Genetic Potential of Exotic Germplasm Introduced from Different Latitudes for the Improvement of Tropical Maize (*Zea mays* L.)

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ABSTRACT

To broaden the genetic base of the tropical maize, adding more favorable alleles from exotic germplasm into the tropical breeding material is one way suggested by plant breeder. For effective utilization of the exotic germplasm, rapid and efficient method of incorporation of exotic germplasm into tropical material is needed. This study was conducted to assess a genetic potential and the effectiveness of exotic germplasm introduced from different latitudes in combination with tropical breeding materials. The results of the study implied that: semi-exotic populations containing 50 % exotic germplasm showed the lowest yield, lowest grain moisture content, earliest days to anthesis and silking, highest leaf disease infection. Semi-exotic populations with 25 % and 12.5 % exotic germplasm showed no significant difference to population with 0 % exotic germplasm, except semi-exotic population of latitude-2 (> 22.5 – 37.5 °North Latitude), Southern U.S. germplasm. Significant quadratic response among population means due to proportion of exotic germplasm was noted for grain yield of the semi-exotic populations of latitude-1 (> 37.5 °N.L.), -2, -3 (> 7.5 – 22.5 °N.L.), and -5 (> 37.5 °South Latitude). Significant linear responses were noted for days to anthesis and silking and grain moisture content. Highly significant linear response to leaf diseases was observed in semi-exotic populations of latitude-1, -2, -3, -4 (> 22.5 – 37.5 °S.L.), and significant response was shown by exotic source from latitude-5. Population with 50 % exotic germplasm from latitude-4 "South Africa" was well adapted to tropical condition and showed no response to the higher degree of tropical germplasm.

Key words : maize, exotic germplasm, genetic diversity, latitude

INTRODUCTION

Genetic diversity is a basic element necessary for effective plant breeding program. To increase selection efficiency, plant breeder devoted considerable effort and time to increase genetic diversity. The methods used for creating genetic diversity including hybridization of adapted germplasm, introduction of germplasm from other sources (exotic), and use of mutagenic agents (Bridges and Gardner, 1987). The reasons for the use of exotic germplasm are: as a source of favorable alleles for yield, increase useful genetic variation, enhance heterosis, source of genes for specific traits such as disease and pest resistance and stress tolerance, and the need to increase genetic diversity as a safe guard against unpredictable biological and environmental hazards (Albrecht and Dudley,1987a and 1987b).

Despite the usefulness of exotic germplasm

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in broaden the genetic diversity of adapted germplasm, many practical disadvantages also exist. Under the temperate environment, problem such as photoperiodic sensitive, susceptibility to disease, late maturity and weak stalk are often found when tropical germplasm is introduced (Holley and Goodman, 1988). While in tropical environment, introduction of exotic germplasm from temperate and sub-tropical regions to tropical region frequently causes problem such as; susceptibility to disease, insect, and heat, early flowering and senescence (Kim, 1990; Khehra *et al.*, 1986). The non adaptability of the material also creates a problem in identifying superior genotypes.

Successful exploitation of exotic germplasm for improving the local germplasm required a systematic approach. Effective choosing source of exotic germplasm and methods applied are very important. Geadelmann (1984), when working with exotic germplasm addressed the following questions: (1) which exotic population(s) should be chosen? (2) what proportion of exotic germplasm should be used? (3) how much recombination should occur before intense selection is practiced? (4) what selection system should be employed? Based on a theoretical genetic and computer simulation, Dudley (1982) found that the optimum generation of backcrossing to generate the foundation population is a function of genetic diversity of the parents, the more diverse the parents, the more useful one and more generations of backcrossing to the local parent becomes.

The objectives of the present study were to: 1) evaluate the potential use of exotic germplasm from different regions as source of unique favorable alleles for improving tropical population, 2) determine the optimum proportion of exotic germplasm of certain region for improving tropical population.

MATERIALS AND METHODS

Six tropical maize inbred lines namely: Nei9008, Nei9202, AMATLC0HS 63-2-5-E-3-1-2, AMATLC0HS 170-2-3-2-1-1-1-B-3, Ag18, and Ki42 were chosen and intercrossed to five groups of exotic hybrids representing exotic groups adapted to five corresponding regions. The five exotic groups and their adapted regions were as follow:

1) Latitude- 1: adapted to > 37.5°North Latitude (NL); US Corn Belt, namely: DI7117A, DK602, DK611, ISU # 1, ISU # 2, ISU # 3, Mitos, and Santos.

2) Latitude-2: adapted to > 22.5 – 37.5°NL; Southern US namely: DK683, DK687, DK720S, DK743, DK727.

3) Latitude-3: adapted to > 7.5 – 22.5°NL; Mexico, namely: D865 and D869.

4) Latitude-4: adapted to > 22.5 – 37.5°South Latitude (SL) ; South Africa, Mozambique, namely: SNK2042, SNK2576, SNK2640, SNK2778 and DK834.

5) Latitude-5: adapted to > 37.5°SL; Argentina, namely: DK663, DK664, DK669, DK752.

Crosses were made between the tropical inbred lines and the exotic groups. Each of the six tropical inbred lines was crossed by bulked pollens of 5 to 7 plants of exotic hybrids in the same group to generate BC_0F_1. In the following season, in order to generate BC_0S_1 and BC_1F_1 seed, the BC_0F_1 plants were self pollinated and backcrossed to the corresponding tropical inbred lines. The BC_0S_2 was derived from selfing of the BC_0S_1. The BC_1F_1 was self-pollinated to generate BC_1S_1. Simultaneously, the BC_1F_1 was backcrossed to corresponding tropical inbred lines to generate BC_2F_1.

In each exotic group, three semi-exotic populations contained 50, 25 and 12.5 % were generated. Details of procedure for the formation of the 50 % semi-exotic populations of each exotic group were as followed: (1) Twenty ears each of the BC_0S_1 were selected to the total of 120 ears. (2) Ten seeds were sampled from each of the 120 ears and uniformly bulked as a foundation material. (3) The bulked seeds were grown in 25 rows of 0.75 ¥ 0.25 m plant spacing with 5-m long (approximately, 500 plants were obtained). (4) At the flowering stage, the 500 plants were recombined by half-sib matting procedure; half number of the plants were arranged as pollen sources and their bulked pollens were pollinated to the other half and vice versa. (5) At harvest, 50 desirable ears were selected. The same procedures were employed to generate 25 and 12.5 % of semi-exotic populations using BC_1S_1 and BC_2S_1 seeds as foundation materials, respectively. The total of 15 semi-exotic populations were generated representing five exotic groups and three proportions of exotic germplasm of each exotic group. One additional population was generated by recombining the six corresponding tropical inbred lines representing the tropical population (0 % exotic).

Four additional populations were included in order to simplify experimental arrangement. Two of the four additional populations were Suwan 1 and Bisma. Suwan 1 is a widely adapted tropical population developed by Kasetsart University and Bisma is a tropical population widely adapted in Indonesia developed by Food Crops Research Center, Department of Agriculture, Indonesia. The other two populations were newly formed populations. The 20 populations were evaluated in 4 x 5 rectangular lattice design with 3 replications.

Yield trials were conducted in the year 2003 at three locations: National Corn and Sorghum Research Center (Suwan Farm, Nakhon Ratchasima, Thailand) is located at 14° 30' North, 101° 30' East, 356 meter above sea level; Bangkok Seed Industry Research Farm (Salengparn, Saraburi, Thailand) is located at 14° 30' North, 101° 30' East, 40 meter above sea level; and PT. BISI Research Farm (Kediri, Indonesia) is located at 7° 55' South, 112° 01' East, 110 meter above sea level. Each plot consisted of six 5-m rows at Salaengpharn and Kediri, and 4.5-m rows at Suwan Farm. Plants spacing were 0.75 m between rows and 0.20 m within row. Plots were over-planted with 44 seeds per row, after two weeks, plants were thinned to 1 plant per hill or population size of 66,667 plant/ha. Standard cultural practices were followed at all locations. Data were recorded on: days to 50% anthesis and silking, ear height and plant height expressed in cm, leaf disease infection "Southern rust and leaf blight" (1 = highly resistance, 9 = highly susceptible), root lodged and stalk lodged expressed in percent plant lodged per plot, grain moisture content at harvest expressed in percent, and grain yield at 15 % moisture expressed in ton/ha.

The analysis of variance was done in two phases. First, population means over locations were computed by running individual location analyses, obtaining lattice adjusted and/or unadjusted means, and then by averaging those means over locations. For all traits, the following single degree of freedom comparisons (group comparisons) between means were performed:

    1) L0 vs L1, L2, L3, L4, L5;
    2) L1 vs L2, L3, L4, L5;
    3) L2 vs L3, L4, L5;
    4) L3 vs L4, L5;
    5) L4 vs L5.

Where L0 stand for 0 % exotic germplasm and Ln stand for population generated from S_1 lines contained exotic germplasm from n^{th} latitude, each Ln consisted of three semi-exotic populations representing three proportions of exotic gemplasm. In the second phase, effect of treatments (proportion of exotic germplasm) was analyzed. The latter analyses were done based on simple randomized complete block design using unadjusted data and

separated for each group of exotic sources. The population and the population x location interaction sum of squares were partitioned into linear and non linear orthogonal polynomials. All statistical computations were done using the MSTAT-C computer program (MSTAT-C, 1988).

RESULTS AND DISCUSSION

Diversity among the 20 populations was clearly displayed as the entry mean squares for all traits showed highly significant difference, except in plant height (Table 1). Highly significant entry x location interaction implied the instability of yield over locations while the other traits under studied were stable. The average of overall semi-exotic populations showed no significant difference to the 0 % exotic population except for grain moisture content. Semi-exotic population of latitude-1 (L1) showed highly significant difference (P < 0.01) to average of semi-exotic populations L2, L3, L4 and L5 for grain yield and days to silking. No significant difference was observed for all traits under studied between semi-exotic population of L3 and the average of L4 and L5, except grain moisture content and stalk lodged.

Grain yield

Mean grain yield of semi-exotic population L1 (5.87 ton/ha) was clearly lower than those of L2 (6.46 ton/ha), and L4 (6.41 ton/ha). Whereas, the difference between mean grain yield of the other groups were not significant (Table 2). However, only mean grain yield of 50 % semi-exotic population L1 showed significantly lower than the 0 % semi-exotic population (L0) and contributed to the significant lower grain yield of L1 than those of L2 and L4. Besides, mean grain yield of 50 % semi-exotic population of every group showed significantly lower yield than the 25 and 12.5 % semi-exotic population of corresponding group, except L4. Indicating that semi-exotic population with lower proportion of exotic alleles (25 and 12.5 % exotic) performed better than the higher

one (50 % exotic). Selig et al. (1999) also found the same results. Based on Restriction Fragment Length Polymorphism (RFLP) analysis of introgression of Brazilian germplasm into U.S. maize inbred lines, they found that US-Brazilian derived lines with lower amounts of Brazilian fragments than average frequently performed better in hybrids evaluation. The same evidences were also found from studies of Lawrence and Frey (1975), Cox and Frey (1984) who studied wide cross of oat and sorghum, respectively. They suggest that, in the F_2 generation, the chance for recombination between chromosome segments from diverse parents is low whereas in early backcross generations the chance for recombination increases and, at the same time, favorable linkages already present in the adapted parent are restored.

Excluding the 50% semi-exotic populations, all 25 and 12.5% semi-exotic populations yielded statistically the same as L0 population except L2 which showed significantly higher yield than the rest of the groups and had comparable yield to Suwan 1 and Bisma. This is not unexpected because the six tropical inbred lines used in this study were selected from different sources without testing for their combining ability. Besides, some lines were not well adapted to the testing sites and contributed to the lower yielding ability of the L0 population as well as the semi-exotic populations.

Even thought, there was a slight difference among semi-exotic populations, the results suggested that all sources of improved exotic germplasm especially commercial hybrids have potential to be used as breeding materials for the improvement of tropical maize. Moreover, discarding of poor adapted plants after each backcrossing and used only adapted ones to generated foundation population led to quick improvement of germplasm. However, to increase the efficiency of incorporation of exotic germplasm into tropical lines, the tropical recurrent lines should be highly adapted lines with high combining ability.

Tabel 1 Mean squares of yield and other traits; a comparison between check and a group of exotic sources, among groups of exotic sources, averaged across three locations.

Source of variation	df	Grain yield	Days to anthesis	Days to silking	Moisture content	Leaf disease[1]	Plant height	Ear height	Root lodging	Stalk lodging
						Mean Square				
Location	2	2.58	133.47 **	157.62 **	28.77 *	69.01 **	2963	145	3.24	31.77
Replication within location	6	0.58	6.46	6.76	3.52	2.49	670	240	0.02	0.48
Entry[2]	19	1.50 **	4.42 **	6.74 **	10.54 **	5.23 **	139	159 **	0.24 **	1.37 **
L0 vs L1, L2, L3, L4, L5	1	0.04	2.08	4.72	7.72 *	5.70	188	99	0.13	1.18
L1 vs L2, L3, L4, L5	1	3.97 **	9.87	18.15 **	1.29	6.45	2	11	0.03	0.16
L2 vs L3, L4, L5	1	0.94	0.52	2.97	0.02	0.89	1	101	0.08	0.81
L3 vs L4, L5	1	0.05	0.75	0.75	8.77 *	0.30	367	262	0.07	4.39 *
L4 vs L5	1	1.16	0.02	0.17	0.01	0.46	50	5	0.18	.92
Loc. x Entry	38	0.45 **	0.99	0.98	1.17	0.98	102	85	0.14	0.45
Pooled error	114	0.20	0.92	1.07	1.54	0.89	99	69	0.11	0.36
Total	179									
CV (%)		7.18	1.92	1.99	5.52	16.89	5.08	7.99	36.75	38.42

Note: * , ** Significant at 0.05 and 0.01 probability levels, respectively.
   [1] Leaf diseases : 1= highly resistance; 9 = highly susceptible
   [2] L0 = 0 % exotic germplasm
       L1 - L5 = Exotic germplasm from latitude-1 to 5

Table 2 Means of yield and other traits, and response due to different proportions of exotic germplasm, averaged across three locations.

Source of exotic[1]	Proportion of exotic	Grain yield	Days to anthesis	Days to silking	Moisture content	Leaf disease[2]
		---ton/ha---	----------days----------		----%-----	----(1 - 9)---
	50%	5.29 b	49.0 b	50.4 c	20.7 c	7.1 a
L1	25%	6.15 a	49.7 ab	51.6 b	21.8 b	6.2 b
(>37.5° N)	12.50%	6.17 a	49.9 ab	51.6 b	23.2 a	5.4 bc
	0%	6.14 a	50.6 a	52.7 a	23.1 a	5.0 c
	Average[3]	5.87	49.5	51.2	21.9	6.2
Response :	Linear	**	**	**	**	**
	Quadratic	*				
	50%	5.81 b	49.4 b	50.8 b	21.5 b	6.6 a
L2	25%	6.70 a	50.1 ab	51.9 a	21.6 b	5.2 b
(>22.5° N - 37.5° N)	12.50%	6.87 a	50.7 a	52.8 a	23.3 a	4.9 b
	0%	6.14 b	50.6 a	52.7 a	23.1 a	5.0 b
	Average[3]	6.46	50.1	51.8	22.1	5.6
Response :	Linear	**	**	**	**	**
	Quadratic	**				
	50%	5.76 b	50.0 a	52.2 a	21.4 b	6.3 a
L3	25%	6.48 a	50.3 a	52.4 a	22.8 a	5.8 ab
(>7.5° N - 22.5° N)	12.50%	6.40 a	50.8 a	52.3 a	23.7 a	5.4 ab
	0%	6.14 ab	50.6 a	52.7 a	23.1 a	5.0 b
	Average[3]	6.21	50.4	52.3	22.6	5.8
Response :	Linear	*			**	**
	Quadratic	**				
	50%	6.24 a	49.8 a	51.8 a	22.0 b	6.4 a
L4	25%	6.46 a	50.1 a	52.2 a	22.0 b	5.9 ab
(>22.5° S - 37.5° S)	12.50%	6.54 a	50.6 a	52.6 a	22.0 b	5.1 bc
	0%	6.14 a	50.6 a	52.7 a	23.1 a	5.0 c
	Average[3]	6.41	50.2	52.2	22.0	5.8
Response :	Linear				*	**
	Quadratic					**
	50%	5.72 b	49.6 b	51.6 b	21.0 b	6.1 a
L5	25%	6.22 a	50.2 ab	52.1 ab	22.3 a	5.7 ab
(>37.5° S)	12.50%	6.41 a	50.8 a	52.6 ab	22.4 a	5.1 b
	0%	6.14 ab	50.6 a	52.7 a	23.1 a	5.0 b
	Average[3]	6.12	50.2	52.1	21.9	5.6
Response :	Linear	*	**	*	**	*
	Quadratic	*				
Additional 1	Suwan 1	6.99	52	54	24.6	4.4
Additional 2	Bisma	6.53	51	53	24.4	4.0
LSD 0.05		0.42	0.9	1.0	1.2	0.9
CV (%)		7.18	1.9	2.0	5.5	16.9

*, ** Significant at 0.05 and 0.01 probability levels, respectively.
[1]   L0 = 0 % exotic germplasm; L1 - L5 = populations with exotic germplasm from latitude-1 to 5
[2]   Leaf diseases : 1= highly resistance; 9 = highly susceptible
[3]   Average of 50, 25 and 12.5 % exotic only, 0 % excluded

It is very likely that most of exotic germplasm used in this study was integrated because most of them came from only two private companies DK and SNK and less from public programs. The results implied that even the tropical inbred lines with moderate performances can convert the highly improved exotic germplasm (hybrids) to semi-exotic population which could adapt to tropical climate. However, the L1 group showed low response to backcrossing as indicated by lowest average yield of semi-exotic population from L1 (Table 2 and Figure 1a). Exotic germplasm from L2, L3 and L4, latitudes ranged from £ 37.5° South to £ 37.5°North, are preferable for broadening the tropical germplasm, followed by L5 (> 37.5°S) and L1 (> 37.5°N), respectively.

Highly significant non-linear (quadratic) response for grain yield was observed in semi-exotic populations of L2 and L3, and semi-exotic population of L1 and L5 showed significant non-linear response for grain yield. On the other hand, no response was shown in semi-exotic populations of L4 (Table 2). Therefore, different exotic germplasm sources responded differently to backcrossing depended upon genetic diversity between tropical and exotic sources. Besides, non significant, significant and highly significant quadratic response among semi-exotic population mean grain yield of each exotic group indicated the curvilinear nature of the response (Figure 1). The results indicated that one or two backcrossing to the tropical lines had increased means of the semi-exotic population above the L0 population, and the quadratic response indicated that additional backcrossing to the tropical lines would not achieve further significant increase in yield. Crossa and Gardner (1987) also reported significant non-linear response among means due to proportion of adapted germplasm for grain yield. On the other hand, a different result was reported by Albrecht and Dudley (1987a), when introgressing an exotic germplasm "South African Photoperiod Insensitive Composite II" to Corn Belt maize population,

RSSSC. He found linear decrease of mean yield with increasing proportion of exotic germplasm.

Days to anthesis and silking

Mean of days to anthesis and silking at all level of semi-exotic populations from all latitudes were stable after the first crossing (50 % exotic) and similar to the L0 population after two backcrosses (Table 2). Therefore, days to anthesis and silking are highly heritable and can be converted within few generations of backcrossing. Highly significant linear response in the direction of late maturity due to lower proportion of exotic germplasm was observed in the semi-exotic populations from latitude-1, -2, and -5, for days to anthesis and silking, While only significant response was observed in exotic germplasm from latitude-5 for days to silking. This results agreed with the result of Albrecht and Dudley (1987a), but contrary to the result of Crossa and Gardner (1987) and Gouesnard *et al.* (1996) and which found significant non-linear response among population means due to the proportion of elite germplasm for the earliness traits (grain moisture and days to silking). On the other hand, after the first crossing, days to anthesis and silking of the semi-exotic populations from latitude-3 and -4 were not responded to further backcrossing (Table 2 and Figure 1b and 1c). Therefore, in order to retain the earliness of the semi-exotic population, selection for earliness in segregating population is necessary. Moreover, selection for earliness should simultaneously retain high level of exotic germplasm in semi-exotic population.

Grain moisture content

All sources of exotic germplasm under study showed significant response in the direction of higher moisture content due to lower proportion of exotic germplasm. Highly significant linear response was observed for mean grain moisture content of semi-exotic populations from latitude-1, -2, -3, -5, with significant response shown by

exotic source from latitude-4. Therefore, grain moisture content at harvest will increase linearly for each generation of backcrossing (Table 2 and Figure 1d). Albrecht and Dudley (1987a) also reported significant linear response of grain moisture content due to proportion of exotic germplasm.

Leaf disease

Two leaf diseases were recorded in this study. Southern rust (*Puccinia polysora* Undrerw) infected the experiment at Salaengpharn Farm and Suwan Farm while, experiment at Kediri Indonesia was infected by leaf blight (*Helminthosporium maydis* Nisik and Miyake). For combined analyses
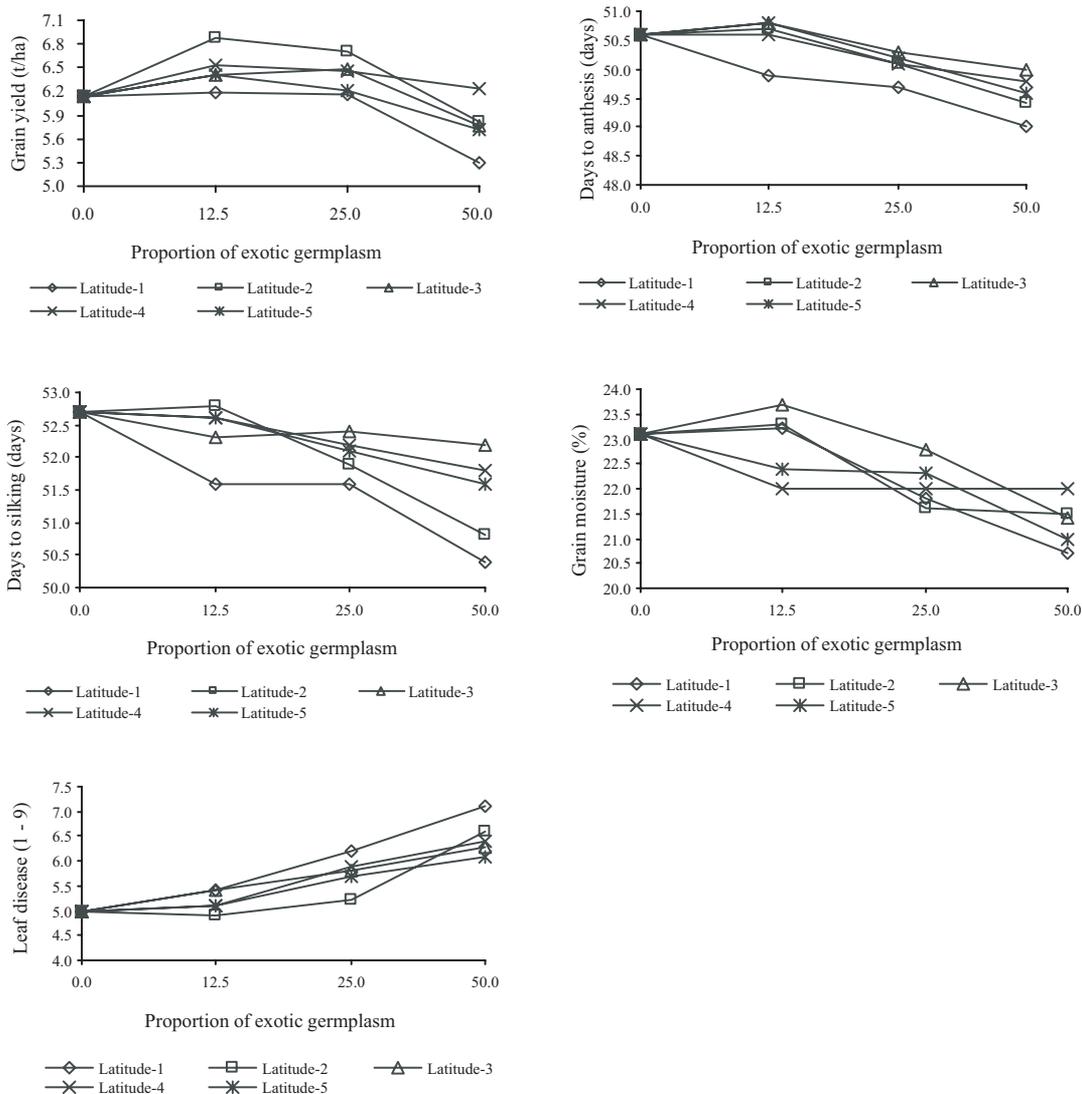
Figure 1 Change in means of semi-exotic populations from different sources (latitudes) and proportion of exotic germplasma, average across three location; a) grain yield, b) days to anthesis, c) days to silking, d) grain moisture content, e) leaf disease infection.

across locations, these two diseases were referred as "leaf disease". All sources of exotic germplasm under study showed significant response in the direction of lower resistance due to higher proportion of exotic germplasm (Table 2). Highly significant linear response was shown by mean leaf disease of semi-exotic populations from latitude-1, -2, -3, -4, with significant response from latitude-5. In general, the highest infection was noted in semi-exotic with 50 % exotic gemplasm followed by 25, 12.5 and 0 % exotic populations, respectively (Table 2 and Figure 1e). This evidence suggested that all introduced exotic germplasm in this study was susceptible to leaf diseases under study in tropical condition. Obviously, lack of defensive genes especially disease resistance and heat tolerance were two major factors affecting adaptation of exotic germplasm and hence lower the grain yield of the 50 % semi-exotic populations.

CONCLUSION

Most of highly developed exotic germplasm, especially commercial hybrids or elite hybrids from public breeding programs are suitable germplasm for broadening the genetic diversity of tropical breeding materials. However, germplasm ranges from latitude £ 37.5°South to £ 37.5°North are preferable. One or two backcrosing to tropical lines was adequate for the conversion of exotic sources into useful tropical breeding materials. Some of them showed heterotic effect over their recurrent tropical populations. However, the merit of converted exotic germplasm (semi-exotic germplasm) in commercial hybrids has yet to be verified.

ACKNOWLEDGEMENTS

LITERATURE CITED

Albrecht, B. and J.W. Dudley. 1987a. Evaluation of four maize populations containing different proportions of exotic germplasm. **Crop Sci.** 27: 480-486.

Albrecht, B. and J.W. Dudley. 1987b. Divergent selection for stalk quality and gain yield in an adapted x exotic maize population cross. **Crop Sci.** 27: 487-494.

Bridges, W.C. Jr. and C.O. Gardner. 1987. Foundation population for adapted by exotic crosses. **Crop Sci.** 27: 501-506.

Cox, T.S. and K.J. Frey. 1984. Genetic variation for grain yield and related traits in sorghum introgression populations. **Theor. Appl. Genet.** 68: 145-153.

Crossa, J. and C.O. Gardner. 1987. Introgression of an exotic germplasm for improving an adapted maize population. **Crop Sci.** 27: 187-190.

Dudley, J.W. 1982. Theory of transfer of alleles. **Crop Sci.** 22: 631-637.

Geadelmann, J. L. 1984. Using exotic germplasm to improve northern corn, pp. 98-110. *In* **Proc. 39th Annual Corn and Sorghum Res. Conf**.

Gouesnard, B., J.Sanou, A. Panouillé and V. Bourion. 1996. Evaluation of agronomic traits and analysis of exotic germplasm polymor-phism in adapted x exotic maize crosses. **Theor. Appl. Genet.** 92: 368-374.

Holley, R. N. and M. M. Goodman. 1988. Yield potential of tropical hybrid maize derivatives. **Crop Sci**. 28: 213-218.

Khehra, A.S., B.S. Dhillon, N.S. Malhi, V.K. Saxena, V.V. Malhotra, S.K. Dey, S.S. Pal, and W.R. Kapoor. 1986. Systematic introgression of the Corn Belt germplasm maize, pp. 291-301. *In* B. Napompeth and Suranant Subhadrabandhu (eds.). **Proc. Fifth International Congress Society for the Advancement of Breeding Researches in Asia and Oceania (SABRAO)**. Thailand, Nov. 25-29, 1985.

Kim, S.K. 1990. Breeding of temperate maize germplasm for tropical adaptation, pp. 208-229. *In* C. De Leon, G. Granados and M.D. Read. (eds.). **Proc. Fourth Asian Regional Maize Workshop**. Pakistan, Sep. 21-28, 1990.

Lawrence, P.K. and K.J. Frey. 1975. Backcross variability for grain yield in oat species crosses (*Avena sativa x A. sterilis* L.). **Euphytica** 24: 77-86.

MSTAT-C. 1988. **MSTAT-C a Microcomputer Program for the Design, Management, Analysis of Agronomic Research Experiments**. Michigan State University. 402 p.

Selig, L., R.J. Lambert, T.R. Rocheford and W.J. da Silva. 1999. RFLP and cluster analysis of introgression of exotic germplasm into U.S. maize inbreds. **Maydica** 44: 85-92.