Chapter 2

Impact of Public and Private Maize Breeding Research in Asia, 1966-1997/98

Roberta V. Gerpacio

This chapter provides an Asia-wide synthesis of the impact of public and private maize breeding research. The data presented in this chapter (and elsewhere in the book) were collected through an extensive survey of public and private research organizations and seed companies located in seven countries: China, India, Indonesia, Nepal, the Philippines, Thailand and Vietnam. These seven countries account for 93% of the maize area in Asia. All told, data were collected from a total of 179 public agencies, private companies and non-governmental organizations (NGOs). Collectively, these organizations sold approximately 167,000 t of maize seed in 1997, representing an estimated 73% of the formal maize seed market in the region (Table 1).

The chapter begins by briefly describing the organization of maize research in the study countries, paying particular attention to the roles played by public research institutes and private seed companies. Estimates are presented of the level of investment in maize breeding research, and the germplasm products of public and private maize breeding programs are described. After analyzing patterns in farm-level adoption of modern maize varieties, the chapter concludes with a discussion of the policy implications of the study findings.

Maize Research and Technology Development in Asia

Organization of Maize Research

The improved open-pollinated varieties (OPVs) and hybrids that eventually make their way into farmers' fields are products of an international maize breeding system that includes CIMMYT (a publicly supported international research center); hundreds of public breeding programs operating at the national, regional, state or district level; and thousands of private seed companies, both national

Table 1. Coverage of the 1998/99 Asia maize impact survey

	Number of public organizations surveyed	Number of private companies interviewed	Maize seed sales, 1997 (t)	Percentage of formal maize seed market
China (south)	59	1	87,600	na
India	30	22	36,000	97
Indonesia	3	6	9,550	95
Nepal	2	21	1,450	6
Philippines	14	7	8,140	67
Thailand	2	7	20,700	94
Vietnam	2	3	3,810	76
Asia	112	67	167,250	73

Source: CIMMYT Asia Maize Impact Survey 1998-99.
Note: na = not available.

and international. The history, organization and performance of this international maize research system are described elsewhere,[1] so this chapter focuses on maize R&D systems in Asia.

In 1997/98, the reference year for this study, approximately 1,000 public agencies, private companies and NGOs in Asia were conducting maize breeding research, producing and distributing maize seed, or both (Table 2). This number should be considered conservative, because even though an extensive effort was made to identify as many seed industry participants as possible, undoubtedly a few were overlooked.

Role of the Public Sector

In most countries around the world, developing as well as industrialized, agricultural research has deep roots in the public sector (Morris 1998). During the period when national research systems are initially formed, state-sponsored organizations almost always play a dominant role in organizing the development of improved technology and financing its transfer to farmers. Over time, however, the role of the public sector typically declines, and functions that were once performed by government or parastatal organizations are gradually taken over by private companies.

In Asia, this process is already well advanced. Today, the dominance of the public sector in agricultural R&D is largely a thing of the past. Of all countries in the region, only China and India retain sizeable public agricultural research and extension systems. Public breeding institutes and seed agencies (including universities and cooperatives) make up about 71% of all seed organizations in Asia, but when China and India are excluded the proportion falls sharply. Excluding China and India, only 75 out of 216 total maize seed organizations (35%) are public (Table 2). The decline in publicly funded agricultural research has been particularly pronounced in Southeast Asia, where public maize breeding research is today carried out only in two or three organizations per country.

Experience from around the world suggests that after the private sector emerges as a major player in maize breeding research, private companies tend quickly to assume control of commercial maize seed markets (Morris 1998). Instead of competing head-on with private seed companies in the lucrative market for commercial hybrids, many public seed organizations choose to redirect their attention to

Table 2. Estimated number of maize seed organizations, selected Asian countries and region, 1997/98

	Public agencies	Private companies		Universities/ cooperatives	NGOs	Total
		Domestic	Multinational			
China (south)	519	na	1	na	na	520
India	27	218	10	6	na	261
Indonesia	3	3	3	1	na	10
Nepal	11	0	0	0	30	41
Philippines	2	6	5	6	na	19
Thailand	2	2	5	73	na	82
Vietnam	57	1	6	0	na	64
Asia	621	230	30	86	30	997
Asia (excluding China, India)	75	12	19	80	30	216

Source: CIMMYT Asia Maize Impact Survey 1998-99.
Note: na = not available.

[1] See Morris, Clancy and López-Pereira (1992); López -Pereira and Filipello (1994); López -Pereira and Morris (1994); and Dowswell *et al.* (1996).

focus on the needs of farmers in marginal areas who do not represent potential customers for profit-oriented private companies. Although some public breeding programs continue to develop hybrids in direct competition with private companies (as for example in the Philippines and Thailand), many public breeding programs opt to move upstream in the germplasm development process, for example by concentrating on genetic resource conservation and pre-breeding activities designed to produce basic germplasm that can be used as source material by commercial breeding programs. Similarly, rather than producing hybrid seed in direct competition with private companies, many public seed agencies concentrate on the promotion of informal seed production and distribution systems (Dowswell *et al.*, 1996).

In Asia, most public agencies that are still actively involved in maize R&D concentrate on developing and evaluating varieties. In a few countries, public agencies also produce maize seed and distribute that seed, along with extension services, especially in marginal areas where maize is an important crop. Public agencies also work in favorable areas, although they face more competition from the private sector in these areas. More commonly, however, public R&D agencies no longer participate directly in seed production and distribution, preferring to cede that role to the private sector. In Indonesia, for example, the Research Institute for Maize and Other Cereals (RIMOC) sells parent seed of improved maize varieties to public parastatals and private seed companies, which multiply the seed for distribution to farmers around the country through their marketing networks. Similar partnerships between public breeding institutes and private seed production companies have also emerged in Thailand, the Philippines and India. China is a significant exception. In most provinces of China, private companies are prohibited by law from producing maize seed, so the maize seed industry is composed almost entirely of state-owned enterprises (Pray *et al*. 1998).

Role of the Private Sector

Private-sector participation in maize R&D in Asia has grown steadily since the early 1990s, when a wave of policy reforms broke up what in many countries had effectively been state monopolies on the seed industry. In 1997/98, about 230 national maize seed companies and about 30 multinational companies were operating in Asia (Table 2). Within individual countries, however, the number of private seed companies varied enormously. The huge maize economy of India was being supported by a large number of private national and multinational seed companies, approximately 30 of which had their own in-house breeding program (Singh *et al.* 1995). At the other extreme, no private companies with in-house breeding programs were operating in Nepal, where seed distributors were marketing seed of maize varieties imported from India.

The research activities pursued by maize seed companies in Asia typically vary depending on the size of the company and the volume of seed that it sells. Generally speaking, the larger the company, the larger is its ability to establish its own breeding program. Many smaller seed companies, lacking any in-house research capacity, contract with public research programs and sometimes even large private companies to multiply and distribute seed of improved OPVs and hybrids developed by others. These smaller companies usually specialize in maize and operate only within a limited area. In addition to the many small seed companies that work exclusively with varieties developed by others, a significant number of companies—probably between 75 and 100—have grown to the extent that it makes sense to establish the capacity to develop their own proprietary cultivars using conventional breeding methods. A much smaller number of seed companies—probably less than 15—are large enough to have ventured into biotechnology research. Most of the multinationals operating in the region fall into the latter category.

Public- and Private-Sector Research Investments

Numbers of Maize Researchers

The CIMMYT survey identified 116 public organizations and 44 private companies operating in Asia in 1997/98 that featured some level of maize breeding capacity (Figure 1). Collectively, these organizations employed approximately 670 scientists in maize genetic improvement (Tables 3 and 4).[2] Approximately 505 scientists were working in public organizations, roughly three times the number working in private companies.

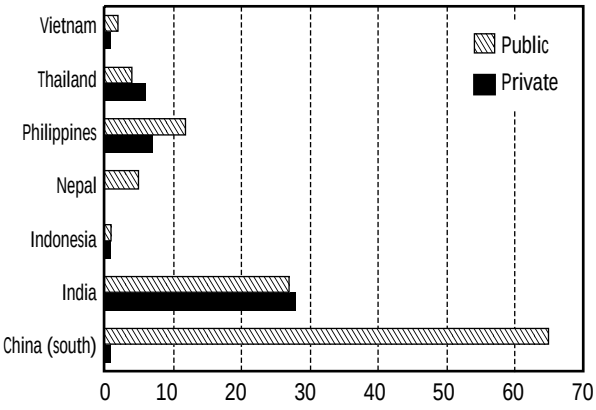

Figure 1. Number of seed agencies with maize breeding programs, Asia, 1997/98.
Source: CIMMYT Asia Maize Impact Survey 1998-99.

The relative intensity of public and private investment in maize breeding research can be determined by examining the number of scientists supported by each sector per 100,000 ha of maize area planted or per 100,000 t of maize produced. According to both measures, in most Asian countries public investment in maize research appears to be much higher than private investment (Tables 3 and 4). Private seed companies tend to target a much smaller maize area than public breeding programs, however, so the intensity of research investment may not be very different.

Level of Maize Research Expenditure

Skilled human capital is obviously a prerequisite for successful research, but even the most skilled maize breeder is unlikely to be effective without resources for screening new materials, making crosses and conducting varietal evaluation trials. How much financial support do Asian maize researchers receive? Table 5 shows the average annual investment in maize breeding research by the public

Table 3. Public-sector maize research indicators, selected Asian countries and region, 1990 and 1997/98

	Number of agencies engaged in maize breeding	Number of scientists engaged in maize breeding (FTE)	Scientists per 100,000 ha of total area planted to maize		Scientists per 100,000 t of maize produced	
			1997/98	1990	1997/98	1990
China (south)	65	270	6.6	3.0[a]	1.8	0.7[a]
India	27	56	0.9	2.8	0.5	1.9
Indonesia	1	13	0.4	1.2	0.1	0.6
Nepal	5	13	1.6	3.9	1.0	2.1
Philippines	12	50	1.9	1.1	1.1	0.9
Thailand	4	35	2.7	1.3	0.8	0.6
Vietnam	2	68	9.9	11.8	3.9	8.9
Asia	116	505	2.6	2.7	1.1	0.8
Asia (excluding China)	51	235	1.5	2.3	0.8	1.4

Source: CIMMYT Asia Maize Impact Survey 1998-99; CIMMYT (1992).
Note: FTE = full-time equivalent.
[a] Data for 1990 are for the whole of China.

[2] Throughout this book, references to scientist numbers denote full-time equivalents.

Table 4. Private-sector maize research indicators, selected Asian countries and region, 1990 and 1997/98

	Number of agencies engaged in maize breeding	Number of scientists engaged in maize breeding (FTE)	Scientists per 100,000 ha of total area planted to maize		Scientists per 100,000 t of maize produced	
			1997/98	1990	1997/98	1990
China (south)	1	na	na	0.0[a]	na	0.0[a]
India	28	74	1.1	0.8	0.7	0.6
Indonesia	1	11	0.3	0.2	0.1	0.1
Nepal	1	6	0.7	0.0	0.4	0.0
Philippines	7	34	1.3	3.1	0.7	2.4
Thailand	6	40	3.1	3.8	0.9	1.8
Vietnam	5	1	0.1	0.0	<1	0.0
Asia	49	166	0.8	0.6	0.4	0.2
Asia (excluding China)	48	166	0.8	0.5	0.4	0.9

Source: CIMMYT Asia Maize Impact Survey 1998-99; CIMMYT (1992).
Note: na = not available.
[a] Data for 1990 are for the whole of China.

Table 5. Estimated level of public- and private-sector investment (US$) in maize breeding research, selected Asian countries and region, 1997/98

	Average annual cost of supporting a senior maize breeder		Total annual research investment (US$ 000)
	Salary and benefits	Operating budget	
Public sector			
China	260	460	7,100
India	12,820	1,160	1,230
Indonesia	680	na	na
Nepal	1,820	1,130	1,250
Philippines	12,050	3,800	160
Thailand	6,000	na	1,200
Vietnam	800	240	90
Asia	12,900	2,950	1,580
Private sector			
China	0	0	0
India	30,000[a]	na	2,050
Indonesia	1,200[a]	na	50
Nepal	0	0	0
Philippines	10,800	31,250	180
Thailand	30,300[a]		480
Vietnam	*	*	*
Asia	20,500	10,420	400

Source: CIMMYT Maize Impact Survey 1998-99.
Note: na = not available; * = internal and confidential.
[a] Includes the estimated operating budget.

and private sectors in Asia in 1997/98. The data should be regarded as conservative; similar to their counterparts in Latin America (Morris and López-Pereira 1999), survey respondents in Asia (especially those working in public research organizations) had difficulty estimating the overhead expenses associated with supporting research personnel.

In 1997/98, the salary and benefits for a senior maize breeder working in the public sector ranged from US$ 260 per year in China to almost US$ 13,000 per year in India. Including annual operating budgets, the public sector spends from as little as US$ 720 per year in China to support a senior maize breeder to as much as US$ 16,000 per year in the Philippines. (Senior maize breeders in India were paid slightly higher salaries than those in the Philippines, but Filipino scientists received operating budgets that were nearly three times higher.) Averaging across the entire region, a senior maize breeder working with the public sector in Asia earns around US$ 13,000 per year in salary and benefits and receives US$ 3,000 in operating funds, for a total support level of about US$ 16,000 per year.

How do levels of support in the public sector compare to levels of support in the private sector? In 1997/98, expenditures by private seed companies on salary, benefits and operating budget for a senior maize breeder ranged from a low of US$ 1,200 per year in Indonesia to a high of US$ 42,000 per year in the Philippines. Averaging across the entire region, a senior maize breeder working with the private sector in Asia earns around US$ 20,000 per year in salary and benefits and receives US$ 10,000 in operating funds, for a total support level of about US$ 30,000 per year.

The estimated number of maize researchers in each country can be multiplied by the estimated annual support costs per researcher to generate a rough estimate of the total annual investment in maize breeding research in each country. Based on this admittedly crude estimation procedure, in 1997/98, public investment in maize breeding research ranged from a low of about US$ 90,000 in Vietnam to a high of about US$ 7.1 million in China (Table 5). These investment data can be adjusted for differences in the size of Asian countries. The research intensity measures indicate that in 1997/98 total public investment in maize research ranged from a low of US$ 13,000 per 100,000 ha of maize planted in Vietnam to a high of US$ 175,000 per 100,000 ha of maize planted in China (Figure 2). The government of Nepal spends relatively more on maize research per 100,000 ha of maize planted than other countries with larger areas planted to maize, such as Thailand and India. This relatively high intensity of Nepal's public investment in maize research presumably reflects a combination of structural factors (indivisibilities in research infrastructure), transactions costs (shortages of skilled personnel, inefficient research facilities) and possibly also compensatory investment by the public sector designed to make up for the absence of a strong private seed industry.

Research intensity measures can also be calculated and used to make inter-country comparisons of the levels of private investment. In 1997/98, the private

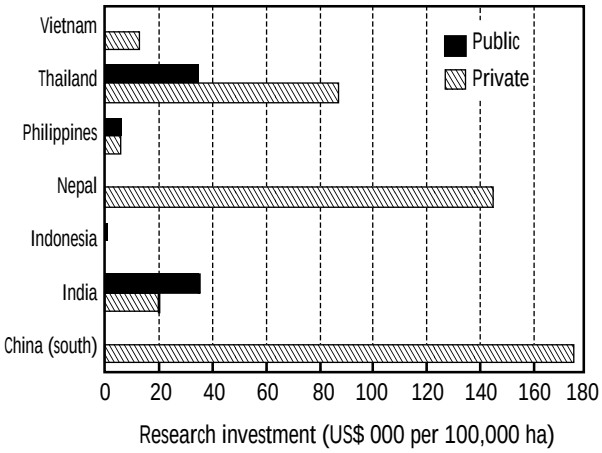

Figure 2. Average annual public and private research investment (US$ 000) per 100,000 ha of maize, selected countries in Asia, 1997/98.
Source: CIMMYT Asia Maize Impact Survey 1998-99.

sector in India and Thailand spent the most on maize research per 100,000 ha of maize planted (about US$ 35,000 in each country) (Figure 5). Inter-country differences in the intensity of research investment can be attributed to a number of factors. Other things equal, private seed companies will be encouraged to invest more heavily in countries with favorable business climates and attractive commercial seed markets. Large multinationals also tend to invest more heavily in countries that serve as the base for a regional breeding program; the expectation is that the investment will generate benefits that will later be captured by exploiting research spillovers to other countries. India and Thailand stand out as two countries that serve as hubs of regional breeding programs; hybrids bred in India and Thailand have been released and sold in Nepal, Vietnam, the Philippines and Indonesia.

Why has the private sector increased its investment in maize breeding research in Asia? One reason is that Asia represents an enormous potential market, not only for seed, but also for complementary inputs such as fertilizer, crop chemicals and machinery. Use of improved inputs remains modest in many Asian countries, particularly in subtropical and tropical environments, where most farmers still use traditional production practices. In 1997/98, 60% of the area planted to maize in the countries surveyed (excluding China) was planted to farm-saved seed and cultivated using few or no purchased inputs.

Disenchantment with the performance of public input-supply organizations has also provided an opening for increased participation by the private sector. With few exceptions, public seed production agencies in Asia have operated inefficiently. They frequently suffer from inadequate and unreliable funding, shortages of well-trained employees and a lack of efficient infrastructure and facilities. In addition, poor communication between government agencies frequently leads to poor coordination among various sectors of the industry (Vasal 1998). In an attempt to address these longstanding problems, governments in many Asian countries have introduced policy reforms designed to transfer responsibility for agricultural input supply to the private sector. Forced to compete without preferential subsidies, many government seed agencies have had difficulty maintaining an active presence in the market.

Many countries in Asia have introduced policy reforms designed to facilitate private-sector participation in the maize seed industry.[3] These reforms have encouraged the growth of private national seed companies and fostered a better business environment for multinationals, most of which have a strong maize R&D capacity, well-developed seed production facilities and modern distribution infrastructure that allows them to operate efficiently across national borders.

In India, for example, the 1966 Central Seed Act laid the legal foundation for a modern seed industry. In line with the national objective of attaining self-sufficiency in food production, the Act assigned responsibility for commodity research and seed production to public organizations (Morris *et al.* 1998; Pal *et al.* 1998). Maize breeding research and seed production remained firmly in the public domain until 1988, when the New Policy for Seed Development opened the doors to foreign participation. Today, public and private sectors both play an active role in India's maize seed industry. Public organizations continue to engage in breeding research, seed production and seed distribution, but their efforts are complemented by an increasingly active private seed industry that now dominates releases of new varieties and controls the lion's share of the commercial seed market.

[3] China's maize seed industry, a not-for-profit enterprise that remains entirely within the public sector, remains an exception to this trend (J. Huang, personal communication; Pray *et al.* 1998).

Public-Private Sector Linkages

International maize breeding is carried out by a complex system made up of a large number of diverse organizations—large and small, public and private, national and international. Many of the organizations that participate in the global maize breeding system are linked through the exchange of products, services or information.

How are these linkages playing out in the Asian context? Three types of collaborative activities serve to illustrate how public-private sector linkages are growing in Asia: international germplasm exchanges, public-private germplasm transfers and collaborative varietal testing networks.

International Germplasm Exchanges

Prior to 1960, no formal system existed to provide plant breeders with access to germplasm developed outside their home countries (Traxler and Pingali 1999). Movement of germplasm occurred informally as breeders exchanged promising materials with friends and professional colleagues. With the establishment of the Consultative Group on International Agricultural Research (CGIAR) in 1969, a mechanism appeared that provided the global breeding community with access to research products from public institutions. In Asia, the international maize germplasm distribution and exchange network is coordinated by CIMMYT. Any bona-fide maize breeder can write CIMMYT requesting samples of promising experimental materials. These materials, which are provided by CIMMYT free of charge, may be used by the breeder in his or her breeding program. Once used mainly as a mechanism for distributing materials to public breeding programs, the CIMMYT germplasm distribution network is increasingly being exploited by private seed companies as a source of promising experimental materials.

Public-Private Germplasm Transfers

The privatization of many national maize seed industries has been accompanied by an increase in the rate of germplasm transfers from public breeding programs to private seed companies. Under pressure to reduce expenditures, governments in many Asian countries have scaled back investment in seed production and distribution, activities that are readily assumed by private firms because they offer clear profit opportunities. As a result, managers of public breeding programs have had to seek out new mechanisms for moving their germplasm products into farmers' fields. In many countries, they are attempting to do this by making improved germplasm available to seed companies, often on a commercial basis. Thailand is a good example of the new types of germplasm transfer mechanisms being forged between public breeding organizations and private seed companies. Thailand's two main public maize breeding programs (based at Kasetsart University and in the Department of Agriculture) provide elite inbred lines to multinational and domestic private companies for use in forming commercial hybrids (see the Thailand country report, Chapter 7). Traditionally, the elite inbred lines were provided free of charge, but beginning in the mid-1990s, Kasetsart University started collecting royalties from private-sector recipients. An important feature of the arrangement is that the recipient is assured exclusive use of the germplasm.

Collaborative Varietal Testing Networks

The strengthening of linkages between the public and private sectors is also reflected in collaborative varietal evaluation trials, which provide a mechanism for public breeding programs and private seed companies to compare promising experimental materials and

exchange information. The Tropical Asian Maize Network (TAMNET), whose membership includes public breeding programs and private seed companies from Asian countries, was established in 1993 with financial support from the Food and Agriculture Organization (FAO) of the United Nations. The purpose of TAMNET, which is managed by CIMMYT, is to facilitate and strengthen regional collaboration among and between member institutions, with the ultimate goal of increasing maize production and productivity (FAO 1999). One of TAMNET's main functions is to manage a multilocational varietal evaluation program; annual field trials are conducted throughout the region, and the resulting data on field performance across countries are synthesized and shared among TAMNET members.

Products of Maize Breeding Programs

The first CIMMYT maize impact survey published in 1994 yielded detailed descriptive data on the physical characteristics and genetic backgrounds of 842 maize varieties[4] released in developing countries between 1966 and 1990 (López-Pereira and Morris 1994). Of these, about 190 varieties were released by the public sector in South, East and Southeast Asia (135 in the seven countries included in the current study).

The current study updated the information collected in the earlier study and significantly expanded the varietal releases database. As in the earlier study, the coverage of public- and private-sector materials is not the same. Public breeding organizations were asked to provide information about all maize varieties developed since 1966, the year that CIMMYT was founded. In contrast, private seed companies were asked to provide information *only* about the maize varieties that they were currently selling; most of these materials consisted of hybrids released during the 1990s. In the case of the private sector, it was not possible to compile a complete list of all varieties developed since 1966; many private seed companies that operated during the 1960s, 1970s and 1980s no longer exist, and many of those that still exist would have difficulty retrieving information from 20-30 years ago. (A few private companies did provide information about varieties that were no longer being sold at the time of the survey, although the coverage of these older varieties was incomplete.)

The survey of public breeding organizations identified 360 maize varieties released by public breeding programs between 1966 and 1997/98 in the seven Asian countries that participated in the study (Table 6).[5] Nearly two-thirds of these public-sector varieties (232, or 64%) were being marketed at the time of the survey. The survey of private seed companies generated information about 302 maize varieties developed by private breeding programs. Over three-quarters (235, or 78%) were being marketed in Asia at the time of the survey.

Public-Sector Releases

Types of Materials

Of the 360 maize varieties released since 1966 by public maize breeding programs in Asia, 211 (59%) were OPVs and 149 (41%) were hybrids (Table 7). Public breeding programs in the Philippines released the largest number of OPVs (55), while those in China released the largest number of hybrids (69). In most Asian countries, there has

[4] In this report, the term "varieties" is used in a generic sense to mean "improved OPVs and hybrids," whereas the terms "improved OPVs" and "OPVs" are used in a specific sense to mean "improved OPVs developed by a formal breeding program."

[5] Unless noted, the varietal counts refer only to field maize varieties. Specialty types, including baby corn, are not included.

Table 6. Characteristics of maize varieties released in Asia, by sector[a]

Indicator	Public sector[b]	Private sector[c]
Maize varieties in CIMMYT database (number)	360	302
Maize varieties being sold during late 1990s (number)[d]	232	235
Type of maize released (%)[a]		
Improved OPVs	59	Nil
Hybrids		
Single cross	21	21
Double cross	7	41
Three-way cross	6	35
Other	7	3
Maize characteristic (%)		
Ecological adaptation		
Lowland tropical	69	94
Subtropical/mid-altitude	30	6
Temperate	1	0
Grain color		
White	25	10
Yellow	75	90
Grain texture		
Flint	26	30
Semi-flint	40	37
Dent	12	10
Semi-dent	22	23
Maturity range		
Extra-early (<100 days)	29	30
Early (100-110 days)	34	46
Intermediate (110-120 days)	19	16
Late (120-135 days)	10	4
Extra-late (>135 days)	8	4
Age of varieties		
<10 years	47	84
11-20 years	35	14
21-30 years	13	2
>30 years	5	0

Source: CIMMYT Asia Maize Impact Survey 1998-99.

Note: Data for China, India, Indonesia, Nepal, Philippines, Thailand and Vietnam.

[a] Without double-counting varieties sold by different agencies within a country and/or released in more than one country in Asia.

[b] Released from 1966 to 1997/98.

[c] Snapshots of 1992 and late 1998/early 1999; not a complete listing of all private-sector varieties released since 1966.

[d] Many older OPVs are still being grown from farm-saved seed, even though seed is no longer sold.

been an inverse relationship between the number of OPVs released and the number of hybrids released. Only in Vietnam have public breeding programs given roughly equal emphasis to the development of OPVs and hybrids.

Since 1966, Asia's public breeding programs have released maize varieties at an increasing rate (Figure 3). Aggregating across the seven countries covered by the survey, during the late 1960s public breeding programs released maize varieties at an average rate of one per year. By the late 1990s, this had increased to five per year.

Not only the rate but also the composition of public releases has changed through time. Development of OPVs was emphasized until the 1990s, when attention shifted to hybrids (Figure 4). There are at least three reasons for this shift in research emphasis. First, most Asian countries were interested in promoting the adoption by farmers of higher-yielding cultivars that could help meet rapidly increasing demand for maize grain.[6] Second, managers of public breeding programs perceived an opportunity to provide hybrids to farmers at more affordable prices than those

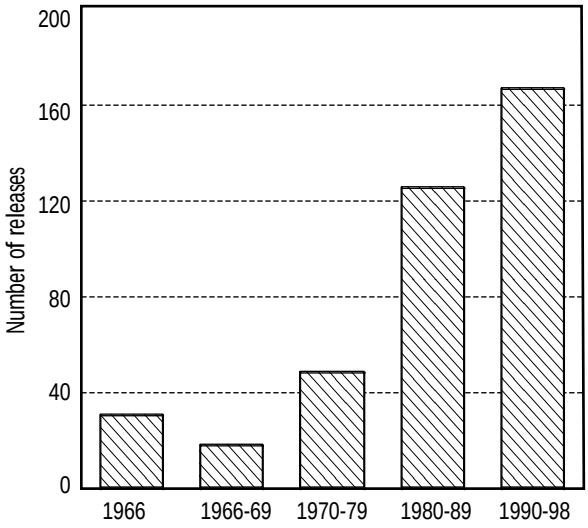

Figure 3. Number of maize releases by public breeding programs, Asia, 1966-97/98.
Source: CIMMYT Asia Maize Impact Survey 1998-99.

Table 7. Types and numbers of field maize varieties released by public breeding programs, selected Asian countries and region, 1966-1997/98

		Hybrids			
	Improved OPVs	Single cross	Three-way cross	Double cross	Other
China (south)[a]	14	50	7	2	10
India	80	8	5	10	8
Indonesia	21	1	3	2	0
Nepal	18	0	0	0	0
Philippines	55	1	3	4	0
Thailand	5	7	3	0	0
Vietnam	24	10	0	6	10
Asia[b]	211	77	21	24	27
Proportion	59	21	5	7	8

Source: CIMMYT Asia Maize Impact Survey 1998-99.

[a] Summary figures for each country do not double-count varieties marketed by different seed agencies within the same country.

[b] Regional summary figures do not double-count varieties marketed by different seed agencies within the same country and/or released in more than one country.

[6] The development of hybrids exploits hybrid vigor, or heterosis, which refers to the increase in size or rate of growth of offspring over parents, and can be observed in an increase in grain yield or reduction in the number of days to flowering. On average, hybrids yield 15% more grain than OPVs. Heterosis is also an important cause of hybrid superiority in yield and yield stability (Duvick 1999).

charged by private seed companies. Third, hybrids offered increased opportunities for public breeding programs to generate resources for themselves.

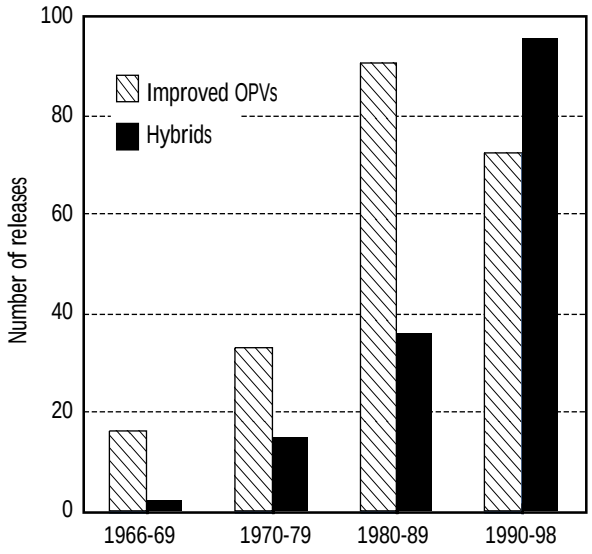

Figure 4. Number of public maize releases by type of material, Asia, 1966-97/98.
Source: CIMMYT Asia Maize Impact Survey 1998-99.

Ecological Adaptation

Over two-thirds (69%) of the maize varieties released by public breeding programs in Asia during 1966-97/98 have been adapted to lowland tropical environments (Table 8). As expected, only in China, India and Nepal have public breeding programs released varieties adapted to subtropical/mid-altitude environments.

Grain Characteristics

Three-fourths (75%) of the maize varieties released by public breeding programs in Asia during 1966-97/98 were yellow-grained and one-fourth were white-grained (Table 9). In countries such as the Philippines, where considerable quantities of maize are still consumed directly as food, especially by subsistence farmers, relatively more white-grained maize varieties were released. In countries such as Thailand, where maize is grown mainly for use in livestock feed industries, yellow-grained varieties predominated.

Table 8. Number of maize varieties released by public breeding programs, by ecological adaptation, selected Asian countries and region, 1966-1997/98

	Lowland tropical	Subtropical/mid-altitude	Temperate[a]
China (south)[a,b]	3	15	1
India	20	55	3
Indonesia	27	0	0
Nepal	9	9	0
Philippines	63	0	0
Thailand	15	0	0
Vietnam	50	0	0
Asia[c]	181	78	4
Proportion	69	30	1

Source: CIMMYT Asia Maize Impact Survey 1998-99.

[a] Many maize varieties released in northern China are adapted to temperate conditions, but these varieties are not included in the CIMMYT database.

[b] Summary figures for each country do not double-count varieties marketed by different seed agencies within the same country.

[c] Regional summary figures do not double-count varieties marketed by different seed agencies within the same country and/or released in more than one country.

Table 9. Number of maize varieties released by public breeding programs, by grain characteristic, selected Asian countries and region, 1966-1997/98

	Grain color		Grain texture			
	White	Yellow	Flint	Semi-flint	Dent	Semi-dent
China (south)[a]	15	56	6	11	22	24
India	20	90	71	11	9	14
Indonesia	3	22	11	12	0	1
Nepal	7	11	14	0	1	3
Philippines	34	27	25	10	1	1
Thailand	0	15	5	10	0	0
Vietnam	3	31	1	23	4	9
Asia[b]	81	246	129	76	36	51
Proportion (%)	25	75	44	26	12	18

Source: CIMMYT Asia Maize Impact Survey 1998-99.

[a] Summary figures for each country do not double-count varieties marketed by different seed agencies within the same country.

[b] Regional summary figures do not double-count varieties marketed by different seed agencies within the same country and/or released in more than one country.

More than two-thirds (70%) of the maize varieties released by public breeding programs in Asia during 1966-97/98 were hard-grained flint or semi-flint materials; the rest (30%) were soft-grained dent or semi-dent materials (Table 9). The emphasis of most Asian public breeding programs on flint and semi-flint materials can be attributed to the greater suitability of these materials for use as livestock feed and their added advantage of storing well. Only in China have public breeding programs focused more on dent and semi-dent materials, a pattern that may reflect a preference among Chinese consumers for soft-grained food maize that is easier to process. The relatively high proportion of soft-grained materials among Chinese releases may also reflect the fact that Chinese breeders make extensive use of breeding materials from the US Corn Belt, most of which are dents or semi-dents.

Most of the maize varieties released by public breeding programs in Asia during 1966-97/98 were short-duration varieties. Nearly two-thirds (63%) of all public-sector releases were classified as "extra early" (maturing in less than 100 days) or "early" (maturing in 100-110 days) (Table 10). Short-duration varieties offer both technical and economic advantages: they can be accommodated more easily into intensive cropping patterns in which two or more crops are grown annually; they enable the maize crop to escape drought in areas where the rainfall period is too brief to support late-maturing varieties; and they shorten the length of the "hungry season" by providing a source of food well before other food sources become available. These advantages are offset by several potential disadvantages, however. Compared to full-season varieties, short-duration varieties tend to be lower yielding, more susceptible to diseases and more vulnerable to insect damage. The challenge for maize breeders therefore has been to develop short-duration varieties that combine high yield potential with acceptable levels of disease and insect resistance or tolerance.

Private-Sector Varieties

In interpreting the tables and figures presented in this section, it is important to recall that the data on private-sector varietal releases are not directly comparable with those presented earlier on public releases. Two points must be kept in mind.

Table 10. Number of maize varieties released by public breeding programs, by maturity class, selected Asian countries and region, 1966-1997/98

	Extra-early (<100 days)	Early (100-110 days)	Intermediate (110-120 days)	Late (120-135 days)	Extra-late (>135 days)
China (south)[a]	3	16	16	18	10
India	23	34	8	0	5
Indonesia	17	5	0	1	1
Nepal	4	4	4	2	4
Philippines	31	21	1	0	2
Thailand	1	2	12	0	0
Vietnam	3	11	11	7	0
Asia[b]	78	91	52	28	22
Proportion (%)	29	34	19	10	8

Source: CIMMYT Asia Maize Impact Survey 1998-99.

[a] Summary figures for each country do not double-count varieties marketed by different seed agencies within the same country.

[b] Regional summary figures do not double-count varieties marketed by different seed agencies within the same country and/or released in more than one country.

First, whereas the information collected from public breeding programs relates to all public varieties released between 1966 and 1997/98, the information collected from private seed companies relates only to varieties available on the market in 1992 (collected during the original CIMMYT impact survey) and in 1997/98 (collected during the recent follow-up survey). These mostly consisted of commercial hybrids released during the 1990s. In other words, coverage of private-sector varieties developed and sold during the 1960s, 1970s and 1980s is incomplete.

Second, although varieties developed by public breeding programs typically are released only in the country in which they were developed, commercial hybrids from the private sector often are introduced simultaneously in several countries (especially hybrids developed by multinational seed companies).[7] Also, multinational companies often contract with one or more private national seed companies within the same country to produce and distribute seed. Under these conditions, multiple counting is difficult to avoid, because many varieties appear a number of times in the database. To avoid distortions due to multiple counting, if a variety was sold by more than one seed company within the same country, it was listed only once in the varietal releases database (under the name of the company that developed and released the variety).

Country-level analyses based on the private-sector varietal releases database are presented in Tables 11-14. Regional analyses are presented in Figures 5-8.

Types of Materials

Table 11 shows the number of private maize varieties available on the market in Asia during 1997/98, disaggregated by type of material (OPVs vs. hybrids) and by type of seed company (private national vs. multinational).

[7] India and Nepal present a special case. All of the private-sector varieties and some public-sector varieties available in Nepal were developed by private seed companies and public maize R&D agencies in India. Nepali input traders market the seed across the borders.

During the late 1990s, most of the private-sector varieties being sold in Asia had been developed by multinational companies; only in India had the majority of private-sector varieties been developed by national companies. In interpreting these figures, it is important to keep in mind that no national seed companies were engaged in maize R&D in Indonesia, Nepal or Vietnam. In Indonesia and Vietnam, private-sector maize R&D was being carried out only by multinationals. In Nepal, no national seed companies were engaged in maize R&D; seed companies in Nepal were selling seed mainly of imported varieties developed by Indian companies. In China, virtually no private-sector maize R&D of any description was being carried out.

As expected, both national private companies and multinationals were concentrating heavily on hybrids. Only one private company had developed an OPV—P.T. BISI of Indonesia, a multinational (Table 11).

The number and types of hybrids being marketed by private seed companies varied between countries. Private companies in India had the largest number of different hybrids on the market (102), while private companies in Vietnam had the fewest (11). Three-way-cross and double-cross hybrids dominated private-sector offerings in India, Nepal and the Philippines, whereas single-cross hybrids dominated in Thailand and Vietnam.

Differences between countries in the numbers and especially the types of hybrids being sold can be explained by economic as well as political factors. In a number of countries, especially those in which maize production is still predominantly subsistence-oriented, demand for higher-priced hybrid seed types has simply been lacking. In other countries, demand for hybrid seed has been strengthening, but seed companies have had difficulty responding to this demand.

Table 11. Types and numbers of private-sector maize varieties available on the market, selected Asian countries, late 1990s

		Hybrids			
	Improved OPVs	Single cross	Three-way cross	Double cross	Other
Private national companies					
China (south)[a]	na	na	na	na	na
India	0	14	19	40	0
Indonesia	na	na	na	na	na
Nepal[b]	0	2	2	8	0
Philippines	0	1	14	3	0
Thailand	0	4	1	0	0
Vietnam	na	na	na	na	na
Multinational companies					
China (south)[a]	na	na	na	na	na
India	0	2	4	19	4
Indonesia	1	7	13	1	1
Nepal[b]	0	0	1	2	1
Philippines	0	1	14	6	0
Thailand	0	16	11	2	0
Vietnam	0	7	2	1	1

Source: CIMMYT Asia Maize Impact Survey 1998-99.

Note: na = not available, because type of company is not involved with maize R&D in the country.

[a] Summary figures for each country do not double-count varieties marketed by different seed agencies within the same country.

[b] Maize varieties from private national and multinational companies of India, exporting to Nepal.

Since hybrid seed tends to be expensive to produce, it must be sold at premium prices to recoup production costs. In a number of Asian countries, private companies have difficulty implementing prices at levels that ensure full cost recovery. Direct seed price controls are no longer common in Asia (except in China), but the ability of private companies to set remunerative prices is affected indirectly by policies that favor public seed agencies. In Vietnam, for example, representatives of several private companies interviewed for the CIMMYT survey observed that they are forced to compete with government seed agencies that not only receive subsidies but also benefit from favorable regulatory treatment. As an example of the latter, shortly before the survey was conducted, the Vietnamese government announced plans to require private seed companies to establish in-country seed production facilities. For most of the multinationals operating in Vietnam, in-country seed production would be inefficient owing to the small size of the Vietnamese hybrid seed market; most multinationals would prefer to import commercial seed into Vietnam from more efficient production facilities located in neighboring countries.

High production cost is only one of the factors that have discouraged some private seed companies from selling hybrids. To produce commercial seed of hybrids, the seed companies must provide contract growers with the parent inbred maize lines. In the absence of enforceable intellectual property rights, private companies are often reluctant to release their best hybrids, especially single-cross and three-way-cross hybrids, since it may be extremely difficult to protect the inbred lines used to produce these types of hybrids. Fear of losing their valuable inbred lines to unscrupulous competitors has discouraged several multinationals from marketing their best hybrids in several Asian countries.

Despite these economic and political constraints, private seed companies have in recent years been expanding their product lines, and many now sell seed of several different types of hybrids. Many seed companies recognize that they can increase sales by segmenting the market, and that selling into a commercial farming sector willing and able to pay for technically sophisticated single-cross and three way-cross hybrids does not prevent them from at the same time targeting other segments of the market for whom less sophisticated double-cross and top-cross hybrids may be more appropriate. For this reason, companies that sell single-cross and three-way-cross hybrids often also sell double-cross, top-cross and double-top-cross hybrids.

Ecological Adaptation

Most of the maize varieties developed by the private sector and sold in Asia during the late 1990s were adapted to lowland tropical environments (Table 12). This is hardly surprising, given that most of the area planted to maize in Asia (excluding China's temperate maize area) was located in such environments. The proportion of private-sector varieties showing lowland tropical adaptation was particularly high in Indonesia (100%), Vietnam (100%), the Philippines (98%) and Thailand (85%). Only in India and Nepal were a significant number of private-sector varieties adapted to other production environments (subtropical/mid-altitude environments).

Grain Characteristics

Most of the maize varieties developed by the private sector and sold in Asia during the late 1990s were yellow-and hard-grained (flint or semi-flint) materials (Table 13). This suggests that private companies have made a deliberate attempt to meet the large and increasing demand for livestock feed. The Asian feed industry generally prefers yellow maize because it imparts desirable color to eggs and poultry meat. Hard-

Table 12. Number of maize varieties from the private sector available on the market, by ecological adaptation, selected Asian countries, late 1990s

	Private national companies			Multinational companies		
	Lowland tropical	Subtropical / mid-altitude	Temperate	Lowland tropical	Subtropical / mid-altitude	Temperate
China (south)[a]	na	na	na	na	na	na
India	1	5	0	3	0	0
Indonesia	na	na	na	23	0	0
Nepal[b]	5	3	na	4	0	0
Philippines	17	1	0	24	0	0
Thailand	5	0	0	29	0	0
Vietnam	na	na	na	11	0	0

Source: CIMMYT Asia Maize Impact Survey 1998-99.

Note: na = not available, because type of company is not involved with maize R&D in the country.

[a] Summary figures for each country do not double-count varieties marketed by different seed agencies within the same country.

[b] Maize varieties from private national companies and multinational companies of India, exporting to Nepal.

Table 13. Number of maize varieties from the private sector available on the market, by grain characteristic, selected Asian countries, late 1990s

	Grain color		Grain texture			
	White	Yellow	Flint	Semi-flint	Dent	Semi-dent
Private national companies						
China (south)[a]	na	na	na	na	na	na
India	4	69	19	26	9	19
Indonesia	na	na	na	na	na	na
Nepal[b]	0	12	3	4	0	5
Philippines	1	17	4	5	0	0
Thailand	0	5	0	2	0	3
Vietnam	na	na	na	na	na	na
Multinational companies						
China (south)[a]	na	na	na	na	na	na
India	8	20	5	12	7	5
Indonesia	4	19	6	17	0	0
Nepal[b]	0	4	0	1	1	2
Philippines	1	28	12	4	0	1
Thailand	1	28	18	7	3	1
Vietnam	0	11	3	6	0	2

Source: CIMMYT Asia Maize Impact Survey 1998-99.

Note: na = not available because type of company is not involved with maize R&D in the country.

[a] Summary figures for each country do not double-count varieties marketed by different seed agencies within the same country.

[b] Maize varieties from private national and multinational companies of India, exporting to Nepal.

grained (flint or semi-flint) maize is preferred because it tends to be more resistant to fungi and insects, and because it is less likely to spoil during shipping and storage than soft-grained (dent or semi-dent) maize (Dowswell *et al.* 1996). The latter characteristic is particularly important in less-developed countries, where it often takes time to transport maize grain from production zones to processing points in larger cities. Only in India were private seed companies offering a wide range of maize grain textures.

With regard to the maturity class of maize varieties sold during the late 1990s by private companies, short-duration varieties (extra-early and early) predominated in India, Indonesia and the Philippines, whereas medium-duration varieties (intermediate) featured more prominently in Thailand and Vietnam (Table 14). As cropping intensity increases in the region's more favored production environments, the demand for high-yielding, short-duration varieties can be expected to increase.

Regional Patterns in Varieties Developed by the Private Sector

Regional patterns in maize varieties developed by the private sector can be discerned by summing the country-level data, but this method may give misleading results because the same hybrid was often released in several countries. To avoid problems with multiple counting, a single-entry database was constructed containing information about all private varieties being sold in Asia during the late 1990s. The database was constructed by eliminating redundant entries (i.e., multiple entries for varieties that were released in more than one country). To allow comparisons between varietal release patterns of private and public breeding programs, a single-entry database was also constructed containing information about all of the public varieties being sold during the late 1990s.

Table 14. Number of maize varieties from the private sector available on the market, by maturity class, selected Asian countries, late 1990s

	Extra-early (<100 days)	Early (100-110 days)	Intermediate (110-120 days)	Late (120-135 days)	Extra-late (>135 days)
Private national companies					
China (south)[a]	na	na	na	na	na
India	28	32	9	1	0
Indonesia	na	na	na	na	na
Nepal[b]	4	5	3	0	0
Philippines	6	10	0	0	2
Thailand	0	3	2	0	0
Vietnam	na	na	na	na	na
Multinational companies					
China (south)[a]	na	na	na	na	na
India	9	8	8	0	4
Indonesia	12	8	0	0	0
Nepal[b]	1	1	1	0	1
Philippines	6	14	0	0	3
Thailand	1	12	12	3	0
Vietnam	1	8	2	0	0

Source: CIMMYT Asia Maize Impact Survey 1998-99.

Note: na = not available because type of company is not involved with maize R&D in the country.

[a] Summary figures for each country do not double-count varieties marketed by different seed agencies within the same country.

[b] Maize varieties from private national and multinational companies of India, exporting to Nepal.

As in other regions of the developing world (Morris and López-Pereira 1999, Hassan *et al*. 2001), in Asia the private sector has concentrated on selling hybrids (Figure 5). Among all the maize varieties developed by the private sector and marketed in Asia during the late 1990s, double-cross hybrids predominated (41%), followed by three-way-cross hybrids (35%) and single-cross hybrids (21%). Double-cross and three-way cross hybrids were marketed both by national seed companies and multinationals; single-cross hybrids were marketed much more frequently by multinationals. The strong emphasis by private seed companies on hybrids contrasted sharply with the emphasis of public seed agencies in Asia, which during the same period were selling mainly OPV seed. The private sector's strong emphasis on hybrids was based on commercial considerations: farmers who plant hybrids are often commercial growers who not only require significant quantities of seed but who also tend to purchase fresh seed every year. In addition, hybrid seed usually commands higher prices than seed of OPVs and thus provides increased profit opportunities for seed companies.

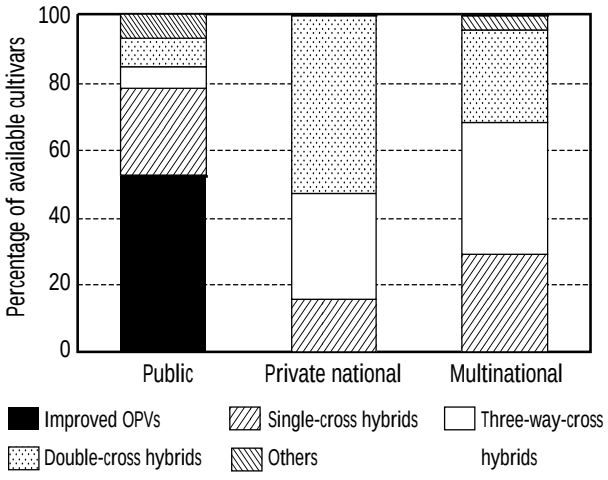

Figure 5. Maize varieties available in the late 1990s in Asia, by type of cultivar and seed agency (in %).
Source: CIMMYT Asia Maize Impact Survey 1998-99.

The vast majority of maize varieties being marketed in Asia by private seed companies during the late 1990s (94%) were adapted to lowland tropical environments. A relatively small number of varieties (6%) were adapted to subtropical/mid-altitude environments. With the notable exception of northern China (which was not included in the CIMMYT survey), none of the maize varieties being marketed in Asia by the private sector was adapted to temperate environments.

Regional patterns in grain color, grain texture and maturity class are summarized in Figure 6. In the private sector as in the public sector, most of the varieties sold in Asia during the late 1990s were yellow, hard-grained (flint or semi-flint) and short-duration (extra-early, early or intermediate). By implication, both public and private breeding programs mainly were targeting feed grain producers. In terms of absolute numbers, public breeding programs were selling many more white- and soft-grained varieties than were private companies, but expressed as a proportion of their overall product lines, the relative attention given to white vs. yellow varieties and to flint vs. dent varieties was comparable in both sectors. Given the apparent preponderance of feed-type varieties, the question arises whether public and private breeding programs have been giving undue attention to the needs of commercial farmers at the expense of the subsistence-oriented farmers who represent the majority of the region's poorest households.

How old were the maize varieties available in Asian markets during the late 1990s?[8] Generally speaking, the available private varieties were

[8] The list of varieties is based on commercial seed being sold during the late 1990s, which was not necessarily correlated with the actual area planted to modern maize varieties. In the case of OPVs, farmers can replant farm-saved seed, so many older OPVs were still being grown even though seed of those varieties was no longer available in the market. Also, seed of some of the varieties available in the market may not have been sold.

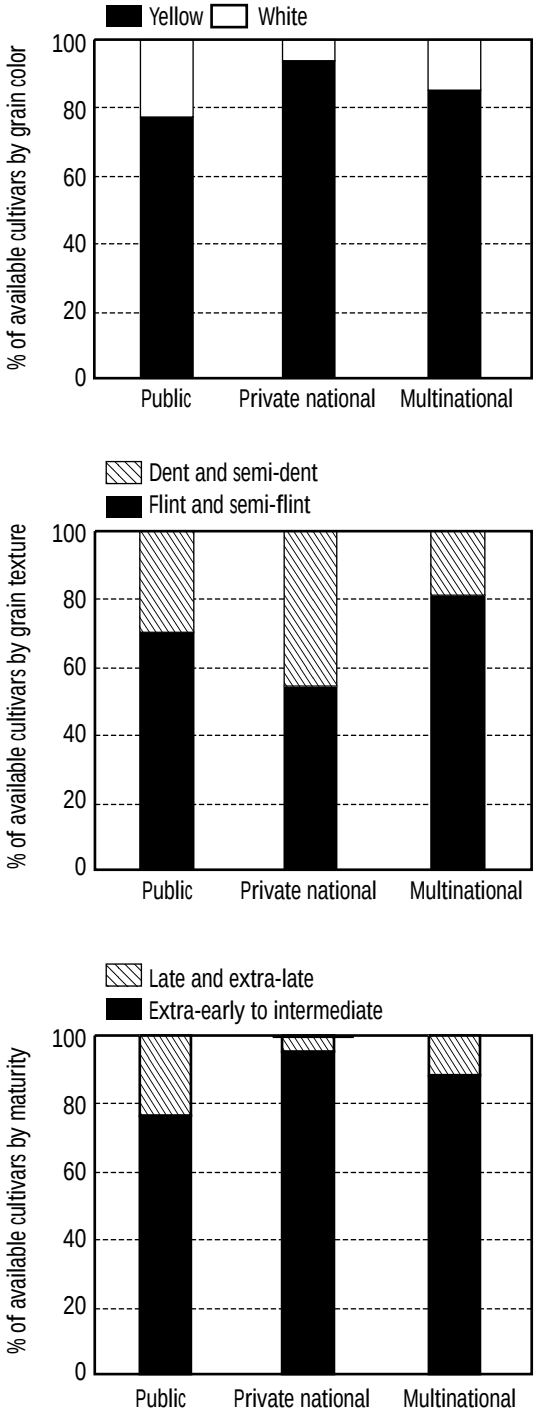

Figure 6. Characteristics of improved maize cultivars available in the market, by type of seed company, Asia, late 1990s.
Source: CIMMYT Asia Maize Impact Survey 1998-99.

considerably younger than the available public varieties (Figure 7). Only about 2% of the available private varieties had been released during the 1970s or earlier. In contrast, approximately 13% of the available public varieties were at least 30 years old. A number of factors could explain this difference. For example, the continuing presence in the market of old public varieties could be due to the fact that small local seed companies which lack their own R&D capacity continue to produce seed of these varieties. Alternatively, it is possible that private seed companies have simply been more aggressive in introducing new varieties and more successful in convincing farmers to replace their varieties on a regular basis.

Despite the differences mentioned earlier, on the whole the public and private maize varieties being sold in Asia during the 1990s were fairly similar (see Figure 8, next page; see also the discussion in the previous section).

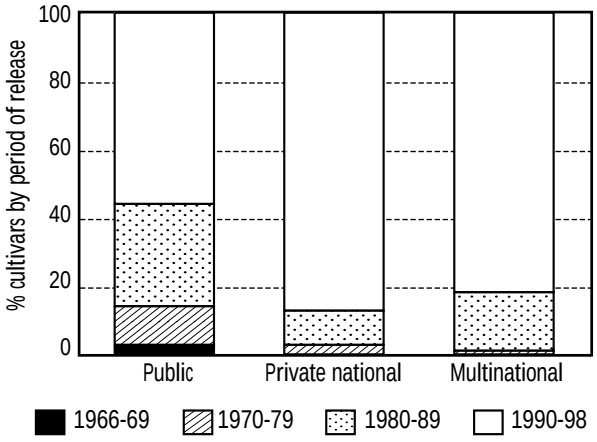

Figure 7. Percentage of materials available in the late 1990s in Asia, by type of seed company and age of material.
Source: CIMMYT Asia Maize Impact Survey 1998-99.

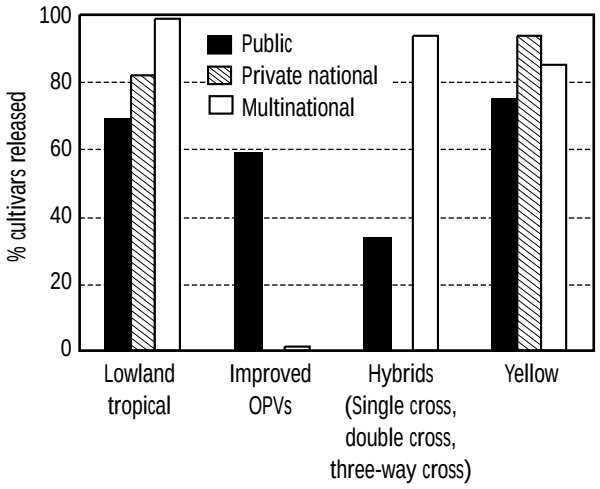

Figure 8. Selected characteristics of public varieties released during 1966-97/98 vs. private varieties available during the late 1990s, Asia.
Source: CIMMYT Asia Maize Impact Survey 1998-99.

Status and Performance of the Maize Seed Industry

Commercial Maize Seed Sales and Market Shares

By analyzing patterns in releases of maize varieties, it is possible to draw inferences about the activities of public and private maize breeding programs. But varietal releases in and of themselves do not reveal anything about impact at the farm level, because some varieties are grown much more widely than others. To estimate the farm-level impact of maize breeding programs, it is therefore necessary to examine evidence on adoption of varieties.

The most direct way to estimate adoption is through farm-level surveys. Farm-level adoption surveys are costly to implement, however, and they are rarely performed at the national level. Therefore it is usually necessary to estimate varietal adoption indirectly. One way to do this is by examining data on commercial maize seed sales. Unfortunately, commercial seed sales are difficult to estimate with precision. In most countries, data on commercial seed sales are not compiled by the government, and even where they are compiled, they are often inaccurate, because government seed agencies and private seed companies both may have incentives to misrepresent their sales figures.

Data on commercial maize seed sales in Asia were collected from public seed agencies and private seed companies as part of the CIMMYT survey. While it was not possible to collect information about all of the commercial maize seed sold in Asia during the reference year (1996/97), the coverage of the survey was extensive. Information was collected for well over two-thirds of total estimated 1996/97 commercial maize seed sales in Asia. Assuming that the seed which was not included in the survey was similar to the seed included by the survey, it is possible to draw conclusions that are valid for the entire commercial maize seed market.

The 179 public and private seed agencies in Asia interviewed for this study reported selling just over 167,000 t of improved maize seed in 1996/97 (Table 15), of which 5,000 t (3%) consisted of OPV seed and 162,000 t (97%) consisted of hybrid seed. China had by far the largest commercial maize seed market in the region; in 1996/97, Chinese seed organizations (all of which were public companies) sold 87,600 t of hybrid maize seed, equivalent to 52% of all commercial maize seed sold throughout Asia.[9] India and Thailand ranked second and third in commercial maize seed sales, followed by Indonesia, the Philippines and Vietnam. Nepal had the region's smallest commercial maize seed market; only 1,500 t of commercial maize seed was sold in Nepal, equivalent to slightly less than 1% of the Asian market.

Because all commercial maize seed sold in China is produced by public organizations, and because

[9] The numbers for China would of course be much larger if northern China were included.

Table 15. Sales of maize seed (t) from the public and private sector, by type of organization, selected Asian countries and region, 1997

	Public seed agencies	Private national companies	Multinational companies	Total	Percent of total	Percent of total, excluding China
China	87,600	0	0	87,600	52.4	–
India	4,500	12,250	19,250	36,000	21.5	45.2
Indonesia	900	300	8,350	9,550	5.7	12.0
Nepal[a]	150	1,300	0	1,450	0.9	1.8
Philippines	140	1,300	6,700	8,140	4.9	10.2
Thailand	200	3,500	17,000	20,700	12.4	26.0
Vietnam	2,660	0	1,150	3,810	2.3	4.8
Asia	96,150	18,650	52,450	167,250	100.0	–
Asia, excluding China	8,550	18,650	52,450	79,650	–	100.0
Asia (%)	57.5	11.2	31.4	100.0	–	–
Asia (%), excluding China	10.7	23.4	65.9	100.0	–	–

Source: CIMMYT Asia Maize Impact Survey 1998-99.

[a] Private national maize seed companies in Nepal trade improved seed from India. No multinational maize seed companies operate in the country.

China's maize seed market is so large, seed sales by public organizations exceed seed sales by private companies for the region as a whole. Including the data for China, 58% of all commercial maize seed sold in Asia during 1996/97 was produced by public organizations. When China is excluded from the analysis, however, the picture changes dramatically: excluding the data for China, private seed companies dominate the Asian maize seed industry, accounting for 89% of all commercial maize seed sales during 1996/97. Within the private sector, multinational companies are much more important that national companies; in 1996/97, multinationals accounted for 66% of all commercial maize seed sales, whereas nationals accounted for only 23%.

China's enormous public maize seed industry differs from the public maize seed industries in other Asian countries in having emphasized hybrids rather than OPVs. For this reason, even though most commercial maize seed in Asia is produced by public organizations, seed sales in Asia have been dominated by hybrids. Of all commercial maize seed sold in Asia during 1996/97, 56% was seed of public hybrids, 41% was seed of private hybrids and only 3% was seed of OPVs from public and private agencies[10] (Table 16). Excluding the data for China, the picture changes: fully 85% of all commercial maize seed sold during 1996/97 consisted of hybrid seed produced by private seed companies.

What explains the increasing domination of private hybrids, especially outside China? Three factors appear to be at work. First, many of the hybrids developed by private seed companies are simply better than the hybrids developed by public breeding programs. The superior performance of many private-sector hybrids reflects the longstanding concentration of private seed companies on hybrid breeding, as well as more focused targeting of production environments. Second, the quality of the hybrid

[10] This proportion is probably an underestimate because of poor documentation of sales and distribution by public seed agencies.

Table 16. Maize seed sales (t) by the public and private sector, by maize type, selected Asian countries and region, 1997

	Public sector			Private sector			Both sectors		
	Improved OPVs	Hybrids	Total	Improved OPVs	Hybrids	Total	Improved OPVs	Hybrids	Total
China	0	87,600	87,600	0	0	0	0	87,600	87,600
India	650	3,850	4,500	700	30,800	31,500	1,350	34,650	36,000
Indonesia	350	550	900	1,250	7,400	8,650	1,600	7,950	9,550
Nepal	150	0	150	900	400	1,300	1,050	400	1,450
Philippines	60	80	140	0	8,000	8,000	60	8,080	8,140
Thailand	170	30	200	400	20,100	20,500	570	20,130	20,700
Vietnam	360	2,300	2,660	0	1,150	1,150	360	3,450	3,810
Asia	1,740	94,410	96,150	3,250	67,850	71,100	4,990	162,260	167,250
Asia, excluding China	1,740	6,810	8,550	3,250	67,850	71,100	4,990	74,660	79,650
Asia (% total)	1.0	56.4	57.5	1.9	40.6	42.5	3.0	97.0	100.0
Asia (%, excluding China)	2.2	8.5	10.7	4.1	85.2	89.3	6.3	93.7	100.0

Source: CIMMYT Asia Maize Impact Survey 1998-99.

seed produced by private companies is often better than that of the hybrid seed produced by public seed agencies. Private companies tend to pay a lot of attention to seed quality assurance, since their economic survival depends on the reputation that they are able to establish among farmers. In contrast, public seed agencies usually have little incentive to look after seed quality. Third, private seed companies on the whole have been much more effective in marketing their hybrids through aggressive advertising and promotion campaigns. They have generally done an excellent job of building production and distribution networks that allow seed to be delivered efficiently to the end user, often on credit, and sometimes along with complementary inputs such as fertilizer and crop chemicals. In contrast, public seed agencies have tended to distribute their seed through centralized distribution facilities that frequently are difficult for farmers to reach.

If the rising popularity of private-sector hybrids can be explained largely by technical and economic factors, what explains the increasing dominance of Asian seed markets by multinational companies? Case study evidence suggests that many farmers in Asia make seed purchasing decisions based on the reputation of the seed company, rather than on detailed knowledge about the performance of specific hybrids (for example, see Singh and Morris, 1997). In other words, when it comes to selling maize seed, brand name recognition is important. Many multinational companies have been able to establish national reputations by investing aggressively in advertising and promotion. In contrast, most national companies are known only within certain regions of a country or at the local level. Public seed agencies, which usually have limited resources to promote and advertise their products, are known even less widely. Although public and private national seed agencies in some countries have been able to sell hybrid seed through government-supported maize production campaigns, this outlet can dry up abruptly when the subsidies end. In the Philippines, for example, maize farmers are provided subsidized hybrid seed through the Agrikulturang Makamasa (Agriculture for the Masses) Program; without the program, farmers generally will not buy hybrid seed because of financial constraints.

Evolution of Commercial Maize Seed Sales

How have commercial maize seed sales in Asia changed through time? Aggregating across the region as a whole, commercial maize seed sales rose from about 91,000 t in 1990 to just over 167,000 t in 1997 before decreasing to 144,000 t in 1998 (Figure 9). The decline recorded in 1998 was a direct result of the severe financial crisis in the region, which among other things dramatically increased the real cost of seed and other purchased inputs. Over the entire 1990-98 period, sales of OPV seed declined at an average rate of 4% per year, while sales of hybrids increased at an average rate of nearly 8% per year (Table 17).

These aggregate growth numbers conceal important differences between what was happening in the public and private sectors. Between 1990 and 1998, sales by public seed organizations grew at an average rate of 2% per year, while sales by private companies grew at the much higher average rate of 24% per year. The relatively sluggish growth in sales by public seed organizations was driven mainly by sales of OPV seed, whereas the explosive growth in sales by private companies was fueled entirely by increased sales of hybrid seed. The divergent rates of seed sales growth between the public and private sectors led to the increasing dominance of the private sector alluded to previously (Figure 10).

Prices and Price Ratios

Table 18 shows average maize seed prices prevailing in Asian countries in 1997/98. To eliminate possible exchange rate distortions, seed prices are expressed not only in terms of US

Table 17. Annual growth (%/yr) in commercial maize seed sales by the public and private sector, by maize type, Asia, 1990-98

	1990-93	1994-98	1990-98
Public sector			
Improved OPVs	-16.3	28.6	10.9
Hybrids	1.8	2.0	2.0
Total	1.7	2.4	2.2
Private sector			
Improved OPVs	-19.7	0.9	-9.0
Hybrids	58.9	13.4	32.4
Total	35.5	12.7	24.4
Both sectors			
Improved OPVs	-19.3	9.6	-4.0
Hybrids	8.2	5.7	7.9
Total	6.9	5.8	7.4

Source: CIMMYT Asia Maize Impact Survey 1998-99.
Note: Data for China, India, Indonesia, Nepal, Philippines, Thailand and Vietnam.

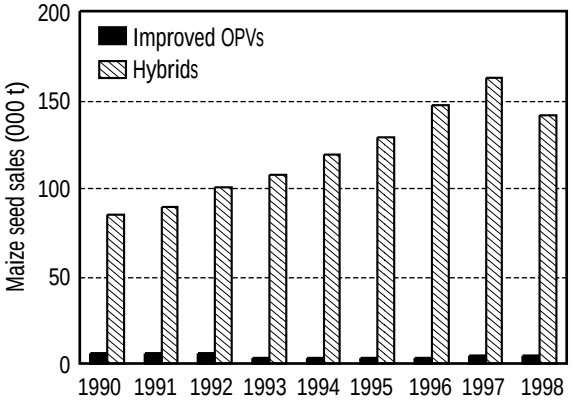

Figure 9. Evolution of maize seed sales by type of cultivar, Asia, 1990-98.
Source: CIMMYT Asia Maize Impact Survey 1998-99.

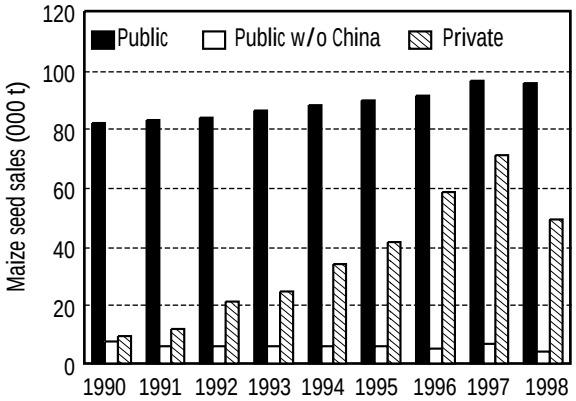

Figure 10. Evolution of maize seed sales by sector, Asia, 1990-98.
Source: CIMMYT Asia Maize Impact Survey 1998-99.

Table 18. Average maize seed prices and seed-to-grain price ratios, by type of material and seed company, Asia, 1997/98

		Private sector			
	Public sector	National companies	Multinational companies	All private companies	Both sectors
Maize seed price (US$/kg)					
Improved OPV	0.71	0.57	0.57	0.57	0.59
Single cross	na	1.61	2.48	2.07	2.07
Three-way cross	2.00	1.15	1.69	1.46	1.51
Double cross	1.17	1.33	1.23	1.29	1.27
Non-conventional	na	1.11	1.84	1.35	1.35
All hybrids	1.45	1.37	1.87	1.58	1.57
All types of seed	1.15	1.09	1.85	1.38	1.35
Seed-to-grain price ratio					
Improved OPV	7.51	4.53	5.94	4.64	5.05
Single cross	na	11.65	21.13	16.71	16.71
Three-way cross	24.00	8.89	13.81	11.70	12.77
Double cross	9.37	10.62	9.54	10.21	10.11
Non-conventional	na	6.26	13.68	8.73	8.73
All hybrids	14.25	10.76	15.75	12.85	12.99
All types of seed	10.81	8.63	15.48	11.26	11.21

Source: CIMMYT Asia Maize Impact Survey 1998-99.
Note: na = not available. Data for China, India, Indonesia, Nepal, Philippines, Thailand and Vietnam.

dollars per kilogram (US$/kg), but also as seed-to-grain price ratios (which show the number of kilograms of maize grain that must be sold to pay for one kilogram of seed).

As expected, seed of single-cross hybrids commanded the highest prices, averaging US$ 2.07/kg across the region as a whole, followed by seed of three-way-cross hybrids, which averaged US$ 1.51/kg. Seed of OPVs commanded the lowest prices, averaging US$ 0.59/kg across the region as a whole. These differences in retail selling prices correlate closely to differences in production costs. Seed of single-cross hybrids is the most expensive type of seed to produce (mainly because seed yields are low), followed by seed of three-way-cross hybrids. Seed of OPVs is relatively inexpensive to produce (not only because seed yields are high, but also because many costly and laborious operations required for hybrid seed production are unnecessary).

Do maize seed prices in Asia differ depending on whether the seed is produced by public agencies or private companies? Averaging across all types of materials for which complete data were available (single-cross hybrids, three-way-cross hybrids, double-cross hybrids, OPVs), seed sold by multinational companies was the most expensive (US$ 1.85/kg), followed by seed sold by public agencies (US$ 1.15/kg) and seed sold by private national companies (US$ 1.09/kg). Contrary to expectations, in many instances seed sold by public agencies commanded higher prices than seed sold by private companies, especially national companies.[11] Several possible explanations might account for this unexpected finding. For example, public agencies may be less efficient at producing

[11] In some countries, however, the prices of OPV seed from the public and private sectors were similar, mainly because private companies produce and market OPVs for the public agencies (see the Indonesia country report, chapter 4).

seed than private companies, and they may be passing along higher seed production costs in the form of higher prices. Alternatively, varieties marketed by public agencies may perform better, with the result that their seed can be sold at higher prices. It is also possible that the public-sector varieties simply are not priced competitively.

To exploit the full genetic potential of modern maize varieties, especially hybrids, farmers must use complementary inputs, especially fertilizer and pesticides, and they must perform improved management operations that often require additional labor. The profitability of using complementary inputs and of performing improved management practices depends among other things on their cost. Input-to-grain price ratios can be used to make inter-country comparisons of the relative costliness of key inputs, which in turn can serve as rough indicators of the profitability of adopting modern varieties. Nitrogen-to-grain price ratios and labor-to-grain price ratios prevailing in Asia during 1998/99 are shown in Table 19. Across all seven countries that participated in the CIMMYT survey, the nitrogen-to-grain price ratio averaged about 2.5, and the labor-to-grain price ratio averaged about 14. Input-to-grain price ratios were highest in Thailand and lowest in Nepal.

How do prices for maize seed and complementary inputs prevailing in Asia compare to prices prevailing in other developing regions? In Latin America, seed-to-grain price ratios ranged from 6 for OPVs to 16 for double-cross hybrids to 33 for single-cross hybrids (Morris and López-Pereira, 1999). Also in Latin America, nitrogen-to-grain price ratios ranged from 1.1 to 1.9 in most countries (CIMMYT 1999). This suggests that improved maize seed is less costly in Asia relative to Latin America, but nitrogen fertilizer is more costly in Asia relative to Latin America.

Composition of Maize Seed Prices

In an effort to gain insights about the production cost structure of commercial maize seed, survey respondents were asked to break down the retail selling price of maize seed into five major components: (1) R&D costs, (2) seed multiplication costs, (3) marketing and distribution costs, (4) overhead and (5) gross margins. Since the relative importance of these components can be

Table 19. Average input prices and input-to-grain price ratios for nitrogen fertilizer and labor, selected Asian countries and region, 1997/98

	Input price (US$)		Input-to-grain price ratio	
	Nitrogen fertilizer (per kg N)	Farm labor (per person-day)	Nitrogen fertilizer	Farm labor
China	na	na	na	na
India	0.24	1.07	2.27	9.35
Indonesia	0.19	1.05	1.99	13.08
Nepal	0.27	1.27	1.88	8.45
Philippines	0.34	3.93	2.16	24.36
Thailand	0.38	3.55	2.82	26.06
Vietnam	0.40	1.31	2.82	9.62
Asia	0.34	1.92	2.48	13.72

Source: CIMMYT Asia Maize Impact Survey 1998-99.
Note: na = not available.

expected to vary depending on the seed type, the respondents were asked to base their estimates on the production cost structure for double-cross hybrid seed. Double-cross hybrid seed serves as a convenient standard for this comparison because it is a common seed type sold in all seven of the survey countries.

The composition of retail maize seed prices is shown in Figure 11. Averaging across the entire sample, public seed agencies reported relatively high research and development costs compared to private seed companies and relatively low seed multiplication costs. Marketing and distribution costs and overhead made up comparable proportions of the retail price of seed for both types of organizations. Summing the first four categories and subtracting the total from the retail selling price, private companies earn higher gross margins (15% on average) than public seed agencies (8% on average).

When the data for private seed companies are disaggregated by type of company (national vs. multinational), differences are evident between the two categories. Research and investment costs make up a relatively greater proportion of the retail price of seed sold by multinationals (21% vs. 12%), while seed multiplication costs and marketing and distribution costs make up a relatively smaller proportion (43% vs. 53%). Expressed as a proportion of the retail selling price, gross margins are comparable for both types of private company (14-17%), but since seed sold by multinationals tends to command higher prices, in absolute terms gross margins are higher for multinationals.

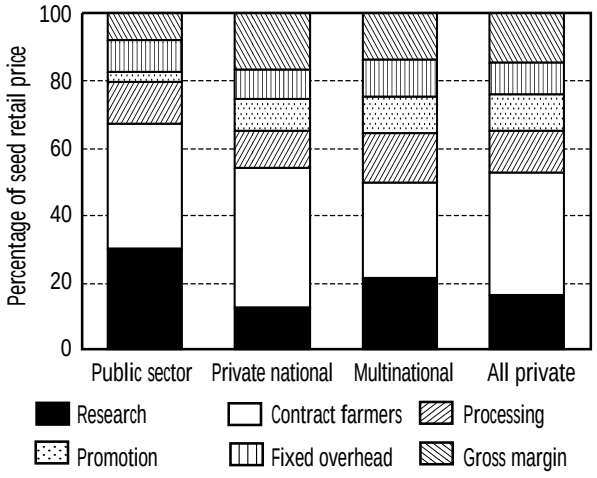

Figure 11. Composition of maize seed prices by type of seed organization, Asia, 1997/98.
Source: CIMMYT Asia Maize Impact Survey 1998-99.

Adoption of Modern Maize Varieties in Asia

The number of modern maize varieties developed and released by public and private breeding programs in Asia has increased steadily during the last 30 years. During the same period, commercial maize seed sales have risen sharply. Has the development, release and sale of increased numbers of modern maize varieties been reflected in greater adoption by Asian farmers?

Estimating the area planted to improved maize varieties is difficult for two reasons. First, maize in Asia is grown in a wide range of environments and as a component of many different cropping systems, many of which are poorly monitored by government crop reporting services. Second, because maize is an open-pollinating species, it is often very difficult to identify improved germplasm in the field. Many farmers (and even researchers) have difficulty distinguishing between so-called "local" or "traditional" varieties and improved maize varieties, especially when the latter have been grown from farm-saved seed that has been recycled many times. These considerations should be kept in mind when interpreting the adoption estimates presented in the following section.

Area Planted to Improved Germplasm

Crop varietal adoption surveys are rarely conducted at the national level, so in impact studies such as this it is often necessary to rely on subjective methods to estimate the area planted to improved varieties. For this study, the data on area planted to modern maize varieties in each Asian country were based on "expert opinion" estimates made by senior scientists working in national maize programs and by representatives of private seed companies. In each country, these knowledgeable informants were asked to estimate the percentage of the national maize area planted to local varieties, OPVs and hybrids. These estimated percentages were then applied to the total national maize area for 1997 to derive estimates of the number of hectares planted to each type of material.[12]

Table 20 presents estimates of the area planted in 1997 to local varieties, OPVs and hybrids in the seven Asian countries covered by the study. Of the 19.6 m ha planted to maize in 1997, 6.1 m ha (31%) were planted to local varieties, 4.8 m ha (24%) were planted to OPVs and 8.7 m ha (44%) were planted to hybrids. The combined 13.5 m ha planted to OPVs and hybrids represent a significant increase over the 8.2 m ha estimated to be planted to modern varieties in Asia during the early 1990s (López-Pereira and Morris 1994).

Adoption rates vary significantly between individual countries (Table 21). In Thailand and China, virtually the entire national maize area is planted to OPVs and hybrids. At the other extreme, in the Philippines only about 36% of the national maize area is planted to OPVs and hybrids.

As in other regions of the developing world, in Asia the area planted to hybrids is now more than twice as large as the area planted to OPVs (Table 21). At the individual country level, only in Nepal and Indonesia is the area planted to OPVs still larger than the area planted to hybrids. These findings, which are consistent with the commercial maize seed sales data presented earlier (Table 16), reflect the active role of the private sector in promoting hybrids in many Asian countries (except for China, where hybrids have been promoted by public seed companies).

Summary and Conclusions

This chapter has presented data on the activities of national maize seed industries in Asia. It has documented the human and financial resources invested over the last three decades in developing

Table 20. Area planted to maize, selected Asian countries and region, 1997

	Estimates of local experts / scientists (000 ha)	FAO statistics (000 ha)	Ratio of local experts' estimates FAO scientists
China (non-temperate)	4,113.7	4,113.7	1.00
India	6,180.0	6,511.0	0.95
Indonesia	4,900.0	3,456.4	1.42
Nepal	860.0	802.3	1.07
Philippines	2,757.0	2,701.0	1.02
Thailand	1,400.0	1,300.0	1.08
Vietnam	659.1	686.9	0.96
Asia	20,869.8	19,571.3	1.07

Source: CIMMYT Asia Maize Impact Survey 1998-99; FAO database, Production Domain, April 2001.

[12] The estimates of total area planted to maize in each country in 1997 provided by survey respondents sometimes differed slightly from official FAO data. To resolve inconsistencies, the local experts' estimates were adjusted by multiplying the percentage area planted to each type of maize material by the official FAO data on the total area planted to maize in each country.

Table 21. Area planted to maize, by maize type, based on estimates of national public-sector researchers (adjusted using FAO area data), selected Asian countries and region, 1997

		Area planted to improved germplasm			
	Farm-saved seed	OPVs	Hybrids	Total modern varieties	Total maize area (adjusted FAO)
		(000 ha)			
China (non-temperate)	41.1	485.4	3,587.1	4,072.6	4,113.7
India	3,190.4	1,432.4	1,888.2	3,320.6	6,511.0
Indonesia	1,036.9	1,417.1	1,002.4	2,419.5	3,456.4
Nepal	288.8	364.2	149.2	513.5	802.3
Philippines	1,728.6	324.1	648.2	972.4	2,701.0
Thailand	3.9	180.7	1,115.4	1,296.1	1,300.0
Vietnam	305.7	101.0	280.3	381.2	686.9
Asia	6,595.4	4,305.0	8,670.8	12,975.8	19,571.3
		(percentage of maize area)			
China (non-temperate)	1.0	11.8	87.2	99.0	100.0
India	49.0	22.0	29.0	51.0	100.0
Indonesia	30.0	41.0	29.0	70.0	100.0
Nepal	36.0	45.4	18.6	64.0	100.0
Philippines	64.0	12.0	24.0	36.0	100.0
Thailand	0.3	13.9	85.8	99.7	100.0
Vietnam	44.5	14.7	40.8	55.5	100.0
Asia	33.2	21.8	44.9	66.7	100.0

Source: CIMMYT Asia Maize Impact Survey 1998-99.

improved maize and delivering improved seed to Asian farmers, described the products of public and private maize breeding programs and estimated the area planted to modern varieties.

Summary of Major Findings

What major conclusions emerge from this overview concerning the organization and performance of Asia's maize seed industries?

- *The area planted to OPVs and hybrids continues to expand.*

The total area planted to OPVs and hybrids in Asia continues to expand at a rapid rate. In 1997/98, approximately 13.5 m ha were planted to OPVs and hybrids in the seven countries covered by the CIMMYT survey, equivalent to 67% of these countries' total maize area. This represents a significant increase from earlier years. For example, the first CIMMYT maize impact study estimated that 8.2 m ha were planted to OPVs and hybrids in 1992. Meanwhile, the area planted to farm-saved seed declined from around 11 m ha in 1990 to only 6.6 m ha in 1997/98.

- *The area planted to hybrids now significantly exceeds the area planted to improved OPVs.*

In 1990, 5.8 m ha in Asia (71% of total maize area) were planted to OPVs, and 2.4 m ha (29% of total maize area) were planted to hybrids. By 1997/98, this trend was reversed: OPVs were being grown on 4.3 m ha (33% of the improved maize area), and hybrids were being grown on 8.7 m ha (67% of the improved maize area).

- *The locus of maize breeding research in Asia has shifted from the public sector to the private sector.*

With the significant exception of China, the primary locus of maize breeding research in Asia has shifted from the public sector to the private sector. In countries where both public research organizations and private seed companies conduct maize breeding research, the level of investment by the private sector significantly exceeds that of the public sector. Although the number of scientists working in public breeding programs is larger than the number working for private seed companies, researchers in the private sector generally are remunerated better. Because of the greater levels of support provided to private-sector scientists (salary, benefits, operating budgets), the total level of investment in the private sector exceeds that in the public sector.

- *Outside China, the private sector dominates the commercial maize seed market in Asia.*

In 1997/98, approximately 56% of the commercial maize seed sold in Asia was seed of public hybrids, 41% was seed of private hybrids and 3% was seed of OPVs (most of these OPVs had been developed by public breeding programs, although in many cases the seed was produced and sold by private companies). When the data for China are excluded, the market share controlled by private companies rises to 89% (85% hybrids and 4% OPVs). Across the region as a whole, multinational seed companies control a larger share of the market than national seed companies. In some countries, the market share of the multinationals is extremely high. For example in Indonesia, the Philippines and Thailand, multinationals hold more than 80% of the commercial maize seed market.

- *Adoption of modern maize varieties has been uneven from one Asian country to another.*

Adoption of modern maize varieties has increased for Asia as a whole, but the level of adoption varies from country to country. As in Latin America and Africa, in Asia the use of modern maize varieties is concentrated in countries (and regions within countries) in which maize is a commercial crop. Meanwhile, adoption has been much more limited in countries where maize is grown mainly as a subsistence crop intended for home consumption. Thailand and the Philippines represent two extreme cases. Virtually all of the area planted to maize in Thailand in 1997/98 was planted to OPVs and hybrids, whereas only about one-third of the area planted to maize in the Philippines was planted to OPVs and hybrids.

- *Maize R&D efforts by the public and private sectors are complementary, and links between the public and private sector appear to be expanding.*

In recent years, governments throughout Asia have had to confront two major challenges: first, increasing demand for improved maize production technologies, and second, a stagnant or declining resource base that has constrained the ability of public research organizations to develop and disseminate improved production technology. In response to these challenges, Asian policy makers have enacted measures to encourage the private sector to participate more actively in the maize seed industry.

Private seed companies have responded to policy reforms by increasing their investment in maize R&D. The emergence of a private seed industry in all countries of the region except China has been accompanied by increasing specialization in both public and private sectors. Hoping to avoid wasteful competition with private seed companies, public breeding programs in many countries have begun to concentrate on activities that are unlikely to be attractive to profit-oriented firms, for example, genetic resource conservation, pre-breeding, population improvement, development of special trait materials and development of OPVs. Private seed companies meanwhile have emphasized inbreeding, hybrid development, hybrid seed production and hybrid seed marketing

and distribution. Despite this increasing specialization, however, public and private maize seed organizations continue to be linked through various types of collaborative activities. In Asia these include international germplasm exchanges, public-private germplasm transfers and collaborative varietal testing networks.

Looking to the Future

How will the relationship between public organizations and private seed companies evolve in the future? A group of experts convened by CIMMYT recently met in Tlaxcala, Mexico, to discuss the conditions necessary for productive and harmonious collaboration between public and private sectors with respect to R&D for maize and two other leading staple crops, wheat and rice (CIMMYT 1999). This group of experts, which included scientists from public and private sectors, development agency officials, NGO representatives, media specialists and farmers, agreed upon the following points:

- Public organizations can and should continue to play an active role in maize research and seed production; public-sector involvement will help to reduce R&D costs for private firms (for example by generating improved germplasm that can be used as inputs into commercial breeding programs and by training researchers).
- Where conditions permit the existence of competitive seed markets, the public sector should complement and support rather than compete with the private sector in providing improved seed and related technology to farmers.
- The public sector has a particularly important role to play in supporting local private seed companies, which can enhance competition in seed markets.
- Where technical, economic or institutional conditions discourage private companies from providing improved seed technology to farmers, public agencies may be called upon to assume responsibility for meeting farmers' needs.
- Even where international research organizations and private seed companies are active, strong national public research programs will often be needed to adapt privately and internationally developed research products to local conditions.

This chapter has presented recent evidence showing that elements of the productive and complementary relationship described at the Tlaxcala meeting are beginning to take shape in Asia. Examples of successful collaboration are especially evident in India and Thailand, where strong public breeding programs have encouraged and supported the development of extremely successful and competitive private seed industries.

The lack of effective plant varietal protection laws in Asia, however, makes the private sector (especially the large multinational seed companies) skeptical about sharing its materials with public research agencies. Without property protection regulations, the private sector feels that it is difficult to safeguard research outputs. While the private sector has established a strong presence with the introduction of many excellent hybrids in Asia, particularly in India, the Philippines and Thailand, the lack of essential intellectual property laws can discourage many private seed companies from introducing their best materials into the market. In such a scenario, the range of better production technologies available to farmers becomes restricted.

While acknowledging the potential benefits of increasing the private sector's participation in Asia's maize seed industries, at the same time it is important to remember that those benefits may not be available to all of the region's maize farmers, including millions of subsistence farmers.

How might the roles and responsibilities of the public sector be developed in the future to accommodate the needs of these farmers that until now have attracted limited attention from private seed companies? The anticipated expansion in demand for maize in Asia will lead to the intensification and commercialization of existing production systems, as well as expansion into less favorable maize production environments. These marginal environments will play an increasingly important role in feeding the region's rapidly

growing populations. The public sector can work on identifying principal technological constraints to increasing maize productivity in these areas, designing crop and resource management technologies to alleviate the principal constraints and support sustainable practices in the fragile environments, and develop technology dissemination plans and more effective agricultural extension strategies.

The strong likelihood that the private sector will be reluctant to address the needs of farmers in marginal areas should encourage public-sector research organizations, including international research centers like CIMMYT, to continue their active role in maize R&D and seed production, particularly for improved OPVs. Within each country, the public sector should assume a more complementary and supportive role with regard to the private sector by developing policies that facilitate private-sector operations. These policies may include the simplification of product test rules or seed certification procedures and the formulation of intellectual property rights laws, which together will ensure that the best varieties will be available to maize farmers as quickly as possible.

Finally, it is important to recognize that improved maize seed is not the only key to increasing maize productivity and uplifting the conditions of resource-poor maize farmers in Asia. No amount of advanced public- or private-sector maize research will help the most disadvantaged farmers unless substantial parallel investments are made in infrastructure, agricultural extension, input production and distribution systems, grain harvest and post-harvest facilities and grain marketing. In the end, the role and impact of appropriate government policies—from those on input and grain prices to those on intellectual property rights—should certainly not be overlooked.

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