

Evaluation of Seven Sorghums, Selfed and Crossed to Three Cytoplasmic Male-Sterile Lines¹

A. Sotomayor-Ríos and D. E. Weibel²

ABSTRACT

Seven grain sorghum lines (*Sorghum bicolor* (L.) Moench) selected from the Sorghum Conversion Program (SCP) and their F₁ hybrids from crosses with CK-60, Martin, and Redlan were evaluated. Days to midflower, height, rust (*Puccinia purpurea* Ckd.) reaction, number of heads/plot, test weight, threshing percentage, and grain yield were rated or measured. The seven lines when selfed were, in general, the latest to reach midflower. Four height groups were observed; the taller hybrids were the result of the complementary effect of different height factors in the parents. Rust ratings ranged from 2.9 to 4.9; F₁ hybrids Martin × 4, Martin × 7, and Redlan × 7 were the most susceptible to rust. Generally, sorghums with a high grain yield also had a high test weight and threshing percentage. The grain yield ranged from 1,866 to 4,261 kg/ha. Mean yields were, on the average, 26% higher for F₁ hybrids than for their respective male parents. A 67% heterosis for grain yield was observed in two crosses involving Martin and Redlan female parents.

INTRODUCTION

The Sorghum Conversion Program (SCP) is an excellent channel through which selected tropical types are made available to breeding programs in the temperate climates (3). This program involves a series of crosses and backcrosses in Puerto Rico and careful selections in Texas for the final conversion of tropical to temperate sorghum types (1, 5). The SCP is changing the sorghum breeding patterns in the temperate and tropical zones by providing material for improvement of such properties as disease and insect resistance, drought tolerance, sterility, grain quality, and many others. Schertz (3) listed 12 improvements that are possible through the SCP, one of the most important being the reduction of genetic vulnerability to diseases by use of new cytoplasmic-genetic sterility systems.

The purpose of this study was to compare seven lines from the SCP and their F₁ hybrids from crosses with three male-sterile lines, all grown under short-day conditions in Puerto Rico, for grain yield, rust resistance, and a series of morphological characters.

MATERIALS AND METHODS

The experiment was conducted at the Isabela experiment farm of the Mayagüez Institute of Tropical Agriculture (MITA), ARS, USDA,

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² Research Geneticist, Mayagüez Institute of Tropical Agriculture, ARS, USDA, Mayagüez, P.R. 00708, and Professor of Agronomy, Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater. Ok. 74074, respectively. The help of Dr. Rodrigo Alconero in evaluating plants for rust ratings is deeply appreciated.

which is located about 128 m above sea level and has temperatures ranging from 18° to 31° C. The soil is Coto clay (an Oxisol) with a pH of about 5.5. Before planting, a complete fertilizer (15-5-10) was applied to all plots at about 448 kg/ha.

Seven grain sorghum lines selected from the Conversion Program were crossed with three cytoplasmic male-sterile lines (CK-60, Martin, and Redlan) to produce 21 F₁ hybrids, which were compared with the same seven lines, selfed. The description and origin of these seven lines were reported in a previous paper by Sotomayor-Ríos and Miller (4). The experimental design was randomized complete blocks with six replications. Each plot consisted of two rows spaced 101 cm apart about 6 m long. A 6-m² area of each plot was used for grain-yield sampling.

Methiocarb [4-(methylthio)-3,5-xylol methylcarbamate] (Mesuro³) was applied to sorghum heads at about 3 kg/ha at the initiation of the grain filling period as a bird repellent.

The following data were collected: 1) Number of days from planting to midflower (visual estimate); 2) height of plants (from the ground to the tip of the head), average for 5 plants/plot; 3) rust (*Puccinia purpurea* Ckd.) rating (1 = trace to 25% infection of leaf blades; 2 = 26-50%; 3 = 51-75%; 4 = 76-100%; and 5 = at least half of leaf blades dying or dead, and pustules on stems, visual estimate); 4) number of heads/6-m² plot (H/p); 5) test weight (TW), determined with a container of known volume and expressed in kg/hl; 6) threshing percentage (TP) (weight of threshed grain × 100/weight of unthreshed grain), determined on the yield sample; 7) grain yield (GY) at 14% moisture, determined from the harvested 6-m² plot; and 8) heterosis (%) = $\frac{\text{hybrid} - \text{parent}}{\text{parent}} \times 100$.

RESULTS AND DISCUSSION

Table 1 shows the means for number of days from planting to midflower, height, rust rating, H/p, TW, TP, and GY of the seven lines selfed and their F₁ hybrids. The mean effects of the male and female parents on these traits are shown in table 2. These traits in the seven lines selfed and in their best or highest value F₁ hybrids are compared in table 3.

Days to midflower for all selfed lines and hybrids ranged from 56.3 to 67.8 days (table 1). All male-parental lines reached midflower later than any of their F₁ hybrids. Redlan hybrids were earlier than Martin

³ Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of equipment or materials by the Agricultural Experiment Station of the University of Puerto Rico or an endorsement over other equipment or materials not mentioned.

TABLE 1. — Means for number of days from planting to midflower, height, rust rating, heads/plot, (H/p), test weight (TW), threshing percentage (TP), and grain yield (GY) of seven sorghum lines and their F₁ hybrids from crosses with three cytoplasmic male-sterile lines (CK - 60, Martin, and Redlan), all grown at Isabela, P.R.

Line or hybrid	Days to midflower	Height	Rust rating	H/p	TW	TP	GY
		<i>Cm</i>			<i>Kg/hl</i>		<i>Kg/ha</i>
4	64.0c ¹	131.7 f	4.3 b	52.0 fgh	72.3 g	67.0 k	1,951 j
5	67.8 a	81.0 h	3.0 fg	49.7 h	76.3 ef	70.7 ijk	2,100 j
6	66.0 b	127.7 f	2.9 g	56.2 bcdefgh	78.5 abcde	75.8 defg	3,006 ghi
7	64.7 bc	127.2 f	4.1 bc	53.0 defgh	78.7 abcde	73.0 hij	2,041 j
8	65.2 bc	103.8 g	3.0 fg	59.3 abcdef	78.2 abcdef	76.3 defg	2,254 j
9	66.3 ab	125.3 f	3.1 fg	52.5 efgh	79.2 abc	77.5 bcdef	3,609 bcdefg
10	66.0 bc	123.3 f	3.9 bc	59.2 abcdef	80.7 a	75.7 efg	3,286 efg
CK-60 × 4	62.2 d	163.3 de	4.6 a	55.3 cdefgh	73.5 g	71.8 ijk	2,431 ij
5	61.8 de	124.5 f	3.1 fg	54.2 defgh	76.5 def	74.3 fghi	3,100 gh
6	60.2 efgh	181.8 abc	3.4 def	49.8 h	78.0 bcdef	77.5 bcdef	3,607 bcdefg
7	61.3 def	160.5 de	4.8 a	50.5 gh	78.3 abcdef	71.2 ijk	2,290 j
8	60.8 defg	134.2 f	3.2 fg	55.0 cdefgh	79.3 abc	79.5 abcde	3,355 defg
9	61.0 defg	182.2 abc	3.2 fg	52.3 efgh	79.0 abcd	77.7 bcdef	4,217 ab
10	59.7 efgh	187.3 ab	3.9 bc	49.7 h	79.3 abc	81.2 abc	3,851 abcdef
Martin × 4	59.3 ghij	172.5 cd	4.9 a	52.7 efgh	73.8 g	74.5 fghi	2,491 ij
5	60.7 defg	133.2 f	3.2 fg	55.8 bcdefgh	78.0 bcdef	76.2 defg	3,514 cdefg
6	58.3 ijk	186.0 ab	3.3 efg	63.3 ab	78.5 abcde	79.8 abcde	3,906 abcde
7	59.3 ghij	162.8 de	4.9 a	56.2 bcdefgh	76.0 f	71.3 ijk	1,866 j
8	58.2 ijkl	134.2 f	3.9 bc	58.3 abcdefg	79.5 ab	79.8 abcde	3,432 defg
9	59.8 efgh	194.0 a	3.4 def	59.3 abcdef	79.2 abc	80.0 abcd	4,104 abc
10	58.8 hij	193.3 a	3.8 cd	55.2 cdefgh	77.5 bcde	81.3 abc	3,452 defg
Redlan × 4	58.7 hij	177.3 bc	4.8 a	53.5 defgh	73.5 g	70.0 jk	2,350 j
5	58.3 ijk	133.2 f	3.1 fg	56.7 bcdefgh	76.8 cdef	77.2 cdef	3,229 fg
6	56.3 m	181.0 abc	3.2 fg	60.7 abcd	78.5 abcde	80.7 abc	3,957 abcd
7	58.0 jklm	156.5 e	4.9 a	53.8 defgh	76.8 cdef	73.0 hij	2,119 j
8	56.8 klm	127.3 f	3.3 efg	62.5 abc	79.3 ab	82.2 a	3,779 abcdef
9	56.8 klm	190.5 a	3.3 efg	64.8 a	78.3 abcdef	80.8 abc	4,261 a
10	56.5 lm	191.7 a	3.7 cde	60.2 abcde	78.0 bcdef	81.7 ab	3,795 abcdef

¹ Values in a column followed by one or more letters in common do not differ significantly at the 5% level, using Duncan's multiple range test.

hybrids, which, in turn, were earlier than CK-60 hybrids (table 2). Selfed lines 6, 8, and 10 produced the earliest hybrids. The difference between the earliest hybrid (Redlan \times 6) and its male parent was -9.7 days (table 3). In all cases the differences in earliness between the best hybrids and their male parents were significant.

Height for selfed lines and hybrids ranged from 81.0 to 194.0 cm (table 1). The types can be grouped into four height categories. In descending order these are: 1) Hybrids with male parents 6, 9, and 10 (181.0 to 194.0 cm); 2) hybrids with male parents 4 and 7 (156.5 to 177.3 cm); 3) hybrids with male parents 5 and 8, and selfed lines 4, 6, 7, 9, and 10 (123.3 to 134.2 cm); and 4) selfed lines 5 and 8 (81.0 to 103.8 cm). Complementary effects of different height factors in the two parents

TABLE 2.—Mean effects of female and male parents on days to midflower, height, rust rating, heads/plot (H/p), test weight (TW), threshing percentage (TP), and grain yield (GY) of F_1 hybrids from crosses of seven sorghum lines with three cytoplasmic male-sterile lines (CK-60, Martin, and Redlan), all grown at Isabela, P.R.¹

Lines or hybrids	Days to midflower	Height	Rust Rating	H/p	TW	TP	GY
		<i>Cm</i>			<i>Kg/hl</i>		<i>Kg/ha</i>
Seven male parents	65.6	117.1	3.5	54.6	77.7	73.7	2607
Hybrids having female parent:							
CK-60	61.0	162.0	3.7	52.4	77.7	76.2	3264
Martin	59.2	168.0	3.9	57.3	77.5	77.6	3252
Redlan	57.3	165.4	3.8	58.9	77.3	77.9	3356
Hybrids having male parent:							
4	60.1	171.0	4.7	53.8	73.6	72.1	2424
5	60.3	130.3	3.9	55.6	77.1	75.9	3281
6	58.3	182.9	3.3	57.9	78.3	79.3	3824
7	59.5	159.9	4.4	53.5	77.0	71.8	2091
8	58.6	131.9	3.4	58.6	79.4	80.5	3522
9	59.2	188.9	3.3	58.8	78.8	79.5	4194
10	58.3	190.8	3.8	55.0	78.3	81.4	3699

¹ No statistical tests were performed on these data.

were apparently responsible for the hybrids in groups 1 and 2 being too tall for harvesting with combines. The tallest F_1 hybrids were those with female parents Martin and Redlan (table 2). All F_1 hybrids were significantly taller than their male parents (table 1).

Rust ratings for selfed lines and F_1 hybrids ranged from 2.9 to 4.9 (table 1). The most susceptible genotypes were the hybrids of male parents 4 and 7, and the most resistant, the hybrids of 6, 8, and 9 (table 2). Hybrids of male parent 9 were slightly more resistant than the paternal line selfed, but the differences were not significant (table 3). The rust ratings for hybrids having male parents 5 and 10 were not

TABLE 3.—Comparison of means for days to midflower, height, rust rating, heads/plot (H/p), test weight (TW), threshing percentage (TP), and grain yield (GY) of seven sorghum lines and the best F₁ hybrids from their crosses with male-sterile lines CK-60, (A₁), Martin (A₂), and Redlan (A₃), all grown at Isabela, P.R.

Male parent	Days to midflower		Height		Rust rating		H/p		TW		TP		GY	
	Female parent ¹	d ²	Female parent	d	Female parent	d	Female parent	d	Female parent	d	Female parent	d	Female parent	d
4	A ₃	-5.3* ³	A ₃	+45.6*	A ₁	+0.9 ^{NS4}	A ₁	+3.3 ^{NS}	A ₂	+1.5 ^{NS}	A ₂	+7.5*	A ₂	+540 ^{NS}
5	A ₃	-9.5*	A ₂ or A ₃	+52.2*	A ₁ or A ₃	+1.1 ^{NS}	A ₃	+7.0 ^{NS}	A ₂	+1.7 ^{NS}	A ₃	+6.5*	A ₂	+1,414*
6	A ₃	-9.7*	A ₂	+58.3*	A ₃	+3.3 ^{NS}	A ₂	+7.1 ^{NS}	A ₂ or A ₃	.0 ^{NS}	A ₃	+4.8*	A ₃	+951*
7	A ₃	-6.7*	A ₂	+35.6*	A ₁	+7.7*	A ₂	+3.2 ^{NS}	A ₁	-.4 ^{NS}	A ₃	.0 ^{NS}	A ₁	+249 ^{NS}
8	A ₃	-8.4*	A ₁ or A ₂	+30.4*	A ₁	+1.1 ^{NS}	A ₃	+3.2 ^{NS}	A ₂	+1.3 ^{NS}	A ₃	+5.8*	A ₃	+1,525*
9	A ₃	-9.5*	A ₂	+68.7*	A ₁	+1.1 ^{NS}	A ₃	+12.3*	A ₂	.0 ^{NS}	A ₃	+3.3 ^{NS}	A ₃	+652*
10	A ₃	-9.5*	A ₂	+70.0*	A ₃	-.2 ^{NS}	A ₃	+1.0 ^{NS}	A ₁	-1.4 ^{NS}	A ₃	+6.0*	A ₁	+565*

¹ Producing best or highest value F₁ hybrid.

² d = Mean value for hybrid-mean value for male parent (from table 1).

³ Hybrid significantly different from male parent at the 5% level, according to Duncan's multiple range test.

⁴ Nonsignificant.

significantly higher than those of their male parents (table 1). Selfed lines or hybrids with ratings above 4 usually sustained considerable loss of leaves.

Heads per plot ranged from 49.7 to 64.8 (table 1). Redlan \times 9 had the most H/p, whereas CK-60 \times 10 and male parent 5 had the least. Male parent 10 and hybrids Martin \times 6, Martin \times 8, Martin \times 9, Redlan \times 6, Redlan \times 8, Redlan \times 9, and Redlan \times 10 had mean H/p values ranging from 58.3 to 64.8, with no significant differences among them. The remaining 20 sorghums, with mean values ranging from 49.7 to 56.7, likewise had no significant differences. Comparison of the highest value F_1 hybrids with their male parents showed only one significant difference, that between male parent 9 and Redlan \times 9 (table 3). Hybrids of CK-60 had fewer H/p than did those of Martin or Redlan (table 2). Hybrids of male parents 4 and 7 produced the fewest H/p, whereas hybrids of 6, 8, and 9 produced the most.

Line 10 had the highest TW, 80.7 kg/ha (table 1). Male-parent lines 6, 8, and 9 and their F_1 hybrids all had lower, very similar TW's with no significant differences among them. The TW was significantly higher for line 10 than for its F_1 hybrids Martin \times 10 and Redlan \times 10, but the difference between line 10 and CK-60 \times 10 was not significant. Line 4 and its F_1 hybrids had the lowest TW's, ranging from 72.3 to 73.8 kg/ha. The differences between the best F_1 hybrids and their male parents (in most cases, favoring the male parent) were nonsignificant (table 3).

The TP's for selfed lines and hybrids ranged from 67.0 to 82.2 (table 1). Redlan \times 8 had the highest TP, followed in descending order by Redlan \times 10, Martin \times 10, CK-60 \times 10, Redlan \times 9, Redlan \times 6, Martin \times 9, Martin \times 6, Martin \times 8, and CK-60 \times 8. These 10 types all had statistically similar TP's ranging from 79.5 to 82.2. The 10 lines or hybrids with the lowest TP's were (in ascending order) 4, Redlan \times 4, 5, CK-60 \times 7, Martin \times 7, Redlan \times 7 and 7, CK-60 \times 4, Martin \times 4, and CK-60 \times 5. Hybrids of male parents 6, 8, 9, and 10 had the highest TP's, whereas hybrids of 4, 5, and 7 had the lowest (table 2). The greatest difference between a male parent and its best F_1 hybrid was that between 4 and Martin \times 4 (table 3). With all male parents except 7, the best F_1 hybrids had significantly higher TP's.

The GY's for all sorghums ranged from 1,866 to 4,261 kg/ha (table 1). The three top hybrids were Redlan \times 9, CK-60 \times 9, and Martin \times 9, with 4,261, 4,217, and 4,104 kg/ha, respectively. These were followed, in descending order, by Redlan \times 6, Martin \times 6, CK-60 \times 10, Redlan \times 8, Redlan \times 10, male parent 9, and CK-60 \times 6, with yields ranging from 3,607 to 3,957 kg/ha. There were no significant differences among these 10 sorghums, but their GY's were significantly higher than those of most of the remaining parents and F_1 hybrids. The 10 lowest grain

yields (ranging from 1,866 to 2,491 kg/ha) were, in ascending order, those of Martin \times 7, 4, 7, 5, Redlan \times 4, and Redlan \times 7, 8, CK-60 \times 7, CK-60 \times 4, and 6. There were no significant differences among these 10 sorghums. Male parents 9 and 6 (and, to a lesser degree, 10) clearly showed superior combining ability, but male parents 4 and 7 appeared to lack this ability (table 2). Figure 1 shows the yield relationship between parents and F_1 hybrids. The hybrids having a common male parent performed very similarly. These results suggest that, in an evaluation of lines, one hybrid or test cross is enough.

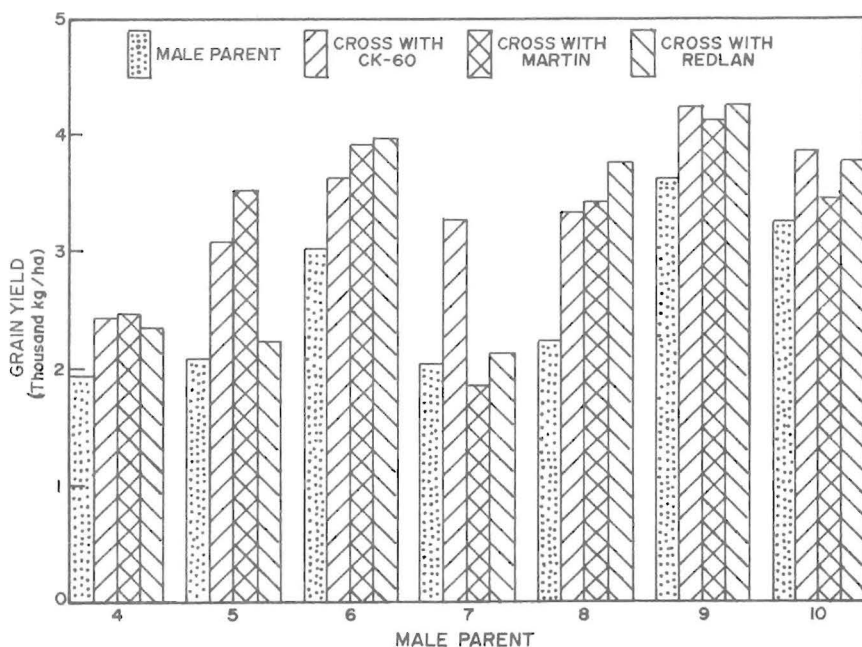


FIG. 1.—Relationship between grain yield of seven sorghum male-parent lines and grain yield of their F_1 hybrids from crosses with male-sterile lines CK-60, Martin, and Redlan, all grown at Isabela, P.R.

Of the selfed lines, 10 and 9 had the highest GY's, 3,286 and 3,609 kg/ha, respectively (table 1). These means were significantly higher than those of all other selfed lines except 6. A similar pattern of GY in the same lines was observed in a previous study by Sotomayor-Ríos and Miller at Isabela, P.R. (4). The GY's of CK-60 \times 4 and CK-60 \times 7 were not significantly different from those of their male parents; these findings suggest that male parents 4 and 7 lack combining ability, although heterosis was 24.6 and 17.4% respectively, in the two F_1 hybrids. Martin \times 5 and Redlan \times 8 had GY increases of about 67.3

and 67.4% over their respective male parents; the combining ability of male parents 5 and 8 was clearly superior to that of the other selfed lines.

The research on grain sorghum in Puerto Rico is very limited. Wahab et al. (6) and Fox (2) have reported yields in Puerto Rico that vary from 2,600 to 4,300 kg/ha. In our study, GY's of over 4,000 kg/ha are reported for some F₁ hybrids, although only about 60 kg N/ha was applied. Even higher yields can be expected under more intensive management.

When the three cytoplasmic male-sterile lines, CK-60, Martin, and Redlan, were crossed to the seven male parents, the hybrids sometimes performed differently in the various traits studied. Calculation of the mean effect of each female parent (table 2) showed that Redlan produced the earliest hybrids; Martin, the tallest, and Redlan, the largest number of heads/plot (H/p). The mean effects of the three female parents on rust rating and test weight (TW) were very similar. In terms of grain yield (GY) Martin and Redlan produced the best hybrids, especially in crosses with male parents 5 and 8; the highest heterosis was observed in these hybrids.

The results of this study indicate that the Sorghum Conversion Program (SCP) can provide excellent sorghum lines, with desirable morphological properties and good potential for yield, which could be valuable in a further improvement program. This study shows the value of the SCP for sorghum production in the tropics, although it was designed for breeding improvement for temperate zones. The hybrids obtained from crosses with any of the three well-known cytoplasmic male-sterile lines tested performed highly satisfactorily in the main traits studied, especially total grain yield per hectare.

RESUMEN

Siete líneas de sorgo de grano (*Sorghum bicolor* (L.) Moench) seleccionadas del Programa de Conversión, y sus híbridos (F₁) se evaluaron en la finca experimental del Instituto Mayagüezano de Agricultura Tropical. Tres líneas androestériles, CK-60, Martin y Redlan, se utilizaron como progenitores femeninos.

Los días transcurridos hasta que la mitad de las plantas florecieran fluctuaron entre 56.3 y 67.8. En general, las líneas masculinas (autofecundas) fueron más tardías que sus respectivos híbridos. Los híbridos de Redlan fueron más precoces que los de Martin y éstos aún más tempranos que los de CK-60. La diferencia entre el híbrido más temprano y su correspondiente línea masculina fue de -9.7 días. Se observaron cuatro grupos con respecto a la altura de las plantas; su fluctuación fue de 81 a 194 cm. Se atribuyó al efecto complementario de factores de altura el que los híbridos de los grupos 1 y 2 (181.0 a 194.0 y 156.5 a 177.3 cm) fuesen demasiado altos para recolectarse con máquinas cosechadoras (combinas). La incidencia de la roya causada por *Puccinia purpurea* fluctuó entre 2.9 y 4.9. Los híbridos Martin × 4, Martin × 7 y Redlan × 7 fueron los más susceptibles al ataque de roya.

El porcentaje de rendimiento para las líneas masculinas e híbridos fluctuó entre 67.0 y 82.2. El híbrido Redlan × 8 obtuvo el más alto.

La producción de grano fluctuó entre 1,886 a 4,261 kg/ha. Los tres híbridos superiores fueron Redlan × 9, CK-60 × 9 y Martin × 9 con 4,261, 4,217, y 4,104 kg/ha, respectivamente. Las líneas 9 y 6 mostraron tener la mejor aptitud combinatoria. De

las líneas masculinas las 10 y 9 fueron las mejores productoras con 3,286 y 3,609 kg/ha, respectivamente. Los híbridos Martin \times 5 y Redlan \times 8 mostraron tener una superioridad en producción de grano de 67.3 y 67.4% sobre las respectivas líneas masculinas.

Se concluye de este estudio que, el Programa de Conversión de Sorgo es capaz de proveer líneas de excelente valor, las cuales podrían utilizarse directamente tanto para el consumo como alimento de animales o en un programa de mejoramiento. Los híbridos (F_1) obtenidos utilizando cualquiera de las tres líneas androestériles mostraron poseer caracteres muy deseables, especialmente una magnífica producción de grano por hectárea.

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