CARIBBEAN FOOD CROPS SOCIETY

SERVING THE CARIBBEAN SINCE 1963

MEMORIA DE LA 28ª REUNION ANUAL

Agosto 9-15, 1992
Santo Domingo, República Dominicana

Publicado por:

Sociedad Caribeña de Cultivos Alimenticios y
Fundación de Desarrollo Agropecuario

Santo Domingo, República Dominicana

FDA FUNDACION DE DESARROLLO AGROPECUARIO, INC.

THE USE OF FULL-SIB RECURRENT SELECTION IN THE IMPROVEMENT OF AN OPEN POLLINATED CORN POPULATION FOR USE IN SUSTAINABLE AGRICULTURAL SYSTEMS

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ABSTRACT

Synthetic varieties of Corn (*Zea mays* L.) are better buffered against environmental stresses in sustainable agricultural systems than cuiti-vars with a narrow genetic base. A full-sib (FS) recurrent selection (RS) program was started at the University of Florida using a tropical open pollinated corn population. The goal was to develop a synthetic with a broad genetic base suitable to be grown during the fall in north-central Florida under conservation practices. Full-sib crosses were made in the spring of 1987. Then, in August a progeny test was planted in a randomized complete block design with six replications. Collected data included; ear, husk, and grain weight, insect damage (ID), whole plant yield (WY), seed and leaf N percent, and plant height. Analyses included ANOVA, correlations (r), heritabilities, and frequency distribution. There were differences between FS families for most of the traits. Ear weight (EW) was highly positively r (+ r) with yield and plant height traits. Ear weight was negatively r (-r) with ID and + r with leaf N percent of FS families. Tip ID was -r with husk weight. Heritability varied for all traits. The mean EW of the FS were higher than the parents and the Pioneer hybrid X-304C. Selection for EW improved WY, earworm (*Heliothis zea* L.) toleran-ce and N uptake.

INTRODUCTION

The genetic improvement of corn (*Zea mays* L.) within the concept of sustainable agricultural systems must receive high priority. Duvick

(1981) reported that the diverse gene pool contained in synthetic varieties serves as a buffer against environmental stresses allowing their use in many areas of the world. Synthetic varieties of corn are proposed by CIMMYT (international maize and wheat improvement center) (1984) for areas of the world where farmers do not have the means to secure high yields that justify the cost of hybrid seeds. Ikerd (1989) explained the need for more sustainable, energy efficient production systems and the development of more adapted cultivars.

Sinha and Swaminathan (1984) say plant breeders will have to anticipate the changes which are likely to take place in the major farming systems of the world. Crosson and Rosenberg (1989) predict researchers will have to develop many new technologies for expanding food production while preserving land, water, and genetic diversity. Within the mentioned concepts Fehr (1987b) defined plant breeding as the genetic adjustment to the physical, biological, technological, economic, and social component of the environment.

Recurrent Selection and The Selection Criteria

Synthetic varieties are obtained by bulking the product from each cycle of recurrent selection and allowing random interbreeding in succeeding generations. According to Briggs and Knowles (1977) the initial stock for a recurrent selection program may be an open pollinated variety, a successful single-cross or double-cross hybrid, or a synthetic variety. Inbred lines are convenient to use as components of a synthetic variety because they are not difficult to maintain. Random crossing of the components (parents) is assumed, and each should contribute the same amount of inheritance to the next generation.

As pointed out by Tingey and Singh (1980) a synthetic variety is a mixture of many genotypes, hence it has been subjected to changes from selection pressure. The degree of inbreeding decreases as the number of unrelated families mated to form the synthetics is increased. The number of families may range from 2 to more than 100. Busbice et al (1972) suggested that the use of more than 16 unrelated families provides little additional advantage. In the case of related parents or those whose relationships are unknown, the use of more than 16 families may be advisable.

Fehr (1987a) pointed out that the methods used to identify superior individuals for use in a synthetic cultivar involve both phenotypic and genotypic selection. Johnson (1981) emphasized that many characteristics can be evaluated in the development of new cultivars. Breeders must be able to determine which ones are important in later selection cycles. Phenotypic and genetic correlations are useful in plant breeding because they facilitate the interpretation of results and provide the basis for planning more efficient breeding programs. Falconer (1960) stated there are two causes of correlation between characters, genetic and environmental. The degree of genetic correlation expresses the extent to which two characters are influenced by the same gene(s). The genetic and environmental factors will give the phenotypic correlation. Sherrard et al (1984) proposed correlating physiological traits and growth parameters to predict yield, nutrient assimilation, and pest resistance.

One of the most important characterictics needed for a fall Corn cultivar is resistance to earworm (*Heliothis zea* L.). Bullard and York (1985) found resistance to be associated with husk length and thickness. Brewbaker and Kim (1979) associated earworm and fall armyworm (*Spodoptera frugiperda* L.) resistance with husk number. Cameron and Anderson (1966) found that long husks by itself are of no value in insect resistance unless they are compressed over the tip (small silk-channel diameter). As a result of studies done by Ullstrup (1978), it is recognized that a positive correlation exists between weevil infestations, earworm damage and bird damage to maize hybrids.

The traits of a good silage cultivar include high yields, proper maturity, and excellent standability. Theoretically, multiple-eared plants should be more efficient than singleeared types. Non-tillering types usually are for grain; heavy-tillering is useful for silage and green feed. Here, there is a problem in developing a variety for both purposes, grain and silage production. However, evaluations for both uses were important.

In an effort to achieve some of the above quidelines, a full-sib recurrent selection (RS) program was started in March 1987 at the University of Florida to develop a synthetic variety using conservation agriculture practices. The objectives were the following: I) Develop a synthetic cultivar with a broad genetic base suitable to be grown during the fall in a succession no-tillage cropping system, II) Determine the degree of correlation among all traits and use these correlations to predict yield, III) Determine the heritability of traits contributing to yield and quality, and IV) Evaluate the synthetic against commercial hybrids and the parental population.

MATERIALS AND METHODS

The Mass Selection Proqram

This corn program had its origin in 1982, when Dr. Raymond N. Gallaher, Professor of Agronomy at the University of Florida went on a trip to Central America. He collected three ears from a farm in the Limon province of eastern Costa Rica. The corn had been grown on a subsistence farm, where low or no inputs had been used.

When he returned to Florida Dr. Gallaher began a mass selection program with the Costa Rica germplasm crossed with temperate and tropical hybrids. The objective was to create a diverse genetic population adapted to Florida. Various degrees of low input agriculture prevailed. A total of six mass selection cycles were accomplished in a 5-yr period under no-tillage double cropping management.

The Full-sib Recurrent Selection Program

A recurrent selection program was started in 1987 to increase the frequency of genes for yield. The program was conducted under the no-tillage late summer environmental conditions prevailing at the Green acres agronomy farm located 13 miles west of Gainesville, Florida.

A nursery was established in early spring (march). The plot was rectangular (0.18 ha) with no replications. The area had been under no-tillage for the last 3 yr. Weed control was done before seedling emergence with Paraquat (paraquat) (1,1 dimethyl,4,4 bipyridinium-ion) at a dosage of 0.5 kg a.i. ha^{-1}. Broadcast preplant fertilization included 23 kg K as KCl, 5 kg of K_2SO_4, 10 kg S and 10 kg Mg as

$MgSO_4$. Ammonium nitrate was sidedressed preplant at a rate of 152 kg ha^{-1}. When plants were about 33 cm tall N as Ammonium nitrate was sidedressed by hand. Insect pests were controlled with Furadan 10G (carbofuran) (2,3-dihydro-2,2-dimethyl 7-benzofuranyl methylcarbamate) at a rate of 2 kg a.i. ha^{-1}. Irrigation was done with overhead sprinklers.

The genetic pool included Flopup'86, Flopdown'86, two Levy County open-pollinated cultivars, and 6 open-pollinated varieties from the Central America and the Caribbean. This blend of 10 different germplasms was called Population 1 (P_1). The tassel-bag method (Jugenheimer, 1976) was the technique used to make the 65 hand pollination full-sib crosses. Ears were harvested at physiological maturity, dried to 12% moisture, and shelled. The grain was cleaned and placed in storage bags.

The Progeny Test

The full-sib progeny test was planted in early August (fall), at the Green Acres Agronomy farm in soil classified as Arenic and Glossarenic Paleudults. A Randomized complete block (RCB) design with six replications was used. Single row plots were 6.00 m long. The parents, the cycle 6 of the mass-selected population and a tropical hybrid (Pioneer brand X304C), were used as control.

A jab-type planter was used to establish a plant population of 65,000 seed ha^{-1}. A preplant application of 300 kg N ha^{-1} as anhydrous ammonia was applied. Also P, K, Mg, S, and micronutrients were broadcast. Weed control was with a preemergence spray of Atrazine (Atrazine) (2-chloro-4ethylamino-6-isopropylamino-s-triazine) at a dosage of 2.2 kg a.i. ha^{-1}, Paraquat at a dosage of 0.5 kg a.i. ha^{-1}, and Lasso (Alachlor) (2-Chloro-2^{1}-6^{1}-diethyl-N-methoxymethyl) acetanilide at a dosage of 2.2 kg a.i. ha^{-1} Also post-directed Paraquat sprays with a CO_2 backpack sprayer were used as needed. Fall armyworm and earworm were controlled with 5 applications of Furadan (carbofuran) directly to the whorl with a bottle (bazooka) at a dosage of 1.0 g m^{-2}. Irrigation was provided as needed.

Selection Methodology

Although it was not possible to calculate the genotype x environment interaction, other parameters of performance were determinated to achieve the selection goals. Data collection included the evaluation of 18 traits in the field and postharvest. Field data collection corresponded to Traits 6, 7, 9, and 10 at the 50% silking stage and Traits 16 and 17 at harvest time (Table 1). Post-harvest data collection corresponded to Traits 1, 2, 3, 4, 5, 8, 11, 12, 13, 14, 15 and 18 (Table 1).

Four categories were considered for the ear insect damage evaluations. No insect damage, tip damage, body damage and total insect damage were considered as indicative of insect attack. The number of harvested ears was calculated by adding the number of ears showing no insect damage and the total insect damage. Whole plant dry matter was calculated using six plant samples taken at random. The fresh weight was recorded and samples dried for 2 days at 70°C in a forced air oven. The dried samples were weighed to calculate the dry weight percentage. The micro-Kjeldahl N analysis method was used to determine the N concentration in leaves and seeds. The amount of ammonium sulfate in the solution was determined using a technicon autoanalyzer following the procedure by Schuman et al. (1973).

There was a 33°F freeze on 2nd and 3rd December at 106 days after planting; at this point some of the families had reached the black layer stage. Considering the black layer stage as physiological maturity, ears were harvested with an average moisture of 18%.

Several statistical parameters were used to analyze the data. The analysis of variance (ANOVA) of a randomized complete block (RCB) design for all traits was obtained. Traits showing differences at the 5% probability level were assumed to have real differences between the full-sib family means. Correlation coefficients (r) between all traits were determined. In every case the selection of the dependent variable was based on highly significance differences among full-sib families. Also, those traits having a probability lower than 5% when correlated with the selected trait and showing a r value greater than 0.50 in the case of positive correlations (+r), or greater than -0.50 in the case of negative correlations (-r), were selected for further analyses and comparisons.

Since only one year and one location was tested, full-sib families and error were used to obtain the genetic component of variance (σ^2_t). The formula for the expected mean sguare as adopted from Allard (1966a) is expressed as follows:

$\sigma^2_t = (MS_t - MS_e) \div r$
In which: σ^2_t = the genetic variance, MS_t = mean square for FS families,
MS_e = mean square error, and r = replications.

Heritability (h^2) is defined as the ratio of the genotypic variance (σ^2_t) divided by the total (phenotypic) variance (σ^2_p). It provides a measure of the effectiveness by which selection can be expected to exploit the genetic variability. The total variance was used as the denominator in the following h^2 formula:

$h^2 = \sigma^2 t / [\sigma^2_t + (\sigma_e^2 / r)]$
In which: σ_e^2 = expected error mean square (MS_e).

After identifying the desired full-sib families, the expected genetic gain (G_g) was calculated. Then, the mean of all FS families was added to obtain the expected mean of the second FS cycle formed by the selected full-sib families.

The frequency distribution of the FS families in classes was for ear weight. Ear weight was selected as the results of ANOVA, correlations, h^2, and expected genetic gain. Also, its use in selection for yield performance is desirable based on ease of data collection in order to save time and resources. In order not to erode the genetic diversity of the populations, taking into consideration that only one environment has been evaluated, it was necessary to be flexible in the intensity of selection. The top 27% of the full-sib families were selected for the creation of the next cycle.

RESULTS AND DISCUSSION

Analyses of variance (ANOVA) for a RCBD showed a highly significance difference ($P = 0.01$) among full-sib families in P_1 for 15 of the 18 traits evaluated. Body insect damage, grain weight, and lodging percent showed differences at the 0.05 probability level (Table 1). The lowest coefficients of variation (CV) were found for N traits (from 4.26 to 6.45%). Ear weight had a CV of 23.70%.

Ear weight was +r with 13 of the traits (Table 2). Acceptable r were with whole plant dry matter, grain weight, number harvested ears, stalk weight, and tassel height with r values of 0.94, 0.89, 0.63, 0.58 and 0.53, respectively with $P<0.01$. Total insect damage and tip insect damage were -r with ear weight $r = -0.25$, and -0.19, respectively with $P<0.01$. Tip insect damage was -r with husk weight, having $r = -0.30$ and $P = 0.01$. Lodging per cent is a function of tassel height and silk height showing $r = 0.26$ and 0.21 respectively with $P = 0.01$.

The best h^2 was given by parent's seed N and the full-sib leaf N with 99 and 98%, respectively (Table 3). Yield traits had h^2 ranging from 54% for husk weight to 29% for grain weight. Ear weight had h^2 of 41%. Both plant height traits showed the same $h^2 = 52\%$. Ear insect damage had h^2 fluctuating from 48% for total insect damage to 32% for body insect damage.

The highest G_g was given by the stalk weight (11.4%), followed by ear weight (6.1%). Since they were positively correlated ($r = 0.58$) any improvement in ear weight will result in a general improvement of the quality of the plant. Also, because ear weight had adequate σ^2_t and h^2 coefficients, it was decided to use it as the main selection criterion.

The ear weight data shows a phenotypic distribution characteristic of mixed populations (Figure 1). This assumption is supported by two distinctive peaks in the frequency distribution, corresponding to 560 and 650 g m^2. The ear weight of the top 15 full-sib families ranged from 675 to 823 g m^{-2} with a $\bar{x}$ of 710 g m^{-2}. The ear weight mean of the selected families has 92 g m^{-2} (10%) increase over the population mean. The population $\bar{x}$ was found in Class 6. The $\bar{x}$ of the two parents, Flopup'86 and Flopup'87, was 515 and 531 g m^{-2}, respectively. Cenia-12 and hybrid Pioneer brand X-304C had almost the same ear weight equal to 496 and 490 g m^{-2}, respectively.

CONCLUSIONS

The contributions of the temperate and tropical hybrids, used in the mass selection program, to the diversity of the Costa Rican germplasm is unknown. However, free mating occurred as well as a reduction in plant height, improved grain yield, and changes in grain type, texture and color (Gallaher, 1986).

The full-sib breeding technique used was successful. Significant differences among full-sib families were obtained for most of the traits. Increases in yield performance are expected in future selection cycles for both populations.

Traits were correlated, suggesting the control by many genes having nearly equal effects. According to Simmonds (1979) non-independence of characters and especially of fitness characters is not uncommon and most breeders encounter them frequently. Ear weight was the trait that most positively correlated with other yield and plant height traits. Therefore, selection for high ear weight should result in both improved grain and whole plant yield. Tip insect damage was negatively correlated with husk weight in both populations. These results imply the effect of the weight and thickness of the husk in preventing insect larvae entrance, a well known mechanism of resistance studied by Wiseman (1985).

Heritability estimates for the evaluated traits varied. In general the N and plant height traits had the largest h^2, indicating either the precision of the evaluation procedure or the genetic variance was larger than for the other traits. The yield and insect damage traits, in most of the cases, had acceptable h^2 coefficients.

The mean of all full-sib families was better than the mean of the parents. Also, the mean of all full-sib families was better than the control hybrid Pioneer brand X-304C. Since this hybrid is recommended for planting during the late summer, its use as a control is recommended in future selection cycles. An interesting performance was given by Cenia-12, a parent. This improved variety from the Dominican Republic was highly tolerant to earworm damage.

Table 1, Analysis of variance of full-sib families in Population 1.

Trait	Computed F	Probability Value	Signif.	CV
Insect damage traits:				%
1- Harvested ears	1.90	0.000	**	18.50
2- No damage	1.70	0.004	**	66.60
3- Tip damage	1.80	0.001	**	23.90
4- Body damage	1.50	0.024	*	52.00
5- Total damage	1.90	0.000	**	10.90
Nitrogen conc. traits:				
6- Parent's seed	79.50	0.000	**	4.30
7- FS family leaf	23.20	0.000	**	6.45
8- F5 family seed	2.40	0.000	**	6.10
Plant height traits:				
9- Tassel	2.00	0.000	**	6.85
10- Silk	2.10	0.000	**	13.50
Yield component traits:				
11- Ear weight	1.70	0.003	**	23.70
12- Grain weight	1.40	0.042	*	27.80
13- Husk weight	2.20	0.000	**	23.90
14- Cob weight	1.90	0.000	**	33.20
15- Shelling percent	1.80	0.000	**	27.30
16- Stalk dry weight	2.20	0.000	**	28.90
17- Lodging percent	1.50	0.018	*	147.80
18- Whole plant DN	1.70	0.003	**	23.80

(*, **)= different at the 95% and 99% level of significance, respectively.

Table 2. Correlation matrix of all traits in Population 1.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1.00																	
2	0.01	1.00																
3	-0.04	-0.50**	1.00															
4	0.01	-0.02	-0.78**	1.00														
5	-0.05	-0.83**	0.62**	0.00	1.00													
6	0.10	-0.15*	-0.04	0.03	-0.04	1.00												
7	0.04	-0.01	0.05	-0.05	0.03	0.16*	1.00											
8	-0.01	0.04	-0.18*	0.17*	-0.08	0.13	-0.06	1.00										
9	0.35**	0.08	-0.03	-0.00	-0.07	0.02	0.00	-0.11	1.00									
10	0.32**	0.06	-0.11	0.10	-0.06	0.05	-0.07	0.09	0.60**	1.00								
11	0.63**	0.26**	-0.19**	0.04	-0.25**	0.02	-0.11	-0.13	0.53**	0.40**	1.00							
12	0.60**	0.17*	-0.09	0.17*	-0.17*	-0.02	-0.12	-0.25**	0.54**	0.37**	0.89**	1.00						
13	0.53**	0.29**	-0.30**	0.14	-0.31**	0.09	-0.02	0.07	0.40**	0.41**	0.65**	0.46**	1.00					
14	0.43**	0.22**	-0.17*	0.05	-0.21**	0.03	-0.09	-0.02	0.33**	0.23**	0.83**	0.53**	0.40**	1.00				
15	0.07	0.25**	0.04	-0.04	0.01	-0.20**	-0.00	-0.17*	0.17*	-0.00	0.12	0.25**	0.06	-0.07	1.00			
16	0.48**	0.15*	-0.15*	0.25**	-0.13	-0.00	-0.03	0.11	0.48**	0.44**	0.58**	0.52**	0.51**	0.41**	0.07	1.00		
17	0.01	0.08	-0.14	0.10	-0.10	0.06	-0.11	-0.06	0.26**	0.21**	0.17*	0.18*	0.11	0.11	0.00	-0.01	1.00	
18	0.64**	0.24**	-0.19**	0.06	-0.23**	0.01	-0.08	-0.05	0.41**	0.46**	0.94**	0.86**	0.67**	0.76**	0.11	0.82**	0.12	1.00

*,** = significance at the 95 and 99 per cent level respectively

Trait	Description	Trait	Description
1	Harvested ears	10	Silk height
2	No insect damage	11	Ear weight
3	Tip insect damage	12	Grain weight
4	Body insect damage	13	Husk weight
5	Total insect damage	14	Cob weight
6	N Parent's seed	15	Shelling
7	N FS family leaf	16	Stalk weight
8	N FS family seed	17	Lodging
9	Tassel height	18	Whole plant DM

Table 3 Heritability and expected gain of traits in population 1.

Trait	Unit	σ^2_t	h^2	Gg	G%
			%		%
Insect damage traits:					
1- Harvested ears	#	3.40	48	1.40	5.40
2- No damage	%	11.15	40		
3- Tip damage	%	28.40	44.		
4- Body damage	%	12.20	32		
5- Total damage	%	13.30	48	-3.00	-0.03
Nitrogen conc. traits:					
6- Parent's seed	$dag\ kg^{-1}$	0.10	99		
7- FS family leaf	$dag\ kg^{-1}$	0.20	98	0.60	20.90
8- FS family seed	$dag\ kg^{-1}$	0.01	60		
Plant height traits:					
9- Tassel	m	0.01	52	0.00	0.00
10- Silk	m	0.01	52	0.01	0.80
Yield component traits:					
11- Ear weight	$9\ m^{-2}$	2,482.10	41	37.90	6.10
12- Grain weight	$9\ m^{-2}$	419.20	29	13.40	4.70
13- Husk weight	$9\ m^{-2}$	194.70	54		
14- Cob weight	$9\ m^{-2}$	672.50	47		
15- Shelling	%	38.90	46		
16- Stalk weight	$9\ m^{-2}$	1,367.10	53	33.20	11.40
17- Lodging	%	3.40	34		
18- Whole plant DM	$g\ m^{-2}$	5,323.80	41	55.90	6.20

σ^2_t = Genetic variance component. h^2 = Heritability.
Gg = Expected gain in the corresponding unit over the population mean. See table 7 for unit of measurement for each trait.
G% = Expected gain in percent over the population mean.

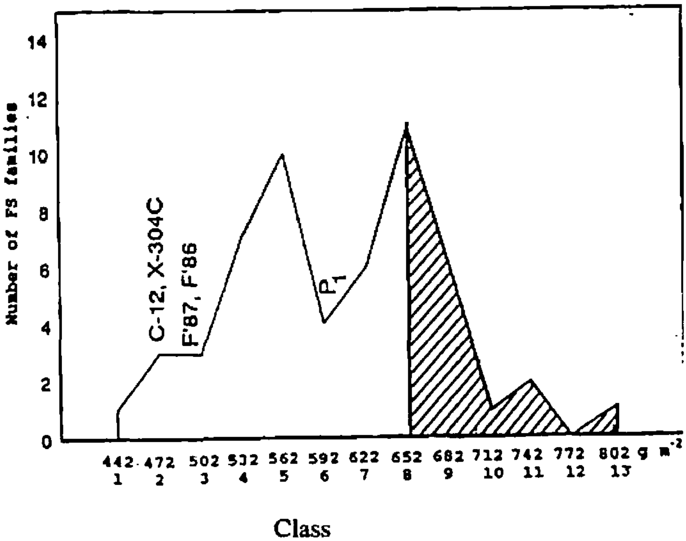
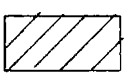


Figure 1. Frequency distribution for ear weight in Population 1.



Top 27 % FS families selected based on ear weight.

The frecquency classes where the mean of the population (P_1), parents (F'86, F'87 and C-12) and the control (X-304C) fell, are included.

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