Breeding an "Amaizing" Crop

Improved maize in Kenya, Malawi, Zambia, and Zimbabwe

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Maize is the world's most widely grown cereal, cultivated in the tropics and in temperate zones, at high and low altitudes, in dry climates and wet ones, on slopes and fields, and in a range of soil types. Large-scale commercial farmers grow it using equipment worth hundreds of thousands of dollars, while poor farmers with small plots, such as those in East and Southern Africa, grow it using little more than a hoe. Given maize's enormous versatility and popularity, when scientists in East and Southern Africa were able to develop more productive maize seeds through innovative breeding programs, their success translated into better livelihoods for millions of farm households.

This story begins on the eve of independence for Kenya, and several decades before the independence of Zimbabwe, with colonial maize-breeding programs geared primarily to the needs of European settler-farmers. In Kenya, the products of these early scientific efforts were as promising as the hybrids that swept across midwestern farmlands in the United States beginning in the 1930s. They served as the basis for generations of new maize hybrids and other improved varieties that spread rapidly among smallholders in newly formed African states from 1965 to 1990. With the spread of modern maize, farmers' yields multiplied several-fold and contributed significantly to improving food production and food security in the region. The experiences of four countries in the region—Kenya, Malawi, Zambia, and Zimbabwe—demonstrate just how influential improved maize and maize breeding were during this period in history.

A New World Import

Maize arrived in Africa relatively recently. During the 1500s, traders introduced maize and cassava—New World crops—into Africa, where they supplemented indigenous staples like sorghum, millet, and yams. Initially, most African farmers adopted maize as a niche crop tucked in their already complex farming systems. But because maize was so well suited to growing conditions in the region, by the end of the 19th century it had become widely cultivated as a secondary food crop.

Between 1900 and 1965, maize pushed aside other crops to become the dominant food crop in Kenya, Malawi, Zambia, and Zimbabwe. Between 2000 and 2005, maize covered more than three-quarters of the land under cereal cultivation in the four countries, and most of the maize being grown consisted of modern (improved) varieties (see Table 4.1).

The initial spread of maize during the colonial era is attributed to several factors. First, it could be grown by newly arrived European settlers—who were novices at farming in the tropics—because it required less capital and technical skill than cotton and tobacco. Second, it could yield higher returns than indigenous cereals and was both easier to process and more marketable, particularly as an export to the British starch market. Third, maize became a form of in-kind wage payment for African workers who left their farms to work on settler-owned farms, mines, and industrial plants, particularly in Zambia, Kenya, and Zimbabwe.

As a result of this close link between maize, European settlers, and colonial governments

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Table 4.1—Maize in East and Southern Africa, 2000–05

Country	Total average annual production (thousand tons)	Maize area as a % of total cereal area	Average per capita consumption of maize as food (kg/year)	Average % of maize used in human consumption
Kenya	2,597	79	86	96
Malawi	1,770	95	121	79
Zambia	868	82	86	94
Zimbabwe	1,076	80	89	72

Note: Consumption data refer to 1997–99. All other data are averages for the period 2000–05.

Source: Aquino, P., F. Carrion, R. Calvo, and D. Flores. 2001. Selected maize statistics: Part 4. In *Meeting world maize needs: Technological opportunities and priorities for the public sector*, ed. P. L. Pingali. Mexico City: International Maize and Wheat Improvement Center; FAO (Food and Agriculture Organization of the United Nations). 2009. FAOSTAT statistical database. Rome.

in the region, state-directed marketing systems emerged that tied grain marketing to the delivery of seeds, fertilizer, and credit on beneficial terms for settler farmers. Yet in spite of this system, which favored settlers over indigenous farmers, maize cultivation still managed to spread rapidly among smallholders. Following independence, as newly independent governments tried to support smallholder farmers, maize was elevated to the center of the "social contract" between these new states and their citizens. Maize thus became the cornerstone of the modern states of Kenya, Malawi, Zambia, and Zimbabwe.[1]

Years of independence

Kenya:1963
Malawi: 1964
Zambia: 1964
Zimbabwe: 1980

Scientific Achievements in Maize Improvement

The investments in maize research made by colonial governments and settlers, and eventually by independent governments, radically transformed maize production in the region from the 1930s through about 1990. A major element of this success story was the introduction of maize hybrids in East and Southern Africa. Maize hybridization, first demonstrated by scientists in the United States in 1918, is a process in which inbred parent lines of maize are crossed to create seeds with greater yield potential than either parent, an outcome known as "hybrid vigor" (see box next page).[2] The downside is that this vigor tends to decline with each successive generation of seed saved and replanted by farmers. To realize the full gains conferred by hybridization, farmers need to purchase new seed each season.

Zimbabwe's maize breeders were the first outside the United States to produce double-cross hybrids for commercial use (see box), releasing a hybrid called Southern Rhodesia-1 (SR-1) in 1949. In 1960, the maize-breeding program released the first commercially grown single-cross hybrid in the world, SR-52, which boasted a greater yield advantage and greater uniformity despite seeds that were more costly to produce. SR-52 spread rapidly and widely among commercial farmers, becoming one of the most popular hybrids in the region and a parent of many others. Farmers who grew SR-52 seed using fertilizer and improved agronomic practices increased their yields by 46 percent more than yields from the most common improved local variety.[3]

Following independence in 1980, Zimbabwe's maize breeders continued to chalk up successes. Independence saw the rapid adoption of R200, R201, and R215—fast-growing maize hybrids that were originally bred for European settlers seeking to diversify from tobacco exports; they also provided smallholders with maize seed suitable for cultivation in sandy soils in low-rainfall areas. Although these hybrids were all three-way crosses, which are generally intended for the annual seed purchase and high levels of management typically associated with large-scale commercial farmers, they still performed well for smallholders who could only afford relatively low levels of management.

The Techniques and Technologies of Breeding Better Maize

Maize is predominantly a cross- or open-pollinating crop rather than a self-pollinating crop like rice. In cross pollination, genetic material is exchanged as pollen flows among neighboring plants. Unless cross-pollination is carefully controlled, the progeny resulting from it in a given field will differ from the preceding generation—and from each other—in terms of yield, size, shape, and other characteristics.

When maize *does* self-pollinate, its progeny often have undesirable traits. This is called inbreeding, and after successive generations, it leads to weakened plants called inbred lines. These inbred lines produce small plants, have small cobs, and result in lower yields.

By interbreeding or crossing different varieties of maize, breeders can create "modern" maize that overcomes some of the disadvantages of unimproved and inbred varieties. When two inbred lines are crossed, for example, the progeny's yield can be significantly greater than their parents' yield. This "hybrid vigor" results from the interaction between the sets of genes in the two different inbred lines. The effect of some of the harmful genes expressed in one of the inbred lines is masked by more beneficial ones found in the other parent plant. Maize breeders exploit this process, called heterosis, to develop hybrid cultivars that are now widely grown by farmers.

Breeders produce several main types of maize hybrids:

- Single-cross hybrids—hybrids that result from the cross pollination of unrelated inbred parent lines.
- Double-cross hybrids—hybrids that result from the cross pollination of parent lines that are both single-cross hybrids.
- Three-way hybrids—hybrids that result from crossing three parent lines, where the female parent is a single-cross hybrid and the male is an inbred line.
- Top-cross hybrids—hybrids that result from cross pollinating a single-cross hybrid or an inbred line with an open-pollinated variety.
- Varietal hybrids—hybrids that result from crossing two open-pollinated varieties.

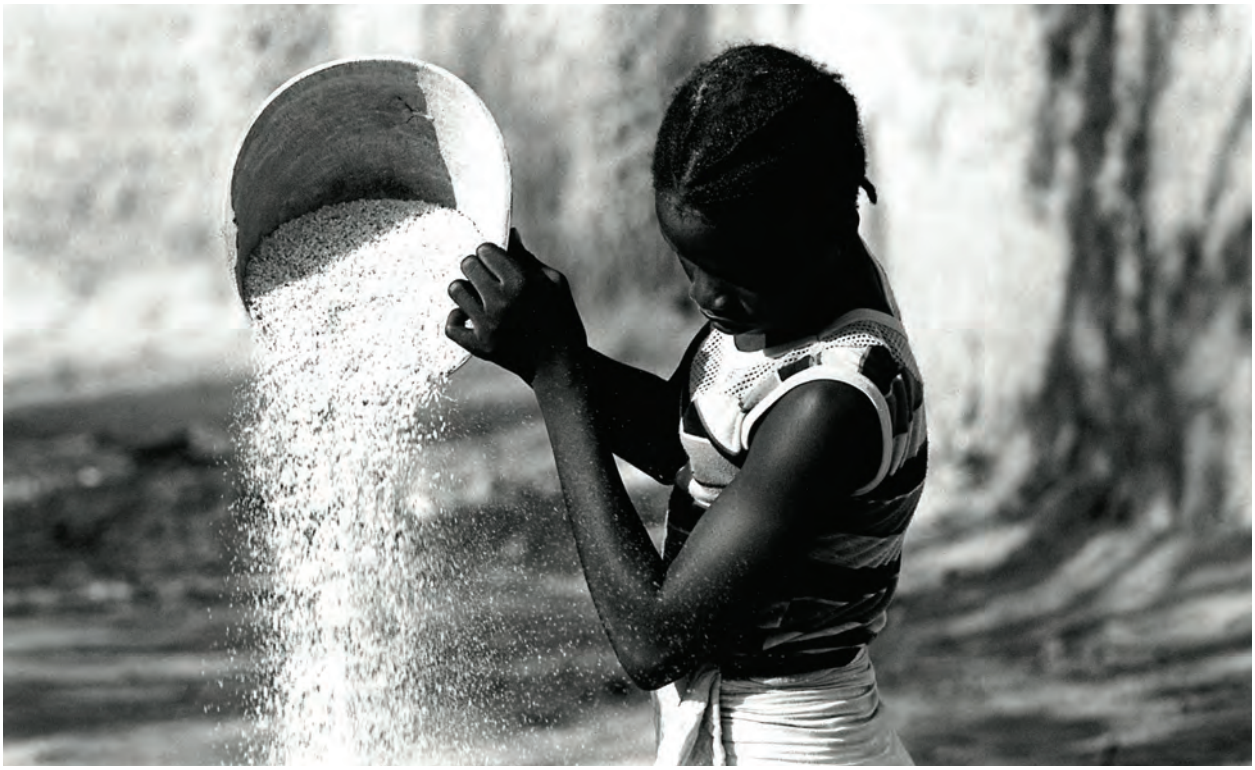
Growing hybrid maize offers some real advantages:

- Hybrids generally produce higher yields than open-pollinated varieties, if grown under suitable conditions.
- Hybrids are uniform in color, maturity, and other plant characteristics, enabling farmers to carry out certain operations, such as harvesting, at the same time.
- The uniformity of the grain harvested from hybrids can have marketing advantages when sold to buyers with strict quality standards.

Hybrid maize also presents some disadvantages:

- To maintain the greatest yield advantage, farmers should buy fresh hybrid seed every planting season.
- Hybrid seed is more expensive than open-pollinated maize seed.
- A farmer needs to produce more than 2 tons of maize per hectare to justify the cost of the seed. Farmers situated in areas with poor growing conditions who cannot afford extra inputs such as fertilizer will not recover the cost of the hybrid seed.
- The grain from a crop grown with hybrid seed should not be used for seed. Farmers cannot replant grain as seed without yield reductions of 30 percent or more.
- Farmers might not always be able to obtain new seed in time for the planting season.

Source: Authors; Morris, M. L. 1998. Maize in the developing world: Waiting for a Green Revolution. In *Maize seed industries in developing countries,* ed. M. L. Morris. Boulder: Lynne Rienner.



Farmer handling maize

These breeding successes in Zimbabwe spread rapidly to neighboring Zambia, where studies suggest that they doubled commercial farmers' yields from 1.3 metric tons per hectare between 1949 and 1953 to 2.7 tons per hectare between 1959 and 1963.[4] Following independence in 1964, Zambia's maize breeders introduced an impressive array of both hybrids and improved open-pollinated varieties. Farmers found that these hybrids out-yielded most other available varieties, even without fertilizer, in all but the most difficult growing environments. They also had other advantages: unlike the single cross SR-52, these double- and three-way crosses lost little yield advantage when farmers saved and replanted seeds from one season to the next. Meanwhile, the improved open-pollinated varieties offered their own distinct advantages to smallholders—ears of these early-maturing, drought-tolerant varieties could be consumed green as a source of food during the hungry period preceding harvest.

Kenya's maize breeders were also successful in breeding improved maize that eventually spread to its large smallholder population. Kenya's program began in 1955 in Kitale, the center of maize production in the highlands, which were then heavily populated by European settlers. In 1961, the program released an improved, open-pollinated maize variety called Kitale Synthetic II.

After crossing Kitale Synthetic II with dozens of germplasm samples collected from Latin America, Kenya's maize scientists released their first varietal hybrid—Hybrid 611, made from Kitale Synthetic II and Ecuador 573. This hybrid became the basis of all subsequent hybrids developed by the national breeding program.[5] The yield advantage of Hybrid 611 over Kitale Synthetic II was 40 percent, with the added advantage of having lower seed costs than conventional hybrids and less loss of yield advantages when replanted in successive seasons, Hybrid 611 diffused among large- and small-scale farmers in the high-potential areas of western Kenya at rates comparable to those in the U.S. Corn Belt during the 1930s and 1940s.[6]

Malawian smallholders waited much longer for suitable hybrids, for two main reasons. First, Malawi, unlike Zimbabwe or Kenya, did not have a large settler population with an interest in high-yielding maize or the political clout to establish a research system. Unlike Zambia, Malawi had

Table 4.2—Maize performance in Kenya, Zimbabwe, Zambia, and Malawi

Country/episode of success	Annual yield growth (%)	Annual production growth (%)
Kenya, 1965–80	1.44	3.30
Malawi, 1983–93	1.18	3.10
Zambia, 1970–89	4.92	1.85
Zimbabwe, 1980–89	2.21	1.77

Source: FAO (Food and Agriculture Organization of the United Nations). 2009. FAOSTAT statistical database. Rome.

no rich mineral deposits with dense urban populations to feed. Malawi's real maize research clients have always been smallholder farmers, the majority of whom lacked the formal organization and supporting institutions to articulate their needs. These farmers preferred *flint* maize types that processed and stored well on their farms. Second, regional breeding efforts were too focused on *dent* maize types, and flint breeding materials from outside Malawi were not easy to identify. This supply problem was compounded by staffing and funding discontinuities in the national maize breeding programs, and shifting emphasis between efforts to breed hybrids as compared to improved, open-pollinated varieties.

Malawi's first semi-flint hybrids were released in 1990—top-crosses of Malawian lines derived from SR52 and a flint population from the International Maize and Wheat Improvement Center. They had several features small farmers were looking for.[7] Most important was that they satisfied smallholder demand for the flint maize types that processed and stored well on farms.[8] Also important, given the high cost of fertilizer, was the fact that the hybrids grown without fertilizer still yielded more than local maize grown without it, even during the severe droughts that occurred in Malawi during the early-1990s. In particular, MH18 was an early-maturing variety that was more likely to "escape" drought. As top-cross hybrids, they were more likely to retain some of their yield advantage when seed was saved for a season.

The Rapid Spread of Improved Maize

The episodes of success in maize production in the four countries overlapped somewhat, but they varied because of the different conditions and policies within each country. These growth episodes were from 1965 to 1980 in Kenya, 1970 to 1989 in Zambia, 1980 to 1989 in Zimbabwe, and 1983 to 1993 in Malawi.

During these episodes, yields began a steady advance, and overall maize production surged in the four countries at rates that compare respectably with yield and production growth rates in countries such as the United States (see Table 4.2). The share of smallholder farmers growing hybrid maize rose to 43 percent in Malawi, 65 percent in Zambia, and 87 percent in Kenya. It jumped from 40 percent in 1979 to 98 percent in 1985 in

Harvesting maize

Zimbabwe, while total smallholder maize production tripled between 1980 and 1988.

In each country, the growth in maize yields and production was accompanied by the expansion of state marketing infrastructure to smallholder areas, making it easier for government agencies to distribute credit and subsidized inputs like seed and fertilizer, purchase smallholder maize surpluses, and collect loan repayments. Parastatal marketing boards would supply farmers with maize seed and fertilizer on credit then buy the resulting maize harvest from farmers at a fixed, nationwide price, subtracting the cost of any loans. Malawi's Agricultural Development and Marketing Corporation, for example, assumed total responsibility for delivering inputs like seeds and fertilizer to farmers, marketing maize output, maintaining storage facilities, stabilizing maize prices, and transporting maize into food-deficit areas during the hungry season.

In addition, farmers could obtain credit and inputs for growing maize at reduced rates, thanks to government subsidies. For example, Zambian fertilizer subsidies in 1982 averaged 60 percent of the cost of the fertilizer itself, cutting the cost to farmers by more than half.[9]

These state interventions generally benefited smallholders during this 25-year period. On the production side, even when the full costs of seed and fertilizer were taken into account, small farmers growing maize hybrids could earn returns on their land and labor that were nearly twice as much as what they could earn for the local seed varieties cultivated without fertilizer. On the marketing side, smallholders in even the remotest areas profited from policies that set a single purchase price for maize across the entire country.

Yet the effectiveness of the marketing and input credit policies in promoting maize production growth contained the seeds of their own demise. Treasury costs ballooned as small farmers produced more maize than the country could consume and massive stocks accumulated in state warehouses or were exported at a loss. In some cases these costs accounted for 15 percent or more of total government spending and contributed to macroeconomic instability; hence, the maize support prices offered by the marketing boards could not be sustained. As support prices were reduced or withdrawn in many areas farmers opted to sell their grain in illegal parallel markets. The rise of parallel markets also enabled farmers

Maize crop: (left) hybrid and (right) nonhybrid

to avoid repaying the loans they had taken out to buy inputs. These policies eventually led to fiscal crisis and, in some cases, hyperinflation. The maize-breeding programs literally helped to feed millions while also providing a source of income for many smallholder farmers in the region, but the package of policies that accompanied them could not be sustained in the long term.[10]

Ingredients for Success

The main ingredient in each country's episode of success was an innovative breeding program that produced high-quality materials needed to provide smallholders with modern maize. In Kenya, success was partly attributable to the continuity of the breeding program's staff and leadership, and to the fact that the program actually consisted of four separate research stations—one for each of the nation's agroclimatic zones—that released a succession of improved maize varieties suited to each zone. Moreover, the program was backed by consistent and constructive support from aid donors: during these initial years, the Rockefeller Foundation and the United States Agency for International Development (USAID) facilitated the exchange of germplasm between continents as well as the sharing of new research on hybrid genetics. Similarly, Zimbabwe's program succeeded because of its dedicated (and well-paid) scientists who devoted their entire careers to maize research, with the added advantage of being backed by the revenues earned and contributed by commercial farmers.

But good breeding programs are just some of the factors that contributed to the growth and spread of modern maize in Kenya, Malawi, Zambia, and Zimbabwe. All four countries also made complementary investments in agronomic research, extension, seed distribution systems, and rural infrastructure, and all four countries also operated institutions to coordinate grain marketing with seed, fertilizer, and credit delivery. In short, these four countries recognized that smallholder agriculture was an integrated system and, accordingly, they invested heavily in many different ways to promote modern maize as a means of boosting maize yields and production.

The Kenya Maize Research Program, for example, was backed by a larger national maize program that included a dense transport network, marketing boards, preferential pricing policies

Farmer holds a handful of maize, Malawi

for farmers, extension services, and a national seed company. Modern maize spread throughout Kenya as a result of thousands of farming demonstrations carried out by extension agents, seed sales and credit disbursements managed by rural seed stockists, and a supportive policy regime (see Chapter 14).

In Zimbabwe, the government also supported smallholder maize cultivation through input delivery, credit, and marketing programs that had previously served only large-scale European settlers. One of the hallmarks of Zimbabwe's success story was the Seed Maize Cooperative—known in the colonial era as the Seed Maize Association of Southern Rhodesia—that was designed as an autonomous body to transfer monitoring and inspection costs from the government to its maize-producing members, arrange tax breaks, secure exclusive commercial rights over the sale of some seed types, and provide access to subsidized credit. As a result of these interventions, credit allocated to smallholders between 1979 and 1986 rose eightfold, stimulating fertilizer use, increasing maize yields, and encouraging the growth of private investment in input supply. As mentioned above, however, the model could not be financially sustained. By the late-1980s,

the government had dramatically scaled back credit disbursement and marketing board collection points, reduced the real prices offered by the marketing board, and faced pressure to legalize parallel private markets.

In Malawi, several factors other than modern maize contributed to small farmers' rapid adoption of maize from the mid-1980s until 1993. During the late-1980s farmers could get hybrid seed and fertilizer at favorable prices. At the same time, improvements were being made in the marketing and distribution of high-quality commercial seed.[11] These improvements began in 1978 when the National Seed Company of Malawi (NSCM) took responsibility from Malawi's Agricultural Development and Marketing Corporation for producing, procuring, and marketing improved maize seed. In 1988 Cargill, a multinational company, acquired most of the NSCM's equity and began aggressively producing, procuring, and marketing seeds in Malawi.

Lessons from East and Southern Africa's Maize Programs

Despite the spread of modern maize among smallholders in East and Southern Africa immediately following independence, the growth in maize yields and production has slowed since about 1990. Unstable weather in the 1990s is much to blame, but the withdrawal of state subsidies and market support in all four countries has also shifted cultivated area from maize to other crops, with unclear effects on total agricultural growth. Ultimately, the fiscal burden associated with state-led marketing and credit policies rendered these systems unsustainable. Subsequent efforts to liberalize the maize sector and maize seed industry in the region have been uneven, erratic, and often ensnared by populist political pressures, leaving national seed research systems chronically underfunded and creating uncertainties that discourage investment throughout the maize production chain.

Conclusion

In spite of the shortcomings and occasional criticisms that accompanied the growth and spread of maize in East and Southern Africa, there is little doubt that the period from 1965 to 1990 represents a success story in agricultural development. A combination of factors—primarily the sustained investment in research and development, dedicated scientists, and supportive public policies—all contributed to maize-driven improvements in rural livelihoods and national food security in the region. ■

NOTES

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