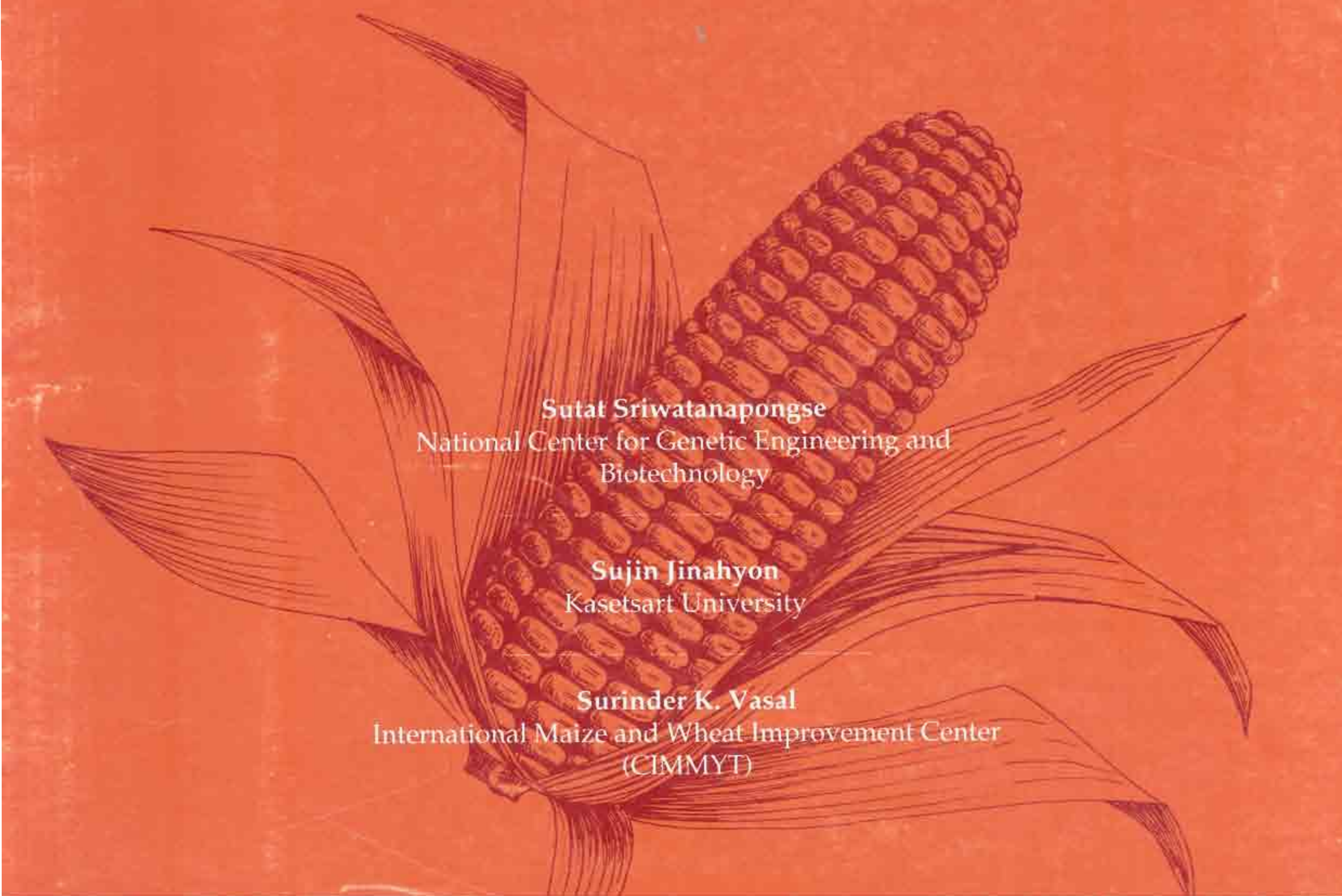
SUWAN-1

MAIZE FROM THAILAND TO THE WORLD



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CIMMYT is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center is engaged in a worldwide research program for maize, wheat, and triticale, with emphasis on improving the productivity of agricultural resources in developing countries. It is one of 17 nonprofit international agricultural research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR), which is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of some 40 donor countries, international and regional organizations, and private foundations.

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The CIMMYT Maize Program is committed to helping national programs develop and disseminate improved germplasm and production technology. Our contributions are well documented; our work could be deemed a success story. This is satisfying but, in a sense, source of little wonder. CIMMYT pools the energies of some of the world's most talented and dedicated researchers, supported by first-class facilities at selected locations. Our mission is clear and, although there may be room for improvement, we are simply doing the job we set out to do.

The story of Suwan-1, though, cannot help but kindle a sense of wonder. Here is a maize product developed by Thai researchers for Thai farmers, yet so well crafted that its welcome has extended far beyond the borders of that nation.

In retrospect, this outcome may also seem natural. Several factors combined serendipitously in Thailand of the 1960s to make the development and diffusion of Suwan-1 possible. The government began to promote maize as part of a national policy to diversify agriculture away from rice. The Rockefeller Foundation moved its Inter-Asian Corn Program headquarters to Thailand, bringing in financial resources and experienced human capital. The country's previously fragmented national maize breeding efforts were consolidated into a single program under Kasetsart University and the Ministry of Agriculture. The Rockefeller Foundation and Thai researchers established a collaborative breeding program at Farm Suwan, a state-of-the-art research station where irrigation permitted up to three crops each year. Close collaboration with CIMMYT began which, in addition to providing useful germplasm, opened training opportunities for many Thai maize researchers. Later on, fruitful cooperative arrangements between public and private entities in Thailand benefited farmers with a steady supply of quality seed.

These circumstances alone, however, are not enough to account for the development and spread of a variety as successful as Suwan-1. The principal credit for this accomplishment belongs to a group of persons who saw an opportunity and worked hard and intelligently to bring it to fruition. I am referring, of course, to the collaborative breeding team at Farm Suwan. Theirs was the strategy of assembling a genetically heterogenous composite from which to develop a broadly adapted variety; theirs was the work that led to steady improvements in grain yield and other important characteristics of the composite; theirs was the successful incorporation of resistance to downy mildew as an additional trait that would ensure the usefulness of this material to farmers throughout Asia.

It is therefore fitting that, in honor of the 50th Anniversary of Kasetsart University, members of that team should undertake an account of the research that brought forth Suwan-1. This is the first time the story has been told in such detail. I hope that, in addition to providing interesting reading, the report will prove a welcome source of strategy and inspiration for breeders throughout the developing world in their efforts to offer farmers highly productive, resource conserving maize varieties.

Dr. R.L. Paliwal
Director
CIMMYT Maize Program

Foreword—Kasetsart University

In 1973 the first officially approved maize variety, Suwan-1, was released in Thailand. Since then Suwan-1 has become a household word among maize growers and within the domestic maize industry. Suwan-1 lifted Thailand to fourth largest among maize exporting countries worldwide in 1986, with an annual production of almost four million tons, and has made its impact felt far outside Thailand, being used as a resource material or for direct release in countries of Africa, Asia, Oceania, and South America.

The variety is certainly a source of pride for Kasetsart University, constituting one of the Institution's most outstanding research outputs, in collaboration with the Ministry of Agriculture and Cooperatives. It resulted from a continuous and untiring initiative that serves as a model of teamwork and sets a standard to which other researchers—not merely at Kasetsart but elsewhere—must surely aspire.

Kasetsart University is celebrating its 50th Anniversary this year. As part of commemorative activities that will extend thoughout the year and end February 2, 1994, the publication of *Suwan-1: Maize from Thailand to the World* is highly auspicious and justifiable (if not so timely!). Kasetsart University wishes to express its sincere appreciation to CIMMYT for supporting the production of this report. A Thai version has also been published by the Kasetsart University Research and Development Institute (KURDI) to commemorate the event and for the benefit of Thai researchers and readers.

Suwan-1 is a milestone for Kasetsart University and carries the University's name wherever it travels: Suwan-1, Maize from Thailand to the World.

Dr. Kamphol Adulavidhaya
President
Kasetsart University

Acknowledgements

This paper was initiated while the senior author served as CIMMYT Maize Specialist in the Middle East Region with assistance and support from his colleagues. The authors would like to thank Dr. Ronald P. Cantrell, former Director, CIMMYT Maize Program, Dr. Ripsudan L. Paliwal, Director, and Dr. Richard Wedderburn, Associate Director, for their encouragement and support in preparing this publication. Gratitude is extended to Dr. Bobby L. Renfro for supplying valuable information, correction and addition of the manuscript; to Dr. Shivaji Pandey, Dr. B.K. Mukherjee and Dr. Chamnan Chutkaew for valuable information; and to Dr. Anek Silapapan for supplying some photographs.

The authors are grateful for the initiation and support of Dr. Ernest W. Sprague and Dr. Charles L. Moore during the early phase of Suwan-1 variety development; Dr. Renfro and Mr. Udom Pupipat for downy mildew disease screening work; Mr. Tawatchai Prasatsrisuparb, Mr. Weerasak Duangchantra, Mr. Sansern Jumpathong and many others whose names are not mentioned but who contributed to the development of Suwan-1.

Finally, we thank Uthaiwan Grudloyma who helped prepare the draft of this publication, G. Michael Listman, CIMMYT science writer, for editing, and Eliot Sánchez P. and Miguel Mellado E. for the design.

Dr. Sutat Sriwatanapongse

Introduction

Maize was brought to Thailand some 400-500 years ago by Portuguese merchants. For centuries it was grown on a very small scale to produce fresh ears for human consumption. Commercial production of maize began only in 1932 when Prince Sithiporn, then the Director General of the Department of Agriculture, introduced two varieties of dent corn into Thailand. The varieties, Nicholson's Yellow Dent and Mexican June, were multiplied and subsequently spread to northeastern Thailand, where commercial production first began.

Until 1953, the extent of maize farming in Thailand was negligible. This changed with the national campaign to diversify agriculture, which till then had been limited almost exclusively to rice. Part of the plan included increasing maize output. New land was opened to farming and the area planted to maize increased from 0.3 to 0.7 million hectares during 1960-66 and stabilized at around 1.9 million hectares by 1986 (Fig. 1).

Maize in Thailand is produced mainly in the north and central zones (Fig. 2). Maize production ecologies in Thailand are lowland tropical, with occasional drought stress in many areas, and sorghum downy mildew disease (*Peronosclerospora sorghi*) is by far the most serious biotic constraint throughout.

Annual domestic maize production varies from 3.0 to 4.9 million tons. Maize yields have increased over the past few decades, mainly as a result of improved varieties and growth in the seed production industry. Most of this production has traditionally gone to foreign markets—export volume rose steadily till 1986 to almost 4 million tons and Thailand at that time ranked fourth among world maize exporting countries. Subsequently, though, the rising internal demand for maize, particularly for use as animal feed, has reduced exports considerably. In 1990, for example, Thailand exported only 1.2 million tons and had to import 723 tons (Office of Agricultural Economics, 1991). This trend is expected to continue, unless national maize production increases.

Early Maize Research

Maize research in Thailand was initiated in the early 1950s by the Department of Agriculture, Ministry of Agriculture, and Kasetsart University. Variety improvement research during the early period concentrated on hybrid development. With assistance from USAID under a Kasetsart-Oregon State University contract, many US hybrids were tested during 1958-1959. None, though, proved to be adapted to

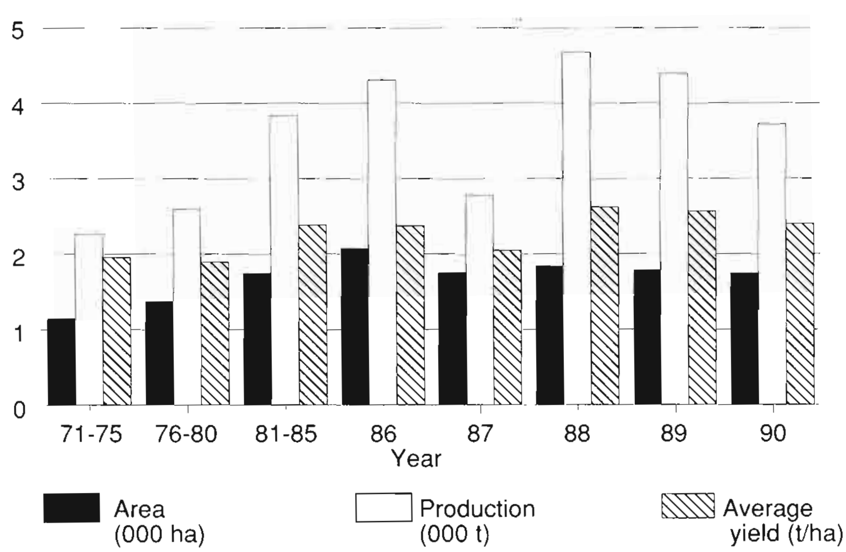
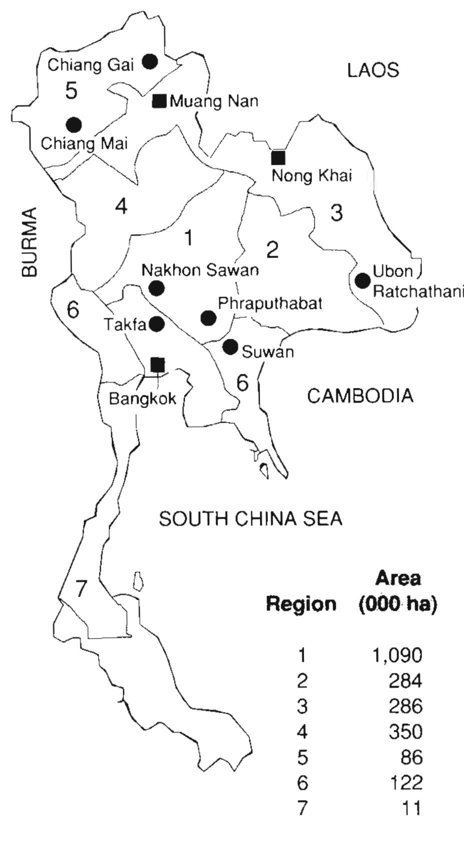


Figure 1. Maize area, production, and average yields in Thailand, 1971-90.

Source: Agricultural Statistics of Thailand, Crop year 1990/91. Ministry of Agriculture and Cooperatives.



Region	Area (000 ha)
1	1,090
2	284
3	286
4	350
5	86
6	122
7	11

Figure 2. Maize production regions of Thailand.

Source: CIMMYT Maize Program, 1988. Maize production regions in developing countries. Internal document available on request.

Thailand's production conditions and, in any case, seed of parental lines could not be reproduced, so this research was discontinued.

In the absense of suitable, nationally developed maize cultivars, varieties were introduced from other sources. In 1953 USAID staff in Indonesia provided a variety developed in Guatemala by the late I.E. Melhus, Professor Emeritus at Iowa State University, from a composite of Caribbean collections. Known as "Guatemala" (Tequisate Golden Yellow Flint), it enjoyed success in Indonesia as "Metro" and showed broad adaptation in Thailand, tolerance to some diseases and insects, good grain texture (flint), and acceptable color (orange yellow). Despite being tall, of only moderate productivity, and susceptible to downy mildew disease, the variety Guatemala was released by the Thai Ministry of Agriculture and farmers used it until 1974, when sorghum downy mildew became a major threat to corn production. Thereafter, seed of Guatemala was no longer distributed but the cultivar itself became a component of Suwan-1.

Following an intensive review in 1960, Kasetsart University began to focus its efforts on developing open-pollinated varieties. Many tropical varieties and collections of CIMMYT/Rockefeller Foundation precedence were received from Mexico and India, and composites were obtained from the Philippines, Taiwan and Indonesia. These materials were grown, observed for a range of traits, and a few were selected for use in breeding.

Institutional and Organizational Development

The groundwork for significant advances in maize breeding in Thailand was laid in 1966, when the Rockefeller Foundation established the headquarters of its Inter-Asian Corn Program (IACP) there. To support this regional cooperative effort, a simple farm in central Thailand (14.4^{0}N and 300 meters above sea level) was transformed into a first-class research station, featuring suitable field, laboratory, and irrigation facilities to handle three crops a year. "Farm Suwan," as the station came to be called, was designated as a research center for both the Thailand National Corn and Sorghum Program and the IACP.

Another arrangement that greatly contributed to the success of maize research in Thailand was the well structured cooperation among staff of the IACP team, Kasetsart University, the Department of Agriculture, and the Department of Agricultural Extension, Ministry of Agriculture. Members of these institutions functioned as a tight-knit research unit, able to address effectively issues of varietal improvement, production, utilization, and marketing. The following persons of that group had a major role in the development of Suwan-1:

- Dr. Ernest W. Sprague, IACP Team Leader
- Dr. Charles L. Moore, IACP Maize Breeder
- Dr. Surinder K. Vasal, IACP Postdoctoral Maize Breeder
- Dr. Bobby L. Renfro, IACP Plant Pathologist
- Dr. Sujin Jinahyon, Maize Breeding Project Leader, Kasetsart University
- Dr. Sutat Sriwatanapongse, Assistant Maize Breeding Project Leader, Kasetsart University
- Mr. Udom Pupipat, Plant Pathologist, Kasetsart University
- Dr. Edwin J. Wellhausen, CIMMYT

The variety "Guatemala" (left) and Thai Composite #1 (right) grown for comparison.

Close collaboration with the CIMMYT Maize Program began as soon as CIMMYT was established in 1966, drawing on both available germplasm and training opportunities. Drs. Sujin and Sutat, for example, worked as visiting scientists with the CIMMYT Maize Program in Mexico during the late 1960s, early 1970s. Thereafter, many Thai researchers (several of whom later contributed to the development of Suwan-1) received in-service training or spent time as visiting scientists at CIMMYT.

2a, b, c: The Farm Suwan station: the entrance, maize experiment fields, and the seed processing facility.

Early Varietal Improvement

The maize breeding group at Kasetsart University was optimistic that better products could be developed by crossing the variety Guatemala to exotic germplasm. They pursued this strategy by forming broad germplasm pools and performing recurrent selection within them. An effort was also made to discover heterosis in varietal crosses, some of which later underwent recurrent selection. None of these approaches, though, resulted in the superior varieties that researchers had sought. Finally, the Kasetsart maize breeders tried the route of converting an improved cycle of Guatemala to downy mildew resistance, but otherwise left the responsibility of improving "Guatemala" in the hands of the Department of Agriculture.

At this point, it dawned upon these researchers that the limited genetic diversity of the variety Guatemala, comprising mostly germplasm of Caribbean origin, could be holding back progress. The emphasis thus shifted to assembling new germplasm complexes and composites based on more diverse sources.

During the early-to-mid-1960s, staff at Farm Suwan gathered maize varieties and cultivars from around the world. Applying the criteria of known good performance, relative adaptability to Thailand's production conditions, diversity of origin, and useful genetic variability (particularly for traits of economic importance), they finally chose 36 germplasm sources to form a population designated "Thai Composite #1" (Table 1).

Table 1. Germplasm assembled in Thai Composite #1

Source	Group	Material
Caribbean Islands	Argentino	Cuba Gr.
		Cuba 11J
		Puerto Rico Gr.1
	Tuson	Cuba 40
	Tuson-Canilla-	Cuba 1J
	Criollo-Tuson	Cuba 59
		Antigua Gr.1
		Antigua Gr.2
		Puerto Rico Gr.2
		Barbados Gr.1
		Cupurico
		Caribb.Flint Composite
		Flint Comp. Amarillo
		Comp. Caribb. Amarillo
		Tiquisate Golden Yellow x Caribb. Comp.
		Tiquisate Golden Yellow x Guadalupe 12D-14D
Mexico and Central America	Tuxpeño	Veracruz 163
		Veracruz 181
		Veracruz Gr.48
		Tamaulipas 8
	Salvadoreño	Salvadoreño Amarillo
	Argentino-Criollo	Tiquisate Golden Yellow
S.America	N. Catato	Guayana Francesca III
	Cuban Yellow Dent	Bahai III BCO
		Dentado Amarillo
	Argentino-Criollo -Tuson	Nariño 330-Peru 330
		DV 103
India	Caribbean-Tuxpeño -India-USA	Composite A1*
		Multiple Cross 2
		Multiple Cross 4
		Synthetic A3B
		Synthetic A11
Other	Tuxpeño-Caribbean -USA	Tuxpantigua
		Veracruz 181 x Antigua Gr.2
		Usatigua
		Florida Synthetic

Sources:
Jinahyon, Sujin. 1973. Maize Germplasm Utilization in Thailand. Proceedings, the Ninth Inter-Asian Corn Workshop, Kuala Lumpur, Malaysia.
Grobman, A., W. Salhuana, and R. Sevilla. 1961. Races of Maize in Peru. Nat. Acad. Sci.-Nat. Res. Council, Publication No. 915.
Hatheway, W.H. 1957. Races of Maize in Cuba. Nat. Acad. Sci.-Nat. Res. Council Publication No. 453.
Paterniani, E. and M.M. Goodman. 1977. Races of Maize in Brazil. Mexico, D.F.: CIMMYT.
Wellhausen, E.J., A. Fuentes O., and A. Hernandez C. 1957. Races of maize in Central America. Nat. Acad. Sci.- Nat. Res. Council Publication No. 511.
Wellhausen, E.J., L.M. Roberts, and E. Hernández Xolocotzi, and P.C. Mangelsdorf. 1952. Races of maize in Mexico: Their origin, characteristics and distribution. Cambridge: The Bussey Institution, Harvard University.

Systematic intermating among all sources was begun at Farm Suwan in 1968 using a modified ear-to-row scheme (Fig. 3). The 36 contributors were designated as females and each entry was planted in a 3-row plot on different dates. A balanced composite of seeds from all 36 entries represented the male component and was sown in a single row adjacent to and alternating with each female entry. At harvest, 50% of the ears from selected female entries were saved and shelled in bulk within each entry. Thus, the new intermated seed of each entry was used in the second cycle crossing block as female rows and the balanced composite seed of all 36 entries as male rows.

The layout of crossing blocks in all cycles was similar except that, after cycle 1, only 30% of the ears from each entry was selected. The new population was judged to have approached genetic equilibrium by 1970, after four cycles of intermating.

The above intermating/compositing system accomplished the following:

- Systematic genetic mixing and recombination of the germplasm sources
- A comparable genetic contribution from all entries
- Maximum intermating among entries
- Mild selection pressure during recombination and compositing

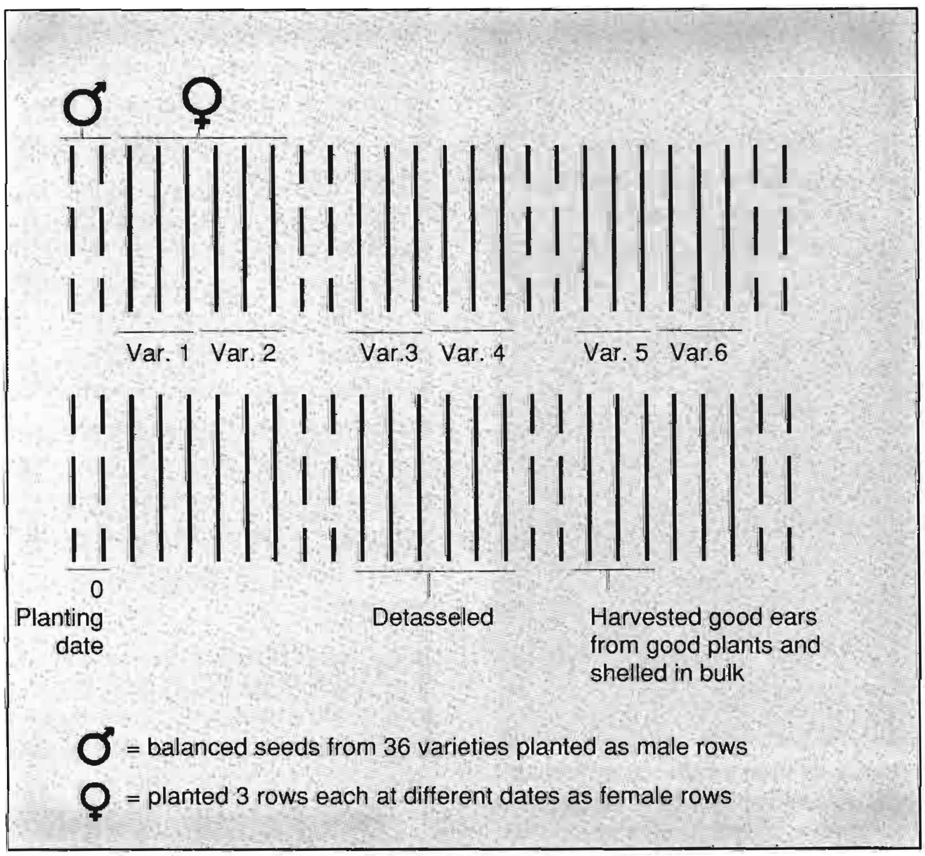


Figure 3. Planting plan for 36 germplasm sources assembled in Thai Composite #1.

Population Improvement

The newly formed Thai Composite #1 was improved for yield and other agronomic characters through recurrent S-1 selection at Farm Suwan. The process was expedited by the fact that an entire cycle of recurrent selection in maize—three crop generations—can be completed there in a single year. Improvement involved 1) generating S1 families using selected healthy, short-statured plants; 2) evaluating the families for grain yield, lodging resistance, and foliar diseases during the main rainy season (August-November); 3) recombining selected progeny during the dry season (December-March); and 4) repeating the process, using the improved version as the base population.

In April, 1970, the Thai Composite #1(S) C-0 was planted in a block where desirable plants were self-pollinated from more than a thousand selfed plants and 700 ears were selected at harvest. Each selfed ear was shelled separately and kept as an S-1 family. The 700 S-1 families were grown in a replicated progeny trial in the late rainy season. Heavy lodging from a severe storm allowed intense selection for standability and the families left upright were evaluated for grain yield, disease reaction, and plant height, resulting in the final selection of 45 S-1 families.

These were recombined using remnant seed the following dry season, completing the first cycle of recurrent selection. Two additional cycles of recurrent selection in 1971 and 1972 resulted in

Thai Composite #1 (S) C-3. Table 2 provides details on the performance of S-1 families, selection intensity, and average yield in each cycle of selection.

Performance evaluation

Even after the second cycle of random mating (prior to improvement), Thai Composite #1 already produced 28% more grain than the variety Guatemala. In tests at three locations in 1970, yields of the composite averaged 20% higher than those of the check variety. After two cycles of selection, grain yield was 17% higher than in the original population (Table 3). In 11 tests at 3 locations in 1971, yields of the composite averaged 23% more than those of checks. As a result of selection, the composite was distinctly shorter in stature, three days earlier in silking, superior in root lodging resistance, and with a harvest index higher than that of most lowland tropical maize varieties. In 1972, the first agronomic study was conducted and the composite yielded 30% more than the check variety at densities ranging from 40,000-100,000 plants per hectare and 21% more at the standard population of 53,000 plants per hectare. In the same year, Thai Composite #1 (S) C2 was tested in other trials, including the Regional Variety Tests, dry season variety tests, fertility trials, and the IACP Regional Yield Trial. Thai Composite #1 consistently ranked first in yield across years in trials in Thailand and throughout Asia, showing broad adaptation, good standability, and high yield potential (Tables 2-4).

Table 2. Summary data on the performance of S1 families in different cycles of selection of Thai Composite #1

		Number of progeny		Average yield (t/ha)	
Cycle	Year	Tested	Selected	All progeny	Selected
1	1970	700	45	NA*	2.2
2	1971	500	38	3.5	4.5
3	1972	500	40	3.7	5.0

* NA = not available

Table 3. Performance of a Thai Composite #1 selection in Thailand, 1971-72

Material	Grain yield (t/ha)	Height (cm) Plant	Height (cm) Ear	Lodging (%)	Days to silk	Harvest index
Thai Composite #1	4.7	226	130	8	56	.45
Commercial variety (Guatemala PB5)	3.9	260	160	20	59	.39
No. of tests	24	10	10	10	7	1

Table 4. Performance of Thai Composite #1 (S) C2 in Asia

	Grain yield (t/ha)	Rank	Height (cm) Plant	Height (cm) Ear	Days to silk
Thai Composite #1 (S) C2	5.0	1	216	111	58
UPCA VAR 1 (Philippines)	4.1	13	228	125	59
Bogor Composite 2 (Indonesia)	4.5	7	225	120	58
JML 305 (India)	4.7	5	232	122	60
Tuxpeño Planta Baja (CIMMYT)	4.3	12	211	107	61
Guatemala PB5 (Thailand)	4.4	11	242	136	61
Trial mean [1]	4.3		217	112	59

[1] Data from 1972 IACP Trial #2 (18 entries grown at 19 locations in 11 countries).

Incorporating and Improving Downy Mildew Resistance

In 1968, a new threat to production was identified in the maize areas of Thailand. Sorghum downy mildew disease, caused by the fungus *Peronosclerospora sorghi*, reduces yields by as much as 80% in susceptible maize varieties. Throughout the early 1970s, the disease increased rapidly in prevalence and severity, reaching devastating proportions. Downy mildew can be controlled through the application of systemic fungicides, but a more economical and ecologically sound alternative is the use of maize varieties that are inherently resistant to the pathogen.

In 1971 the Farm Suwan team undertook to add downy mildew resistance to Thai Composite #1. From the IACP Downy Mildew Yield Trial, they singled out the high yielding, downy-mildew-resistant varieties Philippine DMR 1 and 5[1] and crossed them to Thai Composite #1 (S) C-1.

Backcrosses were made to the most recent cycle of selection of Thai Composite #1. Selection for downy mildew resistance was performed in the segregating generation. Thus, BC-1 and BC-2 were backcrossed to Thai Composite #1 (S) C-2 and BC-3 to Thai Composite #1 (S) C-3. After the third backcross, the recurrent selection program was shifted entirely to the downy-mildew-resistant version of the composite.

Progress came rapidly as a result of the excellent resistance sources used, the effectiveness of screening, and the appropriateness of the breeding methodology.

Resistance to downy mildew in maize was found to be conditioned by several genes acting in both an additive and non-additive manner (Renfro, 1985). The non-additive component was controlled by dominant genes. The additive portion seemed to play a dominant role and showed relatively high heritability.

The plant pathology team, led by Dr. Bobby Renfro and Mr. Udom Pupipat, developed an artificial inoculation technique that allowed easy identification of resistant plants:

1. Systemically infected leaves were collected at about noon (1200-1300 hrs).
2. The detached leaves were washed to remove the old conidiospores and conidiophores and kept for eight hours in a dark, temperature-controlled, humidified room. (Optimum temperature for good sporulation: around 22-250C.)
3. Conidial spores were harvested by washing the leaves with clean water. An inoculum suspension of 40,000-60,000 conidials/cc was used to artificially inoculate at 2000-2100 hours.

A nursery setup with spreader rows was the normal practice; i.e., 2 border rows alternating with 20 progeny rows to separate progenies of different materials. A susceptible variety was planted in border rows and alleys about 10 days before sowing the progeny. Border rows were artificially inoculated as many as 4 times at the 2-to-6-leaf stages to guarantee a uniform and intense infection. Artificial inoculations were often made again in the progeny rows, thus ensuring virtually no escape. The level of disease challenge was regulated either by the number of days susceptible donor plants were left in the nursery or by the planting date of breeding materials in relation to that of donor plants.

Thai Composite #1 DMR BC2 was tested in 1972 to compare its performance with that of Thai Composite #1 (S) C2. The results indicated no significant changes in grain yield, plant

Screening for resistance to downy mildew at Farm Suwan, showing the arrangement of test progenies and spreaders .

1 Philippine DMR 1 is derived from MIT VAR 2 x Cuba Gpo. 1; Philippine DMR 5 is derived from MIT VAR 2 x Cupurico. The resistant version of both sources was yellow grained and well adapted to Asian growing conditions. (MIT VAR 2, developed in the Philippines at the Mindanao Institute of Technology, is a white flint, low-yielding composite formed from local varieties resistant to downy mildew.)

height, lodging, or days to silk. Progress in transferring downy mildew resistance to this composite was also assessed during that period. After the third backcross, the composite was rapidly shifted toward the resistant sources. Infection was reduced from 85% to approximately 30% after 2 cycles of screening under artificial inoculation.

Improving the Composite

Once a downy mildew resistant version of Thai Composite #1 had been developed, the next step was to improve its grain yield, agronomic characters, and resistance levels. To accomplish this, during 1972-74 many thousands of plants were screened for multiple characteristics under both artificial infection and disease free conditions.

Figure 4, for example, provides an idea of the selection pressure applied in trials under downy mildew infection in 1973. Again, progress was furthered by the possibility of growing three crops (i.e., one complete cycle) per year.

Table 5 lists data of yield trials and downy mildew reaction for 200 S1 families evaluated in 1974. Forty superior families selected from those materials were bulk-pollinated in the downy mildew nursery to reconstitute Thai Composite #1 BC3 (S) C-2. Figure 5 illustrates the breeding scheme used to arrive at this composite, which was soon after to be released as Suwan-1.

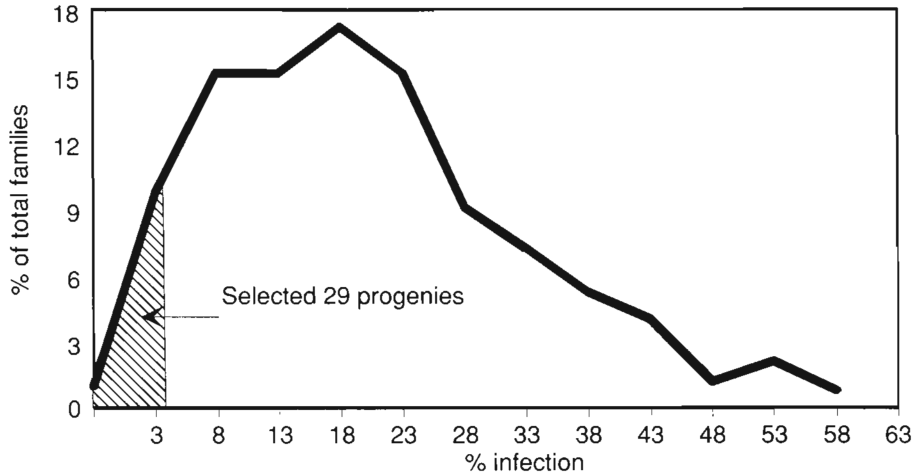


Figure 4. Distribution of Thai Composite #1 S1 lines (29 lines) for downy mildew reaction under natural epiphytotic at farm Suwan, 1973.

Table 5. Performance of 200 S1 families of Thai Composite #1 evaluated in yield trials, 1974

Set[a]	Grain yield (t/ha) Mean of progeny	Range of progeny	Mean of selected	Selection differential (%)	CV (%)	Disease mean of progeny	% DM[b] mean of selected	Height (cm) Mean of progeny Plant	Ear	Mean of selected Plant	Ear
1	4.4	3.4-5.7	5.2	19.3	11.4	6.4	8.8	192	105	198	112
2	4.5	2.8-5.8	4.6	2.8	13.4	6.4	6.0	192	109	190	108
3	4.5	2.6-6.2	5.4	19.6	9.5	6.5	3.5	187	102	183	99
4	4.2	2.6-6.4	4.5	7.4	8.7	5.5	2.8	187	101	183	94
5	4.3	2.1-5.8	4.7	7.7	10.6	5.3	2.3	195	106	194	103
6	4.3	2.8-5.9	5.1	18.8	12.0	3.8	4.5	199	115	208	122
7	4.7	2.8-5.7	5.2	10.6	9.5	4.3	2.0	203	112	212	119
8	4.3	1.5-5.8	5.0	14.5	13.3	6.6	2.5	186	104	175	101
9	4.4	2.5-6.3	5.0	13.4	11.0	3.0	1.3	197	111	197	105
10	4.3	2.3-5.8	5.1	18.1	7.4	4.3	2.5	193	105	198	112
Mean	4.4	2.6-5.9	5.0	13.2	10.7	5.2	3.6	193	107	194	107

[a] A set consisted of 20 lines.
[b] Data from crossing block, disease nursery 1974.

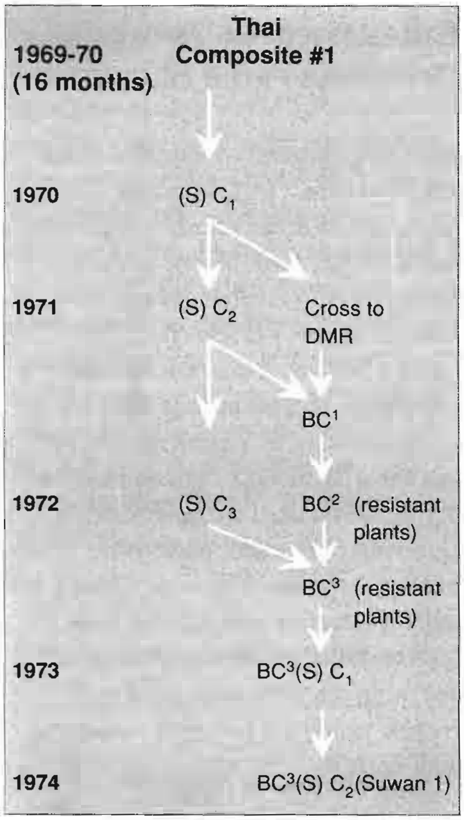


Figure 5. Developmental scheme for Suwan 1.

The Release of Suwan-1

With the rise of downy mildew as a threat to maize production in Thailand, in 1973 the Department of Agriculture, Ministry of Agriculture, ordered the release of a resistant variety from Indonesia, Bogor Synthetic No. 2, as a stop-gap measure. By the following year, when this variety succumbed to the disease and its distribution was discontinued, the Farm Suwan team had completed work to develop a downy-mildew-resistant version of Thai Composite #1. A large quantity of Thai Composite #1 DMR BC2 F4 seed was distributed unofficially to interested farmers in areas where downy mildew was a serious problem and the Ministry of Agriculture approved the official release of Thai Composite #1 DMR BC3 (S) C2, naming the new variety "Suwan-1."

It was the first official maize variety developed by Thai scientists. The Ministry of Agriculture and Kasetsart University subsequently appointed a varietal release committee and subcommittee to handle future proposals for the release of varieties. The subcommittee was to gather data on grain yield, agronomic performance, and acceptability among farmers and in the market, and submit this information and a suggestion for a commercial name to the release committee for final consideration. The following researchers were asked to serve on the release subcommittee formed at that time:

- Dr. Dale G. Smeltzer, Rockefeller Foundation, Bangkok (Chairman)
- Mr. Ampol Senanarong, Department of Agriculture
- Dr. Sujin Jinahyon, Kasetsart University

A pile of Suwan-1 ears represents the bountiful yields this variety has brought to maize farmers in Asia.

- Mr. Glom Sombatsiri, Department of Agricultural, Extension, Ministry of Agriculture
- Dr. Sutat Sriwatanapongse, Kasetsart University (Secretary)

Additional Population Improvement

Improvement of Suwan-1 continued even after its official release, with initial emphasis on downy mildew resistance and, later, yield and other agronomic characters. In all, 11 cycles of selection were completed.

In 1975, 2000 S1 families of Thai Composite #1 BC3 (S) C-2 or Suwan-1 (S) C-2 were tested in sets of 50 families each during the early rainy season at Farm Suwan under artificial inoculation with downy mildew. The ten most resistant S1 progenies were selected from each set. The 400 families selected were divided into 20 sets of 20 progenies and yield tested in the main rainy season. One month later a companion nursery with all 400 progenies was planted in a downy mildew nursery with artificial inoculation. After yield evaluation, 3 progenies were selected from each set, giving a total of 60 selected families. The selected progeny rows were identified and recombined in the downy mildew nursery to reconstitute Thai Composite #1 DMR (S) C-3. Roughly the same breeding procedure was followed in subsequent cycles, with very encouraging results (Table 6).

In early 1976, 2000 S1 progenies were generated from Thai Composite #1 DMR (S) C-3. After testing under downy mildew, 10 progenies were selected from each set (a total of 400). The 400 progenies were yield tested and recombined, resulting in Suwan-1 (S) C-4.

Suwan-1 (S) C-5 was developed in 1977 from 3,200 S1 progenies of the previous cycle, using the same breeding procedure as in 1975. This methodology was applied in 1978 and 1979 to generate
C-6 and C-7. In subsequent cycles of improvement, the step involving downy mildew screening was cut and only regular progeny testing conducted. (However, S1 families of the 200-400 families tested in each cycle were normally grown under artificial downy mildew infection.) Suwan-1 (S) C-10 was completed in 1984.

Evaluation of Progress from Selection

Periodic evaluations of progress from selection in Suwan-1 affirm the effectiveness of the breeding approach and materials used. In tests at Farm Suwan in 1979 involving seven versions of Suwan-1 (cycles 0-6), C-6 yielded 30% more than the original population, and the average gain per cycle was a highly significant 238 kg/ ha (Table 7). In 1981, Suwan-1 cycles 0-7 were evaluated for grain yield, agronomic characters, and downy mildew resistance (Figure 6). Downy mildew infection was reduced from 80% (cycle 0) to less than 5% (cycle 7) and, as in the 1979 tests, yield increased nearly 5% per cycle, compared with cycle 0.

A study in 1985 included two additional cycles, Suwan-1 (S) C-8 and C-9 (Table 8). Though differences between cycles of selection for grain yield were significant, those for harvest index were not. Under favorable conditions at Farm

Table 6. Number of S1 families tested and selected, along with average yield, in 10 cycles of selection of Suwan-1

		Number of S1 Families			Average yield (t/ha)	
Cycle	Year	DM-Screen	Yield-tested	Selected	Progenies	Selected
1	1973	Pop.	296	29	NA	NA
2	1974	1,150	200	40	4.4	5.0
3	1975	2,000	400	60	3.4	4.2
4	1976	2,000	400	40	Green ear weight taken	
5	1977	3,200	400	40	4.3	5.8
6	1978*	1,000	400	40	3.7	4.9
7	1979	1,000	400	40	4.6	5.3
8	1980	NT	400	40	4.9	6.4
9	1981	NT	400	40	3.7	4.4
10	1984	NT	400	40	6.5	7.7

NA = Data not available.
NT = Not tested.
* Data not published.

Suwan, all entries yielded well, again with a nearly 5% difference between cycles, indexed on cycle 0. Progress was also made in reducing ear height and number of tassel branches. Cycle 7 showed the highest harvest index (0.52), significantly different from that of cycle 0 (0.47). Black layer formation or physiological maturity was also different from one cycle to the next, with a tendency for advanced cycles of selection to take longer to reach physiological maturity (perhaps permiting more time for photosynthate translocation to the grain, thus increasing yield).

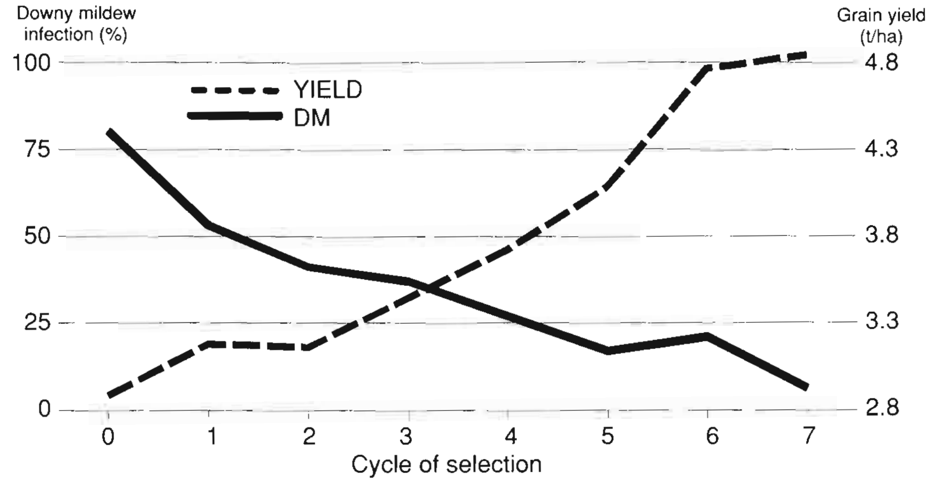


Figure 6. Recurrent selection for yield and downy mildew resistance in Suwan-1.

Table 7. Grain yield and other agronomic characters for seven cycles of selection of Suwan-1 in trials at Farm Suwan, 1979

Cycle	Days to silk	Disease response: H. spp. (1-5)	Curv. (1-5)	Rust (1-5)	Stalk rot (%)	Ear rot (%)	DM (%)	Ear aspect (1-5)	Grain yield (t/ha)	Rank
0	58	1.8	1.4	1.7	10	2.0	2.0	2.6	4.8	7
1	55	1.3	1.4	1.6	11	1.0	0.0	2.1	5.4	5
2	56	1.5	1.6	1.8	3	4.0	2.0	2.4	5.2	6
3	58	1.5	1.6	1.8	7	0.0	0.5	2.1	5.4	4
4	54	1.6	1.4	1.8	2	0.0	0.0	1.9	6.0	3
5	55	1.4	1.4	1.8	2	1.0	0.0	1.9	6.1	2
6	56	1.4	1.4	1.7	3	0.5	0.0	1.8	6.3	1
								Mean	5.6	
								C.V. (%)	8.3	
								L.S.D.(5%)	0.68	

Table 8. Mean grain yield and other agronomic characters of Suwan-1, cycles 0-9, tested at Farm Suwan, 1985

Cycle	Days to silk	Height (cm) Plant	Height (cm) Ear	No. of tassel branches	Leaf area (cm^2/pl)	Lodging Root (1-5)	Lodging Stalk (%)	Yield (t/ha)	HI	Leaf disease (1-5)	Husk cover (1-5)
0	53	237	135	19	7.2	2.4	9	8.0	.41	3	3
1	53	236	135	16	7.0	2.3	7	8.5	.51	2	3
2	53	233	141	17	6.9	2.0	7	8.5	.47	3	2
3	53	231	134	20	7.5	2.3	5	8.3	.50	2	2
4	53	234	130	19	6.6	1.9	8	8.2	.48	2	3
5	53	239	134	19	7.0	2.1	3	9.1	.48	2	2
6	53	241	141	21	7.2	2.3	5	9.1	.46	2	2
7	53	231	134	19	8.0	2.3	4	9.6	.52	2	2
8	53	233	130	18	7.4	1.8	7	9.4	.46	2	2
9	53	237	130	15	7.5	2.1	4	9.4	.49	2	2
						L.S.D. (.05)		0.3	.02		
						L.S.D. (.01)		0.4	.03		
						C.V.		3.7	3.9		

Suwan-1 has proved well adapted across various environments and its yield has remained quite stable since its release in Thailand in 1974. This may be attributed to both its resistance to downy mildew and its inherent high yield potential. Major disease epidemics in 1972, 1977, and 1988 coincided with periods of drought at planting, a circumstance that fostered systemic development of the disease in the slow growing plants. The use of Suwan-1 in severely affected areas reduced disease levels, and yields in these zones increased progressively in subsequent years.

Maintenance, Distribution, and Use of Suwan-1 in Thailand

As mentioned earlier, population improvement was continued in Suwan-1 for many cycles after its release. In addition to improving grain yield and other desirable traits, this helped maintain varietal purity.

At the end of each cycle, selected S1 progenies were recombined and about 60 kg of F1 seed obtained. A two-hectare block was planted in isolation using this seed to produce some 10 t of foundation seed for researchers, extension, and commercial seed producers. Thus, foundation seed of the latest improved version of Suwan-1 was available every 18 months. (Nine tons of foundation seed used for commercial seed production will yield between 1,300 and 2,000 t of certified seed.)

Thailand's maize seed production and distribution system was established in the framework of the Coordinated National Corn and Sorghum Program. Kasetsart University and the Department of Agriculture were responsible for producing breeder's seed and the Department of Agricultural Extension, Ministry of Agriculture, for foundation seed, including certified or extension seed. Private seed companies could purchase foundation seed from the Department of Agricultural Extension for commercial seed production.

This seed production and distribution system has worked very well and Suwan-1 continues to enjoy widespread acceptance among Thai farmers. Despite competition from hybrids, approximately 80% of the country's maize area is sown to Suwan-1.

Moreover, the success of Suwan-1 stimulated the development of Thailand's seed industry. Early on this business met with many difficulties, but the superiority of Suwan-1 and proper promotion led to a fairly swift solution of problems. Charoen Pokphaband, a leading agribusiness in the country, was the first to commercialize Suwan-1 seed in 1979, in collaboration with DeKalb AgResearch, Inc. After leaving the National Corn Program, Dr. Sutat Sriwatanapongse served as Director of Research of this seed company. The first private seed processing plant was built to process Suwan-1, in anticipation of hybrids capturing large portions of the market. Today the plant still produces Suwan-1.

The same year marked the beginning of a hybrid development program in Thailand. Certain S1 families from Suwan-1 (S) C-4 were advanced to S4 lines and selections from these were topcrossed to Suwan-1 (S) C-6, Amarillo Dentado, and Caripeño DMR, and yield tested in 1979. After tests of combining ability , some lines were chosen for use in the hybrid program.

Thailand national maize programs have used Suwan-1 as a source of high yield potential and downy mildew resistance in developing composites and hybrids. Beginning in 1977, many topcrosses were made between Suwan-1 (S) C-4 and other populations. An OPV called NS-1 was developed from Suwan-1 x Amarillo Dentado and released in 1989. Suwan-2301, Suwan-2601, and Suwan-3101 are hybrids developed from Suwan-1 inbred lines.

Six elite inbred lines from Suwan-1 (S) C-4 have been used in both public and private breeding programs. One single cross hybrid, KU Hi 2301, developed by Kasetsart University from two related Suwan-1 lines and released in 1987 as Suwan-2301, yields well, shows some tolerance to drought, and has a good plant type.

Many inbred lines have been extracted from different cycles of Suwan-1. It is believed that private seed companies in Asia have been using these lines to develop hybrids. An example is Pioneer Overseas Corporation-Philippines, which developed parent lines of P 6181 and P 3228 from Thai Composite #1 DMR and other Thai DMR sources. Another example is CP-1, released in Thailand by a local company as a topcross hybrid using Suwan-1 as a parent. To date, however, commercial hybrids developed in Thailand have not been able to compete in yield with Suwan-1, especially in tests at Farm Suwan.

Finally, through contact with Suwan-1, maize farmers in Thailand now better understand the attributes of a "good" variety and "quality" seed, and the tradition of farmers saving seed to plant next season is slowly disappearing. These developments have paved the way for the sale of hybrid seed, as well as demonstrating that commercial seed production of an open-pollinated variety can be profitable.

USE OF SUWAN-1 OUTSIDE THAILAND

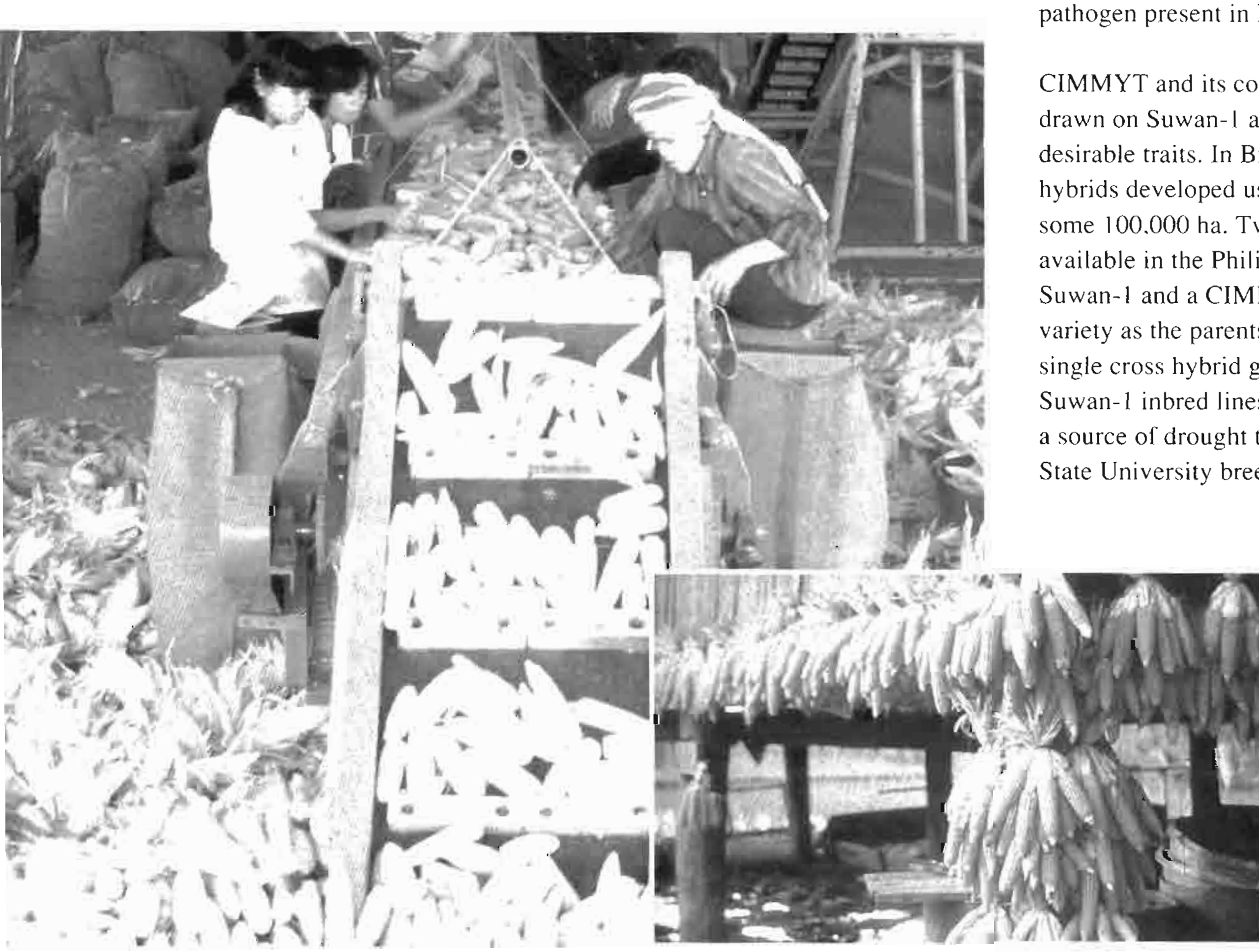
The many good qualities of Suwan-1 --broad adaptation, yield stability, and resistance to downy mildew—have led to its use in breeding programs throughout the developing world, either as a resource material or for direct release (Table 9). We have reports of such cases from the following countries:

Region	Countries
Asia:	Burma, China, India, Laos, Kampuchea, Malaysia, Nepal, the Philippines, Sri Lanka, Vietnam.
Oceania:	Fiji, Mauritius, Papua New Guinea, and Reunion.
Africa:	Cameroon and Nigeria.
S. America:	Brazil, Bolivia, Colombia, Ecuador, Peru, and Venezuela.

Several examples of its release in countries other than Thailand are documented. In 1970, Thai Composite #1 was introduced into Sri Lanka through the IACP, where it was improved and released as "Bhadra-1" in 1977. Bhadra-1 produced 23% more grain than T-48, a local variety, in multilocational trials during 1974-1977 and remains popular among Sri Lankan farmers.

In light of reports of downy mildew disease in Nepal beginning in 1966, Thai Composite #1 DMR was introduced there and later released as Rampur Composite in 1975. It was one of the top yielders in variety trials conducted at ten locations in 1985 and is resistant to the downy mildew pathogen present in Nepal.

CIMMYT and its collaborators have drawn on Suwan-1 as a source of desirable traits. In Brazil, OPVs and hybrids developed using Suwan-1 cover some 100,000 ha. Two varietal hybrids available in the Philippines have Suwan-1 and a CIMMYT experimental variety as the parents. Suwan-2301, a single cross hybrid generated using Suwan-1 inbred lines, has been used as a source of drought tolerance. The Iowa State University breeding program is



Commercial seed processing versus farmers' practice of saving seed in Thailand.

currently using Suwan-1 as a base population in selecting for earliness and photoperiod insensitivity.

Combining Ability of Suwan-1

Considering the widespread use of Suwan-1, little information is available about its combining ability in relation to other widely used maize germplasm. Naspolini et al (1981) found that Suwan-1 combined well with several Brazilian maize populations.

CIMMYT's Maize Program has conducted research on the combining ability of several of its pools and populations. In one diallel involving tropical late yellow maize of CIMMYT origin (Crossa et al., 1990), Suwan-1 was included as a parent because of its widespread use in national programs. The 7 parents and 21 crosses were evaluated at multiple locations. Data from seven locations are presented in Table 10.

Though Suwan-1 ranked fourth in per se yield, the difference in yield between the variety and the top three entries is quite small. In average cross performance Suwan-1 ranked second. The specific cross performance of Suwan-1 with other CIMMYT materials is given in Table 11. It was quite encouraging to note that, in specific crosses with six tropical late yellow materials, it performed very well. Some of the highest-yielding materials were crosses of Suwan-1 with populations 27, 28, and 24. The cross performance of Suwan-1 with CIMMYT Population 36 and Pools 25 and 26 was also quite good. Suwan-1 and Population 24 also registered the highest general combining ability estimates. From these results it is quite clear that Suwan-1 holds good promise for use in developing both conventional and non-conventional hybrids of tropical maize.

Table 9. International use of Suwan-1

Country	Variety released	Description
Bolivia	Suwan Saavedra	OPV grown on some 30,000 ha
Brazil	EMPASC 152	Yellow OPV derived from Suwan-1
	BR 105	Yellow OPV derived from Suwan-1
	BR 5103	OPV derived from Suwan-1
	BR 300, Br 302 and BR 310	Variety crosses involving national cultivars x Suwan-1
Columbia	Population SA-1	Suwan-1 x La Posta Blanco
	Population SA-2	Suwan-1 x La Posta Amarillo
	ICA V-2114	OPV grown on some 5,000 ha
Nepal	Rampur Composite, 1975 release	Derived from DMR version of Thai Composite #1
Sri Lanka	Bhadra 1, 1977 release	Derivative of Thai Composite #1
	Composite 6	Derived from Thai Composite, Cupericox Flint Compuesto and Poza Rica 7425
Philippines	SMC 101	Varietal hybrid (EV of Pop.28 x Suwan-1)
	SMC 102	Varietal hybrid (EV of Pop.36 x Suwan-1)[1]
Thailand	Suwan-2, 1978 release	DMR and early version of Suwan-1
	Suwan-3	Developed from crosses of Suwan-1 (1987 release) to 7 varieties
	NS-1	OPV (Suwan-1 x Amarillo Dentado)
	Suwan-2301, 1987 release	Single cross hybrid (Suwan-1 inbred lines)
	CP-1, 1982 release	Topcross hybrid (Suwan-1 and a Dekalb hybrid)
	Suwan-260, 1986 release	Three-way cross (Suwan-1 inbred lines)
	Suwan-3101	Three-way cross (Suwan-1 inbred lines)

[1] Both hybrids are being produced by San Miguel Corp.

SUWAN-1'S BROAD ADAPTATION

Suwan-1 was bred and tested almost exclusively at Farm Suwan, except for some tests elsewhere during 1974-75. What, then, are the reasons behind the broad adaptation that has made this variety so popular? Several points come to mind:

1. Great care was taken in selecting varieties to form the composite, the principal criterion being evidence of good performance in Thailand and/or in other countries.

2. The compositing process allowed maximum random mating among entries, resulting in a broad based pool that combined 36 tropical and subtropical germplasm sources of different races and backgrounds.

3. Though bred basically at a single location, Suwan-1 was developed using selection during three different seasons per year over several years. Variations in daylength, light intensity, temperature, moisture, pests, etc. could have affected the population in a way analagous to multilocation testing.

4. Great care was taken to maintain the composite's genetic variation during all steps of varietal development. After 10 generations of recurrent selection, this genetic variability has not been exhausted.

5. S-1 recurrent selection allows the easy detection of undesirable recessive genes in families and plants, which can then be discarded.

Table 10. Mean grain yields of Suwan-1 and six tropical late yellow populations and their diallel crosses over seven locations

							Mean yield (t/ha)	
Material	Pop.28	Pop.36	Pop.24	Pool 25	Pool 26	Suwan-1	Per se	Crosses
Pop.27	5.72	5.99	6.27	5.95	5.77	6.55	5.29	6.04
Pop.28		5.87	6.50	5.71	6.10	6.41	5.99	6.05
Pop.36			6.78	5.35	5.60	6.37	5.89	6.00
Pop.24				6.20	6.15	6.67	6.04	6.43
Pool 25					5.68	6.29	5.18	5.86
Pool 26						6.29	5.64	5.93
Suwan-1							5.78	6.42

Table 11. Mid- and high-parent heterosis in crosses involving Suwan-1 and six CIMMYT tropical late yellow populations tested at seven locations

	Grain yield	% heterosis	
Cross	(t/ha)	Mid-parent	High-parent
Pop. 27 x Suwan-1	6.6	118	113
Pop. 28 x Suwan-1	6.4	109	107
Pop. 36 x Suwan-1	6.4	109	108
Pop. 24 x Suwan-1	6.7	113	110
Pool 25 x Suwan-1	6.3	115	109
Pool 26 x Suwan-1	6.3	110	109

SUWAN-2 AND 3

In 1970, in response to a strong demand for a variety to fit short-season production niches, IACP researchers began to develop an early maturing version of Thai Composite #1. Two cycles of mass selection for early silking in Thai Composite #1 were followed by S1 recurrent selection to retain the original high yield potential of the composite. Downy mildew resistance was then added, and in 1975 this material was released as Suwan-2.

In 1981 on-farm tests across the country, Suwan-2 yielded only 3-4% less than Suwan-1, reached silking seven days earlier, and seemed to suit second-crop maize areas well.

Like its later-maturing predecessor, Suwan-2 has traveled well outside Thailand. It was used in Indonesia, for instance, to develop the short-season variety "Ajuna," released in 1980 and now sown on some 20% of the country's maize area.

Suwan-1 is also the main component of Suwan-3, released by Kasetsart University in 1987. Suwan-3 was developed using the composite from crosses of Suwan-1 (S) C4-F3 to IPTT 34 (CIMMYT Pop. 34), H3369 A, SR 52, Florida Synthetic, CIMMYT Population 45, USA 342, and Corn Belt Composite. In 1983 this was named Kasetsart Synthetic 4 (KS4). After four cycles of S1 recurrent selection, KS4 was released in 1987 as Suwan 3. It yields 15% more than Suwan-1 and shows increased vigor.

Conclusion

The success of Suwan-1 demonstrates the following:

1. Broad-based germplasm coupled with a good breeding methodology can result in a successful variety.

2. A team approach works well in breeding for disease resistance and wide adaptability.

3. A good working environment with strong institutional support and private sector participation are key factors.

The strong devotion of Dr. Sujin Jinahyon, Project Leader, and the hard work of his team in the development of Suwan-1 should be mentioned. The work has resulted in a significant contribution to the improvement of maize research and production.

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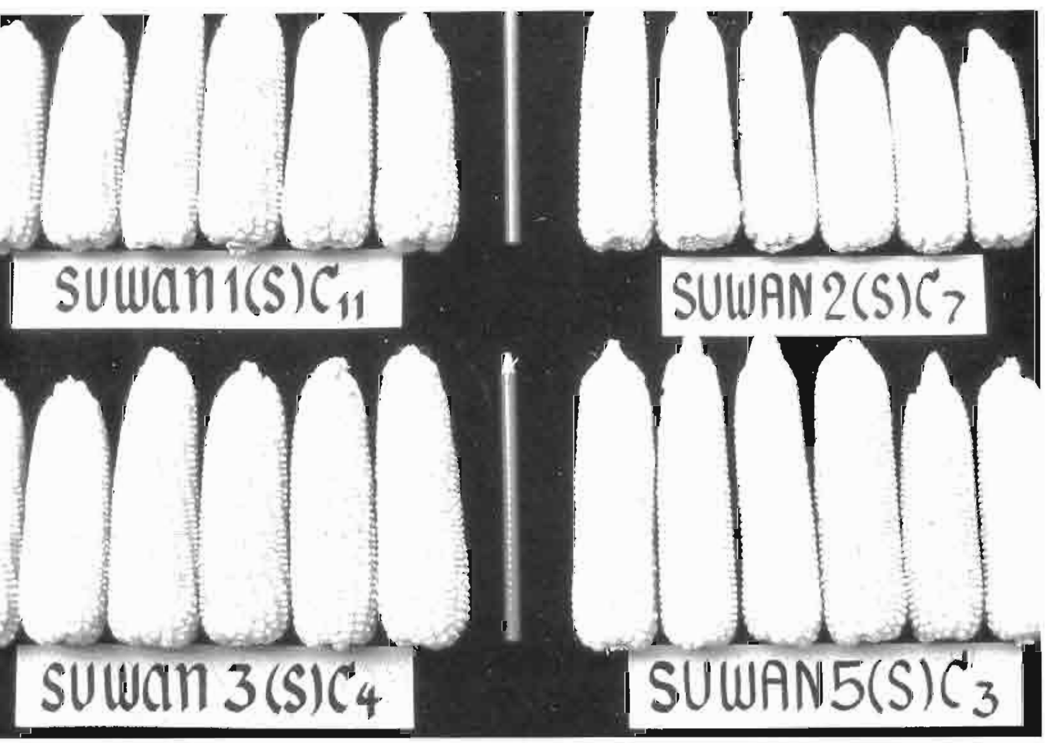

Ears of Suwan-1 and its derivatives, Suwan-2, 3, and 5.