# 9 Fifty Years of Change in Maize Research at CIMMYT

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At the end of the twentieth century, maize became the world's most important crop in terms of tons produced and calories supplied. Originating in the tropics and subtropics of Mexico, maize was spread by Indigenous populations throughout much of the Americas, and then to the Old World from the sixteenth century as part of the Columbian exchange.[1] However, its rise to world dominance began only after World War II as global production leaped to over ten times its pre-1938 level. Much of this growth was due to the use of grain for animal feed and, more recently, for biofuel. However, maize remains the staple food crop in its Latin American center of origin, and in the first half of the twentieth century it became a staple in much of Africa.[2]

In the United States, the almost universal adoption of hybrid maize and associated growth in yields from the 1930s reinforced its position as the world's largest producer of maize. Maize became the focal crop in early US foreign assistance programs, private-sector investment, and international exchange of breeding materials (germplasm).[3] Maize research was also internationalized, with consequences for agricultural research more broadly. In 1950, Ricardo Acosta, a Mexican government official, proposed an international institute for maize research. His proposal was the catalyst for the development of the international center model for agricultural research, which resulted in the creation of the International Rice Research Institute (IRRI) in 1960 in the Philippines, the International Maize and Wheat Improvement Center (CIMMYT) in

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[1] Alfred W. Crosby, *The Columbian Exchange: Biological and Cultural Consequences of 1492* (Westport, CT: Greenwood, 1972).

[2] James C. McCann, *Maize and Grace: Africa's Encounter with a New World Crop 1500–2000* (Cambridge, MA: Harvard University Press, 2005).

[3] L. B. Kass, C. Bonneuil, and E. H. Coe, "Cornfests, Cornfabs and Cooperation: The Origins and Beginnings of the Maize Genetics Cooperation Newsletter," *Genetics* 169, no. 4 (2005): 1787–1797; Derek Byerlee, "Globalization of Hybrid Maize, 1921–1970," *Journal of Global History* 15, no. 1 (2020): 101–122.

1966 in Mexico, and the Consultative Group on International Agricultural Research (CGIAR) in 1971.[4]

Although maize appeared to be at the forefront, we argue in this chapter that the development of an international maize program at CIMMYT took place in the shadow of experiences with rice and wheat that were already attracting global attention as part of the Green Revolution. The key design element of international research on rice and wheat was a centralized breeding program linked to a network of public-sector research systems at the national level where new varieties were adapted and tested.[5] A fundamental characteristic of the model was its "open-source" approach, in which countries were free to directly release varieties from the testing program or use these as inputs into their own breeding programs. Nonetheless, the first international centers aspired to realize quick payoffs by developing widely adapted varieties that could be immediately used in multiple countries to help meet the food needs of rapidly growing populations.[6]

In applying this model to maize, researchers confronted three characteristics that distinguished this crop from rice and wheat. First, given Malthusian famine scares, attention in the 1960s was firmly focused on Asia, where maize was not a staple food except for marginalized populations in hill areas. It was therefore not a "political crop."[7] Maize was a staple in eastern and southern Africa, but that region only became a major CGIAR priority much later. With the exception of Latin American countries and a handful of white settler economies in Africa, maize research remained a low priority in low- and middle-income country contexts.

Second, nearly all maize in low- and middle-income countries outside of China, Argentina, and South Africa was grown in tropical and subtropical ecologies.[8] CIMMYT naturally focused on these ecologies, but, unlike rice and wheat, which were often grown in relatively uniform

[4] Derek Byerlee and John K. Lynam, "The Development of the International Center Model for Agricultural Research: A Prehistory of the CGIAR," *World Development* 135 (2020): 105080.

[5] Ibid.

[6] Robert S. Anderson, Edwin Levy, and Barrie M. Morrison, *Rice Science and Development Politics: Research Strategies and IRRI's Technologies Confront Asian Diversity, 1950–1980* (Oxford: Clarendon Press, 1991); Marci R. Baranski, "Wide Adaptation of Green Revolution Wheat: International Roots and the Indian Context of a New Plant Breeding Ideal, 1960–1970," *Studies in History and Philosophy of Science* 50 (2015): 41–50.

[7] Several largely unsuccessful attempts to transfer hybrid maize to Asia reflected scientific interest in the hybrid technology rather than a high priority within maize research. See Byerlee, "Globalization of Hybrid Maize."

[8] In the 1960s, nearly half of the global area planted to maize was in the tropics and subtropics. With the exception of Brazil and some commercial farming areas of eastern and southern Africa, nearly all of this area was planted by small-scale farmers.

irrigated areas, nearly all tropical and subtropical maize was grown under rainfed conditions that were highly diverse with respect to altitude, soils, and rainfall.[9] Further, and in contrast to wheat, farmers' preferences for maize grain type and color also varied widely, partly reflecting its varied uses in foods – from tortillas and porridges to fresh corn on the cob and snack foods – and for animal feed. This diversity challenged the established centralized breeding model employed for rice and wheat. It required considerable innovation and learning to develop an appropriate model for international maize research.

Finally, CIMMYT had to deal with significant private-sector involvement in maize research and seed production, a circumstance that did not apply to rice and wheat. In maize, the male (tassels) and female flowers (ears) are separated, making it relatively easy and cheap to produce hybrids by inbreeding parental lines for several generations and then crossing the inbreds to express heterosis (also known as hybrid vigor). These hybrids provide a significant yield advantage under a range of growing conditions; however, farmers need to buy seed annually to maintain this advantage. These characteristics of maize incentivized private firms to invest in the production and promotion of hybrid maize seed and for larger seed companies to invest in their own breeding programs.[10] By 1970, maize farmers in high-income countries had almost completely switched to hybrid seed developed and sold by private firms, and some of these firms had evolved into large multinational corporations.[11]

Some earlier maize-breeding programs had explored the option of improved open-pollinated varieties that allowed farmers to save seed.[12] CIMMYT could pursue this option, too, and focus on open-pollinated varieties at the cost of potentially lower yields, or it could develop hybrids and partner with the public and private sector to deliver its seed. Working with the private sector naturally introduced tensions for an international center set up to produce "international public goods" – that is, products that could be freely exchanged and used across countries (see the discussion of these issues in David J. Jefferson, Chapter 12, this volume).

[9] For a fuller comparison of these crops, see D. Byerlee and G. O. Edmeades, *Fifty Years of Maize Research in the CGIAR: Diversity, Change, and Ultimate Success* (Mexico City: CIMMYT, 2021), https://hdl.handle.net/10883/21633.
[10] M. L. Morris, ed., *Maize Seed Industries in Developing Countries* (Boulder, CO: Lynne Rienner, 1998).
[11] Byerlee, "Globalization of Hybrid Maize"; Jack R. Kloppenburg, *First the Seed: The Political Economy of Plant Biotechnology, 1492–2000*, 2nd edn. (Madison: University of Wisconsin Press, 2004).
[12] For a review of open-pollinated varieties and hybrids in Mexican maize-breeding programs prior to CIMMYT, see Karen E. Matchett, "Untold Innovation: Scientific Practice and Corn Improvement in Mexico, 1935–1965," Ph.D. dissertation, University of Minnesota (2002).

With these facets of maize history and biology in mind, this chapter aims to describe and analyze the design and evolution of international maize research at CIMMYT during its first fifty years. We identify three distinct periods in this research between 1966 and 2020, recognizing that the transition between periods is often blurred. Our focus is on breeding research, although CIMMYT invested significant resources in maize agronomic and social science research that mostly complemented its breeding efforts. We do not consider West Africa, where a strong maize research program of the International Institute of Tropical Agriculture (IITA), another CGIAR center, focused its work with varying degrees of collaboration and sometimes competition with CIMMYT.[13]

## Building a Global Program with Scientists in the Lead, 1966–85

CIMMYT was formally established in 1966 in the context of widespread concern over global population growth and impending food and resource shortages. Its founders enthusiastically embraced the food-population challenge and defined its mission as increasing the "quantity of food produced." However, CIMMYT, along with other development actors at the time, poorly articulated the pathway from increasing the "pile of food" to reducing hunger.[14] This narrow focus on production would dominate CIMMYT's narrative for the next fifteen years.

Given the high priority assigned to increasing food supply by international organizations, CIMMYT in this period enjoyed strong initial financial support from the Rockefeller and Ford Foundations, joined by the United States Agency for International Development (USAID) and several other multinational and bilateral donors after CGIAR was created in 1971. Stable and largely unrestricted financial support provided CIMMYT scientists substantial freedom to set priorities, as well as to pursue research objectives with potentially high but uncertain long-term payoffs. The eminent scientists on CGIAR's Technical Advisory Committee (TAC) exercised considerable influence over donors in allocating funds and consistently endorsed a high priority for maize research.[15]

[13] For a fuller treatment of maize research in CGIAR, see Byerlee and Edmeades, *Fifty Years of Maize Research in the CGIAR*.

[14] Bruce H. Jennings, *Foundations of International Agricultural Research: Science and Politics in Mexican Agriculture* (Boulder, CO: Westview Press, 1988).

[15] Technical Advisory Committee, *CGIAR Priorities and Future Strategies* (Rome: CGIAR, 1987), https://hdl.handle.net/10947/324.

International maize research was not new in the 1960s. Indeed, CIMMYT's maize program was built from the legacy of eight country and regional programs of the Rockefeller and Ford Foundations that operated relatively independently of each other across Latin America, Asia, and Africa.[16] Transforming these legacy research programs and networks into an integrated, coordinated international program was challenging. As noted in the introduction, the centralized breeding model employed for rice and wheat had to be adapted to the diversity of maize types and growing conditions, as well as to accommodate the sensitivity of maize varieties to changes in day length as they moved across latitudinal zones. The centralized model was further challenged by the narrow adaptation of maize to local conditions, which stood in contrast to the relatively wide adaptation of CIMMYT's wheat varieties.[17] Many maize landraces had been developed through millennia of farmer selection in geographically isolated areas where they performed well, but were susceptible to diseases, pests, and other problems when sown in other locations. In the widely publicized Plan Puebla project, established by CIMMYT and the Mexican Colegio de Postgraduados in 1967 to improve farmers' maize yields in the Mexican highlands, scientists were unable to identify a single improved open-pollinated variety or hybrid that was superior to the varieties developed by farmers in their specific locations, despite more than two decades of prior investment in maize research in Mexico.[18]

When Ernest W. Sprague, the leader of the Inter-Asian Corn Program (one of the legacy programs of the Rockefeller Foundation) was transferred to become director of CIMMYT's Maize Program in 1970, he began to design a well-coordinated global maize program (Figure 9.1). Under his leadership, CIMMYT hosted two international maize conferences, one to assess national demands for its products and a second to review the work of all maize staff from across its legacy programs.[19] These efforts led to the first systematic approach to international maize breeding

[16] The legacy programs included the Rockefeller Foundation programs in Mexico, Kenya, and Nigeria, its regional networks in Central America, the Andes, and Asia, and the Ford Foundation's maize programs in Egypt and Pakistan (from 1967).

[17] The maize biologist Paul Mangelsdorf, an advisor to the Rockefeller Foundation's agricultural program, had argued "emphatically" against an international institute for maize because of the local specificity of maize varieties. Warren Weaver, diary, October 11, 1950, Rockefeller Foundation Archives, Rockefeller Archive Center, RG12, S-Z (FA394).

[18] Donald L. Winkelmann, *The Adoption of New Maize Technology in Plan Puebla, Mexico* (Mexico City: CIMMYT, 1976).

[19] CIMMYT, *Proceedings of the First Maize Workshop* (El Batan: CIMMYT, 1971); CIMMYT, *World Wide Maize Improvement and the Role of CIMMYT: Symposium Proceedings* (El Batan: CIMMYT, 1974).

Figure 9.1 Ernest Sprague lecturing to visitors in Poza Rica, Veracruz, 1979. CIMMYT Repository. © CIMMYT.

and testing. The geographic location of CIMMYT headquarters in the highlands of central Mexico meant that its staff could conduct maize breeding across varied tropical and subtropical growing environments within a 250-kilometer range of the institute. Another core asset inherited by CIMMYT was the extensive collections of Latin American maize landraces assembled under the auspices of the US National Academy of Sciences during the 1950s and 1960s.[20] Twenty-eight "populations" were developed from these landraces to represent diversity in grain color, texture, ecological adaptation, and maturity. Each population was then evaluated at dozens of sites across the world to identify its suitability for that location. A small subset (six) of these sites' 250

[20] Helen Anne Curry, "From Working Collections to the World Germplasm Project: Agricultural Modernization and Genetic Conservation at the Rockefeller Foundation," *History and Philosophy of the Life Sciences* 39, no. 2 (2017): 5; Diana Alejandra Méndez Rojas, "Los libros del maíz: Revolución Verde y diversidad biológica en América Latina, 1951–1970," *Letras Históricas* 24 (spring–summer 2021): 149–182.

"families" of each population were evaluated to identify the best families for further improvement of that population.[21]

Through the testing network, national scientists gained access to an array of new, tropically adapted breeding materials. International testing also helped to broaden the adaptation of these populations. However, overall progress was slowed by some mismatches between populations and testing environments, the two-year cycle needed to receive results from both hemispheres, and the reality that many national programs had limited capacity to conduct precise field trials. Although CIMMYT's international testing program provided a well-structured way to expose CIMMYT's germplasm to national scientists and vice versa, it was an inefficient route to genetic improvement.[22]

The relative freedom given to CIMMYT in this early period allowed its maize scientists to go against the grain with respect to the prevailing orthodoxy in maize breeding that emphasized hybrids. Instead CIMMYT focused all its breeding and testing work in the early years on open-pollinated varieties. The decades prior to CIMMYT's founding had seen many attempts to extend hybrid technology to the tropics and frequent failures.[23] Many researchers believed hybrids to be unsuitable for small-scale farmers producing maize in risky rainfed areas, given the need for farmers to buy relatively expensive seed annually and the national resources and skills required to develop an effective hybrid seed industry.[24]

CIMMYT's focus on open-pollinated varieties was led by Sprague. In 1958 Sprague had been posted by the Rockefeller Foundation to India, where he initially worked exclusively on hybrids. However, by 1964 he was actively promoting open-pollinated varieties. It seems that his frustration with the slow pace and inconsistent quality of hybrid seed production in India, mostly in the public sector, together with his visits to Thailand to establish the Inter-Asian Corn Program, were important in this transition. Thailand had become a leading maize producer and exporter in the 1950s, based on the widespread adoption of an open-pollinated variety imported from Guatemala.[25] When Sprague moved to Mexico in 1970 to head CIMMYT's maize program, he vigorously championed the role of open-pollinated varieties over hybrids, asserting

[21] S. Pandey and C. O. Gardner, "Recurrent Selection for Population, Variety, and Hybrid Improvement in Tropical Maize," *Advances in Agronomy* 48 (1992): 1–87.

[22] Ibid. [23] Byerlee, "Globalization of Hybrid Maize."

[24] Matchett, "Untold Innovation"; P. W Heisey, M. L. Morris, D. Byerlee, and M. A. Lopez-Pereira, "Economics of Hybrid Maize Adoption," in Morris, ed., *Maize Seed Industries in Developing Countries*, pp. 143–158.

[25] Byerlee, "Globalization of Hybrid Maize."

that "none of the developing countries with small farm holdings should be working with hybrid development . . . fortunately, a number of countries with more advanced programs abandoned their work on hybrids."[26] Although his views prevailed in CIMMYT, they were questioned by others. The distinguished maize geneticist George F. Sprague (no relation to E. Sprague) of the US Department of Agriculture and Iowa State University disagreed, citing Kenya as an example of smallholder adoption of hybrid seed.[27]

During its first two decades, CIMMYT focused almost exclusively on working with the public sector to develop and promote varieties. This strategy was in line with the prevailing view among foreign assistance agencies and governments of the leading role of the "development state."[28] Given CIMMYT's close relations with national programs, especially through its extensive training of their scientists, most countries that did not already have a well-developed hybrid program followed CIMMYT's policy of developing open-pollinated varieties. The share of these varieties among all public-sector releases in the tropics and subtropics increased steadily, peaking at two-thirds of the total in the 1980s.[29]

Stable and flexible funding also allowed CIMMYT scientists to pursue several risky, long-term research ventures that would have lasting influence on breeding strategies for tropical maize. The first was an effort to reduce plant height. Especially when fertilized, many landraces grew very tall, to over 3 meters, and their grain yield was modest because of their low harvest index (the ratio of grain to total dry matter) and susceptibility to lodging (the tendency to fall over before harvest). Breeders' initial efforts to duplicate the Green Revolution approach by introducing a dwarfing gene to tropical maize populations were not successful because the process resulted in variable height reduction and introduced other undesirable traits. As an alternative, CIMMYT breeders started selection for shorter plants with a higher harvest index. After fifteen seasons, they had spectacularly reduced plant height by 1 meter and increased yield potential by 60 percent at the higher planting densities made possible by shorter plants.[30] This process that concentrated many genes with small negative

[26] Ernest W. Sprague, "What Limits World Maize Production," in CIMMYT, *World Wide Maize Improvement*, pp. 2–1 to 2–22, at 2–7.

[27] CIMMYT, *World Wide Maize Improvement,* p. 14–4.

[28] For example, M. C. Saeteurn, *Cultivating Their Own: Agriculture in Western Kenya during the "Development" Era* (Rochester, NY: University of Rochester Press, 2020).

[29] M. A. López-Pereira, and M. L. Morris, *Impacts of International Maize Breeding Research in the Developing World, 1966–1990* (Mexico City: CIMMYT, 1998).

[30] E. C. Johnson, K. S. Fischer, G. O. Edmeades, and A. F. E. Palmer, "Recurrent Selection for Reduced Plant Height in Lowland Tropical Maize," *Crop Science* 26, no. 2 (1986): 253–260.

effects on height within a breeding population provided basic directions for tropical maize breeding over the following decades.

CIMMYT's maize physiologists were also among the first in CGIAR to challenge the prevailing belief that varieties bred for high-yield potential in favorable environments using high levels of inputs would also perform well in less favorable growing environments where use of external inputs was risky.[31] In the 1970s, CIMMYT began a pilot program of selecting under controlled drought conditions within the most important maize type of the lowland tropics, Tuxpeño, seeking at the same time to generate varieties that could yield well in favorable seasons. Initial promising results encouraged an increased focus on breeding for drought tolerance in CIMMYT's maize programs.[32] Using similar methods, CIMMYT researchers began screening for tolerance to low soil fertility (nitrogen) in 1987, seeking to produce better-performing varieties for areas where synthetic fertilizers were not available or their use was unprofitable.[33] These exploratory efforts laid the basis for a later mainstreaming of these methods after 2000 when CIMMYT shifted focus to Africa.

Another risky, long-term program initiated in this period was breeding maize with high levels of the amino acid lysine to enhance protein quality. As Wilson Picado-Umaña and Lucas M. Mueller discuss in Chapters 8 and 5 respectively, this volume, an emerging consensus within the United Nations Food and Agriculture Organization (FAO) and World Health Organization (WHO) in the 1950s identified protein malnutrition as the leading nutritional problem in much of the developing world. The 1960s became the "protein decade" as FAO declared that "the greatest [nutritional] problem . . . results from inadequate protein in the diets of a large proportion of the population."[34] It was in this context that in 1963 scientists at Purdue University discovered the *opaque-2* gene in maize, which increased lysine content by 69 percent over normal maize.[35] This

[31] This belief was strongly promoted by Norman Borlaug as head of CIMMYT's wheat program. The debate is evident in CGIAR Technical Advisory Committee, "Report on the TAC Quinquennial Review Mission to CIMMYT, 1976," September 1976, https://hdl.handle.net/10947/1385.

[32] G. O. Edmeades, W. Trevisan, B. N. Prasanna, and H. Campos, "Tropical Maize," in H. Campos and P. Caligari, eds., *Genetic Improvement of Tropical Crops* (Switzerland: Springer, 2017), pp. 57–109.

[33] M. Bänziger, G. O. Edmeades, and H. R. Lafitte, "Selection for Drought Tolerance Increases Maize Yields across a Range of Nitrogen Levels," *Crop Science* 39, no. 4 (1999): 1035–1040.

[34] FAO, *The State of Food and Agriculture* (Rome: FAO, 1964), p. 98. See also Kenneth Carpenter, *Protein and Energy: A Study of Changing Ideas in Nutrition* (Cambridge, UK: Cambridge University Press, 1994).

[35] E. T. Mertz, L. S. Bates, and O. E. Nelson, "Mutant Gene That Changes Protein Composition and Increases Lysine Content of Maize Endosperm," *Science* 145, no. 3629 (1964): 279–280.

discovery gave rise to visions of a single gene being incorporated into all new maize varieties to boost protein intake worldwide. The opening speaker at a 1966 conference enthused that "within the next five years millions of undernourished people ... would find their diets improved markedly due to the availability of high lysine corn."[36] Norman Borlaug, a wheat breeder for the Rockefeller Foundation and then CIMMYT, also quickly endorsed the potential of high-lysine maize and became an enthusiastic advocate in the following decades.[37]

The new high-lysine varieties manifested undesirable traits associated with the *opaque-2* gene, such as dull grain type, soft endosperm, low yields, and higher pest losses in production and storage. The recessive nature of the gene meant that open-pollinated varieties quickly lost their quality advantage. However, after a meeting with Borlaug in 1971, the United Nations Development Programme (UNDP) invested heavily in research on high-lysine maize at CIMMYT over the next two decades to produce acceptable varieties. (The investment totaled $64 million in 2020 US dollars for 1971–84 alone.)[38] Buoyed by the additional resources from UNDP, CIMMYT enthusiastically promoted the potential of what it called "quality protein maize," projecting that "mankind will have available a super grain which contains everything for complete human nutrition."[39] CIMMYT explicitly aimed to produce quality protein varieties with grain visually indistinguishable from that of normal maize.[40] Meanwhile, the majority view in the nutritional community by 1975 had revised its minimum protein requirements downward and moved decisively towards energy intake as the major problem of hunger. The influential nutritionist John C. Waterlow firmly stated in 1975 that "the concept of a worldwide protein gap is no longer tenable" and that the "protein gap is a myth."[41] UNDP and CIMMYT were aware of these changes in nutritional priorities, but, as described by the CIMMYT social scientist Robert Tripp, "the train was already rolling down the track," and

[36] E. T. Mertz and O. E. Nelson, eds., *Proceedings of the High Lysine Conference, June 21–22, Purdue University* (Washington, DC: Corn Industries Research Foundation, 1966).

[37] N. E. Borlaug, "Weak Spots in the Rockefeller Foundation's Agricultural Programs Considering the Great Need for Expansion of Plant Protein Production to Human Needs," memo to E. Wellhausen, 1966, John Wooston Library, CIMMYT, Mexico City.

[38] P. G. Hoffman, "Development Co-operation: A Fact of Modern Life," *Virginia Quarterly Review* 47, no. 3 (1971): 321–335, at 330.

[39] T. Wolf, "Quality Protein Maize," *CIMMYT Today*, no. 1 (1975).

[40] G. N. Atlin et al., "Quality Protein Maize: Progress and Prospects," *Plant Breeding Reviews* 34 (2011): 83–131.

[41] J. C. Waterlow and P. R. Payne, "The Protein Gap," *Nature* 258, no. 5531 (1975): 117.

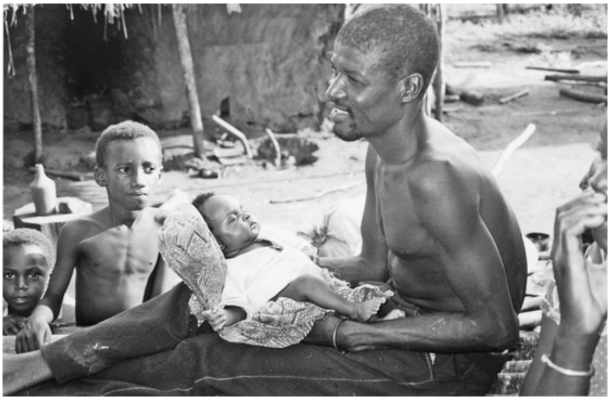

Figure 9.2 Postweaning children and their families, such as this Ghanaian father and his children, were the stated target consumers for Quality Protein Maize, 1995. QPM Program in South Africa, CIMMYT Repository. © CIMMYT.

CIMMYT's breeding for protein quality continued at full speed[42] (Figure 9.2).

In the 1980s, UNDP claimed that the development of quality protein maize with normal grain type was a "spectacular achievement," and that the main problem was "how farmers can be persuaded to use the new varieties."[43] In fact, after a decade of intensive breeding, adoption of the new varieties remained low because of reduced yields and susceptibility to insects, kernel rot, and loss of quality in open-pollinated varieties. By this time, experts also recognized several practical problems that further impeded uptake. A high-lysine grain that was visually indistinguishable from normal maize would not have a price premium in the market and therefore carry no incentive for farmers to adopt it. Farmers also lacked interest in growing the varieties for their own subsistence, since little effort was made to complement varietal introduction with nutrition education programs or even to conduct field trials with farmers to evaluate the nutritional benefits.[44] In short, there was no demand for the product

42 Robert Tripp, email communication to Derek Byerlee, October 22, 2020.

43 UNDP, "Evaluation of Global Programs," Report of the Administrator to the Governing Council, DP/456, March 20, 1984, 14–15, http://web.undp.org/execbrd/archives/sessions/gc/27th-1980/DP-456.pdf.

44 Robert Tripp, "Does Nutrition Have a Place in Agricultural Research?" *Food Policy* 15, no. 6 (1990): 467–474.

and, even if one were created, there was no way to distinguish high-lysine maize from normal maize in the market.

Faced with growing funding stress, CIMMYT closed the quality protein maize program in the 1990s. However, this research was kept alive by Borlaug after he retired from CIMMYT and became the chief technical advisor to the nongovernmental organization (NGO) Sasakawa Global 2000. With leadership from Borlaug and former US President Jimmy Carter, and philanthropic support from Ryōichi Sasakawa of the Nippon Foundation in Japan, Sasakawa Global 2000's mission was to bring the Green Revolution to Africa. In 2000, the award of the World Food Prize to CIMMYT's S. K. Vasal and Evangelina Villegas for their development of quality protein varieties with "normal" grain type helped to revive donor support for CIMMYT's quality protein maize program in Africa, this time mostly to develop hybrids. Although this later phase of research included much-needed investment in nutritional field trials, the problem of creating demand persisted. Without concrete results on the ground, support for quality protein maize was again reduced to a trickle.[45]

In summary, the initial period of CIMMYT's international maize research was characterized by efforts to develop a systematic approach to breeding and testing open-pollinated varieties adapted to highly diverse maize-growing environments around the world. Research products were provided freely to all, and one of the major accomplishments was the increased scale and reach in international maize germplasm exchange. It was also a period of stable and flexible funding that encouraged long-term research with uncertain payoffs, which in turn led to breakthroughs in breeding for stress tolerance that would have lasting value. In contrast, despite generous funding and sound scientific breeding, the large investment in quality protein maize did not pay off because the responses of farmers, consumers, and the market were not adequately considered.

## A Sharpened Focus and Pivot to the Private Sector, 1985–2000

From the mid 1980s, factors external to CIMMYT began to play a larger role in shaping its maize research agenda. With the end of the Cold War, foreign assistance to agriculture sharply declined, and funding for international crop research tightened.[46] In CIMMYT, funding and staffing

[45] Byerlee and Edmeades, *Fifty Years of Maize Research in the CGIAR.*

[46] P. Pingali and T. Kelley, "The Role of International Agricultural Research in Contributing to Global Food Security and Poverty Alleviation: The Case of the CGIAR," in R. Evenson and P. Pingali, eds., *Handbook of Agricultural Economics*, vol. III (Amsterdam: Elsevier, 2007), pp. 2381–2418.

peaked around 1990, and maize-specific budgets and staff were cut by almost half by the end of the decade. In this new funding environment CIMMYT had to focus its limited resources more carefully. Responding to pressure from the development assistance community and reflecting a more nuanced understanding of the causes of hunger, CIMMYT also changed its mission from increasing food production to reducing poverty, prioritized research in Africa, and introduced the role of gender and sustainable management of natural resources. These are still major elements of CIMMYT's research today.

Experience and feedback from national systems indicated that CIMMYT's international testing sites were not well targeted, especially in the very diverse African environments.[47] Testing and breeding priorities were sharpened in the 1980s through the concept of mega-environments – areas of more than 1 million maize hectares often distributed over several countries and perhaps continents, where crop performance, climate, disease and pest incidence, and grain preferences were similar. This was a significant advance over previous extensive efforts by FAO and others to define world agro-ecological zones, because CIMMYT included crop-specific criteria to define environments. Although agro-ecological zones had been used to organize research, crop-specific mega-environments specifically aimed to make international breeding programs and germplasm exchange more effective. By the late 1990s, CIMMYT's maize mega-environments were further refined through the emerging science of geographical information systems, which facilitated the overlay of several types of spatial data.[48]

These changes were accompanied by increasing decentralization of the CIMMYT breeding program to regions that better represented diverse growing conditions. This shift also placed breeders closer to their "clients" where they could better assess demand for new varieties. Breeders had learned that although stable performance over a range of conditions remained key goals, one centralized program could not serve all regions.[49] The Inter-Asian Corn Program, started in 1963, had maintained its own breeding program in Thailand, closely linked with the Thai national program led by Sujin Sriwatanapongse. It focused on downy mildew resistance – largely an Asian problem – and produced the Suwan varieties that became one of the most widely grown varieties in the tropics. An even older Central American maize program, started by the Rockefeller

[47] CGIAR, *1988–1989 Annual Report* (Washington, DC: CGIAR Secretariat, 1989).
[48] A. D. Hartkamp, *Maize Production Environments Revisited: A GIS-based Approach* (Mexico City: CIMMYT, 2001).
[49] Haldore Hanson, "The Role of Maize in World Food Needs to 1980," in CIMMYT, *World Wide Maize Improvement*, pp. 1–1 to 1–19.

Foundation and initially headquartered in Mexico, was shifted to Guatemala in the mid 1980s. In 1985, CIMMYT also built its own breeding station for eastern and southern Africa near Harare, Zimbabwe. As in Asia, region-specific diseases were decisive in developing regional breeding programs for Central America and Africa, although a regional program in the Andes focused on products that would have the floury-grain type typical of that region.

These moves to greater decentralization were still not sufficient to address the considerable microvariation in many rainfed maize environments and differences in farmers' grain preferences. To accommodate local variations, breeders began to engage farmers in testing varieties under their own field conditions and in selecting varieties to fit their specific farm management and consumer preferences. From the late 1970s, CIMMYT social scientists had employed research methods involving farmer participation in the design and testing of maize practices and systems, and the results often provided important feedback to maize breeders. For example, participatory research in southern Africa emphasized the need for early maturing varieties to accommodate farmers' seasonal food needs and delayed planting due to labor or draft power constraints.[50] In Malawi, a participatory study identified strong local preferences for grain texture and ease of shelling that affected adoption by women farmers and processors.[51] Farmer participatory methods were further mainstreamed in maize breeding through "mother-baby trials," where small subsets of varieties were tested by men and women farmers under their management, post-harvest processing, and use. The farmers' ratings were then used in decisions on varietal release.[52]

During this period there was also a sharp shift away from the "development state" towards market-oriented approaches to development in what became known as the Washington consensus. In this new environment, multinational seed companies began to invest in middle-income countries led by Pioneer Hi-Bred, then the world's largest seed company. By 1985 these companies worked at twenty-nine stations in seven tropical and subtropical countries.[53] Regional and local seed companies also held

[50] Angelique Haugerud and Michael P. Collinson, "Plants, Genes, and People: Improving the Relevance of Plant Breeding in Africa," *Experimental Agriculture* 26, no. 3 (1990): 341–362.

[51] M. Smale, "'Maize Is Life': Malawi's Delayed Green Revolution," *World Development* 23, no. 5 (1995): 819–831; McCann, *Maize and Grace.*

[52] M. Bänziger, P. S Setimela, D. Hodson, and B. Vivek, "Breeding for Improved Abiotic Stress Tolerance in Maize Adapted to Southern Africa," *Agricultural Water Management* 80 (2006): 212–224.

[53] C. E. Pray and R. G. Echeverria, "Transferring Hybrid Maize Technology: The Role of the Private Sector," *Food Policy* 13, no. 4 (1988): 366–374.

significant market share, although some were taken over by the expanding multinationals. Private seed companies naturally emphasized hybrid seed, and most of them, especially regional and local companies, used some CIMMYT germplasm in their breeding programs.

Internal forces were also driving CIMMYT towards greater emphasis on hybrids over open-pollinated varieties. By 1986, two decades after CIMMYT's founding, only 11 percent of the tropical and subtropical maize area (excluding large commercial farms in Brazil) was sown to improved open-pollinated varieties, compared with 16 percent sown to hybrids, most of which were developed independently of CIMMYT.[54] Ironically, given that one of the original motivations for CIMMYT's focus on open-pollinated varieties was to allow farmers to save seed, their slow spread was largely due to the difficulty of developing sustainable seed systems. A few seed companies did sell open-pollinated varieties as a sideline to their main business of hybrid seed, as in Zimbabwe, or as an entry point for hybrid sales, as in Thailand. A handful of countries, notably Thailand, successfully produced and disseminated seed of open-pollinated varieties largely through the public sector, but most was supplied through ad hoc arrangements such as development projects and was of variable quality. As early as 1978, Edwin Wellhausen, the original leader of maize research for the Rockefeller Foundation in Mexico and the first director general of CIMMYT, concluded:

> During my 32 years of promotion of maize production in the tropics, I have been unable to interest either the public sector or the private sector in the production of large volumes of seed of OPVs. Where it [open-pollinated variety seed] is produced, it is produced by individual farmers or as a stopgap by commercial seed producers, until some kind of hybrid can be developed.[55]

At the same time, there was mounting evidence of the willingness of smallholders to adopt hybrids even under marginal growing conditions.[56] This was especially true in eastern and southern Africa, where much of the extensive hybrid maize area was sown by smallholders with limited or no fertilizer and was subject to frequent drought. Their choice reflected the development of superior hybrids by strong national programs in Zimbabwe and Kenya, the emergence of an efficient private seed industry producing affordable hybrid seed, and effective public extension programs to promote the initial adoption of hybrids. Elsewhere, national programs were also

[54] CIMMYT, *Maize Facts and Trends: The Economics of Commercial Maize Seed Production in Developing Countries* (Mexico City: CIMMYT, 1987).

[55] Edwin J. Wellhausen, "Recent Developments in Maize Breeding in the Tropics," in D. B. Walden, ed., *Maize Breeding and Genetics* (Chichester: John Wiley & Sons, 1978), p. 81.

[56] Heisey et al., "Economics of Hybrid Maize Adoption."

converting to hybrids and ending their reliance on public-sector seed production.[57] Thailand, the star in the adoption of open-pollinated varieties, had by the 1990s become a leader in hybrid maize. In 2003, the CIMMYT economist Roberta Gerpacio concluded that "the primary locus of maize breeding research in Asia has shifted from the public to the private sector."[58] She also noted the "strong likelihood that the private sector will be reluctant" to "address the needs of farmers in marginal areas."[59]

The 1984 departure of Sprague, the champion of open-pollinated varieties in CIMMYT, opened the way for the center's breeders to turn back to hybrids after a hiatus of twenty years. Resources were shifted from open-pollinated varieties to hybrids, and the international testing program gradually converted to testing inbred lines and hybrids. These materials were made available to both public and private seed companies; however, CIMMYT clearly saw small- and medium-sized local and regional seed companies as its main partners for delivering hybrid seed to smallholders, especially in more marginal environments.[60] In contrast with the multinational companies, these companies were generally nationally owned, served local markets, and had, at best, minimal research capacity to produce their own inbreds and hybrids.[61] By 1988, the first 100 inbreds were made available, with free access to both the public and private sectors. Ten years later, 58 percent of hybrids released by the private sector in the tropics and subtropics contained some CIMMYT germplasm.[62] This transition was overseen by Ripsudan Paliwal, the long-serving deputy director and later program director of the Maize Program, who was experienced in hybrid seed production in India.

The partnership of an international research program established to produce public goods with private-sector actors was not without

[57] The public sector was generally even more ineffective in producing hybrid seed than seed of open-pollinated varieties. See Byerlee, "Globalization of Hybrid Maize."
[58] R. V. Gerpacio, "The Roles of Public Sector versus Private Sector in R&D and Technology Generation: The Case of Maize in Asia," *Agricultural Economics* 29, no. 3 (2003): 319–330, at 328.
[59] Ibid., 320.
[60] CIMMYT, *Seeds of Innovation: CIMMYT's Strategy for Helping to Reduce Poverty and Hunger by 2020* (Mexico City: CIMMYT, 2004). CIMMYT defines small- and medium-sized companies as worth less than $2 million, and between $2 and $5 million, respectively, in terms of annual sales; B. Prasanna, email communication to Greg Edmeades, September 9, 2021.
[61] To facilitate its changing priorities and partnerships, CIMMYT added the director of research at Pioneer Hi-Bred International to its governing board and hired a maize director from the private sector.
[62] M. L. Morris, *Impacts of International Maize Breeding Research in Developing Countries, 1966–98* (Mexico City: CIMMYT, 2002).

controversy in a period when the growing power of large seed companies in research and the ownership of intellectual property was attracting attention.[63] CIMMYT countered critiques by focusing on the development of local seed companies with limited research capacity. Evidence indicated that these companies, with support from CIMMYT and national, public-sector research, could provide hybrid seed at lower prices than the large companies and serve markets that were not attractive to large companies, especially in more marginal areas.[64] Some evidence also suggested that farmers received more than half of the "surplus" generated by use of hybrid seed, with the remainder going to the seed company.[65] This pattern at the international level followed the example in the United States where public development of inbreds for private-sector use continued long after large private companies had developed strong in-house research and development programs.[66]

In recent years, CIMMYT has experimented with other models to incentivize delivery of its products through small- and medium-sized seed companies. In Africa it employs royalty-free licenses to supply hybrids to seed companies that then enjoy exclusive rights for a specific region and duration. This approach recognizes that testing and developing markets for new hybrids entails significant fixed costs, especially for smaller companies.[67] CIMMYT also has established International Maize Improvement Consortia, groups of companies with some research capacity that have first right of access to selected inbreds from CIMMYT and receive services to support hybrid development and seed production in exchange for a modest membership fee.[68]

In this new environment, the seed market has further diversified. For example, the number of seed companies in eastern and southern Africa increased fourfold between 1997 and 2007.[69] Similarly, locally owned seed companies in Mexico increased from 20 companies in 1995 to 114 in

[63] Kloppenburg, *First the Seed*, p. 81. [64] CIMMYT, *Maize Facts and Trends.*

[65] Donald N. Duvick, "The United States," in Morris, ed., *Maize Seed Industries*, pp. 193–211.

[66] The early years of hybrid development in the United States saw lively debate on whether the public sector should continue to develop "open source" inbreds or leave this to the private sector. See Deborah K. Fitzgerald, *The Business of Breeding: Hybrid Corn in Illinois, 1890–1940* (Ithaca, NY: Cornell University Press, 1990).

[67] CIMMYT, "New Pre-commercial Hybrids for Southern Africa," November 29, 2018, www.cimmyt.org/news/new-cimmyt-pre-commercial-hybrids-for-southern-africa.

[68] FAO, "Views, Experiences and Best Practices as an Example of Possible Options for the National Implementation of Article 9 of the International Treaty," July 23, 2019, www.fao.org/3/ca7857en/ca7857en.pdf.

[69] A. S. Langyintuo, W. Mwangi, and A. O. Diallo, "Challenges of the Maize Seed Industry in Eastern and Southern Africa: A Compelling Case for Private–Public Intervention to Promote Growth," *Food Policy* 35, no. 4 (2010): 323–331.

2015, and the share of these companies in maize seed sales rose from 5 percent in 2009 to 31 percent in 2016.[70] In addition, most of these companies serve farmers in rainfed regions where hybrid seed adoption has now reached 40 percent of the area planted to maize, effectively reversing decades of failure to reach these farmers.[71] Even so, it is not clear that seed companies are reaching a significant share of Mexico's poorest farmers in the south of the country.[72]

In retrospect, the early CIMMYT dogma with respect to an exclusive focus on open-pollinated varieties was well meaning but patronizing in terms of small farmers' willingness to adopt hybrid seed and countries' abilities to develop private seed industries. CIMMYT also overestimated the capacity and willingness of the public sector to deliver high-quality seed of open-pollinated varieties. Our assessment is that CIMMYT's single-minded dedication to these varieties in the 1970s delayed the development of hybrids by the public sector and the emergence of small- and medium-sized seed enterprises by about a decade. At the same time, with the development of hybrids and associated private-sector partnerships, CIMMYT has compromised on its original policy of unrestricted access to all its products in the interest of engaging the private sector to quickly increase the number of farmers it reaches.

## Scaling up in Africa and Accessing Proprietary Science, 2000–20

From the 1980s, CGIAR increasingly focused on sub-Saharan Africa. Africa was the only region where the prevalence of undernutrition and poverty continued to grow and yields of food staples were low and stagnant. It was widely recognized that Africa had been bypassed by the Green Revolution, and donors, national governments, and CGIAR set out to ignite an "African Green Revolution." Their ambitions echoed the rhetoric of 1970 when the new headquarters of IITA was opened with much fanfare in Nigeria, aiming to bring the Green Revolution to Africa.[73]

[70] Prior to market liberalization, public research organizations in Mexico were required to "commercialize" their products through the public-sector seed company PRONASE, stifling the growth of local companies.

[71] M. L. Donnet, I. D. López-Becerril, C. Dominguez, and J. Arista-Cortés, "Análisis de la estructura del sector y la asociación público-privada de semillas de maíz en México," *Agronomía Mesoamericana* 31, no. 2 (2020): 367–383.

[72] A. Turrent Fernandez, A. Espinosa Calderón, J. I. Cortés Flores, and H. Mejía Andrade, "Análisis de la estrategia MasAgro-maíz," *Revista Mexicana de Ciencias Agrícolas* 5, no. 8 (2014): 1531–1547.

[73] Ford Foundation, *Sowing the Green Revolution: The International Institute of Tropical Agriculture, Ibadan, Nigeria* (New York: Ford Foundation, 1970). Haldore Hanson, the

The 2008–12 world food crisis also stimulated a doubling of funding for international agricultural research, ending a funding plateau that had lasted nearly two decades. Unlike the first period of strong financial support, funding was now largely restricted to specific projects, and for maize these mostly focused on Africa. The Bill & Melinda Gates Foundation became a major donor to large projects on stress-tolerant maize starting in 2007, and its support has continued until today with the addition of research on disease- and insect-resistance and efficiency in breeding. The Gates Foundation was well aware of the scientific advances in breeding for stress tolerance at CIMMYT; indeed, three of the Foundation's senior scientific staff in this period had prior experience in CIMMYT's maize program.

Against this background, CIMMYT relocated its first female maize director, Marianne Bänziger, to Nairobi in 2004. By 2010, its maize research effort was firmly centered in sub-Saharan Africa, with over half of its staff located there. The prevalence of drought stress, infertile and often degraded soils, and low use of external inputs in much of Africa demanded that priority be given to breeding for stress tolerance (Figure 9.3). CIMMYT's stress-breeding methods, developed earlier in Mexico, had been judged sufficiently mature to make screening for drought tolerance routine in maize breeding in Africa by 1995. Experiment stations were established at Chiredze, Zimbabwe and Kiboko, Kenya, where research under limited irrigation to simulate drought stress could be conducted on a large scale. This research was accompanied by testing at up to sixty largely rainfed locations across eastern and southern Africa, and a smaller number of sites across West Africa. Between 2016 and 2019 alone, over 230 open-pollinated varieties and hybrids with stress tolerance were released across Africa.[74]

Two further factors influenced the focus and reach of CIMMYT in Africa in the early twenty-first century. First, the development pendulum that had swung to market-based approaches in the 1990s now reversed and explicitly recognized the "visible hand of the state" and the "entrepreneurial state" in facilitating change.[75] In Africa, donors supported the development of local, private seed companies, and most countries

Ford Foundation representative in Nigeria and soon-to-become CIMMYT's second director general, was much more thoughtful about the difficulty of translating Asian experiences to Africa. See H. Hanson, "Agricultural Development in Tropical Africa and the Role of the Ford Foundation," December 1970, Ford Foundation Archives, Rockefeller Archive Center, Ford Foundation document 0002799.

[74] Vijesh V. Krishna, Maximina A. Lantican, B. M. Prasanna et al., "Impact of CGIAR Maize Germplasm in Sub-Saharan Africa," *Field Crops Research* 290 (2023): 108756.

[75] World Bank, *World Development Report: Agriculture for Development* (Washington, DC: World Bank, 2007); M. Mazzucato, *The Entrepreneurial State* (London: Demos, 2011).


Figure 9.3 CIMMYT maize breeder Dr. Cosmos Magorokosho with several drought-tolerant maize hybrids developed under managed drought stress and confirmed in on-farm trials, Harare, Zimbabwe, 2011. Photo by Gregory Edmeades.

reintroduced policies to promote technology adoption through subsidies to farmers to purchase seed and fertilizers.[76] Second, donors operating within the context of the new UN Millennium Development Targets began to promote an "impact culture," requiring CIMMYT to establish explicit, time-bound metrics for the adoption and impact of its work. This moved CIMMYT to invest more effort on delivery of its products by working closely with seed companies through training and technical assistance. By 2023 CIMMYT claimed that 165,000 tons of seed of its stress tolerant varieties and hybrids were being produced annually in East and Southern Africa, enough to reach 7.4 million households. Studies of the adoption of stress-tolerant varieties also suggested accelerated uptake of CIMMYT's products, stimulated by input subsidies in some countries.[77] However, in contrast to the first years of CIMMYT's maize program, the focus on short-term impacts and the restricted nature of most funding left little time, resources, and incentives for CIMMYT

[76] T. S. Jayne and S. Rashid, "Input Subsidy Programs in Sub-Saharan Africa: A Synthesis of Recent Evidence," *Agricultural Economics* 44, no. 6 (2013): 547–562.
[77] Krishna et al., "Impact of CGIAR Maize Germplasm."

scientists to pursue longer-term research with more uncertain payoffs. Although too early to assess in 2022, these shifts in maize research funding, which mirror circumstances elsewhere in CGIAR, may undermine the chances of future research breakthroughs.

A second important influence on CIMMYT's maize agenda in the 2000s was biotechnology and its concentration in the private sector. Most of the capacity to apply advances in molecular biological research rested in companies that, protected by stronger intellectual property rights, invested an estimated $1.6 billion in maize research in 2010, compared with CIMMYT's investment of about $28 million in the same year.[78] The quest to gain access to patented technologies stimulated a surge of mergers and acquisitions among seed, chemical, and biotechnology companies. By the 2010s, the top four companies were multibillion-dollar operations accounting for an estimated 82 percent of maize seed sales in the USA (up from 52 percent in 1988). Monsanto alone owned an estimated 85 percent of patents on traits for genetically modified (GM) maize, weighted by area planted in 2010.[79] The growing concentration of intellectual property ownership in the "gene giants" caused an uproar from NGOs, academics, and international organizations.[80] Many argued that genetic resources were the result of millennia of selection and conservation by small-scale farmers who were their real owners.

At CIMMYT, and within CGIAR more generally (see David J. Jefferson, Chapter 12, this volume), scientists and administrators were concerned about their freedom to operate in a world increasingly dominated by patented technologies, some of which they considered relevant to solving intractable problems of poor farmers. CIMMYT did not have the time, funds, or laboratories to "invent around" patents, so it elected to negotiate with private companies to access the most relevant technologies. As CIMMYT concluded in 2002, "the continuing relevance of the international agricultural research centers will depend critically on their ability to forge effective partnerships with the private firms that now control many critical technologies."[81] This view was echoed by

[78] P. W. Heisey and K. O. Fuglie, "Private Research and Development for Crop Genetic Improvement," in K. Fuglie et al., eds., *Research Investments and Market Structure in the Food Processing, Agricultural Input, and Biofuel Industries Worldwide*, USDA Economic Research Report 130 (Washington, DC: USDA, 2011), pp. 25–48.

[79] Ibid. In 2018, Monsanto was acquired by Bayer.

[80] Kloppenburg, *First the Seed*; C. Fowler, *Unnatural Selection: Technology, Politics and Plant Evolution* (Yverdon, Switzerland: Gordon and Breach, 1994); UNDP, *Human Development Report 2001: Making New Technologies Work for Human Development* (New York: Oxford University Press, 2001).

[81] M. L. Morris and B. Ekasingh, "Plant Breeding Research in Developing Countries: What Roles for the Public and Private Sectors?" in D. Byerlee and R. G. Echeverría, eds.,

CIMMYT's consultations with national scientists. Maize was the crop most affected by developments in biotechnology and private-sector control, and in 2002 CIMMYT arranged a small meeting with private companies and international agencies to agree on some common principles for public–private partnerships.[82] The CIMMYT policy of 2012 on GM maize summed up the approach:

> In line with its continued role to develop, use, and share global public goods, CIMMYT sees its role to focus on serving its primary customer base of small and marginal farmers who may not otherwise have access to such innovations/technologies. To this end, CIMMYT strategically uses intellectual property protection systems, including ascertaining and gaining freedom to operate to ensure and further its capacity to serve farmers and R&D organizations in the developing world.[83]

In addition to grappling with intellectual property rights, CIMMYT had to wrestle with the merits of becoming involved in the development of GM maize, considering the acrimonious debate about the value and possible risks of GM crops. Engaging with this technology would also necessitate appropriate biosafety regulatory environments in order to make GM maize available on a country-by-country basis.

Given widespread attention to the role of the private sector and intellectual property protections in limiting farmer seed-saving, one of CIMMYT's first public–private partnerships was an attempt to develop apomictic tropical maize. Allowing asexual reproduction (apomixis) would enable hybrids to retain their yield advantage from one generation to the next even when farmers saved their seed. The partnership included the (then French) Office for Overseas Scientific and Technological Research (ORSTOM) and three private multinational seed companies. It ran for over a decade without achieving its objective. However, it was an important learning experience for CIMMYT in balancing public interest in free access to technologies versus private interest in proprietary technologies for profit.[84]

From the 2000s, partnerships with the private sector to access technology were often funded by the Bill & Melinda Gates Foundation with

*Agricultural Research Policy in an Era of Privatization* (Wallingford, UK: CABI, 2002), pp. 199–225, at 223.

[82] CIMMYT, "Tlaxcala Statement on Public–Private Sector Alliances in Agricultural Research: Opportunities, Mechanisms, and Limits," November 1999, http://hdl.handle.net/10883/3827.

[83] CIMMYT, "Position Statement on Genetically Modified Crop Varieties," January 2012, http://hdl.handle.net/10883/4393.

[84] M. Hodges, "The Politics of Emergence: Public–Private Partnerships and the Conflictive Timescapes of Apomixis Technology Development," *BioSocieties* 7, no. 1 (2012): 23–49.

a special focus on Africa.[85] The largest and longest-running project, Water Efficient Maize for Africa, supported breeding and testing facilities for drought tolerance. It operated under an agreement between Monsanto, CIMMYT, and the African Agricultural Technology Foundation (an NGO in Nairobi supported initially by the Rockefeller Foundation to broker access by African farmers to proprietary technologies) as the executing agent. The project, regarded as controversial given the partnership with Monsanto, the icon of the "gene giants," invested over $100 million from the Gates Foundation between 2008 and 2018. Monsanto provided royalty-free access for five countries in sub-Saharan Africa to its commercial drought transgene, which researchers subsequently combined with a Monsanto insect-resistance transgene. The insect resistance work built on an earlier CIMMYT partnership with the Novartis Foundation from the late 1990s that was halted when CIMMYT was unable to gain access to intellectual property rights for its commercial use.[86]

As of 2022 none of these transgenic options had been released outside of South Africa because of delays in implementing national biosafety regulations and, in the case of the drought transgene, lack of evidence of its value added over CIMMYT's conventionally bred drought-tolerant varieties. A twenty-year effort in East Africa to incorporate Bt (*Bacillus thuringiensis*) genes for stem-borer resistance in maize, although very costly and time-consuming, may eventually pay off, given serious losses caused by the invasion of fall armyworm from the Americas in the late 2010s.[87]

After more than two decades of experience, CIMMYT's partnerships with multinational companies to access new technologies remained marginal to its impacts.[88] More important has been an agreement with the University of Hohenheim, Germany for CIMMYT to "tropicalize" the university's proprietary double-haploid technology, a process that makes the development of its tropical hybrids more efficient and faster.[89] The

[85] M. A. Schnurr, *Africa's Gene Revolution: Genetically Modified Crops and the Future of African Agriculture* (Montreal: McGill Queens University Press, 2019).

[86] J. Mabeya and O. C. Ezezika, "Unfulfilled Farmer Expectations: The Case of the Insect Resistant Maize for Africa (IRMA) project in Kenya," *Agriculture & Food Security* 1, suppl. 1 (2012): S6.

[87] J. Wesseler, R. D. Smart, J. Thomson, and D. Zilberman, "Foregone Benefits of Important Food Crop Improvements in Sub-Saharan Africa," *PLoS One* 12, no. 7 (2017): e0181353.

[88] For a review of these partnerships, see Byerlee and Edmeades, *Fifty Years of Maize Research in the CGIAR*.

[89] With this technology, a single set of maize chromosomes (the haploid set) is generated and then doubled in the laboratory to produce the normal diploid in which both sets of chromosomes are identical. It thereby reduced the time to produce inbreds by half. See

technology, which does not involve transgenes and therefore does not invoke concerns about GM crops, is patented, and seed companies pay a license fee for its use to the university. CIMMYT now routinely uses the technology in its breeding program, making its products more rapidly available to public research systems and seed companies.

## Conclusion

CIMMYT's maize research has undergone profound shifts over fifty years, probably more than any other CGIAR crop program. The type of product, geographical scope, and partnerships of the 2020s are quite different from those seen in the first two decades in which the international maize research program was designed and established. The main product has shifted from open-pollinated varieties for public-sector programs towards mostly inbreds and hybrids for national programs and private-sector use. This was driven by the rapid rise of the private seed sector and the development of public–private partnerships between small- to medium-sized seed enterprises and CIMMYT and/or publicly funded national programs. It reflected mounting evidence of the willingness of smallholders to pay for yield advantages of hybrids even in risky environments. While much of CIMMYT's engagement with the private sector was with local and regional seed companies possessing limited research capacity, the growing dominance of large multinationals in biotechnology pressured CIMMYT to seek further high-level partnerships to access these companies' patented tools and technologies. These partnerships have had a cost, moving CIMMYT away from the "open source" system of its early decades to one more constrained by intellectual property and some limits on access to its products.

Departing from the centralized breeding model that predominated within the early CGIAR, CIMMYT's maize-breeding research steadily became more decentralized as it attempted to serve the wide diversity of growing conditions and grain types found in tropical maize farming. Even with the more decentralized programs, rigorous testing was still required. In recent years, this testing was often performed collaboratively by private seed companies, as well as by CIMMYT's traditional public-sector partners. As it decentralized, the locus of CIMMYT maize research also shifted, moving from Latin America and Asia to eastern and southern Africa. This move reflected high levels of food insecurity in Africa, the

CIMMYT, "Tropicalized Maize Haploid Inducers for Doubled Haploid-Based Breeding," December 28, 2012, www.cimmyt.org/news/tropicalized-maize-haploid-inducers-for-doubled-haploid-based-breeding.

preeminent role of maize as a food staple in the region, and the focus of donor funding on Africa.

There were also important continuities throughout this history. As one example, CIMMYT scientists initiated breeding for stress-tolerant maize early, and against prevailing conventions. This work was maintained and expanded, eventually becoming the mainstream of CIMMYT breeding efforts, especially in Africa, where drought and low soil fertility are pervasive. The stress-tolerant hybrids and open-pollinated varieties produced through these efforts were widely accepted by smallholders operating in risky rainfed environments. By comparison, a long-term effort on quality protein maize, despite strong scientific underpinnings, met with only modest results on the ground. This was largely because the "demand side" of the program was missing, in which farmers' interest in growing quality protein maize and consumer interest in eating it would be assessed and encouraged.

The evolution of CIMMYT's maize program at first sight suggests that the freedom of scientists to set their agenda has been steadily narrowed as "donor sovereignty," restricted funding, and a short-term impact culture have taken center stage in the twenty-first century (as Rebekah Thompson and James Smith highlight in their analysis of the International Livestock Research Institute [ILRI], Chapter 7, this volume). Yet the growing emphasis on achieving "outcome milestones" also underlies breakthroughs in the adoption of maize hybrids and open-pollinated varieties and yield takeoff in several African countries, achievements that have made maize the leading crop in generating CGIAR impacts in Africa in the 2010s.[90] Our history suggests that a better question is whether CIMMYT's funding environment supports sufficient longer-term research needed to tackle emerging and recalcitrant problems of the twenty-first century, such as new pests and diseases or building resilience to climate change.

[90] See, for example, "Climate-Smart Maize," in CGIAR, "50 Years of Innovation That Changed the World" (n.d.), www.cgiar.org/innovations/climate-smart-maize.