

Importance of the Public and Private Sectors

Even though they represent an incomplete measure, these data on direct personnel support costs still provide a basis for comparing the relative size of public and private investment in maize breeding research. Summarizing across all three developing regions, during the late 1990s public expenditure on maize research personnel totaled approximately US \$ 21.3 million per year. Over half of this amount was spent in Latin America (US \$ 11.1 million), while the rest was spent in Africa (US \$ 5.9 million) and Asia (US \$ 4.3 million).

During the same period, private-sector expenditures on maize breeding research were considerably higher. Summarizing across all three developing regions, private-sector expenditures on direct personnel support costs totaled about US \$ 38.7 million per year, of which about US \$ 25.6 million was spent in Latin America, US \$9.7 million in Asia, and US \$ 2.4 million in Africa.

Multinational seed companies outspent national seed companies by nearly 3:1, confirming the increasingly dominant role of multinationals in the developing world's maize seed industry. The investment advantage enjoyed by multinationals was even larger than these figures suggest, because no attempt has been made to factor in the cost of research carried out in industrialized countries. In breeding hybrids destined for developing-country markets, all multinationals draw heavily on technology and improved germplasm produced in their advanced laboratories and breeding stations located in North America and Europe.

Case study evidence from several countries suggests that direct personnel support costs make up 40-50% of total operating costs of a typical maize breeding program, so these figures can be doubled to arrive at a rough approximation of total investment in maize breeding research.

PRODUCTS OF MAIZE BREEDING RESEARCH

The principal product of any maize breeding program is improved germplasm, so an important first step in assessing the impacts of international maize breeding research in developing countries is to compile a complete inventory of germplasm products.

Information about maize varieties developed by public breeding programs was collected in 1992 during the original CIMMYT global impacts survey. The public-sector varietal releases database was updated and expanded during the more recent survey. The database currently contains descriptive information about approximately 1,350 varieties and hybrids released since the mid-1950s by public breeding programs in 37 developing countries.³ Collectively, these countries account for more than 75% of the area planted to maize in Latin America, Eastern and Southern Africa, and Asia and for more than 95% of the area planted to maize in non-temperate environments.

Information about maize varieties developed by private seed companies was collected through direct interviews carried out over a three-year period (1997-99). The CIMMYT maize impacts database currently contains information about nearly 1,900 varieties sold by private seed companies during the late 1990s in the 37 developing countries that participated in the CIMMYT survey. Approximately 1,100 of these were proprietary varieties that had been developed by private breeding programs.⁴ Unlike the public sector, it was not possible to compile a complete list of all varieties developed by the private sector since 1966, the year in which CIMMYT was established.

³ Since a major objective of this study is to assess CIMMYT's contribution to international maize breeding efforts, the following discussion relates only to the approximately 1,200 varieties released since 1966, the year in which CIMMYT was officially established.

Many seed companies that were in business during the 1960s, 1970s, and 1980s no longer exist, and it is simply not possible to obtain information about varieties developed many years ago by companies that are now defunct. Furthermore, few of the currently active companies that date back to those earlier years are able to provide detailed information about varieties that have long since been dropped from their product lines. For these reasons, private seed companies were asked to provide information only about varieties they were selling at the time of the survey. In most instances, these consisted of relatively recent hybrids developed during the 1990s.

The temporal coverage for public- and private-sector varietal releases thus is very different (see Figures 2 and 3). The public-sector varietal releases database includes information about all public varieties released from 1966 through 1998. Since the data form a complete time series, they provide insights into changes through time in the numbers and types of varieties developed by public breeding programs. In contrast, the more limited private-sector varietal releases database includes information only about private-sector varieties that were being sold during the late 1990s; it does not include information about private-sector varieties that were sold in earlier years and have now been discontinued. The private-sector varietal releases database provides a detailed snapshot of the materials found in the market during the late 1990s, but it does not provide a complete picture of changes that have occurred through time in the numbers and types of varieties developed by private seed companies.

Public Varietal Releases

Summary information about the maize varieties released by public breeding programs in developing countries between 1966 and 1999 appears in Table 6.⁵ The data have been broken down into five-year periods to make it easier to

Number of maize varieties released by public breeding programs

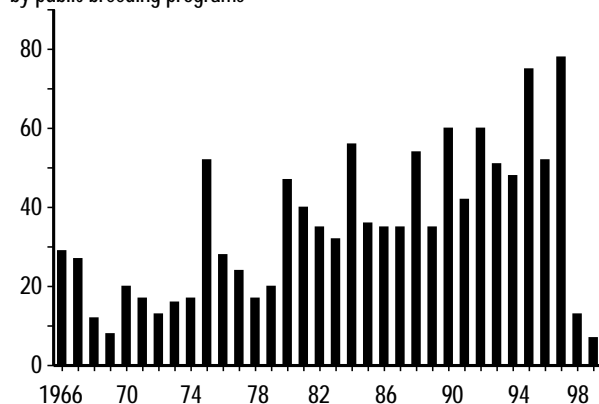


Figure 2. Coverage of CIMMYT's public-sector varieties database.

Source: CIMMYT public-sector varieties database.

Number of varieties sold by private companies during late 1990s

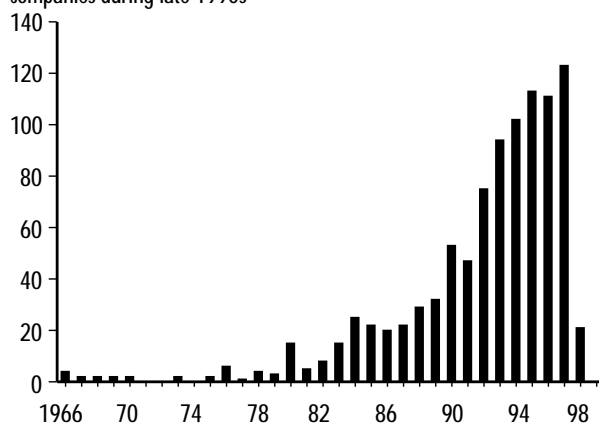


Figure 3. Coverage of CIMMYT's private-sector varieties database.

Source: CIMMYT private-sector varieties database.

⁴ This number includes multiple counts of varieties that were being sold by more than one seed company, in more than one country, and/or under more than one name. Adjusting for multiple counting, the CIMMYT database contains information about approximately 850 *different* private-sector varieties.

⁵ As noted earlier, the CIMMYT varietal releases database contains information about nearly 1,400 varieties released by public breeding programs. For most of these varieties, a complete set of descriptors is available, but in a few cases one or more descriptors is missing. The statistics presented in Tables 6-9 refer to percentages of valid responses, which varied slightly from one descriptor to the next.

discern trends in the pattern of varietal releases through time. To enable regional comparisons, results are also reported separately for Latin America (Table 7); Eastern and Southern Africa (Table 8); and South, East, and Southeast Asia (Table 9).

NUMBER OF RELEASES

Public maize breeding programs have been very productive, developing and releasing a steady stream of improved varieties. On aggregate, the rate at which varieties are released has grown steadily through time and shows no sign of slowing. Assuming that varietal testing and release procedures have not changed, this suggests that public maize breeding programs have not suffered any significant decline in productivity.

Over 60% of all public-sector releases came from Latin America, reflecting not only the large area planted to maize in that region but also the large number of public breeding programs. About 8% of all public-sector varietal releases came from Eastern and Southern Africa, reflecting the relatively modest area planted to maize in that region as well as the small number of public breeding programs. Approximately 32% of all public-sector varietal releases came from Asia, many of them from the powerful national breeding programs of China and India.

In interpreting these data, it is important to keep in mind that the number of varietal releases in and of itself is an imperfect measure of research productivity. To begin with, unless some sort of adjustment is made to control for differences in the area planted to maize, regional differences in

Table 6. Public-sector maize varietal releases, developing countries, 1966-98.

	1966 to 1970	1971 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 1999	1966 to 1998
Total varietal releases (number)	97	114	137	205	216	266	137	1,172
<i>Type of material</i>								
OPVs (%)	0.69	0.57	0.69	0.65	0.69	0.50	0.48	0.61
Hybrids (%)	0.31	0.43	0.30	0.35	0.32	0.50	0.52	0.39
<i>Ecological adaptation</i>								
Lowland tropical (%)	0.50	0.58	0.70	0.61	0.64	0.60	0.55	0.60
Subtropical/Mid-altitude (%)	0.32	0.37	0.18	0.30	0.30	0.23	0.28	0.28
Highland (%)	0.07	0.04	0.11	0.07	0.06	0.05	0.06	0.06
Temperate (%)	0.12	0.02	0.02	0.02	0.00	0.12	0.12	0.06
<i>Maturity range</i>								
Extra early/Early (%)	0.15	0.21	0.19	0.16	0.30	0.27	0.30	0.23
Intermediate (%)	0.34	0.29	0.34	0.32	0.31	0.28	0.28	0.30
Late/Extra late (%)	0.52	0.50	0.47	0.52	0.39	0.45	0.42	0.46
<i>Grain color</i>								
White grain (%)	0.45	0.61	0.50	0.51	0.43	0.50	0.47	0.49
Yellow/Other color grain (%)	0.55	0.39	0.50	0.49	0.57	0.50	0.53	0.51
<i>Grain texture</i>								
Flint/Semi-flint (%)	0.60	0.49	0.50	0.44	0.51	0.59	0.49	0.52
Dent/Semi-dent (%)	0.11	0.30	0.20	0.22	0.26	0.19	0.20	0.21
Other (%)	0.28	0.21	0.31	0.34	0.24	0.22	0.31	0.27
<i>Containing CIMMYT germplasm</i>								
All materials (%)	0.41	0.28	0.50	0.58	0.65	0.56	0.64	0.54
Non-temperate materials (%)	0.45	0.29	0.50	0.60	0.67	0.68	0.73	0.59

Source: CIMMYT maize impacts database.

numbers of varietal releases to some extent simply reflect regional differences in the area planted to maize. In addition, previous analysis has shown that for a number of reasons having to do with the non-divisibility of crop improvement research, small countries have a tendency to overinvest in maize breeding, and the rate of varietal releases in these countries is therefore often disproportionately high (see López-Pereira and Morris 1994). Thus it is perhaps not surprising that the number of varietal releases has been high in Latin America, a region that includes many very small countries.

RATE OF RELEASES

In addition to showing regional differences in numbers of varieties released by public breeding programs, the data also reveal differences in the

historical rate of varietal releases. In Latin America, the rate of varietal releases grew during the late 1960s and 1970s, peaked in the early 1980s, and subsequently leveled off (Table 7). In Eastern and Southern Africa, the rate of varietal releases declined from a low base during the 1960s and 1970s, increased substantially during the 1980s and early 1990s, and appears to have dropped sharply in recent years (Table 8). In Asia, the rate of varietal releases has increased steadily since the 1960s, with every five-year period registering an increase over the previous period (Table 9).

In the absence of comparable data on historical trends in maize varieties released by private companies, it is difficult to establish with certainty whether these trends reflect a “crowding out” effect attributable to the emergence of the private seed industry. Superficially at least, the timing of the observed changes in the rate of public-sector

Table 7. Public-sector maize varietal releases, Latin America, 1966-98.

	1966 to 1970	1971 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 1998	1966 to 1998
Total varietal releases (number)	65	78	98	140	111	126	90	708
<i>Type of material</i>								
OPVs (%)	0.60	0.55	0.67	0.71	0.69	0.63	0.51	0.63
Hybrids (%)	0.40	0.45	0.33	0.29	0.32	0.37	0.49	0.37
<i>Ecological adaptation</i>								
Lowland tropical (%)	0.58	0.63	0.71	0.66	0.69	0.51	0.43	0.61
Subtropical / Mid-altitude (%)	0.17	0.31	0.13	0.23	0.22	0.21	0.32	0.23
Highland (%)	0.08	0.05	0.13	0.08	0.09	0.07	0.08	0.08
Temperate (%)	0.17	0.01	0.02	0.03	0.00	0.21	0.17	0.08
<i>Maturity range</i>								
Extra early / Early (%)	0.07	0.13	0.09	0.09	0.14	0.15	0.11	0.11
Intermediate (%)	0.42	0.26	0.37	0.39	0.42	0.27	0.33	0.35
Late / Extra late (%)	0.52	0.61	0.54	0.53	0.44	0.58	0.56	0.54
<i>Grain color</i>								
White grain (%)	0.40	0.68	0.53	0.57	0.53	0.52	0.59	0.55
Yellow / Other color grain (%)	0.60	0.32	0.47	0.43	0.47	0.48	0.41	0.45
<i>Grain texture</i>								
Flint / Semi-flint (%)	0.57	0.41	0.41	0.40	0.39	0.54	0.37	0.44
Dent / Semi-dent (%)	0.09	0.35	0.22	0.19	0.34	0.18	0.23	0.23
Other (%)	0.35	0.24	0.37	0.41	0.27	0.28	0.40	0.33
<i>Containing CIMMYT germplasm</i>								
All materials (%)	0.37	0.24	0.44	0.61	0.67	0.56	0.66	0.53
Non-temperate materials (%)	0.40	0.25	0.45	0.62	0.67	0.67	0.75	0.56

Source: CIMMYT maize impacts database.

varietal releases seems closely linked to the introduction within each region of seed industry reforms. Seed industry liberalization measures were implemented in many Latin American countries beginning in the mid-1980s and in many countries in Eastern and Southern Africa in the early 1990s; in both regions, the appearance of private seed companies appears to have been immediately followed by a slowdown in the rate of public-sector varietal releases. In Asia, the record has been mixed; while seed industry reforms have been embraced in some countries, private-sector investment in maize breeding research continues to be proscribed in others, including China and Vietnam. A large number of public breeding programs in Asia thus continue to enjoy a relatively sheltered position, so it is not surprising that the rate at which they develop and release new varieties has not slowed.

TYPES OF MATERIALS

Since 1966, public maize breeding programs in developing countries have developed and released significantly greater numbers of OPVs than hybrids, reflecting the traditional emphasis in the public sector on breeding open-pollinating materials (Table 6). However, the ratio of OPVs to hybrids has changed noticeably through time in response to changes in the prevailing philosophy about the suitability of hybrid technologies for small-scale farmers. The proportion of hybrids among public-sector varietal releases rose steadily during the 1990s, and during the most recent period for which data are available (1996-98), hybrids outnumbered OPVs by a slight margin.

Interestingly, the shift to hybrid breeding occurred earlier in Eastern and Southern Africa than in the other two regions. By the late 1970s,

Table 8. Public-sector maize varietal releases, Eastern and Southern Africa, 1966-98.

	1966 to 1970	1971 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 1998	1966 to 1998
Total varietal releases (number)	12	9	6	18	15	36	2	98
<i>Type of material</i>								
OPVs (%)	0.83	0.56	0.33	0.33	0.47	0.44	0.50	0.48
Hybrids (%)	0.17	0.44	0.67	0.67	0.53	0.56	0.50	0.52
<i>Ecological adaptation</i>								
Lowland tropical (%)	0.08	0.11	0.00	0.17	0.20	0.31	0.00	0.20
Subtropical/Mid-altitude (%)	0.75	0.78	0.75	0.72	0.67	0.61	1.00	0.69
Highland (%)	0.08	0.00	0.25	0.11	0.13	0.06	0.00	0.08
Temperate (%)	0.08	0.11	0.00	0.00	0.00	0.03	0.00	0.03
<i>Maturity range</i>								
Extra early/Early (%)	0.17	0.00	0.00	0.06	0.13	0.08	0.50	0.09
Intermediate (%)	0.17	0.44	0.25	0.06	0.13	0.42	0.00	0.26
Late/Extra late (%)	0.67	0.56	0.75	0.89	0.73	0.50	0.50	0.65
<i>Grain color</i>								
White grain (%)	1.00	1.00	1.00	0.89	1.00	0.94	1.00	0.96
Yellow/Other color grain (%)	0.00	0.00	0.00	0.11	0.00	0.06	0.00	0.04
<i>Grain texture</i>								
Flint/Semi-flint (%)	0.25	0.67	0.50	0.22	0.33	0.67	0.00	0.46
Dent/Semi-dent (%)	0.42	0.22	0.50	0.61	0.33	0.31	1.00	0.40
Other (%)	0.33	0.11	0.00	0.17	0.33	0.03	0.00	0.15
<i>Containing CIMMYT germplasm</i>								
All materials (%)	0.00	0.00	0.25	0.28	0.29	0.50	1.00	0.31
Non-temperate materials (%)	0.00	0.00	0.25	0.28	0.29	0.51	1.00	0.32

Source: CIMMYT maize impacts database.

when most public breeding programs in Latin America (Table 7) and Asia (Table 8) were still emphasizing OPVs, programs in Eastern and Southern Africa were already releasing more hybrids than OPVs (Table 9). Quite possibly this was due to the early hybrid “success stories” of Kenya and Zimbabwe, where smallholders demonstrated the ability to grow hybrids that had been developed originally for the commercial farming sector. Convinced relatively early that hybrid technology could be adapted to the needs of small-scale farmers, public maize breeders in Eastern and Southern Africa were the first to complement their traditional work on open-pollinating materials with inbred line development activities.

ECOLOGICAL ADAPTATION

At the risk of oversimplifying, maize growing ecologies can be grouped into four main mega-environments: (1) lowland tropics, (2) subtropical and midaltitude transition zones, (3) tropical highlands, and (4) temperate zones. Table 10 shows the current distribution of the area planted to maize within each of these four mega-environments.

The ecological adaptation of maize varieties released by public breeding programs has been highly congruent with the relative importance of the four main mega-environments, both at the overall global level as well as regionally. Varieties adapted to lowland tropical production environments have accounted for 60% of all releases. Varieties adapted to subtropical and mid-altitude production conditions have accounted for

Table 9. Public-sector maize varietal releases, South, East, and Southeast Asia, 1966-98.

	1966 to 1970	1971 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 1999	1966 to 1999
Total varietal releases (number)	20	27	33	47	90	104	45	366
<i>Type of material</i>								
OPVs (%)	0.90	0.63	0.82	0.62	0.72	0.39	0.42	0.59
Hybrids (%)	0.11	0.37	0.18	0.38	0.28	0.62	0.58	0.41
<i>Ecological adaptation</i>								
Lowland tropical (%)	0.50	0.59	0.74	0.63	0.64	0.91	0.86	0.74
Subtropical/Mid-altitude (%)	0.50	0.41	0.26	0.37	0.36	0.07	0.14	0.26
Highland (%)	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Temperate (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Maturity range</i>								
Extra early/Early (%)	0.55	0.63	0.52	0.55	0.70	0.49	0.71	0.58
Intermediate (%)	0.09	0.32	0.28	0.16	0.11	0.26	0.17	0.21
Late/Extra late (%)	0.36	0.05	0.21	0.29	0.19	0.26	0.12	0.21
<i>Grain color</i>								
White grain (%)	0.26	0.24	0.30	0.20	0.21	0.30	0.20	0.24
Yellow/Other color grain (%)	0.74	0.76	0.70	0.80	0.79	0.70	0.80	0.76
<i>Grain texture</i>								
Flint/Semi-flint (%)	0.94	0.67	0.75	0.68	0.71	0.64	0.82	0.72
Dent/Semi-dent (%)	0.00	0.17	0.09	0.13	0.13	0.14	0.08	0.12
Other (%)	0.06	0.17	0.16	0.18	0.16	0.22	0.11	0.17
<i>Containing CIMMYT germplasm</i>								
All materials (%)	0.93	0.52	0.75	0.59	0.68	0.58	0.60	0.64
Non-temperate materials (%)	0.93	0.82	0.79	0.73	0.76	0.79	0.67	0.77

Source: CIMMYT maize impacts database.

Table 10. Distribution of maize area in developing countries, by mega-environment, late 1990s.

	Lowland tropical (%)	Subtropical and mid-altitude (%)	Highland (%)	Temperate (%)	All (%)	Maize area, late 1990s (million ha)
Latin America	65	12	12	11	100	26.1
Sub-Saharan Africa	50	33	7	10	100	21.4
West Asia and North Africa	0	39	0	61	100	3.6
South, East, and Southeast Asia	34	13	2	51	100	42.9
All developing countries	47	18	6	29	100	94.0

Source: CIMMYT maize mega-environments database, FAO AGROSTAT website.

an additional 28% of all releases. Varieties adapted to tropical highland production conditions have been much less important, accounting for approximately 6% of the total number of releases. These numbers suggest that research resources in public maize breeding programs have been allocated appropriately, in the sense that no single mega-environment has been over- or under-emphasized. Temperate production environments have been relatively neglected by public breeding programs, which makes sense considering the large investment made by private seed companies in breeding for these environments.

MATURITY CLASSES

Since the time needed for a maize crop to achieve physiological maturity depends on numerous environmental factors (e.g., temperature, altitude, rainfall, day length), the length of the maize growing season varies by location. Maize breeders frequently distinguish at least three maturity classes, defined relative to whatever constitutes the normal growing season for a given location. Early-maturing varieties usually require less than 110 days to reach full physiological maturity, intermediate-maturing varieties from 110-120 days, and late-maturing varieties more than 120 days. Generally speaking, late-maturing varieties tend to be grown in favorable production environments characterized by relatively low levels of climatic variability and assured water supplies. Early-maturing varieties tend to be grown in marginal

production environments subject to high levels of climatic variability, including frequent water stress (drought or waterlogging). Farmers in marginal environments choose to grow early-maturing varieties precisely because these varieties' reduced growth cycle minimizes their exposure to stresses. Early-maturing varieties tend to be popular also in highly intensified cropping systems, since the earlier the maize crop can be harvested, the sooner the field can be prepared for the following crop.

Nearly one-half of all varieties released by public breeding programs since 1966 have been late-maturing varieties. About 30% of all public-sector releases have been intermediate-maturity varieties, and about 24% have been early-maturing varieties. Interestingly, late-maturing varieties have dominated in Latin America and Africa, while early-maturing varieties have dominated in Asia. This suggests that Asian breeders have placed a lot of emphasis on developing short-duration materials that can be accommodated into the region's highly intensified cropping systems.

GRAIN COLOR AND TEXTURE

The predominant grain color of publicly bred maize varieties has differed by region, indicating that breeders have made a deliberate effort to respond to local consumer preferences. Latin American releases have been fairly evenly divided between white-colored varieties (used mainly for food) and yellow-colored varieties (used mainly for feed), reflecting the dual-purpose nature of

maize in that region. Releases in Eastern and Southern Africa have nearly all been white-colored, which is not surprising considering that most maize in Africa is consumed as food, and consumers strongly prefer white-colored varieties. Yellow-colored varieties have predominated in Asia, where maize is used mainly as animal feed, and where color preferences for food maize are in any case less pronounced.

Regional differences have also been evident in the grain texture of publicly bred maize varieties. Hard-grained varieties (flints, semi-flints) have predominated in all three regions, reflecting their better storability, particularly in humid tropical and subtropical environments. Soft-grained varieties (dents, semi-dent, floury types) have been relatively more common in Latin America and Africa, where a greater proportion of maize is consumed as human food and consumers generally prefer soft-grained materials

CIMMYT GERMLASM CONTENT

To what extent have public maize breeding programs in developing countries made use of CIMMYT germplasm?

Unfortunately it is not easy to document the use of CIMMYT germplasm by public breeding programs. At least three factors complicate the task:

1. CIMMYT maize breeders routinely work with a wide range of source materials obtained from all over the world. After undergoing improvement at one or more CIMMYT breeding stations, the most promising of these materials are distributed

to collaborators in national programs for testing and evaluation. In this context, it is not always clear how credit should be attributed among the various breeding programs, so the definition of "CIMMYT germplasm" becomes somewhat arbitrary. Much of the germplasm distributed by the CIMMYT Maize Program can be considered a joint product of CIMMYT and national breeding programs.

2. Maize breeders working in national programs who use source materials obtained from CIMMYT themselves may not know exactly how much of the CIMMYT source materials are present in finished varieties that are eventually released to farmers. Modern maize breeding involves repeated cycles of selfing, crossing, and backcrossing. Selection strategies vary widely and change often. Because of the complex and frequently ad hoc nature of the breeding process, the precise genetic composition of finished varieties cannot be known with certainty.
3. Even when maize breeders working in national programs know how much CIMMYT germplasm is present in a finished variety, they may not be willing to reveal this information. Most commercial maize varieties now have closed pedigrees, meaning that information about their genetic background is not publicly available.⁶

Despite these complicating factors, a rigorous effort was made to document the use of CIMMYT germplasm by public breeding programs. Survey respondents were asked whether each variety (OPV or hybrid) had been developed using CIMMYT germplasm, defined as materials that had been improved by the CIMMYT Maize Program. Materials that may have been obtained from CIMMYT's gene bank but that had not been improved by CIMMYT breeders were expressly excluded.

⁶ Breeding programs, especially commercial programs that respond to economic incentives, have an interest in keeping pedigrees closed, because once the genetic background of a variety becomes public knowledge, other breeders will be able to copy the variety. In the past, public breeding programs were rarely concerned with earning profits from sales of their germplasm products, so they were usually willing to provide pedigree information. More recently, the situation has changed. With the strengthening of intellectual property rights on genetic resources, many public breeding programs have adopted closed-pedigree policies. In some cases, they have done this because they hope eventually to generate income from the sale of their germplasm products. In other cases, adopting a closed-pedigree policy is seen as more of a defensive measure designed to prevent losses of intellectual property to unscrupulous competitors. In yet other cases, the motivation may be the reluctance to acknowledge use of proprietary germplasm owned by others, since this might expose them to claims for compensation.

By any standard, use of CIMMYT germplasm by public breeding programs has been extensive. Of all the publicly bred maize varieties released from 1966-99, over one-half (54%) contained CIMMYT germplasm (Table 6). Excluding varieties adapted for temperate environments (which are not targeted by CIMMYT maize breeders), the proportion containing CIMMYT germplasm was even higher (59%).

The use of CIMMYT germplasm by public breeding programs has increased through time. During the most recent period, 64% of all public-sector varietal releases contained CIMMYT germplasm (73% of all non-temperate materials). Belying predictions that CIMMYT's role would decline as national programs gained in strength, the CIMMYT Maize Program continues to represent an important source of breeding materials for public breeding programs in developing countries.

Use of CIMMYT germplasm by public maize breeding programs has varied by region. Public breeding programs in Asia and Latin America have used CIMMYT germplasm most extensively; 64% of the public varieties released in Asia and 53% of the public varieties released in Latin America contained CIMMYT germplasm. Public breeding programs in Eastern and Southern Africa have used CIMMYT source materials somewhat less extensively; only 31% of the public varieties released in Eastern and Southern Africa contained CIMMYT germplasm. These regional differences in the use of CIMMYT germplasm can be explained partly in terms of environmental factors. Since its inception, the CIMMYT Maize Program has invested more resources in breeding for lowland tropical environments than other environments. Most of the maize grown in Asia and Latin America is grown in lowland tropical environments, so public breeding programs in

these regions have been able to take advantage of some of CIMMYT's best materials. By contrast, much of the maize area in Eastern and Southern Africa is located in subtropical and mid-altitude environments, which until the mid 1980s received less emphasis from CIMMYT breeders. Public breeding programs in Africa until recently thus had a more limited range of CIMMYT materials on which to draw.

Within each region, use of CIMMYT germplasm by public breeding programs has varied through time. In Latin America and Asia, use of CIMMYT germplasm did not change much during the 1990s, but in Eastern and Southern Africa it increased appreciably. The increased use of CIMMYT source materials in Eastern and Southern Africa during the 1990s reflects the strengthening of CIMMYT's breeding station in Harare, Zimbabwe.

Private Varietal Releases

Summary information about maize varieties developed by private seed companies and sold in developing countries during the late 1990s appears in Table 11. Unlike varieties developed by public breeding programs, which are released initially in a single country, varieties developed by private seed companies ("proprietary varieties") often are released simultaneously in several countries. In order to avoid double-counting, the database used to calculate the statistics presented in Table 11 contains no duplication (i.e., varieties that may have been released in more than one country were counted only once).⁷

NUMBER OF VARIETIES AND RATE OF RELEASES

Since the private-sector varietal releases database contains only information about varieties sold during the late 1990s, it cannot be used to draw

⁷ As in the case of public varieties, a complete set of descriptors is not available for all private-sector varieties, so the statistics presented in Table 11 were calculated based on valid responses only.

conclusions about the past productivity of private breeding programs. But even if the historical coverage is incomplete (and recognizing that the CIMMYT survey undoubtedly missed some varieties), the regional variability in the data is striking. During the late 1990s, nearly 500 different proprietary varieties were sold in Latin America, and well over 300 different proprietary varieties were sold in Asia. In comparison, only about 25 different proprietary varieties were sold in Eastern and Southern Africa. This pattern is consistent with the research investment estimates reported earlier and confirms that Eastern and Southern Africa has attracted much less attention from the private sector than the two other regions.

TYPES OF MATERIALS

As expected, private breeding programs have focused almost exclusively on developing hybrids. Fully 98% of all proprietary varieties sold during the late 1990s were hybrids.

ECOLOGICAL ADAPTATION

Most proprietary varieties sold in developing countries during the late 1990s were adapted to lowland tropical production environments (59%). Varieties adapted to subtropical and mid-altitude conditions accounted for an additional 21%. Compared to public breeding programs, private companies have evidently made very little effort to target tropical highland environments; only 1% of all proprietary varieties were adapted to these environments. On the other hand, private companies have placed much more emphasis on temperate environments; 19% of all proprietary varieties sold during the late 1990s were adapted to temperate environments. The high proportion of temperate varieties among private-sector releases reflects the efforts of private companies to exploit spillover benefits from breeding research done for industrialized countries.

MATURITY CLASSES

Although the varieties developed by private breeding programs are distributed across all maturity classes, on the whole breeders in the private sector have placed greater emphasis on short duration materials than have breeders in the public sector. Fully 42% of all proprietary varieties sold during the late 1990s were classified as early or extra-early.

GRAIN COLOR AND TEXTURE

In terms of grain color and grain texture, proprietary varieties again reflect the efforts of private sector breeders to take advantage of germplasm originally developed for commercial markets in industrialized countries. Compared to varieties developed by public breeding programs, a much higher proportion of proprietary varieties are yellow-colored (71%) and hard-textured (63%). None of the varieties developed by private seed companies exhibited non-traditional grain texture (starchy or waxy types).

CIMMYT GERmplasm CONTENT

To what extent have private seed companies made use of CIMMYT germplasm?

Some of the difficulties inherent in tracking the use of CIMMYT germplasm were described earlier with reference to public breeding programs (see Section 4.1.7). In the case of private breeding programs, these difficulties are compounded by differences in breeders' perceptions. In order to understand this, it is useful to review a bit of history. Forty years ago, when most private maize seed companies were located in the United States and Western Europe, private-sector breeding programs were oriented almost exclusively toward developing hybrids adapted to the temperate production conditions of the North American and Western European corn belts.

Private-sector interest in breeding for tropical and subtropical environments picked up only during the 1970s and 1980s, when markets for commercial maize seed began to emerge in several large developing countries (e.g., Brazil, China, India, Indonesia, Mexico, the Philippines, Thailand). At that time, many leading seed companies launched maize breeding programs targeted at non-temperate environments. Most stocked their breeding plots with materials obtained from CIMMYT, whose breeding program was one of the few programs with experience working with non-temperate germplasm. Several sets of breeding materials available from CIMMYT were used by almost all private seed companies that had intentions of expanding into non-temperate environments, especially materials derived from the Tuxpeño germplasm complex (used extensively as a source of lines for Latin American hybrids) and materials derived from the composite variety Suwan-1 (used extensively as a source of lines for Asian hybrids).

Since most of the private seed companies that today breed for developing countries started out using Tuxpeño and Suwan materials, it is probably not too much of an exaggeration to say that most of the hybrids grown in non-temperate environments trace their parentage back in one way or another to Tuxpeño or Suwan sources. For this reason, many CIMMYT breeders feel that most of the area currently planted to private-sector hybrids can be considered planted to CIMMYT-derived germplasm. Breeders working in the private sector tend to see things a bit differently, however. Because private-sector breeders constantly make selections within their breeding populations, many of the Tuxpeño and Suwan populations today being maintained by private seed companies have changed significantly from the time they were originally acquired from CIMMYT. For this reason, even if one or more of the parental lines used to produce a hybrid was

developed from Tuxpeño or Suwan sources, breeders in the private sector may not consider the hybrid to be “CIMMYT-derived.”

How to overcome this difference in breeders’ perceptions? If the complete breeding history of a variety is known, credit can be assigned among the different breeding programs that participated in its development with the use of a formal attribution rule. With the so-called geometric rule, for example, credit is assigned to past breeding operations in geometrically declining fashion. Thus the most recent breeding operation receives a large weight, the previous operation receives a smaller weight, the operation before that an even smaller weight, and so on back. In the earliest generation considered, the weight is doubled to make all weights sum to 1 (Heisey, Lantican, and Dubin, 2002). The advantage of the geometric rule is that it acknowledges the contribution made by all breeding programs, but at the same time it explicitly recognizes that selections performed during the later stages of the breeding process merit more credit than selections performed during earlier stages.

Unfortunately for this study, use of formal attribution rules is usually not possible with maize, since the pedigrees of most commercial maize hybrids are closed. Despite the difficulty of obtaining detailed pedigree information, however, it is clear that use of CIMMYT germplasm by private breeding programs has been substantial. Aggregating across the three developing regions, 58% of all maize varieties developed since 1966 by private seed companies and sold during the late 1990s contained CIMMYT germplasm (Table 11). The proportion varied greatly by region, however. In Latin America, nearly three-quarters (73%) of all private-sector varieties contained CIMMYT germplasm. In other regions, use of CIMMYT germplasm by private companies was more modest. In Eastern and Southern Africa, 21% of the varieties developed by private breeding programs

contained CIMMYT germplasm, and in Asia, 19% of the varieties developed by private breeding programs contained CIMMYT germplasm.

The extensive use of CIMMYT germplasm by private breeding programs in Latin America can be attributed to three main factors. First, because the majority of CIMMYT maize breeders are stationed in Latin America (either at headquarters in Mexico or in one of several outreach offices), contacts between private-sector breeders and CIMMYT breeders have been more frequent than in other regions. Second, seed companies in Latin America have been well placed to take advantage of CIMMYT's excellent lowland tropical materials, most of which have been developed in Mexico and Central America from local landraces that themselves benefited from thousands of years of selection pressure at the hands of farmers. Third,

many countries in Latin America have private seed industries that feature large numbers of small seed companies; many of these companies lack strong breeding programs of their own and thus have had to rely heavily on CIMMYT as a source of materials.

The same three factors—opportunities for collaboration, suitability of germplasm, and seed industry structure—also explain the more modest use of CIMMYT germplasm by private breeding programs in other regions, although the relative importance of each factor tends to vary. In Eastern and Southern Africa, the key factors have been the structure of local seed industries and the suitability of CIMMYT's germplasm. Most private seed companies in Eastern and Southern Africa are extremely large and consequently have correspondingly large (and generally very

Table 11. Characteristics of maize varieties developed by private seed companies.^{a, b}

	Latin America	Eastern and Southern Africa	South, East, and Southeast Asia	All regions
Total varieties (number)	498	25	330	853
<i>Type of material</i>				
OPVs (%)	0.03	0.08	0.00	0.02
Hybrids (%)	0.97	0.92	1.00	0.98
<i>Ecological adaptation</i>				
Lowland tropical (%)	0.47	0.04	0.91	0.59
Subtropical / Mid-altitude (%)	0.25	0.78	0.07	0.21
Highland (%)	0.01	0.13	0.00	0.01
Temperate (%)	0.27	0.04	0.02	0.19
<i>Maturity range</i>				
Extra early / Early (%)	0.19	0.17	0.79	0.42
Intermediate (%)	0.36	0.30	0.15	0.28
Late / Extra late (%)	0.46	0.52	0.06	0.31
<i>Grain color</i>				
White grain (%)	0.38	0.88	0.10	0.29
Yellow / Other color grain (%)	0.62	0.12	0.90	0.71
<i>Grain texture</i>				
Flint / Semi-flint (%)	0.59	0.21	0.74	0.63
Dent / Semi-dent (%)	0.41	0.79	0.26	0.37
Other (%)	0.00	0.00	0.00	0.00
<i>Containing CIMMYT germplasm</i>				
All materials (%)	0.73	0.21	0.19	0.58
Non-temperate materials (%)	0.89	0.15	0.18	0.70

^a Includes all proprietary varieties being sold during the late 1990s

^b Varieties sold in more than one country counted only once each (no duplicates)

Source: CIMMYT maize impacts database.

competent) in-house breeding programs. Perfectly capable of developing their own germplasm sources, these companies have usually not had to rely on CIMMYT for breeding materials. Perhaps more importantly, the germplasm available from CIMMYT has not always been well suited for African production environments. Most of the maize produced in Eastern and Southern Africa is grown in subtropical and mid-altitude transition zones, which for many years received relatively little attention from the CIMMYT Maize Program. When it became apparent that germplasm developed in Mexico could not be introduced successfully into Africa without undergoing additional adaptation breeding, CIMMYT established a major breeding station near Harare, Zimbabwe. Fifteen years later, this investment is paying off. The Harare program has released a number of high-yielding, drought-tolerant inbred lines showing excellent levels of resistance to major diseases and pests. These lines are being used by private seed companies and are starting to show up in commercial releases. Seed industry contacts say that many experimental hybrids currently in the pipeline were developed using CIMMYT source materials, suggesting that use of CIMMYT lines is increasing.

In Asia, the relatively modest use of CIMMYT germplasm by private breeding programs can be explained mainly in terms of institutional constraints. Forced to cover a vast area with limited human and financial resources, the CIMMYT Maize Program for a long time was not able to interact as closely with the private sector in Asia as it was in other regions. The situation has improved in recent years following concerted efforts to strengthen links with private companies, and private-sector breeders now actively participate with public-sector scientists in CIMMYT-sponsored collaborative networks.

ADOPTION OF MODERN VARIETIES (MVs)

Information presented in the preceding sections of this report about improved varieties developed by public and private maize breeding programs in developing countries attests to the productivity of these programs and makes clear that breeders in both sectors have made extensive use of germplasm obtained from CIMMYT. What the data about varietal releases do not tell us, however, is the extent to which farmers have made use of these varieties. This section of the report presents information about the adoption of maize MVs in developing countries.

Before we turn to the evidence on adoption, a caveat is necessary. Estimating the area planted to improved germplasm is complicated by at least three factors. First, the physical environments and cropping systems in which maize is grown are extremely diverse, so the uptake of MVs often varies considerably even within the same country. Second, in many developing countries maize is grown by subsistence-oriented farmers who do not regularly purchase commercial seed; since these farmers often plant farm-saved seed, it can be extremely difficult to identify improved germplasm in the field, because the genetic makeup of successive crops can quickly change in the presence of seed recycling (for a review of evidence, see Morris, Risopoulos, and Beck 1999). Third, most commercial maize seed is now produced in the private sector; since many private companies consider seed sales information to be confidential, it is often difficult to get seed sales data for use in gauging varietal adoption trends.

Because of the difficulties inherent in estimating the adoption of improved germplasm, we present two types of data relating to the uptake and use of improved OPVs and hybrids. First we present