plant density, weed infestation, poor tillage practices, labor shortages, increased levels of biotic and abiotic constraints, and high costs of inputs. In addition, serious infrastructural and institutional constraints have limited the adoption of improved maize technologies. Climate change and its associated effects have also resulted in altered weather patterns leading to erratic and unreliable amounts and distribution of rainfall, resulting in drought. Presently, stresses from *Striga* infestation, drought, and low N are the most important biotic and abiotic factors that limit maize production in the region.

Four maturity groups are needed to satisfy the maize varietal requirements of the subregion for human consumption, poultry and livestock feed, and industrial use. These groups are the extra-early varieties (80-85 days to maturity), early (90-95 days to maturity), intermediate (100-110 days to maturity), and late (>120 days to maturity). Extra-early varieties play a unique role in filling the hunger gap in July in the Sudan savanna and the northern Guinea savanna

Maize is the most important cereal crop after rice in West and Central Africa. Photo by IITA.

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zones after the long dry season. The extra-early varieties are also used for late planting when the rains are delayed, for intercropping with cassava, millet, and sorghum, and as "green maize" in the forest agroecology where they allow early access to the market for a premium price. The availability of early and extra-early varieties has significantly contributed to the expansion of maize to new frontiers in the savanna agroecology, replacing sorghum and millet.

A major strategy of IITA's Maize Improvement Program is to breed cultivars that are *Striga* resistant and drought- and low-N tolerant to increase and stabilize maize yield production in the subregion. Two approaches have been adopted for drought tolerance. The first is to breed for extra-early maturing cultivars that are drought escaping. These cultivars are adapted to drought-prone environments in West and Central Africa; they mature and complete their life cycles before severe moisture deficit occurs or before the onset of terminal drought. The second strategy is to breed drought-tolerant cultivars with better adaptation to drought-prone environments under induced drought stress. This is achieved by introgressing or introducing into extra-early cultivars the genes for drought tolerance to enable them to withstand mid-season drought when it occurs during the flowering and grain-filling periods.

Breeding for adaptation to drought-prone environments

The goal of the IITA Maize Program is to develop open-pollinated and hybrid maize cultivars adapted to the different forms of climatic variation prevalent in West and Central Africa with emphasis on drought stress. The naturally available mechanisms for drought escape and drought tolerance in the germplasm and the prevailing production environments in West and Central Africa were exploited to develop cultivars with enhanced adaptation to stressful environments. Drought escape occurs when the plant completes critical physiological processes before drought sets in. This trait is quite desirable in cultivars to be released to farmers in areas where terminal drought is most prevalent. Adaptation to drought-prone environments, on the other hand, is under genetic control and indicates the presence of physiological mechanisms that minimize or withstand the adverse effects of drought if and when it occurs. Cultivars with enhanced adaptation to drought-prone environments are useful where drought occurs randomly and at any growth stage of the maize crop. This is quite relevant in West and Central Africa where drought occurrence is erratic, with varying timing and levels of intensity.

Using the two strategies, IITA has, during the last two decades, developed a wide range of high-yielding drought tolerant or drought-escaping extra-early *Striga* resistant populations (white and yellow endosperm), inbred lines, and cultivars to combat the threat posed by the weed *Striga hermonthica* and recurrent drought in the savannas of West and Central Africa. The extra-early populations from which the inbred lines and cultivars were derived were formed from crosses between local landraces, exotic, and introduced germplasm identified through extensive multilocation trials in West and Central Africa. They were selected based on high grain yield, earliness, and resistance to the maize streak virus (MSV), and above all on adaptation to the high temperatures and drought stress characteristic of the Sudan savanna in Burkina Faso, Mali, Mauritania, Ghana, Nigeria, and Niger.

The extra-early germplasm was expected to have adaptive traits for tolerance to these stresses in the environments where the cultivars had survived. Some of the extra-early inbred lines in the IITA Maize Program did not only escape drought but also seemed to possess drought tolerance genes (Badu-Apraku et al. 2011a, 2013a). The inbreds, early, intermediate, and late-maturing, are also able to withstand the mid-season drought that occurs during the flowering and grain filling periods in the savannas of West and Central Africa.

Selection for tolerance to drought under managed drought stress

Selection for extra-earliness in the IITA Maize Program has been carried out in the savannas of the subregion. So far, several cultivars have been bred, some of which have been released to farmers after extensive testing in the different countries in the subregion.

Induced drought stress for selection for drought tolerance in extra-early maize is achieved by withdrawing irrigation water from 21 days after planting until maturity, with the plants relying on water stored in the soil for growth and development. Promising inbred lines selected for drought tolerance are used to develop extra-early maturing open-

A maize experiment in IITA, Nigeria. Photo by IITA.

pollinated and hybrid cultivars with enhanced adaptation to drought-prone environments. The selected lines are also used as sources of tolerance genes for introgression into extra-early breeding populations that are undergoing recurrent selection. Using this strategy, several extra-early drought tolerant and *Striga* resistant cultivars with enhanced adaptation to drought-prone environments have been bred.

Selection for tolerance to low soil N

In most developing countries, maize production is carried out under conditions of low soil fertility which further compounds the problems of drought stress and *Striga* infestation on productivity. Estimated yield losses from N-stress alone can be as high as 50% (Wolfe et al. 1988). Therefore, the development and adoption of maize germplasm with tolerance to multiple stresses are crucial for increased productivity (Badu-Apraku et al. 2010, 2011b). Banziger et al. (1999) showed that improvement for drought tolerance also resulted in specific adaptation and improved performance under low-N conditions, suggesting that tolerance to either stress involves a common adaptive mechanism.

Identification of inbreds and hybrids with genes for tolerance to low soil N and drought

Three experiments were conducted between 2007 and 2010 in Nigeria to identify extra-early inbreds with tolerance to low N and/or drought stress at flowering and grain-filling periods, and to determine the potential of the inbreds for hybrid production and as a source of germplasm for improving breeding populations. In the first two experiments, 90 extra-early maturing maize inbred lines were evaluated in Nigeria at Ikenne (6º 53′N, 3º 42′E, 60 m altitude, 1200 mm annual rainfall) under managed drought stress and in well-watered environments during the dry seasons of 2007/2008 and 2008/2009. Similarly, the lines were evaluated in low-N (30 kg/ha) and high-N (90 kg/ha) studies at Mokwa (9º 18′N, 5º 4′E, 457 m altitude, 1100 mm annual rainfall) during the growing seasons of 2008 and 2009.

Results identified several stable and high-yielding hybrids ideal for drought environments and pinpointed the fact that the extra-early inbreds and hybrids are not only drought-escaping but also possess genes conferring drought and/or low-N tolerance. TZEEI 6, TZEEI 4, TZEEI 36, and TZEEI 38 were identified as ideal inbreds under drought. Under low N, TZEEI 19, TZEEI 96, and TZEEI 45 were top ranking with TZEEI 19 as the ideal inbred. TZEEI 19, TZEEI 29, TZEEI 56, TZEEI 38, and TZEEI 79 were tolerant to both stresses. Eighteen of the 36 hybrids produced above-average yields across environments with four hybrids identified as very stable. TZEEI 29 × TZEEI 21 was the closest to the ideal genotype because it combined large mean performance with high yield stability.

Badu-Apraku et al. (2013b) evaluated 17 of the 90 extra-early white maize inbreds tolerant to drought and low-N used in the earlier studies under drought, *Striga*, and optimal environments at three locations in Nigeria for 2 years. Results indicated that the test environments were unique and that there were adequate genetic differences among the inbred

In most developing countries, maize production is carried out under conditions of low soil fertility. Photo by IITA.

lines to allow good progress from selection for improvements in the traits and to serve as sources of favorable alleles for improving breeding populations for drought tolerance at the flowering and grain-filling periods and *Striga* resistance and to serve as parents for developing superior hybrids.

Under drought stress, the mean grain yield of the hybrids ranged from 1114 kg/ha for TZEEI 14 × TZEEI 13 to 2734 kg/ha for TZEEI 29 × TZEEI 21. The top-ranking hybrid, TZEEI 29 × TZEEI 21, outyielded by 13% the best *Striga* resistant and drought tolerant early maturing open-pollinated variety, TZE-W DT STR C4. On the average, early maturing varieties out-yield extra-early varieties by at least 1 t/ha (Badu-Apraku and Oyekunle, 2012). Under well-watered conditions, the top-yielding hybrid was TZEEI 3 × TZEEI 13 (5868 kg/ha) while the lowest was TZEEI 14 × TZEEI 13 (2749 kg/ha). Under artificial *Striga* infestation, TZEEI 29 × TZEEI 14 was the top ranking hybrid, outyielding by 22% the best *Striga* and drought tolerant early open pollinated check, TZE-W DT STR C4.

A stability analysis of the top 20 and worst five single-cross hybrids and four early open pollinated check cultivars revealed TZEEI 29 × TZEEI 14 as the second highest yielding and most stable single-cross hybrid across research environments; the highest-yielding single-cross hybrid, TZEEI 6 × TZEEI 14, was the least stable.

Badu-Apraku and Oyekunle (2012) also conducted two more studies for

2 years at five locations in Nigeria. TZEEI 79 × TZEEI 76 turned out to be the highest yielding and most stable hybrid across environments. It was concluded that the available extra-early yellow maize inbred lines are not only drought-escaping but also possess genes for drought tolerance at flowering and grain-filling periods.

The availability of these *Striga* resistant, low N and drought-tolerant extra-early inbreds and hybrids should go a long way in reducing the instability of maize yields in sub-Saharan Africa, especially in the savannas and during the second season in the forest agro-ecologies.

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