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Diversity pattern in *Sesamum* mutants selected for a semi-arid cropping system *

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Summary. Due to the complex requirements of moisture stress, substantial genetic diversity with a wide array of character combinations and effective simultaneous selection for several variables is necessary for improving the productivity and adaptation of a component crop in order for it to fit into a cropping system under semi-arid tropical conditions. *Sesamum indicum* L. is grown in Venezuela after rice/sorghum/or maize under such conditions. A mutation breeding program was undertaken using six locally adapted varieties to develop genotypes suitable for the above system. The diversity pattern for nine variables was assessed by multivariate analysis in 301 M_4 progenies. Analysis of the characteristic roots and principal components in three methods of selection, i.e., M_2 bulks (A), individual plant selection throughout (B), and selection in M_3 for single variable (C), revealed differences in the pattern of variation between varieties, selection methods, and varieties × methods interactions. Method B was superior to the others and gave 17 of the 21 best M_5 progenies. 'Piritu' and 'CF' varieties yielded the most productive progenies in M_5 and M_6. Diversity was large and selection was effective for such developmental traits as earliness and synchrony, combined with multiple disease resistance, which could be related to their importance by multivariate analyses. Considerable differences in the variety of character combinations among the high yielding. M_5 progenies of 'CF' and 'Piritu' suggested possible further yield improvement. The superior response of 'Piritu' and 'CF' over other varieties in yield and adaptation was due to major changes in plant type and character associations. Multilocation testing of M_5 generations revealed that the mutant progenies had a 40%–100% yield superiority over the parents; this was combined with earliness, synchrony, and multiple disease resistance, and was confirmed in the M_6 generation grown on a commercial scale. This study showed that multivariate analysis is an effective tool for assessing diversity patterns, choice of appropriate variety, and selection methodology in order to make rapid progress in meeting the complex requirements of semi-arid cropping systems.

Key words: *Sesamum indicum* – Mutation breeding – Semi-arid cropping system – Diversity pattern – Multivariate analysis

Introduction

Response to simultaneous selection for several variables depends not only on the magnitude of diversity for each variable, but also on the interrelations between them and the genotypic response to induced or natural variations. The utility of induced mutations for crop improvements has been demonstrated for specific characters in several crop species (Micke 1985). However, mutation breeding of a component crop to fit into a cropping system requires a different approach, due to the complexities of maturity, soil-plant-water relations under the residual moisture, disease complex, and agronomical requirements of the previous crop, from that used in mutation breeding of a single variable in any crop. Hence, the diversity of the induced variation should be assessed for a group of agronomical attributes rather than for a single variable like dwarfing or earliness, and should be large enough for effective selection. Multivariate analysis is an effective tool for quantifying variation, and since a large

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number of progenies need to be handlet in each generation, a comparison should be made on the effects of the different selection methods on the divesity generated.

Sesam indicum L., the main edible oil crop of Venezuela, is grown following rice, sorghum, or maize in a semi-arid cropping system on a residual moisture and nutrient supply, under uncertain rainfall, moisture stress, and ecological conditions, in three regions on soils of low water-holding capacity. While such a complex environment should demand a considerable genetic flexibility of adaptation in the genotypes, the available varieties grown across the three zones do not meet any such requirements due to their late and prolonged flowering, asynchrony in maturity of more than 115 days, poor root development, and such susceptibility to *Macrophomina* that results in low, unstable, and declining yields ranging from 350–500 kg/ha. Some success was reported earlier in *Sesamum* on the isolation of some useful mutants with determinate habit, earliness, or disease resistance, but none of these, except for the one in Korea, had higher yields than the controls (Ashri 1982; Torres 1985; Mazzani 1985; Murty et al. 1985; Lee et al. 1985). Diversification of the genetic base was felt to be important in order to develop materials suitable for the complex Venezuelan conditions. With this in mind, a mutation breeding program was initiated using six locally adapted cultivars to provide an array of widely adapted genotypes, such an earliness, limited branching, short duration of flowering, and resistance to moisture stress, pathogens of *Macrophomina*, and leaf disease complex in eastern Venezuela (Oropeza et al. 1984). An attempt was made to: (1) assess and quantify by multivariate analysis the diversity generated in the material for a group of important characters (such as those mentioned); (2) examine varietal differences in the pattern of induced diversity; (3) observe the effect of the three different selection methods on the resultant variation. The shift in character combinations in the mutants compared to the parents was also examined. The results of the above assessment in the M_4 and M_5 generations is reported in this paper.

Materials and methods

Six varieties, 'Aceitera Mejorada' (AM), 'Criollo Falcon' (CF), 'Glauca', 'Piritu', 'V-44', and 'V-52', were used for this study. Seeds were treated with gamma radiation from a ^{60}Co source at 0, 45, 60, and 75 krad. The details of the mutagenic treatment and the handling of the M_1–M_3 generations have been reported earlier (Oropeza et al. 1984). 'Criollo Falcon' is a late-maturing land race adapted to the severe drought conditions and the deep sandy soils of the Paraguana Peninsula in northwest Venezuela. It has responded to mutagenesis with several early lines in M_2. It is tall with many branches restricted to the top one-third of the plant, but with a deep root system, and is similar to the *Sesamum* land races found in the Nuba region of Sudan (Bedigian and Harlan 1983). 'Pritu' is an introduction from Colombia, although probably of African origin. It is well adapted to central Venezuela. 'AM', 'V-44', and 'V-52' are late, nonsynchronous in flowering, tall, and poor in their adaptation to central Venezuela, particularly under the uncertain dates of sowing after the rice harvest. 'CF' is the product of a long process of natural selection similar to that undergone by the Sorghum and Cowpea varieties of that region, which have also yielded early, productive, and disease resistant mutants under an IAEA program (Taborda and Murty 1985).

The M_2 generation consisted of M_2 bulks (A) and M_2 individual progenies (B). The individual plant progenies (B), excluding the controls, comprised 125 individual M_1 plants apparently normal per variety/dose. In var 'Glauca', only 19 plants were available. The other group (A), i.e., M_2 bulks, consisted of a random sample of nearly 100 M_1 plants per dose/variety, threshed separately, and an equal colume of seed from each plant mixed to form each bulk, totaling 24 bulks including the six controls (OKR). In M_2, approximately 30,000 plants per dose/variety were used under group A, and a similar number was used in group B based on 125 progenies per variety/dose with 250–300 plants/progeny. Twenty-five individual plants/progenies per variety were used as controls.

In both groups, selection was practiced for limited or no branching, earliness, synchrony of flowering, resistance to *Macrophomina*, and continuous pod formation from early nodes. Out of nearly 30,000 plants per variety/dose in M_2 of each group, approximately 4,500 plants were selected during flowering on the above criteria. However, at the time of maturity, natural drought and severe natural incidence of *Macrophomina* enabled further selection, and those selections least affected by the disease were finally harvested: 1,912 from individual progenies (B) and 996 from (A), excluding 120 progenies of controls from M_2 bulks. The material was further scrutinized in the laboratory for seed yields. There was significant varietal response in the number of progenies finally selected at maturity, with 222, 196, 587, 300, 422, and 185 selections from 'Glauca', 'Ven 52', 'Aceitera Mejorada', 'Piritu', 'V-44', and 'Criollo Falcon', respectively (χ^2 5 df = 112.05), indicating that the two-stage selection was helpful in evaluating the mutagenic response of the varieties in the recovery of desired mutants. The recovery of useful progenies varied with dose in each variety, with 573 from 45 krad, 822 from 60 krad, and 517 from 75 krad, a total of 1,912 selections harvested from M_2 individual plant progenies. There was a similar tendency of varietal and dose responses in selections from M_2 bulks. In general totalled across all varieties, 45 krad and 60 krad gave a longer number or promising progenies in M_3 than 75 krad.

M_3 generation: On the basis of laboratory examination of the seed of selections from M_2, 112 selections from M_2 bulks (A) and 258 from individual progenies (B) were sown in Maracaibo as M_3, along with controls, in two replicates in 2-row plots with approximately 500 plants/progeny. In addition, 100 of the best-yielding progenies (20 for each variety) of the above material were sown in central and eastern Venezuela to make selections in these different ecological zones and identify lines with wider adaptive potentials. This early testing actually helped identify lines both resistant to the foliar diseases of the east and adapted to the rice-sesame cropping system in central Venezuela, as can be seen from the M_4 and M_5 generations. The number of individuals per progeny was approximately 500 in M_3, 1,080 in M_4, and 3,000 in M_5. Commercial plots of one hectare or more in M_6 were used.

The differences between progenies of each variety and between varieties were significant in both groups, particularly for earliness, synchrony, height, reduced branching, and disease resistance in M_3.

Our experiments with the M_4 generation (1984–1985) consisted of 267 mutant progenies from the six varieties and the six parental lines as controls duplicated at random five to six times in each replicate to provide a total of 301 entries in each replicate. Based on derivation the material was grouped into three categories: (A) selections (67) from M_2 bulks for each variety/dose; (B) single plant progenies from M_2 onwards (150); and (C) specific individual plant progenies selected in M_3 (50) on a visual basis either for productivity, determinate habit, and/or limited branching. The distribution of these three groups from each variety is given in Tables 1 and 3. The M_4 generation was grown on the University Experimental Farm, Maracaibo. The trials on the M_5 generation were conducted from 1985–1986 and consisted of 25 entries; i.e., 4 best controls and 21 best mutant progenies from the M_4 generation combining productivity, resistance to *Macrophomina*, limited branching, synchronous development, and in the eastern zone, superiority to the parents in the field to the leaf disease – mainly *Cylindrosporium* and *Cercospora*, and to a limited extend, *Alternaria*. These 21 lines were selected on the basis of comparable consistent performance in M_4 in the three zones, central, east, and west Venezuela, during 1984–1985. Multilocation trials with the above 25 entries were conducted in three locations, Turen, Punta de Meta, and Maracaibo, respectively, in their corresponding zonal crop seasons during 1985–1986. During 1986–1987, the M_6 generation of the nine best progenies were tested in farmer fields on a commercial scale.

The material in Maracaibo rceived three protective irrigation up to six weeks after sowing and was then subjected to the severe seasonal drought. The materials in the other two locations were grown under rainfed conditions. Fertilizer application at 30 kg N + 50 kg P_2O_5 + 50 kg K_2O/ha and pre-emergence weed control was done using the herbicide Lazo @ (3 l/ha). Artificial inoculation with *Macrophomina* was done with foliar spray at flowering (1 l/5 m row with a spore suspension in distilled water at a concentration of 5×10^5 spores/ml^{-1}). This was followed within a week by inoculation by the toothpick method of all the plants in the central row of each plot.

Statistical methods and sampling

Each plot consisted of 3 rows of 5 m each in M_4, and 4 rows of 5 m each in M_5, with 50 cm spacing. In east Venezuela, 70 cm × 5 cm spacing was followed due to the better rainfall in that region. A randomized complete block design with 3 replicates in M_4 and 6 replicates in M_5 was used unless stated otherwise. Observations were taken on several characters: days to initial flowering in 50% of the plants; (X_1); height at maturity (cm) (X_2); height of the first capsule on the main axis, after which there is regular fruit set (X_3); habit (1 erect – 9 very open) (X_4); synchrony (1 poor – 9 best) (X_7); number of capsules/axis (X_8); number of fruiting branches, including the main stem (X_9); resistance to *Macrophomina* at two stages, the first on 10-week-old plants (X_5), the second at physiological maturity when the capsules turn yellow (X_6). In addition to these nine variables, data on days to final flowering and days to final maturity were collected. Resistance to *Macrophomina* and foliar diseases was scored on a visual basis (1 = free and 9 = highly susceptible) in the field as the natural incidence was quite heavy by the peak flowering period. There was difficulty in separating the incidence of *Cercospora* and *Alternaria* due to coalescing of spots. The data were a row basis for all characters except height, height of first capsule, number of branches, and capsules/axil, which were based on a sample size of 10 plants/plot. Seed yield was per unit area on a plot basis, and not on individual plants due to the altered plant type of the mutants. Duration of flowering was calculated as the difference between days to initial flower and days to final fertile flower on the plant. Seed oil content was estimated on a limited material using REFATEC II 1050 Analyzer (Tecator Co.).

Multivariate and other analyses

Single degree of freedom comparisons in univariate analysis were restricted to comparing the mutants of each variety with the parent, and mutants with the mean of all controls.

Manova tests for significance for the set of nine variables, excluding yield, were based on the common dispersion matrix using Wilk's Λ test, Hotelling-Lawley Criterion, Roy's Maximum Root, and Pillai's trace. Eigen values were exacted from the corresponding characteristic equation $(B - \lambda W) = 0$, where B and W represent the dispersion matrices of between and within treatments and I = the identity matrix. The eigen values and the corresponding eigen vectors are of a symmetric positive definite matrix. The transformed uncorrelated variables were obtained bearing in mind the relation $\lambda_1 > \lambda_2 > .. > \lambda_\varrho$ and the assumed p-variate normality, and the relation $\lambda_1 + \lambda_2 + ... + \lambda_\varrho = \sigma_{11} + \sigma_{22} + ... + \sigma_{\varrho\varrho}$. A $\sum$ A' is the covariance matrix of the transformed varieties Y's), the model being

$$\underset{(p\times 1)}{X} = \underset{(p\times 1)}{\mu} + \underset{(p\times p)}{A^{-1}}\ Y = \underset{(p\times 1)}{\mu} + A'1\ Y.$$

The overall analysis was done for all 301 entries in the M_4 and also for the three groups of selections in order to look for any shift in diversity patterns among the three groups. A comparison of the relative sizes of λ's for the mutants of each variety was done to detect varietal differences in diversity patterns for all nine variables taken together.

Results

The progress in selection in generations M_3 to M_6, as seen from the number of desirable mutant progenies of the six varieties carried forward under the two methods of selection (A, M_2 bulk; B, M_2 individual plants), revealed distinct genotypic responses to the same selection forces on a similar initial population size of 30,000 plants per variety/dose and also between the two selection methods (Table 1). The number of productive progenies present in the M_5 and M_6 generations in multilocation trials was the largest in 'Piritu' and 'Criollo Falcon', followed by 'AM' and 'V-44'; none emerged from 'Glauca' and 'V-52'. Method B was superior to A in all generations and also in the number of progenies resistant to *Macrophomina* in M_4 after artificial inoculation. There were significant differences in varietal response and varietal × radiation dose interactions in the two-stage selection carried out in M_2, both in the field and during subsequent selection in the laboratory, for seed yield and uniform seed development. The results were reported earlier (Oropeza et al. 1984). The differences between M_3 progenies between and within each variety were also significant in both A and B groups, particularly for earliness, synchrony, disease resistance, and branching pattern in each of the generations. The results on M_4 and subsequent generations are now reported.

Table 1. Progress of selection in different generations (M_3–M_5) of mutant progenies of six varieties of *Sesamum* under two methods of selection (A and B)

Variety	No. of progenies carried forward							
	A (Bulk)				B (Individual)			
Year	M_3 1983	M_4 1984	M_5 1985/86	M_5 1986/87	M_3 1983	M_4 1984	M_5 1985/86	M_6 1986/87
AM	213	13 (6)	0	0	587	57 (20)	2	0
Criollo Falcon (CF)	152	12 (8)	2	1	185	27 (16)	3	3
Glauca	151	11 (6)	0	0	222	45 (12)	0	0
Piritu	149	11 (6)	2	1	300	23 (6)	7	3
V-44	193	11 (5)	0	0	422	33 (7)	5	1
V-52	138	9 (3)	0	0	196	19 (5)	0	0
Total	996	67 (34)	4	2	1912	204 (66)	17	7

Figures in parenthesis denote the number of disease resistant progenies finally selected after artificial inoculation

Table 2. ANOVA for nine characters in 301 M_4 progenies including controls at Maracaibo 1984–1985

Source of variation	DF	Mean sums of squares								
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
Blocks	2									
Progenies	300	29.21**	14.6**	14.3**	0.75	3.09**	3.27**	2.12**	0.10	1.27**
Piritu *vs* mutants	1	3.05	14,354.6**	299.3**	0.04	1.11	0.55	1.11	0.01	0.07
Ven-44 *vs* mutants	1	4.54	0.01	75.1	0.03	≃ 0.00	0.26	0.45	0.14	0.06
CF *vs* mutants	1	16.21**	13,405.3**	2,965.7**	0.03	1.57	2.11	10.68**	≃0.00	6.88**
Glauca *vs* mutants	1	1.69	4.5	12,596.6**	3.04	7.80	2.16	0.16	0.01	0.08
Ven-52 *vs* mutants	1	22.27**	260.5**	2,456.0**	0.02	0.02	0.04	0.32	0.09	0.10
AM vs mutants	1	0.10	9,594.7**	2,991.3**	0.31	0.36	2.40	0.19	≃ 0.00	0.06
Residual	597	5.13	6.7	2.5	0.69	0.67	0.73	0.96	0.07	0.37
Total	899									
Mean		42.34	145.0	79.7	2.02	4.5	4.3	6.1	1.1	1.7

X_1 = Days to flower; X_2 = plant height (cm); X_3 = height of first capsule; X_4 = habit; X_5 = resistance to *Macrophomina* at flowering; X_6 = resistance to *Macrophomina* at maturity; X_7 = synchrony; X_8 = capsules/axil; X_9 = number of branches
** Level of significance 1%

M_4 generation

After selection in Maracaibo both between and within M_3 progenies (see Materials and methods), 267 lines + 34 from controls were carried forward to M_4 for a replicated trial. The Anova for individual characters and Manova for the nine characters revealed significant differences among M_4 progenies (Tables 2 and 3). Artificial inoculation at flowering time by a foliar spray of inoculum did not produce consistent infection. The subsequent inoculation of all the plants in the middle row in each plot was useful in eliminating susceptible lines.

Univariate analysis

The differences among the progenies were significant for all characters except habit (Table 2). However, further partitioning of the variation for the single degree of freedom comparison of mutants with the corresponding parents indicated differences among the varieties. The mean of 'Piritu' mutants did not differ from the mean of the parent for flowering time, while the 'CF' mutants as a group were earlier than the 'CF' parent. Individual mutant progenies significantly superior to the parent were also detected for flowering and other characters. The absence of a difference between the mean of mutants versus the mean of their parent could be due to some mutants with larger, and some with smaller, means than the parent, i.e., as in flowering time in 'Piritu' mutants where progenies both earlier and sligthly later than the parent were productive, and therefore selected. Earliness is crucial under moisture stress, and the number of mutants earlier than the corresponding parent were 4 in

Table 3. Relative contribution of the first two characteristic roots for nine variables in three groups of M_4 progenies in *Sesamum*

Variety	Group of selections								No. of progenies			Total
	All (A+B+C)		A (Bulk)		B (Individual)		C (Specific)		A	B	C	
	λ_1 %	$(\lambda_1+\lambda_2)$ %	λ_1 %	$(\lambda_1+\lambda_2)$ %	λ_1 %	$(\lambda_1+\lambda_2)$ %	λ_1 %	$(\lambda_1+\lambda_2)$ %				
AM	45.2	63.5	57.6	73.7	34.7	54.7	84.4	96.0	13	45	8	66
CF	70.4	87.2	61.1	83.9	69.8	85.9	82.7	93.3	12	17	10	39
Glauca	53.4	70.9	81.1	89.1	44.1	64.0	50.3	70.0	11	27	18	56
Piritu	45.1	68.5	53.0	77.8	41.1	63.9	(only one mutant)		11	22	1	34
V-44	38.1	60.8	41.3	63.2	32.2	50.8	46.8	78.5	11	22	11	44
V-52	50.7	71.1	51.5	73.8	52.0	69.7	(only two mutants)		9	17	2	28
All varieties	45.5	61.4	57.8	77.0	42.9	62.4	62.2	81.4	67	150	50	267

A = selections from M_2 bulks; B = individual selections throughout; C = selections from M_2 for a specific character

Table 4. Principal component analysis of overall diversity for nine variables in 301 M_4 progenies in *Sesamum*

Characteristic root			Principal components		
λ_i	Value	% of total	Z_1	Z_2	Z_3
1	6.53	45.5	+0.0146	−0.0018	−0.0021
2	2.29	16.0	−0.0001	−0.0004	−0.0001
3	1.53	10.7	−0.0007	≃0	−0.0001
4	1.04	7.2	−0.0002	+0.0329	−0.0379
5	0.88	6.1	+0.0030	+0.0012	+0.0019
6	0.66	4.6	−0.0038	+0.0008	+0.0013
7	0.58	4.1	−0.0002	−0.0099	+0.0334
8	0.48	3.3	−0.0026	−0.0271	−0.0142
9	0.36	2.5	+0.0128	+0.0502	+0.0268
Total	14.36	100.0			

X_1 = Days to flower; X_2 = plant height (cm); X_3 = height of first capsule (cm); X_4 = habit; X_5 and X_6 = resistance to *Macrophomina*, I and II stages, respectively; X_7 = synchrony; X_8 = capsules/axil; X_9 = number of branches

'Piritu', 5 in 'V-44', 9 in 'CF', 12 in 'Glauca', 8 in 'Ven 52', and none in 'AM' which showed the characteristic varietal response for this character.

Multivariate analysis of diversity between mutants in M_4

This analysis for nine variables consisted of (1) a combined analysis of all the 267 mutants + controls; (2) analysis of M_4 progenies from M_2 bulks (A), those from individual progenies (B), and special selections (C). The differences between the progenies for the set of nine variables were significant by each of the four Manova tests described in the Materials and methods.

Characteristic roots (λ's) and their relative proportions

The multivariate analysis of all three groups of progenies taken together revealed a complex diversity pattern with the first two characteristic roots accounting for only 61% of the diversity and even the first three roots explaining only 72% of the diversity (Tables 3 and 4). However, varietal differences were also observed in the proportion of $\lambda_1+\lambda_2$, with a maximum of 87% in 'CF' and only 61% in 'V-44'. Therefore, a comparison of the diversity between the three groups and among the varieties within each group was also examined. Characteristic roots could not be estimated in group C for 'Piritu' and 'V-52' due to the very few progenies they produced.

The contribution of the first two roots in the three groups was different, indicating that a diverse pattern of variation was generated by the three selection methods. Varietal differences in the proportion of $(\lambda_1+\lambda_2)$ within each group confirmed the presence of genotype × selection method interactions in the diversity pattern. In 'Glauca', the proportion explained by the first two roots was 89% in A, but 64% in B and 70% in C, while in 'CF' the corresponding values were 84%, 86%, and 96% (Table 3). Considering all varieties together, group B has a more complex multidimensional pattern of diversity in which only 62% could be explained by the first two roots in comparison to the much larger corresponding values in A and C. The pattern in group B was comparable to the overall diversity of all three groups taken together. This low proportion of first two roots in B could be due to either (a) a larger variety of character combinations generated by recombination and the breaking of repulsion phase linkages instead of fewer combinations resulting from a correlated response to selection for character like flowering time, or (b) the slow release of variation for most of the characters as compared to a very large variation for a few characters like earliness with high heritability. The successful isolation of larger numbers of productive mutants in M_5 and M_6 from group B (Table 1) suggested that (a) was true in this case.

The intra-group variation in group A was simple enough for an easy two-dimensional representation in

'Glauca', 'CF', and 'Piruti', but more complicated in the other varieties. In group B and C, 'CF' had a simple pattern similar to that in A, followed by 'Piritu', 'V-52', and 'Glauca'. However, response to selection was only good in 'CF' and 'Piritu'. The causes for the differences were examined in the principal components analysis.

Principal components

An examination of the composition of the principal components corresponding to the first three characteristic roots, and the size and direction of the coefficients in each vector in the overall diversity of all the progenies of M_4 revealed the important of earliness, number of branches, and resistance to *Macrophomina* in the first vector; synchrony, capsules/axil, and branching were important in the second vector, while synchrony, habit, and branching were important in the third vector (Table 4). Variables important under natural selection were important in the first vector. The direction and magnitude of the coefficients corresponding to each variables also changed in each vector.

The differences between group and varieties within the same group were also reflected in the composition of the principal components, thus confirming the pattern of varietal differences as revealed by the size of the characteristic roots (Table 5). Only the first two vectors are presented, as the third vector contributed very little. The principal components in group B only for all varieties are presented in Table 5, and comparative information for the other two groups is only summarized below for brevity. In a comparison of the vector composition in all three groups, taking all the varieties together, the first vector (Z_1) indicated that reproductive potential and disease resistance were important in groups A and C, while earliness, habit, branching, and disease resistance were important in group B. In the second vector (Z_2), disease resistance and branching were important in group A, reproductive capacity and habit in group B, and habit and disease resistance in group C. The composition of the first principal component in group B (Table 5) was similar to the corresponding vector when all the 301 progenies of the three groups were considered together (Table 4).

When all the varieties and selection groups were taken together, greater diversity was evident in group B. This was reflected in the difference in the first two principal components between the A and B groups. While in group B, developmental traits like earliness, habit, and synchrony were important in both vectors, with diversity preserved for disease resistance and reproductive potential, disease resistance was important in group A in both vectors, with only limited diversity for synchrony, which is an important attribute under moisture stress.

The major axis of differentiation (Z_1) had a similar pattern in 'CF' and 'Piritu' which gave higher numbers of productive mutants in M_5. The vector composition within each group indicated that 'CF' and 'Piritu' differed from the other varieties. Therefore, a comparison of their principal components in A and B was attempted (Table 6). Group C was not included as only one progeny of 'Piritu' was in this group. This revealed similarities in the importance of the developmental traits followed by yield components and disease resistance in both A and B groups.

In both varieties, group A was different from B in the magnitude and direction of the coefficients in both vectors. The similarity of importance for earliness (X_1) followed by disease rsistance in Z_1, and synchrony (X_7) in Z_2 in the 'CF' progenies in both A and B groups was interesting, while in 'Piritu', synchrony was important in Z_1 in both groups. The pattern was different between 'CF' and 'Piritu' within the same group. It can be concluded that principal component analysis confirmed the results of the characteristic roots on the differences in the diversity pattern between varieties, three selection groups

Table 5. Principal components (Z_1, Z_2) of the M_4 generation from individual selections (B) for each variety

Variety/Character	AM		CF		Glauca		Piritu		V-44		V-52	
	Z_1	Z_2	Z_1	Z_2	Z_1	Z_2	Z_1	Z_2	Z_1	Z_2	Z_1	Z_2
X_1 Days to flower	0.0229	−0.0165	0.1279	0.0611	0.0709	−0.0265	0.0821	0.0567	−0.0027	−0.0189	0.0983	0.010
X_2 Plant height	0.0002	−0.0007	−0.0004	−0.0012	−0.0003	0.0008	−0.0008	−0.0007	0.0029	−0.0002	0.0003	0.000
X_3 Height of first capsule	0.0013	0.0004	0.0024	0.0022	0.0015	−0.0004	0.0007	0.0024	0.0013	−0.0016	0.0019	−0.003
X_4 Habit	−0.0677	0.0731	0.0422	−0.0404	0.0546	−0.0468	0.1644	0.1183	0.0637	0.1790	0.1689	−0.149
X_5 Resistance to *Macrophomina* I	−0.0087	0.0465	−0.0315	0.0419	0.0399	0.0158	0.0319	0.0471	−0.0997	−0.0004	0.1266	−0.080
X_6 Resistance to *Macrophomina* II	0.0187	−0.0601	0.0658	−0.0420	0.0107	0.0169	−0.0163	−0.0269	0.0273	0.0486	−0.1044	0.094
X_7 Synchrony	0.0502	0.0287	−0.0134	0.2392	−0.0406	0.1014	−0.1399	0.0328	0.0495	−0.0724	−0.0964	0.124
X_8 Capsules/axil	−0.0043	−0.2181	−0.8862	2.7157	0.0452	−2.1531	0.0999	−0.2392	−0.2059	−0.2120	0.1681	0.242
X_9 No. of branches	0.1084	0.3518	0.0090	−0.0790	0.1211	0.1105	−0.0258	0.1174	−0.1875	0.4374	−0.0317	−0.103

Table 6. Principal component analysis (Z_1, Z_2) of variation pattern for nine variables in the M_4 progenies of two varieties of *Sesamum* under two selection methods (A, B)

Varietal/characters	A				B			
	CF		P		CF		P	
	Z_1	Z_2	Z_1	Z_2	Z_1	Z_2	Z_1	Z_2
X_1 Days to flower	0.1335	−0.1209	0.0019	−0.0310	0.1279	0.0611	0.0821	0.0567
X_2 Plant height	−0.0004	0.0014	0.0023	−0.0017	−0.0004	−0.0012	−0.0008	−0.0007
X_3 Height of first capsule	0.0023	0.0026	−0.0052	0.0047	0.0024	0.0022	0.0007	0.0024
X_4 Habit	0.1582	−0.2213	−0.0203	−0.1469	0.0422	−0.0404	0.1644	0.1183
X_5 Resistance to *Macrophomina* I	−2.0184	−0.1711	0.1008	0.2043	−0.0315	0.0419	0.0319	0.0471
X_6 Resistance to *Macrophomina* II	0.0802	0.1466	0.0478	−0.1558	0.0658	−0.0420	−0.0163	−0.0269
X_7 Synchrony	0.0131	0.1118	0.2380	0.1875	−0.0134	0.2392	−0.1399	0.0328
X_8 Capsules/axil	0.0000	0.0000	−1.0406	0.7275	−0.8862	2.7157	0.0999	−0.2392
X_9 number of branches	−0.1047	−0.1867	0.1642	−0.0381	0.0090	−0.0790	−0.0258	0.1174

CF = Criollo Falcon
A = M_2 Bulk
P = Piritu
B = Individual selection throughout

Table 7. Diversity pattern and varietal response to selection for five important characters

Variety/character	Group of selections			All together
	A	B	C	A+B+C
a) Variety				
AM	No	Yes	No	No
CF	Yes	Yes	Yes	Yes
Glauca	No	No	Yes	No
Piritu	Yes	Yes	Yes	Yes
V-44	No	Yes	No	No
V-52	No	No	No	No
b) Character				
Resistance to *Macrophomina* (X_5, X_6)	No	Yes	Yes	Yes
Earliness (X_1)	Yes	Yes	Yes	Yes
Habit (X_4)	No	Yes	Yes	Yes
Synchrony (X_7)	No	Yes	Yes	Yes
No. of branches (X_9)	No	Yes	Yes	Limited

(A, B, and C), and the interaction between varieties × selection groups. These differences were reflected in the response to selection.

Response to selection

The differences between the varieties and selection methods in the diversity patterns in M_4 was evident in the availability of the range of desirable character combinations and the response to selection for the variables important in productivity and adaptation (Table 7). Among the varieties, 'CF' and 'Piritu' responded best in all three groups, 'V-52'. 'AM', and 'Glauca', the least, and these was limited success in 'V-44'. Among the five variables related to stable yield, success was achieved in all three groups for earliness followed by disease resistance and synchrony; three was limited success for number of branches. Among the three groups, the superiority of Group B over A was evident for all five characters and their combinations, and for four of the six varieties. In group C, success was restricted to some individual characters only. In group A, selection was effective only for earliness, which has high heritability. These results on differences between varieties and selection methods confirmed the results of the multivariate analyses.

Multilocation trials of selected progenies in M_5

Based on the performance for maturity, disease resistance, overall productivity, and synchrony of maturity during the M_4 generation, 21 mutant progenies were selected for common regional multilocation trials. They (M_5) were evaluated at three locations, Punta de Mata, Turen, and Maracaibo, along with four controls; i.e., 'Aceitera Mejorada' (AM), 'Piritu' (P), 'Criollo de Falcon' (CF), and 'Venezuela 44' (V-44), the popular local varieties, during the years 1985–1986. Detailed analysis was done on the data obtained from Turen and Maracaibo. Yield data could not be collected at Punta de Mata deu to unusual rains. The genotypes included 9, 2, 5, and 5 mutants of 'Piritu', 'AM', 'CF', and 'V-44', respectively, totaling 4 from group A and 17 from group B. None of the genotypes obtained from group C were good enough to be included in this trial.

Table 8. Means of mutants (Mu) and their corresponding parents (P) in the M_5 generation for some characters in diverse locations, Maracaibo (M), Turen (T) in 1985–1987, and Punta de Mata

Comparison/ location	Loca-tion	Yield (kg/ha)		Days to 50% flowering		Days to maturity		Duration of flowering		Days to final flowering		Disease[a] resistance		Synchrony	
		Mu	P	Mu	P	Mu	P	Mu	P	Mu	P	Mu	P	Mu	P
All mutants (21)	M	949	507	42.8	43.3	93.7	113.8	31.1	44.0	73.9	87.3	3.0	6.0	5.2	4.5
vs all controls	T	951	650	40.8	57.0	95.5	102.8	32.5^{ns}	35.5	73.3	87.8	2.2	5.0	7.3	5.0
(4)												[2.8	3.9]	[6.8	4.5]
Piritu mutants (9)	M	805	578	44.0	47.0	95.4	113.0	27.4	34.5	71.4	81.5	2.7	6.0	4.9	3.0
vs Piritu	T	1020	551	41.0	61.0	93.9	98.0	31.5^{ns}	38.0	72.5	84.5	2.0	5.0	8.2	6.0
												[2.4	3.8]	[6.9	5.0]
V-44 mutants (5)	M	959	423	42.4	45.0	94.8	114.0	32.2^{ns}	34.0	75.6	79.0	3.8	7.0	5.0	6.0
vs V-44	T	866	672	45.0^{ns}	46.0	101.0	104.0	29.8	37.0	84.9	99.0	2.4	6.0	5.8	5.0
												[3.0	4.3]	[6.7	6.0]
CF mutants (5)	M	1241	376	42.6	68.0	90.8	121.0	33.6	31.0	76.2	99.0	2.4	7.0	6.6	4.0
vs CF	T	1083	799	39.2	67.0	91.6	111.0	35.2	33.0	72.3	81.5	2.4	6.0	7.8	5.0
												[2.5	4.0]	[6.3	3.0]
AM mutants (2)	M	843	650	39.0	45.3	90.0	107.3	36.5	44.2	75.5	89.5	4.0	4.0	6.6	4.0
vs AM	T	786	579	41.7	54.0	98.5	108.0	37.0	44.0	70.0	91.2	2.0	3.0	7.8	5.0
												[4.9	3.6]	[6.3	3.0]
SE_d	M	112.3		0.97		2.80		2.84		1.41		0.41		0.91	
	T	72.6		0.78		3.22		3.85		1.05		0.47		0.67	
	O											[0.49]		[0.39]	

( ) = Number of progenies; Mu = mutants; P = parent; [ ] = data from Punta de Mata location in eastern Venezuela. All differences are significant except when denoted by ns. M = Maracaibo; T = Turen; O = Oriente (Punta de Mata);
[a] Disease resistance for *Macrophomina* in Maracaibo and Turen; leaf disease complex in Punta de Mata

Table 9. Yield of eleven best *Sesamum* mutants (M_5) from multilocation trails selected for commercial evaluation in M_6 in 1986–1987

Genotype		Yield kg/ha M	Yield kg/ha T
(1) P 10-7412 (Early)	–B	1088	1207
(2) CF 25-9382	–B	1581	1244
(3) CF 18-9371	–A	1526	1163
(4) CF 53-8874	–B	1273	1004
(5) CF 35-9306	–B	1073	996
(6) P 2-7301	–A	1064	931
(7) P 10-7412 (Medium)	–B	895	982
(8) CF 6N3H49A	–B	1007	874
(9) P 56-7624	–A	831	1020
(10) V 8363	–B	1312	904
(11) V 30-8052	–B	1091	967
(12) P (c)		578	551
(13) CF (c)		507	799
(14) V-44 (c)		571	672
SE_d		112.3	72.6

M = Maracaibo; T = Turen; A = bulk; B = individual selection; (c) = control

The material was grown in six replications in Turen from December 1985 to April 1986, in Maracaibo from November 1985 to March 1986, and in Punta de Mata from July to October 1985. The data for yield and six other characters are presented in Table 8.

Yield data at both locations revealed a large significant superiority of the mutants over the controls (Table 8). The location means were similar. The mutants as a group yielded 55.5% more than the controls in Turen and 87.2% more in Maracaibo. Similar significant superiorities of the mutants over their corresponding parents were seen in all cases except 'AM', with the maximum improvement being felt in 'CF'. Moreover, six mutants (four from 'CM' and two from 'Piritu'), namely CF 25-9382, P10-7412 (early), CF-18-9371, P-56-7624, CF 6NB3H49A, and CF 53-8874 yielded more than 1,000 kg/ha, up to a maximum 1,244 kg/ha, in the main zone of central Venezuela. Among them, CF 25-9382 yielded nearly double that of the best control (Table 9).

Interactions with locations was evident in the differences between each group of mutants and their corresponding parents, with the yield superiority of the mutants being higher in Maracaibo than in Turen. The performance of all 'CF' mutants, except CF 6N3H49A, was consistent in both locations, with higher yields in Maracaibo, while the 'Piritu' group yielded better in Turen. However, P10-7412 (early) was an exception, being consistently high yielding in both locations. Thus, genotype × location interactions, even among the mutants derived from the same variety, and more so in the group from 'Piritu', were particularly evident for yield and days to flower.

In Punta de Mata, reliable yield data could not be collected due to bad weather at harvesting. However, the productivity score at the termination of flowering indicated the potentials of CF 25-9382, CF 53-8874, CF 6N3H49A, P 10-7412 (early), P 56-7624, V-44-35-8420, V44-30-8052, and AM-77-6931. The heavy incidence of *Cylindrosporium* and *Cercospora* defoliated the controls and some mutants. The above eight mutants were relatively clean, high in yield, and had an acceptable level of field resistance to these foliar diseases. The consistency of all the CF mutants and P 10-7412 (early) in this location also confirmed their wide adaptability. The resistance of these mutants to foliar diseases also indicated that diversity in 'Piritu' and 'CF' mutants was large enough to enable selection for multiple disease resistance.

Other characters

The differences between the M_5 progenies and their corresponding parents were significant for six other characters related to flowering, synchrony, and disease resistance in both Maracaibo and Turen (Table 8). Additional data from Punta de Mata for resistance to foliar diseases and stability of synchrony in this zone of adequate soil moisture confirmed the superiority of the mutant progenies, except in the case of 'AM' where the mutant progenies were more susceptible to the foliar diseases than their parents. The results revealed that a major structural alteration in plant type achieved by the 'CF' progenies combined earliness, higher productivity, and multiple disease resistance. In the case of 'Piritu', P 10-7412 (early) represented a change in plant architecture combined with synchrony, yield, and a disease resistance that were superior to its parent. This progeny, suitable for higher plant densities, was 8 days earlier than its parent in flowering and 20 days earlier in maturity. Two additional progenies of 'Piritu' had higher disease resistance than P 10-7412 (early) and could be further utilized.

These results confirmed the stability for earliness, yield, and disease resistance of the 'CF' mutants and P 10-7412 (early), and the only limited success with material from 'AM' and 'V-44'. It was clear that even with the induced variability and the selection scheme successful in 'CF' and 'Piritu', the response was not adequate for yield improvement in 'AM' and'V-44' which had been recommended for this zone, but did not fit into the existing cropping system. 'CF' mutants were successful in all zones, probably due to their resistance to drought and their rapid seed filling, traits necessary in the seasonally semi-arid Falcon State where their parent, 'CF', is the locally adapted land race.

M_6 generation

From 1986–1987, the M_6 generation of the best nine mutants, four each from 'Piritu' and 'CF', was sown on a commercial scale over 115 hectares of farmers fields in the semi-arid region of the Guajira Peninsula in plots of one hectare or larger. The yield of the mutant progenies was estimated to be 650–700 kg/ha as compared to the less than 300 kg/ha normally obtained with traditional varieties (personal communication, F. Oropeza). Thus, the multivariate analysis was useful in the final selection of character combinations with high productivity under severe semi-arid conditions.

Discussion

The aim of the present study on mutation breeding in *Sesamum* was to increase the productivity of a cropping system under moisture stress, and as such it has provided valuable information on the nature of the diversity patterns of induced variation, the relative roles of the characters chosen, and the responses to selection as assessed by multivariate analyses. From the array of diverse genotypes having a variety of character combinations, the successful isolation of highly productive lines with acceptable levels of multiple disease resistance under tropical conditions was achieved (Table 7). Substantial diversity was present even among the high yielders obtained, thus still further improvement in yield by hybridization is possible among them (Table 9). The pattern of variation generated was related to the effectiveness of selection for a *constellation* of characters that improved yield and adaptability, and not to changes in one or two variables (Tables 8 and 9). This was reflected in the successful performance of the progenies from 'CF' and 'Piritu', in contrast to the limited success reported in this crop by others (Ashri 1982; Brock 1971; Lee et al. 1985; Sasikala and Kamala 1985; Micke 1985). Significant success was obtained in only two of the six varieties, one of them 'CF', a land race, and the other 'Piritu', a popular recent introduction with contrasting patterns of character combinations. The yield increase in the selected mutants of these two varieties was 40%–100% across the zones. Resistance to *Macrophomina,* the major limiting factor, was obtained to a high degree in 'Criollo Falcon' and at an acceptable level in 'Piritu', as was high tolerance to foliar diseases for which initial selection was not emphasized. The large yield increase and its stability across the zones in these mutants was due to a combination of developmental traits like earliness, synchrony of development, limited branching, and disease resistance, coupled with efficient utilization of the residual moisture under stress. Better root development and root activity was also evident in the mutants as compared to the controls for the root distribution at maturity.

Evaluation of the selection methodology

A comparison of the three methods of selection indicates the superiority of individual selection (B) over the other two, in terms of response to selection and diversity among the mutants from the same variety and between varieties. Individual selection is therefore recommended when improvement for a complex of characters, such as for selection to fit into a cropping system, is required. Any attempt to reduce work by using M_2 bulks, as practiced in cereals like wheat and rice, will probably not be useful for oil seeds like *Sesamum*, which are sensitive to stress and grown under uncertain ecological conditions. The bulk method was only good for earliness, which has high heritability.

Since most of the characters related to yield and adaptation have large environmental components and low heritability, individual selection in each generation rather than in M_2 bulks will better detect genotypes. Among the 21 M_5 progenies in regional trials, 17 were from group B and only 4 were from group A, as seen below (see also Table 1):

	'Glauca'	'V-52'	'AM'	'Piritu'	'V-44'	'CF'	Total
Group A	0	0	0	2	1	1	4
Group B	1	0	2	7	4	4	17
							21

Of these, only the nine best progenies were selected for yield and disease resistance and subsequently included in the yield trials for 1986–1987: four were from 'Piritu', four from 'CF', and 1 from 'V-44', with 'Piritu', 'AM', and 'V-44' as controls. Their performance in the farmers fields on a commerical scale confirmed the superior performance of 'CF' mutants under extreme moisture stress and the effectiveness of group B.

Choice of variety and effective dose

Based on M_4 data, most of the productive selections were obtained from 75rad followed in decreasing effectiveness by 60 and 45 krad, while the M_2 data indicated that 60 krad the most effective, followed by 45 krad. Therefore, any conclusions about the effective dose should not be based on M_1 and M_2 data alone but on the recovery of useful mutants from later generations. The proportion of useful mutants recovered from M_4 progenies was high in 'Piritu' and 'CF' in the three selection groups A, B, and C. This indicates the need for a proper choice of locally adapted varieties for mutational rectification. If we consider each character separately, rapid, effective response was evident for earliness, reduced branches, and synchrony, in descending order. Resistance but not immunity to *Macrophomina* was achieved at high levels in specific varieties as 'CF' and 'Piritu', but was very limited in the other varieties.

Effectiveness of selection for developmental traits and associated pattern of changes

The quantum of change achieved in the mutant progenies of 'CF' and 'Piritu' as compared to their parents was substantial for the set of nine variables for which selection was practiced; this is in contrast to the poor response observed in the other four varieties. The rapid advance under selection in both these varieties was comparable to that observed for highly heritable characters. The large increase in their yield a trait considered to have low heritability and one for which direct selection was not practiced, could only be explained by a major alteration in their developmental features.

'Criollo Falcon' has excellent drought resistance, is very late and tall with many branches, mostly on the top one-third of the plant, but is variable in its susceptibility to *Macrophomina,* all of which are traits responsible for its low yield and survival under natural selection. Its mutants have a completely different plant type, are medium in height, earlier by 3–4 weeks, and stable in earliness, have fewer and erect synchronous branches developing from the lower half of the plant and multiple disease resistance, but they do retain the drought resistance of the parent. 'Piritu', popular in all three zones of Venezuela, is medium-tall, semi-synchronous in maturity, variable for days to flower and maturity, but highly susceptible to *Macrophomina* and leaf diseases. Its mutants are similar to the parent in maturity (or slightly earlier), but are more stable in flowering and maturity, with fewer branches, better synchrony, and a higher resistance to diseases. They also retain the good adaptation of the parent. Thus, a major alteration in plant type and maturity, and superior synchrony and disease resistance are responsible for the higher yields of the mutants of both these varieties. The diversity within each variety during M_4 was considerable for the above characters, particularly for habit, synchrony, and resistance to *Macrophimina* as reflected in the corresponding coefficients in the first and second principal component vectors (Tables 4 and 6). The success of the 'Criollo Falcon' mutants was also due to the simple pattern of variation reflected in the high proportion of the first two characteristic roots (Table 3). In both cases, synchrony, a developmental feature essential for wide adaptation, was achieved in spite of the many branched habit of their parents.

Synchrony was excellent in 'CF' and 'Piritu' mutants despite their branching habit. In addition to earliness by nearly 1 month in 'CF', the duration of flowering was also reduced in the mutants by 7–13 days. However, the duration of flowering could be reduced still further under drought due to its large vegetative period and late flowering. 'Piritu' also could rapidly terminate its flowering under drought and could be treated as a semi-determinate, and thus far superior to the determinate mutant of Ashri (1982) which has a weak stem, shallow root system, and very low yield. Our study produced results similar to those obtained for soybean (Foley et al. 1986) where determinate mutants combined early maturity and a shorter duration of flowering (by 18 days), as compared to their indeterminate counterparts, but were shorter and lower in yield. In contrast, our mutants, which are semi-determinate, were earlier in flowering and shorter in flowering period compared to their parents, and gave much higher yields, due to their synchrony, reduction in duration of flowering, and stable early maturity under drought. Thus, determinate habit alone may not contribute to yield, as seen in *Sesamum* and soybean. While seed size was similar in the two groups of soybean lines, 'Piritu' mutants had more uniform seed with oil content equal to or higher than the parent, which could be traced to their synchrony.

Synchrony combined with earliness may increase the duration of seed filling and, when compared to rates of dry matter accumulation in seed, may improve yield as it did in soybean (Beaver and Cooper 1982). In our study, higher yield in the mutants combined with earliness, synchrony, a superior harvest index, and reduced duration of flowering in 'CF' mutants and only synchrony in 'Piritu' mutants. Reduced branching with synchrony influences grain filling rate in *Sesamum* (Lee et al. 1986). Such differences may also exist in our material.

A re-examination of the data of Lee et al. (1986) showed that seed weight in unbranched types was better than in branched types and differed in lower, middle, and upper parts of the plant. The upper part always had a lower seed weight than the other parts. Therefore, reduced branching and minimum differences in the flowering time between different parts of the same plant might provide better seed filling, more homogeneous seed size, and a possible better accumulation of oil than was obtained in our material.

The identification of nine mutants with high stable yields and acceptable levels of resistance to soil and foliar pathogens across the three regions indicated that selection for developmental characters is important for wide adaptation, disease resistance, and yield (Murty 1971). One of the mutants, CF 25-9382, is free from jassids and vectors of leaf virus when sown late, while others showed varying susceptibility. Selection was never made for jassid resistance in our material. All nine best yielding mutants remained green even after severe drought and regenerated after harvest, an indication of excellent root activity.

Nature of the diversity among the productive progenies

The diversity among best yielding mutants from the same variety, as in 'CF' and 'Piritu', was for several characters with different character combinations, as is evident from their means (Table 8). Even among the four mutants selected for commercial field demonstrations in M_6, the ranges were 34–40 days for days to 50% flower (a), 69–79 days for days to final flower (b), 89–104 days for maturity (c), 5.7–8.5 for synchrony score (d), 19–34 days for seed filling period (e), and a 1.2–1.9 score for resistance to *Macrophomina* (f). In the four 'Piritu' mutants, the corresponding values were 37–49 days (a), 68–90 days (b), 91–119 days (c), 7.6–8.6 for (d), 24–29 days for (e), and 1.1–1.9 for (f). Changes from repulsion phase linkages to coupling phase may have altered the character associations and released variation not available earlier for selection (Arunachalam and Owen 1970; Murty 1979). The diversity even among these few progenies for developmental traits like synchrony, seed filling period, and earliness combined with acceptable levels of disease resistance, showed that the choice of variables for selection in our study was justified.

The concept of plant type for high yield in *Sesamum* under limited moisture and nutrients would appear to be different from the determinate habit in soybean combined with longer seed filling period (Brand et al. 1984) and the temperate forms of Korean *Sesamum*. Soybean is grown in temperate conditions, in fertile soils with adequate moisture, and is not subject to dought conditions comparable to those undergone by sesame in semi-arid tropics. The limitations on high yield for sesame in central Venezuela are set by the preceding rice crop or other cereal, the high temperature in March-April, and the short seed filling period. Very early types have inadequate plant frames for giving high yields. The high temperature at maturity cuts off seed development abruptly. Therefore, a balance of earliness, semi-determinate habit, duration and rate of seed filling, and seed growth rate are necessary in the ideal plant type for the Venezuelan cropping system, as was also found by Swank et al. (1987) in soybean.

The success with 'CF' and 'Piritu' indicated the important role of adaptation in the choice of material for mutation breeding. These mutants will fit excellently into a variety of cropping systems in Venezuela. Mutational rectification of such other varieties as 'AM' and 'Ven-52' has not met with the same success as in 'Piritu' and 'CF', probably due to a fixation of gene complexes with inferior capacity of wide adaptation and poor response to induced variation, as was evident from the comparative multivariate analysis of diversity in these varieties' adaptation. Our results have shown that traditional mutation breeding of a component crop like *Sesamum* which is highly sensitive to ecological changes, in order to fit it into a cropping system would require a different approach from that of a mono-cropping system. The diversity of the induced variation should be large enough for a group of characters and could be assessed by multivariate analysis for an appropriate choice of variety and selection methodology. Selection for developmental traits like synchrony and reduced flowering duration would provide a good genetic base on which disease resistance can be superimposed, as revealed by in our study.

References

Arunachalam V, Owen ARG (1971) Polymorphism with linked loci, 1st edn. Chapman and Hall, London

Ashri A (1982) Status of breeding and prospects for mutation breeding in peanuts, sesame and castor beans. In: Improvement of oil-seed and industrial crops by induced mutations. IAEA, Vienna, 1982, STI/PUB/608:65–80

Beaver JS, Copper RL (1982) Dry matter accumulation and seed yield components of two indeterminate soybean cultivars. Agron J 74:380–383

Bedigian D, Harlan JR (1983) Nuba agriculture and ethnobotany with particular reference to sesame and sorghum. Econ Bot 37:384–395

Brand PJ, Hing PN, Green DE, Shibles RM (1984) Use of principal factors analysis in the study of three stem termination types of soybeam. Euphytica 33:387–400

Brock RD (1971) The role of induced mutations in plant improvement. Radiat Bot 11:181–196

Foley TC, Orf JH, Lambert JW (1986) Performance of related determinate and indeterminate soybean lines. Crop Sci 26:5–8

Lee JJ, Lee ST, Kang CW, Oh SG, Seong NS, Han YS (1985) A new resistant and high yielding sesame variety Ansanggae. Rep Rural Develop Administration 27:199–202

Lee JJ, Kang CW, Son ER (1986) Studies on flowering and maturity in sesame (*Sesamum indicum* L.). VI. Grain filling rate for differently positioned capsules in different plant types. Korean J Crop Sci 31:214–219

Mazzani B (1985) Sesame growing in Venezuela 1980–1984. FAO Plant Prod Prot Paper 66:86–89

Micke A (1985) List of varieties developed by mutation breeding. Mutat Breed News 27:25–27

Murty BR (1971) Developmental traits in disease resistance in some cereals. IAEA Publ No STI Pub 271:93–105

Murty BR (1979) Selection of parental material, breeding methods and evaluation procedures in developing improved crop varieties. Indian J Genet Plant Bred 39:305–314

Murty GSS, Joshua DC, Rao NS, Bhatia CR (1985). Induced mutation in sesame. In: Sesame and safflower: status and potentials. FAO Plant Prod Prot Paper 66 (ISBN 92-5-102306-9): pp 188–190

Oropeza F, Murty BR, Bravo R (1984) Mutation breeding in Ajonjoli (*Sesamum indicum* L.) for adaptation to the cropping system in Venezuela. In: Induced mutations for crop improvement in Latin America. IAEA (Vienna) TECDOC 305:285–298

Sasikala S, Kamala T (1985) Ethidium bromide (EB) induced mutants in gingelly (*Sesamum indicum* L.) cultivar "Vinayak". Theor Appl Genet 70:307–308

Swank JC, Egli DB, Pfeiffer TW (1987) Seed growth characteristics of soybean genotypes differing in duration of seed fill. Crop Sci 27:85–89

Taborda F, Murty BR (1985) Some aspects of tropical adaptation in sorghum. Genet Agrar 29:121–130

Torres ICI (1985) Productiòn del Ajonjolì en Mèxico. Sesame and safflower: status and potentials. FAO Plant Prod Prot paper 66 (ISBN 92-5-102306-9):80–82