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Variety × Line Cross — A Suggested Breeding Procedure for Maize in Developing Countries*

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Summary. Phra-Phutthabat No.5 (PB5), a widely grown local variety in Thailand, was crossed with open-pollinated varieties, S_3 and S_6 lines from different parts of the world. The resulting hybrids were tested in the dry season in Thailand, Laos and Israel with PB5 as the control. A number of hybrids were also tested in the wet season in Thailand and Laos. Hybrids giving significantly higher yields than PB5 were found in both the dry and the wet seasons. The variety × line crosses were superior to the variety × variety crosses at all locations. The hybrids with the South African germ plasm were intermediate, and those with the African and Asian germ plasm gave the lowest yields. The variety × line cross is suggested as a simple and rapid breeding procedure for the developing countries.

Maize is the third-ranking food crop after wheat and rice. There are 51 countries in Asia, Africa and Latin America, each producing over 100,000 hectares of maize. Over half these countries had average yields in 1971 of one metric ton per hectare or less (Cimmyt 1972). In many of these countries, the population increased faster than the maize yields (Cimmyt 1973). Both improved agricultural technology and improved maize varieties should be incorporated in order to increase maize yields in these countries.

Maize production in the developing countries is based mainly on open-pollinated local varieties with low-yielding potential. Usually, this yielding potential is not increased significantly by different selection techniques within the varieties. High-yielding maize hybrids have been grown in the United States and other countries for more than 50 years. The development of the classical single- or double-cross hybrids showing adaptation to local environmental conditions is a long and complicated process. It requires technically trained personnel and physical facilities, and also skilled farmers with improved agricultural practices. Unfortunately, these factors are lacking at present in the developing countries.

In recent years there has been renewed interest in heterosis resulting from intervarietal hybridization. Encouraging results have been obtained by Robinson *et al.* (1956), Pollak *et al.* (1957), Lonnquist and Gardner (1961), Paterniani and Lonnquist (1963), Timothy (1963), Wellhausen (1965), and others. The commercial use of varietal cross hybrids was suggested by Togby *et al.* (1968).

In 1954, a variety × line hybrid (N.Y.170) was developed by the senior author (Shlomi, unpublished). This hybrid was uniform, almost resembling a single cross, with outstanding yields. It is still grown in Israel for silage. This breeding approach was used in a breeding program initiated in 1969 at the Newe Ya'ar Experiment Station, in accordance with the program of agricultural research activities in Israel's agricultural cooperation projects in developing countries.

The purpose of this paper is to suggest the variety × line cross as a simple and rapid breeding procedure to produce improved maize hybrids adapted to the agricultural practice of the developing countries.

Materials and Methods

Phra-Phutthabat No. 5 (PB5), a widely grown local variety in Thailand, was used as a common parent in crosses with a wide range of open-pollinated varieties, and lines from Asia, Africa and Latin America. Some were inbred lines after at least six generations of self pollination; others were self-pollinated for three generations and then maintained by sib pollination. Thirty-four of the variety × variety and variety × line hybrids were tested using PB5 as a tester at three locations - at the Thai-Israel project in Hop-Tapong south of Bangkok, Thailand; at the Laos-Israel project at the Hatdokeo Farm near Vientian, Laos, both in the 1969/1970 dry season (November planting); and at the Newe Ya'ar Experiment Station, Israel, in the summer of 1970.

Six hybrids were tested also in the 1970 wet season (July planting) at the Thai-Israel project, University of Khon-Ken Experiment Station, Thailand, and at the Suwan Farm, Nakornrajsima, Thailand. The hybrids were tested in randomized blocks with four replica-

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Table 1. Grain yield (kg/ha) of different crosses with PB5 in Thailand (Hop-Tapong), Laos (Hat-Dokeo) and Israel (Newe Ya'ar)

Cross No.	Varieties or lines crossed with PB5	Country of origin	Breeding stage	Thailand			Laos			Israel		
				Grain yield kg/ha	% of control	Rank	Grain yield kg/ha	% of control	Rank	Grain yield kg/ha	% of control	Rank
137-1	L-2876	Brazil	S 6	8317 [a]	189	1	5452	105	16	8688 [a]	165	16
201-1	Local Var.	S. Africa	S 6	8072 [a]	183	2	5310	102	18	10480 [a]	199	1
17-1	Cuba Hybrido T-66	Cuba	O.P.	7890 [a]	179	3	6297	121	4	8030 [a]	152	26
31-1	Olote Delgado	Mexico	S 3	7627 [a]	173	4	5110	98	26	9852 [a]	187	4
28-1	Coah	Mexico	S 3	7447 [a]	169	5	5282	102	19	9225 [a]	175	11
217-1	Salvador H-3	Salvador	O.P.	7257 [a]	165	6	6740 [a]	130	1	7945 [a]	151	29
74-1	Capitan	Mexico	S 3	7207 [a]	164	7	5070	98	27	9077 [a]	172	14
61-1	S.A. 415-1	S. Africa	S 6	7063 [a]	160	8	6112	118	9	9870 [a]	187	3
185-1	Polysora	Kenya	S 3	7050 [a]	160	9	6360	122	2	8470 [a]	160	21
69-1	Buake Jaunn Precose	Ivory Coast	S 1	6787	154	10	4017	77	35	8195 [a]	155	24
207-1	Local Var.	S. Africa	S 6	6640	151	11	6237	120	6	9827 [a]	186	6
100-1	Olote Delgado	Mexico	S 3	6570	149	12	6220	120	7	8840 [a]	168	15
72-1	Capitan Amarillo	Mexico	S 3	6380	145	13	6190	119	8	9192 [a]	174	12
4-1	Capitan Amarillo	Mexico	S 3	6372	145	14	6350	122	3	9827 [a]	186	5
19-1	Pinto de Texas	Mexico	S 3	6360	144	15	6262	120	5	10350 [a]	196	2
67-1	Philippines A83 × A113	Philippines	S 6	6297	143	16	5380	104	17	8042 [a]	153	25
11-1	Salvador Compueste Amarillo	Salvador	O.P.	6060	138	17	5757	111	11	7902 [a]	150	30
165-1	Local Synthetic	Ceylon	O.P.	6040	137	18	4070	78	34	7385 [a]	140	32
6-1	Capitan	Mexico	S 3	5857	133	19	5477	105	15	9450 [a]	179	9
9-1	Caribbean Complex	Mexico	O.P.	5815	132	20	5057	97	29	7362 [a]	140	33
57-1	Philippines A-111	Philippines	S 6	5640	128	21	4537	87	31	7012 [a]	133	34
1-1	Buake Jaunn Precose	Ivory Coast	S 1	5570	127	22	5607	108	13	8342 [a]	158	23
92-1	Eto 29-29 A	Mexico	O.P.	5305	121	23	5180	100	24	8345 [a]	158	22
106-1	Amargo Brazil	Brazil	O.P.	5270	120	24	5063	97	28	8565 [a]	162	18
41-1	Nagarit 36	Mexico	O.P.	5162	117	25	4310	83	32	8492 [a]	160	20
54-1	313 a	Morocco	S 6	5060	115	26	5930	114	10	7590 [a]	144	31
84-1	Local collection	Uganda	O.P.	5032	114	27	5265	101	21	8665 [a]	164	17
33-1	Gan Rakha	Burma	O.P.	4932	112	28	5155	99	25	8495 [a]	160	19
35-1	Rhwe Cane	Burma	O.P.	4770	108	29	4087	79	33	7957 [a]	151	28
40-1	Tobloncillo	Mexico	O.P.	4567	104	30	5550	107	14	9330 [a]	177	10
88-1	Pinto de Texas	Mexico	O.P.	4565	104	31	5282	102	20	9730 [a]	185	7
187-1	Kampala Kitale Synth.	Uganda	S 3	4542	103	32	5627	108	12	9090 [a]	172	13
191-1	Tanzania × Illinois hybrid	Tanzania	O.P.	4188	195	34	4950	95	30	7992 [a]	152	27
8-1	Local, high row ears	Mexico	O.P.	4100	93	35	5182	105	23	9677 [a]	184	8
PB5	Control	Thailand	O.P.	4402	100	33	5197	100	22	5272	100	35
	Mean			6007			5405			8645		

[a] Yield significantly higher than the control.

tions at 50,000 and 40,000 plants per hectare for the dry and wet seasons, respectively. The data of the dry season were analyzed by the Neuman-Keul multiple range test and those of the wet season by the least significant difference (L.S.D.) test.

Results

The growing conditions for maize in the semi-arid Mediterranean climate are very different from those prevailing in the tropical lowland of Southeast Asia. Therefore, it was realized that adaptation to tropical conditions should be the main criterion for selection of the breeding germ plasm. Therefore, the basic breeding approach was to develop a cross between a local (tropical) open-pollinated variety and a line which was developed at New Ya'ar from varieties introduced from other tropical regions. Crosses were also made between the local variety and other open-pollinated varieties in order to compare the relative yields of variety × variety and variety × line crosses, and also to select varieties which have good combining ability with PB5 for future breeding work. The results obtained with 34 hybrids which were tested in Thailand, Laos (dry season) and Israel are presented in Table 1. The average yield was highest in Israel and lowest in Laos. Under Israeli conditions the yields of all the hybrids were significantly higher than the yield of PB5. The best hybrid (201-1) yielded about twice as much as PB5. This was to be expected, since PB5 is not adapted to Israel's growing conditions. However, similar results were also obtained in Thailand. Thirty-two hybrids yielded more than PB5. Nine hybrids had significantly higher yields, and 24 hybrids had 20 % higher yields, or more, than the local variety. In Laos the results were not so dramatic as in Thailand and Israel. The average yield in this trial was 5405 kg/ha, compared with 6007 and 8645 kg/ha in Thailand and Israel, respectively. However, the yield of the local variety PB5 was higher in Laos (5182 kg/ha) than in Thailand (4100 kg/ha). Only 21 hybrids yielded more than PB5 and only seven hybrids exceeded PB5 by 20 % or more. One hybrid (217-1) had significantly higher yields than the control, with an increase of 1558 kg/ha.

The relative yields of the hybrids in the three different locations were not always correlated, *e.g.* the hybrid 17-1, which was the third and fourth ranking hybrid in Thailand and Laos, respectively, was the 26th in Israel. The hybrid 31-1 was the fourth ranking hybrid in both Thailand and Israel, but only the 26th in Laos. As might be expected, the correlation between the results obtained in Thailand and Laos is better than that between the results obtained in Israel and Thailand or Laos. Thus, nine out of the ten highest yielding hybrids in Laos were included among the 50 % (17) of the highest yielding hybrids in Thailand. At the same time, only six out of the ten highest yielding hybrids in Thailand or Laos were among the 50 % (17) of the highest yielding hybrids in Israel.

The germ plasm used in the crosses with PB5 was obtained originally from different parts of the world. Even though the number of hybrid combinations with PB5 was small, some information may be obtained about combining ability and adaptability (Table 2). The germ plasm from South Africa (Kenya included) showed the best average combining ability with PB5 in Israel, Thailand and Laos. On the other hand, the germ plasm from Asia and Africa had the lowest average yield at the three locations. The material from Mexico and Latin America produced intermediate results, with a different response in Israel from that obtained in Thailand and Laos. In Israel, the Mexican germ plasm performed better than the Latin American germ plasm, while in Laos and Thailand the opposite was true.

Seventeen open-pollinated varieties - ten lines after three generations of self-pollination (S_3) and seven inbred lines (S_6) - were used in this study (Table 3). The crosses with the open-pollinated varieties were inferior at all three locations. On the other hand, the crosses with the S_3 lines had a higher average yield than the crosses with the S_6 inbred lines in Israel and Laos. In the hybrids 17-1 and 217-1, the open-pollinated varieties were originally hybrids (Cuba Hybrido T-66 and Salvador H-3, respectively) that were maintained at Newe Ya'ar by sib pollination. They were more uniform that the other open pollinated varieties, more resembling an S_3 line. These two hybrids were the highest yielding hybrids among the open-pollinated group.

Six of the above hybrids were also tested in the wet season at Farm Suwan and Khon-Ken University in Thailand (Table 4). The average yield in the wet season was lower than the average yield of the same hybrids in the dry season. The same was found in all our experiments in Southeast Asia (Efron, unpublished). At Farm Suwan, all the hybrids yielded significantly

Table 2. Average grain yield (kg/ha) of germ plasm collected from Asia, Africa, South Africa, Mexico and Latin America in hybrid combinations with PB5 in Israel, Thailand and Laos

Country of origin	Number of hybrids	Israel		Thailand		Laos		Mean	
		Grain yield kg/ha	Percent [a]	Grain yield kg/ha	Percent [a]	Grain yield kg/ha	Percent [a]	Grain yield kg/ha	Percent [a]
Mexico	14	9196	118	5952	108	5466	118	6871	115
Latin America [b]	5	8226	106	6959	126	5862	126	7016	117
South Africa [c]	4	9662	124	7626	138	6005	129	7764	130
Africa	6	8312	107	5197	94	5233	113	6244	104
Asia	5	7778	100	5536	100	4646	100	5987	100

[a] Relative to Asia [b] Central and South America [c] Kenya included

Table 3. Average grain yield (kg/ha) of open pollinated varieties, S_3 lines and S_6 inbred lines in crosses with PB5 in Israel, Laos and Thailand

Breeding stage	Number of hybrids	Grain yield (kg/ha			
		Israel	Thailand	Laos	Average
Open pollinated [a]	17	8377	5543	5151	6357
S_3 lines	10	9337	6541	5795	7224
S_6 lines	7	8787	6727	5565	7026

[a] The two crosses with the S_1 originating from Buake Jaunn Precose are included

Table 4. Grain yield of six crosses with PB5 in Farm Suwan and the University of Khon-Ken Experiment Station, Thailand, during the wet season of 1970

Cross Number	Wet season						Dry season	
	Farm Suwan		Khon-Ken		Mean		Mean Thailand and Laos	
	Grain yield kg/ha	% of control	Grain yield kg/ha	% of control	Grain yield kg/ha	% of control	Grain yield kg/ha	% of control
1-1	3540 [a]	171	5680 [a]	122	4610	137	5589	116
137-1	3420 [a]	165	5910 [a]	127	4665	139	6885	143
57-1	3000 [a]	145	4400	95	3700	110	5089	106
11-1	2920 [a]	141	5240	113	4080	121	5909	123
217-1	2900 [a]	140	4890	105	3895	116	6999	146
17-1	2610 [a]	126	5080	109	3845	114	7094	148
PB5	2070	100	4650	100	3360	100	4800	100
Mean	2923		5121		4022		6052	

[a] Yield significantly higher than the control

more than the control variety PB5. The best hybrid (1-1) gave a 71 % higher yield than the control. The lowest yielding hybrid (17-1) exceeded the control by 26 %. Five hybrids had higher yields than PB5 in Khon-Ken, but only in two of them, 137-1 and 1-1, were the yields significantly higher. The same two hybrids also had the highest yields at Farm Suwan. On the other hand, the correlation between the results obtained in the dry and the wet season was not good. The highest yielding hybrids in the dry season (17-1 and 217-1) were the lowest yielding in the wet season, and hybrid 1-1 had a high yield in the wet season and a relatively low yield in the dry season. The hybrids 137-1, 11-1 and 57-1 showed relatively similar high, intermediate

and low yields, in both seasons. This may suggest that different varieties should be developed for the dry and the wet seasons in the tropics.

Discussion

The results of this study have shown that a significant yield increase may be obtained in the developing countries in both the dry and the wet seasons in a short time and with relatively little effort. Only 35 varietal crosses and variety × line hybrids were tested. It is to be expected that testing a larger number of similar hybrids would increase the chances of isolating even better hybrids. The results have indicated, also, that the variety × line cross might be more fruitful than the varietal crosses. The hybrids with the S_3 and the S_6 lines exceeded the hybrids with the open-pollinated varieties by 14 and 11 %, respectively.

The variety × line cross is one form of the topcross testing (Jenkins and Brunson 1932) which is a known breeding practice for evaluation of unknown germ plasm. As a breeding procedure it may be considered as an intermediate approach between the classical single cross hybrids and the varietal cross hybrids. The variety × line hybrids are expected to be more uniform and more stable than the varietal cross hybrids, but with greater genetic diversity than the single cross hybrids. Populational diversity has been shown to be advantageous as an average over varying environments within crop species (Allard and Hensche 1964). In maize, it was found that double crosses are more stable over years and locations than single crosses, though less likely to produce top yields (Sprague and Federer 1951; Jones 1958; Eberhart and Russell 1969). Populational buffering due to genetic diversity might be even more important under the suboptimal environmental conditions and the underdeveloped agricultural practice in the developing countries. Therefore, the variety × line cross might be a more useful breeding approach in developing countries than production of single-cross hybrids. In this study, the importance of populational buffering may be demonstrated by the fact that the hybrids with the S_3 lines gave on average higher yields than the hybrids with the S_6 lines.

Summarizing the data of intervarietal crosses, Wellhausen (1965), concluded that the degree of heterosis depends upon genetic diversity of the varieties crossed and that crosses of adapted varieties with varieties unadapted in a given environment may in many cases yield as much as or more than crosses between adapted parents. Moreover, selection techniques such as reciprocal recurrent selection (Comstock *et al.* 1949) are based on the assumption that any improvement in the breeding population for yield and other agronomic traits should give improvement in the hybrids of lines from the improved population. The results obtained in this study are in agreement with these arguments. The crosses with the temperate zone South African germ plasm out-yielded all other sources of germ plasm at all three locations. The South African germ plasm is an improved germ plasm with relatively high yielding potential in the temperate climate, but it may be less adapted to the tropics than all other sources. Thus, both greater genetic diversity and higher yielding potential were probably important factors contributing to the highest yields of these hybrids. On the other hand, the hybrids with the Asian germ plasm, which is locally adapted but probably more closely related and with relatively low yielding potential, were the lowest yielding hybrids.

Based on the adapted local variety, the variety × line cross is a rapid and simple breeding procedure. Inbred lines, not necessarily pure lines, may be introduced from different countries, giving consideration to genetic diversity and the level of productivity. The possibility of growing the introduced lines under local conditions should also be considered. In the tropics it is recommended that the breeding program should be initiated in the dry season (under irrigation), when problems of adaptability should be less severe than in the wet season. Thus, a wider range of introduced germ plasm may be selected. In the first dry season, a large number of variety × line hybrids should be produced between the local variety and the introduced lines. These hybrids would be tested in the wet season (the normal season for growing maize in the tropics). Based on the results, seeds of the best hybrids would be produced again, in larger quantities, in the next dry season. The amount of seeds from the parental lines of the best crosses would be increased at the same time. The selected hybrids should be tested again in the next wet season at several locations. Seeds of the best one or two hybrids may be produced on a semi-commercial scale in the third dry season.

If the local variety is used as female parent, commercial seed production is a simple process requiring only one field. Seeds of the male line would be obtained in the seed production field and seeds of the local variety can be found on the market. Seed yield would not be so low as in the production of a single cross, since the female parent is an open-pollinated variety.

Following the release of the commercial variety × line hybrid, further improvement in yield and agronomic characters may be achieved by a test cross selection program. Individual plants from the open-pollinated variety would be selfed and at the same time crossed with the other parental line. After testing of the crosses, a bulk of seeds from the best S_1 plants would be grown in an isolated plot for intercrossing. The seeds from this field would be used as female parent in the seed production field and as a source for the next cycle of selection.

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