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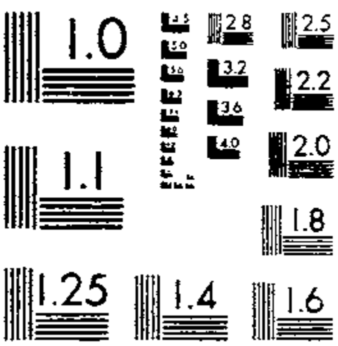

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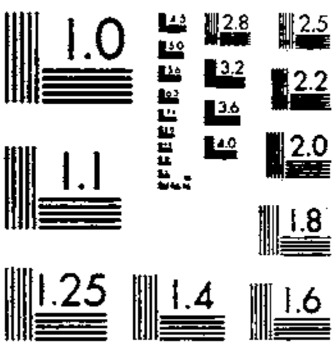

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INHERITANCE IN KENAF AS RELATED TO SELECTION OF INBRED LINES FOR COMPOSITE VARIETIES

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INHERITANCE IN KENAF AS RELATED TO SELECTION OF INBRED LINES FOR COMPOSITE VARIETIES

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Kenaf (*Hibiscus cannabinus* L.) is a subtropical species of the Malvaceae. Cotton (*Gossypium* spp.), okra (*H. esculentus* L.), and several ornamental species of *Hibiscus* are members of the family that are better known in the United States.

Kenaf is used mainly for the manufacture of burlap, and is probably indigenous to Africa. Most of its commercial production is in southeast Asia. In the Western Hemisphere it gained widespread interest during World War II when a jute substitute was needed. Kenaf fiber is slightly coarser and weaker than jute, but it can be separated more readily by mechanical methods, and the crop is less restrictive in its soil and climatic requirements.

Under favorable conditions the plants grow 8 to 10 feet high in about 100 days. The Salvadorian variety has been most widely grown in the Western Hemisphere. Several of its inbred lines were used in this study. It blooms only when day lengths are about 12½ hours or less, according to the U.S. Department of Agriculture (*13*).[1] Day-length response is a varietal characteristic.

When grown for fiber in Florida, where most of the domestic interest in kenaf is centered, kenaf is planted any time from May to August; but June plants produce highest yields. Harvest at the beginning of flowering gives the best, most easily cleaned fiber. Because of a rapid decrease in fiber quality after the plants begin to flower, fiber from seed fields is seldom saved.

Since kenaf is still at the stage where high yield and disease resistance are more sought for in a variety than quality refinements, plant breeders have been concerned with getting varieties that are productive. Most breeders have worked to develop pure-line varieties, although some have bulked pure lines and introduced them as "synthetic varieties."[2] In these, however, some undesirable segregates have resulted. This has revealed the need for studying inheritance in the hybrid progenies that would develop from natural cross-pollination in a composite of lines (a composite variety).

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[1] Italic numbers in parentheses refer to Literature Cited, p. 27.

[2] "Synthetic variety" is a term that has been used extensively by corn and forage breeders to refer exclusively to highly cross-pollinated types. As such, it calls to mind very specific qualifications, several of which kenaf does not have. Although kenaf breeders frequently apply the term to a composite of lines, "composite variety" is the more usual terminology.

Although hybrid vigor in kenaf had not been studied as such, it had been observed in various breeding programs. Since there is no practical method of producing hybrid kenaf seed on a commercial basis, a composite variety is now the only means of utilizing heterosis.

The research that has been done on natural crossing has not demonstrated the effectiveness of this means of using hybrid vigor. Studies along this line have been limited, however, to the amount of natural crossing and, in the present study, to effects of crossing on specific variables.

To be successful commercially, composite varieties of kenaf must first of all be uniform in date of first flower (maturity). Also, they must contain lines that are vigorous and produce vigorous offspring. They should be uniformly tall, and the percent fiber should be high. In order to extend the harvest season, composite varieties should differ in maturity, ranging from early to very late, each with a narrow range in date of first flower.

The inheritance of these characters has been studied primarily to evaluate factors that a plant breeder would need to consider in putting together suitable inbred lines for a composite variety. Many variables can be considered in selecting such inbred lines, but certain ones are particularly limiting. Except for disease resistance, the most critical of these have been considered in this study.

REVIEW OF LITERATURE

Little scientific information on kenaf is available. Most of what has been published concerns studies of existing types and varieties and natural cross-pollination. The most extensive literature on work done with existing types of kenaf is that of Howard and Howard (*4*). They described eight agricultural types and divided them into five varieties. These they classified mainly on leaf shape, maturity dates, and stem and petiole color. The commercial Salvadorian variety, which is the source of inbred lines 1, 2, 6, 7, and 8 in this study, is a mixture of two basic types that are most nearly *Hibiscus cannabinus* var. *viridis* How. & How. and *H. cannabinus* var. *vulgaris* according to the descriptions by Howard and Howard. The Javanese kenaf also used in this study—parent 0 and one parent of inbred lines 3, 4, and 5—is *H. cannabinus* var. *purpureus* How. & How. The Howard and Howard varieties were reported by Baque (*1*) as having typical yield and quality characteristics. However, Lynn et al. (*9*) and others found a fairly wide range in yield, quality, and other agronomic characteristics within these varieties.

Pate, Seale, and Gangstad (*11*) reported that Javanese varieties are lower in fiber percentage and have fewer capsules per plant than the commercial Salvadorian kenaf. They also found lower yields of stalks per acre, which, with low fiber percentages, made even more marked differences in net yield of fiber.

Several workers, including Baque (*1*) and Horst (*3*), classified kenaf as a "naturally self-pollinated" crop, and it has been handled on that basis in most breeding and commercial production undertakings. But Howard and Howard (*4*) observed that when varieties were grown close together, cross-pollination was very common. They noticed that when the flowers began to close about midday, frequently no pollen was on the stigmas. Thus, pollen brought from other flowers by insects would have resulted in cross-fertilization any time during the morning. They believed that self-pollination is nearly always effected by the closing of the petals in the afternoon.

Jones and Tamargo (*7*) found that natural cross-pollination in varieties grown in alternate rows varied from 1.79 to 23.76 percent, with an average of 7.23 percent for the six strains tested. Varieties included in this test differed in maturity date. The ones of similar maturity date, as would be used in a composited variety, were found to have the highest percentage of natural crossing. This suggested to the authors that the percentage of natural crossing might be greatly increased if compatible varieties of similar maturities were grown in areas where the chief pollinators, the honeybee, were plentiful.

Jones and Tamargo (*6*) found in another study that wild bees and wasps did some cross-pollination, but that the wild bees were too scarce in Cuba to be a factor; the wasps worked on kenaf flowers only if forced to do so when the supply of other nectar was short. Honeybees were the most effective insects in pollinating kenaf flowers.

Some incompatibility between lines of kenaf has been observed. This may have been the result of timing, or it may have been from other causes.

Jones, Puentes, and Suarez (*5*) reported considerable hybrid vigor in natural kenaf hybrids and related their findings to those in cotton. They noticed that the natural hybrids were large enough to make roguing easy by looking for large plants.

MATERIALS AND METHODS

The inbred material used in this study originated from two basic types—Salvadorian and Javanese. Both had been brought into the United States as varieties, but they were actually mixtures of types. All the material had been selfed for five or more generations. As shown in table 1, parent 0 is an inbred selection from the Javanese introduction; parents 1, 2, 6, 7, and 8 are inbred selections from the

TABLE 1.—*Inbred lines used in making diallel crosses in fall of 1957, Lake Worth, Fla.* (*planted in September*)

Parent No.	Source of selection [1]	Date of first flower (November 1957)	Plant height	Retted fiber [2]
			Inches	*Percent*
0	Javanese	[3] 13	47	2.96
1	Salvadorian	17	49	3.67
2	do	5	46	4.39
3	Javanese × Salvadorian	4	53	4.49
4	do	4	48	--------
5	do	4	53	--------
6	Salvadorian	11	52	5.10
7	do	9	47	5.88
8	do	9	42	4.84

[1] Variety (usually named for source country) from which selection was made.
[2] Decorticated fiber further cleaned by retting.
[3] Not checked for shedding of buds.

Salvadorian introduction; and parents 3, 4, and 5 are inbred selections from Javanese-Salvadorian hybrids,[3] in which the disease resistance of the Salvadorian variety had been incorporated. These will be refered to as J × S lines. The Javanese line was included in order to provide a divergent source of germ plasm.

In the fall of 1957 the inbred lines described in table 1 were crossed in all possible combinations, using each line as a male parent and as a female parent. Crosses were made in the fields. Flower buds were emasculated in the afternoon, and pollinations were made early the following morning. Kenaf pollen grains are easily seen on the exposed stigmas, which were observed through a magnifier before the pollen was applied. Very few emasculated flowers had to be discarded because of foreign pollen. Petals were removed during emasculation and thus the bees were not attracted to the emasculated flowers.

F_1 Spring Nursery

On January 29, 1958, parents and F_1 progenies of crosses in all possible combinations between the nine lines of kenaf were planted in the greenhouse at Belle Glade, Palm Beach County, Fla. On March 3 they were transferred to the field at Lake Worth in the same county on sandy soil, using two randomized blocks of 80 plots each—35 F_1's (one progeny missing), 36 reciprocal F_1 progenies, and the nine parents.

Each plot consisted of three greenhouse plants spaced 2 feet apart in rows 2 feet apart. The wide spacing was to encourage branching and flowering. Each parent and each reciprocal of each cross were treated as a separate plot.

Data on several characters were taken, but only information on date of first flower (days after March 31) was analyzed and is reported here.

The main purpose for this spring nursery was to produce seed for an F_2 nursery. Notes taken were incidental.

To supply the missing F_1 hybrids and to supplement the seed supply from the fall crossing block for some progenies, a few cross-pollinations were made in the spring nursery. All flowers of F_1 plants were selfed to provide F_2 seed. Selfing was assured by applying a pinch-type paper clip to the petals that protrude from the bud the evening before the flower opens. Efforts were made to obtain as many F_2 seeds as possible from all F_1 progenies. However, some of the F_1 plants produced few seeds and some did not produce any because of unfavorable day lengths. (Kenaf flowers only when days are short.)

F_1 Summer Nursery

The F_1 summer nursery was planted on July 22, 1958. Seed originated from the same crosses as for the spring nursery and was planted on the same soil type.

In 40-inch F_1 plots, five F_1 seeds were planted in 20 inches of row and five reciprocally produced seeds of the same F_1 were planted in the

[3] The Javanese selections are highly susceptible to *Colletotrichum hibisci* Poll., a disease of kenaf that could destroy a susceptible line.

other 20 inches of the same row. Where seed was insufficient or missing, additional seeds of the reciprocal cross were planted. In parent plots, 11 seeds were planted 4 inches apart in the rows. Progeny and parent rows were spaced 3 feet apart with guard rows of Everglades 41 variety of kenaf on each side of each row, 1 foot from the progeny row. Also, a guard row of the same variety was planted across each end of the plots. The interplanted and guard rows were pulled from around each progeny at the time of harvest.

Notes were taken in the field on each plant for date of first flower (days after August 31). All other data reported here were taken on harvested stems.

Most of the F_1 and inbred plants were harvested 7 to 10 days after the first flowers opened, but a few were outside that range. (The irregularity of harvest is assumed to have contributed to experimental error.) The plants, cut 5 inches above the ground, were then measured for height, and a 15-inch section was cut from the base of each stem and weighed to the nearest gram. These 15-inch samples were partly dried in an oven to avoid spoilage in transit to the fiber laboratory at Beltsville, Md.

F_2 Summer Nursery

The F_2 summer nursery was planted on July 23, 1958—1 day later than the F_1 nursery and in the same field. The 21 plots (15 hybrid plots and 6 parent plots) were randomized in each of four replications. (F_1 progenies involving parents 6, 7, and 8 were so late in the spring nursery that no flowers, or only a few, developed on many of them.) Thirty-five seeds of each F_2 progeny were planted in a 16-foot row, and 35 seeds of its reciprocally related progeny were planted in an adjacent row 12 inches away. Thirty-five seeds of each parent were planted in a 16-foot row, and nonrelated seed was planted in the adjacent row to make parent plots the same size as the progeny plots. A guard row of Everglades 41 was planted on each side of each plot and across the ends of the plots in the alley.

Beginning in September, a few early plants from all four replications of the F_2 nursery were harvested at the time of first flower, and notes were taken on the harvested plants for date of first flower (days after August 31) and plant height. Basal samples were cut and weighed as in the F_1 nursery, but green-stem diameters were not measured. All harvesting of F_2 plants was temporarily discontinued on October 18 because of the amount of time required and the resulting delays that would occur in the F_1 harvest. Meanwhile, notes continued to be taken in the field on standing plants. Date of first flower, plant height, and stem diameter were recorded for each plant of all four replications. Harvesting was resumed on October 29 only of the plants in the second replication. Basal samples were cut and weighed as in the F_1 nursery. No further harvesting was done in the first, third, and fourth replications. Harvesting in the second replication was continued at intervals as the plants flowered until all except a few very late plants were harvested. Then, after a 15-day interval, those of the late plants that had grown for 20 to 30 days were harvested; 30 days later the remaining few plants were harvested.

Single-Plant Measurements and Calculations

Diameter measurements of the stems in the F_2 nursery in the field were made 20 inches above the ground with a caliper on the standing plants. Green-stem diameters were not measured in the F_1 nursery. Dry-stem diameter measurements were made on all plants harvested, both F_1 and F_2. The dry-stem measurements (in millimeters) were made at the upper end of the 15-inch sample section, which, including the 5-inch stubble, had been 20 inches above the ground. With only dry-stem diameter measurements from the F_1 nursery and only green-stem measurements from the first, third, and fourth replications in the F_2 nursery, a conversion factor was necessary. This was established as a ratio of the measurements in the second replication in the F_2 nursery, where both dry and green-stem measurements were available. With this factor, all green-stem diameter measurements on unharvested plants were converted to an estimated dry-stem diameter (in millimeters). Conversions were made on individual-plant data. Subsequently, only dry-stem measurements—actual or converted—were used in all analyses and frequency distributions.

Height of plants was measured in inches from the ground to the top of the plant. (For harvested plants, measurements took into account the 5-inch stubble.)

In the F_1 nursery and the second replication of the F_2 nursery, these measurements were made as the plants were being harvested. The plants in the F_2 nursery that were not harvested (first, third, and fourth replications) were measured at about the middle of the flowering period.

Laboratory Measurements and Fiber Determinations

At Beltsville the stems were dried for 2 days or more at about 70° C. with air circulation. They were then held in a room where 65-percent humidity and 21° C. were constant. After the samples reached a constant moisture content, each was weighed to 0.1 gram, and the diameter was measured to the nearest millimeter.

From 3 to 3½ kg. of sample stems were cooked in a copper wash boiler in 30–35 liters of 2-percent sodium hydroxide solution. Pressure in the autoclave was brought up to 9 pounds. The automatic control was then set at 6 pounds' pressure and maintained for 1 hour, after which all valves were closed and the steam was turned off. Bringing the autoclave up to 9 pounds' pressure with that quantity of solution required about 40 minutes; cooling to atmospheric pressure required about one-half hour more. Thus, the samples were cooked for more than 1 hour.

After being thoroughly washed by running tap water through the boiler, the stems were allowed to stand overnight in a weak solution of approximately 0.2-percent acetic acid.

Since two batches were required to cook a complete replication, such factors as dilution, temperature, ratio-of-stems to solution, and time were carefully controlled, even though small differences in cooking are probably not important. As a test, some extra samples of cooked and washed fiber were put through a complete second cooking and washing and lost only about 5 percent in weight.

Gums and nonfiber cells were washed out of the fiber by working it by hand under running water before it was slipped off the woody central cylinder of the stem. The fiber was dried overnight at about 70° C. in a forced-draft oven and then allowed to regain a constant weight at 65-percent relative humidity and 21°. Fiber samples were weighed to the nearest 5 mg.

Percent fiber was then calculated for each plant. Calculations were made on the basis of the dry weight of fiber from the 15-inch section of stem divided by the dry weight of that stem section and multiplied by 100. Since it is known that fiber percentages are affected by stem size—the larger the stem, the lower the percent fiber on generally homogeneous material—percentages were adjusted to compensate for such effects (percentage=y on diameter=x). (In the F_1 nursery, $b=-0.429$ and in the F_2 nursery $b=-0.455$. These regression coefficients were calculated on a within-plot basis.) Adjustments were made on the individual-plant data. The term "percent fiber" in this bulletin refers to adjusted data unless otherwise noted.

Explanation of Methods 1–4

In the calculation of the analysis of variance, four methods were used. These were based on (1) whether or not the parents were included and (2) whether single-plant data were averaged as a separate figure for each reciprocal progeny or as a combined figure for the two reciprocal progenies.

The following four methods were used: (1) Reciprocals averaged *separately*, parents *not* included; (2) reciprocals averaged *together*, parents *not* included; (3) reciprocals averaged *separately*, parents *included;* and (4) reciprocals averaged *together*, parents *included.*

Calculation of Means

All F_1 spring nursery plots were calculated with reciprocals separate, since reciprocals were planted as whole plots rather than split plots, as in the summer nurseries.

F_1 progeny means from the summer nursery were calculated (1) on the basis of reciprocals averaged separately and (2) with reciprocals averaged together. Since the means with reciprocals separate have 12 missing values, 14 plots with only one plant and 43 plots with only two plants, they were used only for the analysis of reciprocal differences (method 1). For all F_1 analyses on the F_1 summer nursery the data were averaged with reciprocals together (methods 2 and 4). Thus averaged, only one plot was missing, two means represented only two plants each, and four represented three plants. All other means represented more plants.

Means for the F_2's were calculated only with reciprocals separate (methods 1 and 3), since 10 or more plants were processed from all except one (split) plot, which had 8 plants and all four replications of one cross (0 × 5) that were missing. Twenty or more plants were harvested from most of the plots. For cross 0 × 5, missing in all replications, the reciprocal values 5 × 0 were substituted.

Since flowering data on some plants were missing in several progenies in both nurseries, those means were calculated on fewer plants

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than for other variables. Also, in several F_1 plots, flowering data on all plants were missing. Values had to be estimated on more plots for flowering than for other variables.

Estimation of Missing Values

Reciprocal values were substituted for missing plots throughout the calculations reported here except in the second replication of 6 × 7 in the F_1 summer nursery, where both crosses were missing. These values were estimated by a formula proposed by Yates (*14*).

Calculating Sums of Squares

The procedure used here follows closely that described by Sprague and Tatum (*12*) with modification described by Kempthorne (*8, pp. 113–119*).

Using each line as a male as well as a female, p inbred lines were crossed in all possible combinations. Thus, there are $p(p-1)$ progenies with reciprocals separate; there are $\frac{p(p-1)}{2}$ progenies with reciprocals averaged together.

Analyses of variance were made on plot means calculated by one or more of the four methods (p. 7).

The F_1 sums of squares were calculated by methods 2 and 4 for all except reciprocal effects; these were by method 1.

The F_2 sums of squares were calculated by methods 1 and 3. F_2 plot means of the separate reciprocals were totaled for main plot effects, since the F_2 nursery contained sufficient plants per plot and the variation in number per plot was small enough to permit such a procedure.

Calculating F_1/Midparent and F_2/Midparent Ratios

The F_1/midparent and F_2/midparent ratios were calculated from array means. The term "array" refers to the mean or sum of all replications of all progenies with a common parent. Parent values are not included. The F_1/midparent and F_2/midparent ratios for each inbred as it appears as a common parent were calculated by the following formula, beginning with table 3:

$$\frac{2(p-1)\bar{x}_{i..}}{S\bar{x}_{ii.}+(p-2)(\bar{x}_{ii.})}$$

Where

p =number of parents or inbred lines.
$\bar{x}_{i..}$ =mean of all progenies with common parent.
$\bar{x}_{ii.}$ =mean of all plots of parent line.
$S\bar{x}_{ii.}$ =sum of all parent means.

Calculating Estimates of General Combining Ability

Estimates of general combining ability ($\hat{g}_{i..}$) were calculated from array sums. The formula used in calculating $\hat{g}_{i..}$ in method 1, where reciprocals are averaged separately (F_2 data), is as follows:

$$\frac{X_{i.} + X_{.i} - 2X\ldots/p}{2n(p-2)}$$

Where

$X_{i.}$ = sum of progenies with i-th parent as female.
$X_{.i}$ = sum of progenies with i-th parent as male.
$X\ldots$ = sum of all progenies (parents excluded).
p = number of parents or inbred lines.
n = number of replications.

The formula used for calculating $\hat{g}_{i..}$ in method 2, where reciprocals are averaged together (F_1 data), is as follows:

$$\frac{X_{i..} - 2X\ldots/p}{n(p-2)}$$

Where

$X_{i..}$ = sum of progenies with i-th parent as both male and female, totaled after two reciprocals were averaged in each replication.
$X\ldots$ = sum of all progenies (parents excluded). Note that its value is approximately one-half that of $X\ldots$, as used in method 1 (preceding formula).
n and p are the same as for the preceding formula.

RESULTS

In this study, analyses of variance showed some reciprocal differences, especially in the F_1 nurseries. However, these are assumed not to be real, except perhaps in cross-compatibility, for the following reasons: The number of F_1 plants per plot was small, numerous plots were missing in the F_1 nurseries, the nature of the differences in the F_1 nurseries was erratic, and only one of the variables—date of first flower—in the F_2 nursery had significant reciprocal differences. On the basis of this assumption, the information from both reciprocals has been combined as follows: For the F_1 data in the summer nursery, as a single mean for each pair of reciprocals; for the F_1 spring nursery and the F_2 data, as the sum of the two means (see p. 7). In this way the information has been combined in all calculations beginning with table 3.

The results of the analyses are assumed to be essentially the same whether the means are added together as in methods 1 and 3 or whether it is necessary that the two reciprocals be combined from the original data as in methods 2 and 4.

Original Pollinations

The number of seeds from each cross-pollination made in the nursery between specific inbred lines, as shown in table 2, is an indication of cross-compatibility. Indications are that the differences between individual crosses (hybrids) and between specific combining ability (s.c.a.) values are not significant, but that differences between the general combining ability (g.c.a.) values (all the progenies of each parent combined as an array) are significant.

TABLE 2.—*Seeds produced per pollination in crossing block, showing male and female array means and general combining ability, fall of 1957*[1]

Inbred line No.	Mean seeds per pollination as—		General combining ability*
	Male parent	Female parent	
	Number	*Number*	$\hat{g}_{i.}$
0	7.9	7.8	−0.499
1	10.0	5.5	−.535
2	11.8	7.4	−.002
3	9.2	8.7	−.192
4	8.0	11.0	−.036
5	11.3	13.1	.737
6	9.3	11.6	.230
7	9.9	11.2	.262
8	9.3	10.2	.035
Mean	9.6	9.6	

*Differences significant at 5-percent level of probability.
[1] Data not replicated.

The deductions arrived at from the above analysis are based on a method used by Yates (*14*) for unreplicated data. Without a true error value, reciprocal mean squares have been used for testing the other sources of variation. Observation in the field indicated a strong probability of reciprocal effects; certain crosses were successful whenever tried out, but with the reciprocal cross, repeated pollinations failed to produce seed. Such effects would cause the mean square for reciprocals (the error) to be large. The mean square value for g.c.a. would have been even larger had there been no reciprocal difference.

Spring Nursery

The spring nursery was grown primarily to obtain F_2 seed. However, notes were taken, and those on date of first flower are summarized in table 3. Since kenaf is not ordinarily planted in the early spring in Florida, except in a breeding nursery, these data have little importance except for the light they shed on genetic relationships in day-length response. Thus, unless specifically indicated, all subsequent material deals with summer nurseries.

Date of First Flower (Maturity)

The inbred line parent 0 shed buds early in the season, as did many of the progenies of that line and a few of the progenies of parent 1. This somewhat complicated the reporting and interpreting of the results on maturity. When bud shedding on a plant was noticed in time, it seemed practical to estimate the date of flowering by relating bud scars to the buds that actually opened in the same progeny. Superficial checks in the field suggested that such an estimate was fairly reliable. Little, if any, bud shedding occurred on the late-maturing segregates. All plants bloomed eventually, but for those that lost their early buds, flowering date was either estimated as indicated or was not recorded.

TABLE 3.—*Date of first flower: Summary by parent and array, with parent-progeny comparisons and estimates of general combining ability, F_1 spring nursery*

Parent or array No.	Progeny array mean[1] **	Parent mean[2] **	Progeny/midparent (array mean)[3]	General combining ability**
	Days after March 31	*Days after March 31*	*Ratio*	*Pt.*
0	21.1	30.5	0.82	6.2
1	15.7	17.2	.80	0
2	13.2	14.2	.74	−2.9
3	15.1	12.0	.87	−.7
4	13.7	15.5	.73	−2.3
5	13.2	11.0	.81	−2.9
6	18.0	[4] 40.0	.56	2.6
7	15.9	37.0	.56	.2
8 [5]				
General mean	15.8	22.2		

**Differences significant at 1-percent level of probability.
[1] Mean of all progenies with parent indicated.
[2] Mean of 2 replications of each parent.
[3] See text for method used in calculating ratio.
[4] Indicates buds formed but shed, as days became too long for flowering.
[5] So many progenies failed to flower that they could not be included.

The F_2 data on flowering, as shown in tables 4 and 5, indicate that the flowering behavior of Javanese and Salvadorian varieties is controlled by different genes. F_2 plants from crosses between parent 0, the Javanese, and any of the other lines—all of which contained Salvadorian germ plasm—ranged from very early to very late; some progenies had a range of about 90 days in date of first flower from earliest to latest plant. This range is well beyond that of either parent, especially in lateness. Also, many of the progenies of the other crosses showed more range than the parental material did.

Evidence of multiple factors for flowering is found in the plant frequency distribution given in table 5. As an example of breeding behavior of all lines considered, parent 0 represents one type in this table and parents 1 and 2, all the others. F_1's and F_2's, with their parents, were grown in adjacent nurseries. All distributions except F_1 progenies are from F_2 nursery data. The modes for the parents occurred for the same period in both nurseries. This table shows the wide range in maturity in the F_2 progenies of crosses with parent 0. It also shows two modes in the frequency of flowering. The greatest frequency occurred between the modes of the parents (period 10–19 for P_0 and period 40–49 for P_1 or P_2), but about 60 days later a second and smaller mode appeared in progenies of four (only two shown in table) of the five crosses with parent 0. This second mode could have been the result of weather.

Earliness seems to be at least partly dominant. The values shown in table 4 for the F_1 divided by the two-parent, or midparent, mean and averaged on the basis of each array (progenies with a common parent) show a ratio of less than 1 in all F_1 arrays. The dominance

TABLE 4.—*Date of first flower: Summary by parent and array, with parent-progeny comparisons and estimates of general combining ability, F_1 and F_2 summer nurseries*

F_1 NURSERY

Parent or array No.	Progeny array mean [1] **	Parent mean [2] **	Progeny/midparent (array mean) [3]	General combining ability **
	Days after Aug. 31	*Days after Aug. 31*	*Ratio*	$\hat{g}_{i..}$
0	20.8	18.0	0.64	−21.1
1	40.5	48.0	.89	1.4
2	41.9	46.5	.92	3.0
3	38.1	38.2	.92	−1.3
4	40.1	44.0	.91	1.0
5	41.4	44.3	.94	2.4
6	45.8	54.5	.95	7.4
7	42.5	46.8	.94	3.7
8	42.3	47.5	.93	3.5
Means:				
General	39.3	43.1	.89	
High parent		48.8		
Low parent		37.4		

F_2 NURSERY

Parent or array No.	Progeny array mean [1] **	Parent mean [2] **	Progeny/midparent (array mean) [3]	General combining ability **
0	48.8	18.0	1.58	2.8
1	47.8	46.8	1.15	1.5
2	48.7	46.8	1.18	2.6
3	43.3	36.5	1.17	−4.2
4	44.8	43.8	1.11	−2.3
5	46.4	46.2	1.12	−.3
Means:				
General	46.6	39.7	1.22	
High parent		45.6		
Low parent		33.8		

** Differences significant at 1-percent level of probability.

[1] Mean of all progenies with parent indicated.

[2] Mean of 4 replications of each parent.

[3] See text for method used in calculating ratio.

of earliness is particularly striking in crosses involving parent 0. In four out of the five crosses, the F_1 mode coincided with the early parent 0. In the F_2 nursery (table 4) the progeny/midparent ratios were all greater than 1. This appears to be due to the earliness of parent 0. The progeny/midparent ratio for parent 0 is high (1.58). The very small value of the common parent (0) decreases this midparent value, which, when divided into the 0 progeny array mean, gives a high ratio. In the other ratios (ranging from 1.11 to 1.18) parent 0 occurs only once. In nearly all F_2 progenies, the frequencies were skewed toward the later periods (table 5).

TABLE 5.—*Date of first flower: Plant frequency distribution of 3 selected groups, each composed of parents (P_0, P_1, P_2), F_1's, and F_2's*

Parent and cross	Number of plants during indicated periods (days after Aug. 31) when first flower appeared											Number of plants with no flowering data[1]	Mean days after Aug. 31 in—	
	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110-119		F_1 nursery	F_2 nursery
P_0	[2] 73											73	[2] 18.0	[2] 18.0
F_1 0 × 1	11	3										5	18.8	
F_2 0 × 1	4	24	30	46	10	4	12	5	10	9	7	31		50.5
P_1				49	11							5	48.0	46.8
P_0	[2] 73											73	[2] 18.0	[2] 18.0
F_1 0 × 2	17	3										1	19.0	
F_2 0 × 2	1	27	41	29	13	12	18	6	14	7	5	32		54.5
P_2				64	11							5	46.5	46.8
P_1				49	11							5	48.0	46.8
F_1 1 × 2				20								6	43.8	
F_2 1 × 2			1	71	50	3	1					18		49.1
P_2				64	11							5	46.5	46.8

[1] In some cases, buds were shed before flowers opened. In others, plants had started late and were badly stunted. Since stunted plants were observed in parent plots to have delayed maturity, they were generally omitted.

[2] Date of flowering estimated from a few F_1 plants of same inbred line on which flowers were produced without buds dropping. None of these 73 plants flowered, but apparently their buds matured about the same time.

The mean date of flowering for the parents was significantly different from that of the progenies in all three nurseries. In the F_1 nursery, parents were significantly later and in the F_2 nursery, significantly earlier.

As would be expected, lateness appears to be associated with high yield. A correlation between the estimated fiber yield per plot and maturity date has an r value of 0.68. This may arise from the fact that the time during which nutrients are going into vegetative development in early-maturing types is shorter than in late-maturing types, for kenaf plants continue to increase in size while setting seed, but grow more slowly after flowering starts.

Diameter and Height

In this study stem diameter and plant height were treated as separate variables. However, the diameter: height correlations of 0.83 for progenies and 0.70 for error indicate that they may be two measurements of essentially the same thing—vigor. As a further indication, estimates of general combining ability for both diameter and height are high or low in the same arrays (progenies with a common parent).

In the F_1 nursery, hybrid vigor is evidenced by progeny array means, as shown in table 6, that exceed the high-parent mean in all except the 0 array. The mean diameter of all parents (inbreds) in the F_1 nursery was 12.5 mm., and the high-parent mean was 14.0, both considerably below the progeny mean of 15.5. The difference between diameters of inbreds and progenies is highly significant.

It is obvious from table 6 that none of this hybrid vigor continued into the F_2 generation. Progeny and parent means were almost identical and, as would be expected, the difference between hybrids and inbreds was nonsignificant.

General combining ability in the F_1 nursery was high; the mean square was approximately nine times as large as for the specific combining ability in the F_1 nursery. In the F_2 nursery, general combining ability was significant, but the mean squares for general combining ability were only a little more than twice as large as for specific combining ability. Specific combining ability was not significant.

Parents 0 and 3 were poor combiners for diameter in both the F_1 and F_2 nurseries. In general, parent 0 (the Javanese) and parents 3, 4, and 5 (J × S) were smaller in diameter as inbreds and produced smaller progenies than the Salvadorian types.

Correlations between diameter measurements and dry weight of a 15-inch section of stem (the actual weight of the sample that was estimated by diameter measurements in this study) had an r value of 0.97.

Diameter measurements proved to be especially useful in this study in estimating yield. For first, third, and fourth replications in the F_2 nursery, time did not permit the customary harvesting, weighing, measuring, and processing. Thus, diameter (and height) measurements were made in a short time without destroying the plants. This simple method provides a reliable estimate for yield if the stand is fairly constant, as it was in this experiment.

TABLE 6.—*Stem diameter: Summary by parent and array, with parent-progeny comparisons and estimates of general combining ability, F_1 and F_2 summer nurseries*

F_1 NURSERY

[Diameter measurements in millimeters, 20 inches above ground]

Parent or array No.	Progeny array mean [1] [2]	Parent mean [3]	Progeny/midparent (array mean) [4]	General combining ability [2]
	$x_{i..}$	$x_{ii.}$	*Ratio*	$\hat{g}_{i..}$
0	13. 2	8. 5	1. 23	−2. 58
1	16. 3	13. 2	1. 27	. 88
2	16. 0	14. 5	1. 20	. 53
3	14. 4	10. 5	1. 24	−1. 22
4	16. 1	9. 2	1. 46	. 71
5	15. 1	11. 5	1. 25	. 44
6	16. 9	15. 2	1. 24	1. 64
7	16. 1	14. 8	1. 19	. 67
8	15. 3	14. 8	1. 13	. 19
Means:				
General	15. 5	12. 5	1. 24	
High parent		14. 0		
Low parent		11. 0		

F_2 NURSERY

Parent or array No.	Progeny array mean [1] [2]	Parent mean [3]	Progeny/midparent (array mean) [4]	General combining ability [2]
0	13. 2	10. 2	1. 07	−0. 68
1	13. 9	16. 5	. 93	. 26
2	13. 8	14. 8	. 97	. 07
3	13. 2	12. 8	. 98	−. 58
4	14. 1	15. 2	. 98	. 51
5	14. 0	13. 5	1. 02	. 42
Means:				
General	13. 7	13. 8	1. 00	
High parent		15. 6		
Low parent		12. 6		

[1] Mean of all progenies with parent indicated.

[2] In F_1 nursery, differences significant at 1-percent level of probability; in F_2 nursery, at 5-percent level.

[3] Mean of 4 replications of each parent; differences significant at 1-percent level of probability.

[4] See text for method used in calculating ratio.

Measurements for height showed less evidence of heterosis than those for diameter; a progeny/midparent ratio averaged 1.11, as shown in table 7. F_1 progenies of parent 0, the most divergent in origin, were the shortest; they averaged about 20 inches less than the next shortest array mean. Only one of these progenies was taller than its taller parent, whereas all except one of the progenies of parents 1–8 exceeded the taller parent in height, and that one progeny was as tall as its taller parent. Nevertheless, the differences were small, as the following means show: All progenies, 112.7 inches; the high parents, 109.9 inches; and the means of all parents, 101.4 inches.

TABLE 7.—*Plant height: Summary by parent and array, with parent-progeny comparisons and estimates of general combining ability, F_1 and F_2 summer nurseries*

F_1 NURSERY

[Height of plant measured in inches at time of harvest]

Parent or array No.	Progeny array mean[1] **	Parent mean[2] **	Progeny/midparent (array mean)[3]	General combining ability**
	$\bar{x}_{i..}$	$\bar{x}_{ii.}$	*Ratio*	$\hat{g}_{i..}$
0	92	72	1.04	−23.27
1	117	104	1.14	4.98
2	116	115	1.09	4.55
3	112	98	1.12	−.73
4	116	84	1.24	3.52
5	113	102	1.11	.37
6	116	108	1.11	4.09
7	118	116	1.09	5.59
8	114	112	1.07	.91
Means:				
General	112.7	101.4	1.11	
High parent		109.9		
Low parent		92.9		

F_2 NURSERY

Parent or array No.	Progeny array mean[1] **	Parent mean[2] **	Progeny/midparent (array mean)[3]	General combining ability**
0	102	83	1.04	−7.35
1	111	123	.97	3.11
2	111	117	.99	2.80
3	108	110	.99	−.64
4	108	111	.99	.05
5	110	107	1.02	2.02
Means:				
General	108.2	108.5	1.00	
High parent		116.2		
Low parent		100.8		

**Differences significant at 1-percent level of probability.
[1] Mean of all progenies with parent indicated.
[2] Mean of 4 replications of each parent.
[3] See text for method used in calculating ratio.

The difference between parents and progenies in the F_2 nursery is small, as shown in table 7, and is not significant.

The g.c.a. mean square for height was more than 30 times the s.c.a. in the F_1 summer nursery and more than double the s.c.a. in the F_2 nursery. As would be expected from the data reported above, the g.c.a. estimate for parent 0 was extremely low (−23.27 for the F_1's and −7.35 for the F_2's). That for parent 3 was also low.

Percent Fiber

The percent fiber in the stem of a bast fiber plant decreases as the diameter of the stem increases. This is based on the ratio of diameter (or circumference) to cross-sectional area. Although the bark containing the fiber is thicker on a large stem, it does not compensate for the ratio mentioned above. Thus, to minimize the effect of diameter, the actual fiber percentages were adjusted in this study, on the basis of regression coefficients (see pp. 6–7). Only adjusted, or corrected, percent fiber is reported here, and "percent fiber" not otherwise modified refers to adjusted percentages.

The data in table 8 give no clear-cut evidence of dominance for high or for low percent fiber. The progeny/midparent ratios are near unity, varying slightly above or below in the two nurseries.

TABLE 8.—*Adjusted percent fiber: Summary by parent and array, with parent-progeny comparisons and estimates of general combining ability, F_1 and F_2 summer nurseries*

F_1 NURSERY

[Percentages adjusted on basis of diameter = x and percent fiber = y]

Parent or array No.	Progeny array mean [1]	Parent mean [2]	Progeny/midparent (array mean) [3]	General combining ability [4]
	$\bar{x}_{i..}$	$\bar{x}_{ii.}$	*Ratio*	$\hat{g}_{i..}$
0	19.4	18.6	1.01	−0.69
1	19.9	19.2	1.02	−.04
2	19.4	18.5	1.01	−.59
3	19.5	18.2	1.03	−.48
4	19.1	17.2	1.02	−1.01
5	19.6	20.0	.98	−.46
6	21.3	23.2	1.00	1.51
7	21.4	22.9	1.01	1.60
8	20.1	19.4	1.03	.17
Means:				
General	20.0	19.7	1.01	
High parent		20.9		
Low parent		18.6		

F_2 NURSERY [5]

Parent or array No.	Progeny array mean [1]	Parent mean [2]	Progeny/midparent (array mean) [3]	General combining ability [4]
0	18.1	18.6	0.94	−1.69
1	20.2	21.2	.99	.90
2	20.3	20.3	1.01	.96
3	19.5	20.6	.97	−.03
4	19.3	18.3	1.01	−.19
5	19.5	20.0	.98	.06
Means:				
General	19.4	19.8	.98	
High parent		20.7		
Low parent		19.1		

[1] Mean of all progenies with parent indicated; differences significant at 1-percent level of probability.

[2] In F_1 nursery, mean of 4 replications of each parent and differences significant at 1-percent level of probability; in F_2 nursery, 1 replication and no significant differences.

[3] See text for method used in calculating ratio.

[4] Differences significant at 1-percent level of probability.

[5] In absence of true error term, reciprocal mean square is used, as suggested by Yates (*14*), for determining F values.

Results as a whole on adjusted fiber percentages indicate there was no heterosis. Some F_1 progenies are below the low parent and some are above the high parent, but most values are intermediate. This is the only variable studied in which the average of the F_1 progenies was not significantly higher or lower than the average of the parents. Only three crosses show possible heterocic effects. In 0×2 and 2×4, the F_1 mode is above either parent and in 0×3 both the F_1 and F_2 modes are below either parent.

On the other hand, the heritability of percent fiber is strong. There is a close relationship between the midparent and progeny array means, as shown in table 10, as well as between individual crosses and their respective parents. Table 11, comparing progeny performance from different combinations of high and low parents, brings out the extremes and again shows a very close relationship between parents and progenies.

Fiber percentage is an important component of fiber yield. Total yield, as calculated by fiber weight × height × plant count, is significantly correlated ($r=0.55$) with adjusted percent fiber in the F_1 nursery. Thus, in this study the fiber percentage is responsible for about 30 percent of the variation in fiber yield.

Data on percent fiber are further evidence of the poor performance of inbreds 0 and 4 as potentials for a composite variety.

Fiber Weight Per Sample

In the F_1 nursery the mean square for specific combining ability for fiber weight per sample was only about 7 percent as large as the mean square for general combining ability—an indication that dominance was relatively unimportant in obtaining the high values found for the hybrid progenies. However, dominance apparently had some effect, as indicated by the highly significant F value for s.c.a. In the F_2 nursery, as given in table 9, the progeny/midparent ratios were varied; some were less than 1 and some were greater than 1. This might be interpreted as differences in dominance in some of the inbreds. For example, parent 0 might have dominance for high fiber weight and parent 1 might have dominance for low fiber weight. The 0 progeny/midparent ratio was 1.23; the ratio for 1 was 0.89.

Fiber weight per sample in the F_1 nursery showed pronounced heterosis—more than any other variable studied. The progeny array mean (0.340) was much greater than the parent mean (0.239), and this difference is highly significant. The progeny mean was also well above the high parent mean (0.306). Also, a frequency distribution (not included here) shows that 10 of the 36 F_1 progenies had modes that exceeded either parent, and 2 of these were two units above the higher parent. Even in the F_2 generation, there was some evidence of heterosis, especially in the 0 progeny array. The 0 progeny array mean (0.216) was only a little below the average for all F_2 progenies (0.230). In fact, 0 progeny array produced relatively much better in the F_2 nursery than in the F_1 nursery. For the F_2 nursery as a whole, the F_2 mean was below the mean for the higher parents, which would somewhat discount evidence of F_2 heterosis.

Parents 6 and 7 (included in the F_1 nursery only) had not only the highest fiber weights as inbreds but also the highest general com-

TABLE 9.—*Fiber weight per sample: Summary by parent and array, with parent-progeny comparisons and estimates of general combining ability, F_1 and F_2 nurseries*

F_1 NURSERY

[Weight in grams of dry fiber from 15-inch section of stem]

Parent or array No.	Progeny array mean [1,2]	Parent mean [3]	Progeny/midparent (array mean) [4]	General combining ability [2]
	$\bar{x}_{i..}$	$\bar{x}_{ii.}$	*Ratio*	$\hat{g}_{i..}$
0	0.247	0.106	1.36	−0.107
1	.374	.250	1.53	.039
2	.343	.296	1.30	.004
3	.303	.160	1.48	−.042
4	.329	.100	1.84	−.013
5	.306	.169	1.47	−.039
6	.430	.397	1.39	.102
7	.389	.363	1.33	.056
8	.341	.314	1.25	.001
Means:				
General	.340	.239	1.44	
High parent		.306		
Low parent		.173		

F_2 NURSERY [5]

Parent or array No.	Progeny array mean [1,2]	Parent mean [3]	Progeny/midparent (array mean) [4]	General combining ability [2]
0	0.216	0.104	1.23	−0.018
1	.248	.365	.89	.023
2	.252	.301	.99	.028
3	.214	.194	1.01	−.019
4	.225	.175	1.11	−.005
5	.222	.196	1.05	−.010
Means:				
General	.230	.222	1.05	
High parent		.279		
Low parent		.166		

[1] Mean of all progenies with parent indicated.
[2] In F_1 nursery, differences significant at 1-percent level of probability; in F_2 nursery, at 5-percent level.
[3] In F_1 nursery, mean of 4 replications of each parent; in F_2 nursery, 1 replication; differences significant at 1-percent level of probability.
[4] See text for method used in calculating ratio.
[5] In absence of true error term, reciprocal mean square is used, as suggested by Yates (*14*), for determining F values.

bining ability for this variable, indicating how well they would be suited for a composite variety. Parents 1 and 2 were next best in combining ability in the F_1 nursery and produced well as inbreds. In the F_2 nursery, parents 1 and 2 also showed high combining ability.

Fiber Yield

Estimates of fiber yield per plot were made by combining data on fiber weight per sample, plant height, and plants per plot. Data thus calculated may be considered as "fiber yield." In general, the results found for fiber yield are essentially the same as for fiber weight per sample except that fiber yield differences are relatively greater. This shows that fiber weight per sample is a good indicator of fiber yield in this experiment; the calculated yield data are not shown here.

Heritability Estimates and Progeny Performance From High and Low Parents

All the characters under consideration show high heritability, as indicated by a correlation between progeny array means and parent means: r values ranged from 0.68 to 0.98 (r^2 from 46 to 96 percent) in the F_1 summer nursery and from 0.03 to 0.94 (r^2 from practically 0 to 88 percent) in the F_2 nursery. The r values squared are shown in table 10 and represent an estimate of the amount of variability in the F_1 and F_2 progenies that is attributable to heritability.

TABLE 10.—*Heritability estimates (r^2) based on correlations between progeny array means and parent means, F_1 and F_2 summer nurseries*

Nursery	First flower	Stem diameter	Plant height	Adjusted percent fiber	Fiber weight
F_1	0.96	0.46	0.65	0.92	0.72
F_2	.03	.52	.88	.55	.79

In order to demonstrate simply the high heritability of the factors being studied, the two highest and the two lowest inbreds for each variable were selected on inbred performance only. The performance of hybrids involving them is presented in table 11. (The high × low represents one cross only—the highest × the lowest. Also, the parents that excel are not the same in the different variables.)

TABLE 11.—*Comparisons of progeny performance from different combinations of high and low parents, with selection based on inbred performance only, F_1 and F_2 summer nurseries* [1]

F_1 NURSERY

Parent performance	First flower	Stem diameter	Plant height	Adjusted percent fiber	Fiber weight
High × high	50.2	17.5	120	22.7	0.504
High × low	34.8	16.0	92	21.8	.361
Low × low	16.5	11.5	87	17.7	.155

F_2 NURSERY

Parent performance	First flower	Stem diameter	Plant height	Adjusted percent fiber	Fiber weight
High × high	49.1	14.6	112	20.6	0.275
High × low	50.5	13.8	109	18.2	.241
Low × low	46.9	14.2	108	17.8	.160

[1] Progeny means from parent types indicated.

For the F_1 comparisons, the high × high inbred produced the highest progeny, the low × low produced the lowest, and the high × low was intermediate.

For the F_2 comparisons, the differences in general were less consistent and smaller than for the F_1 comparisons, but nevertheless they show strong trends. In some variables, particularly in adjusted percent fiber and fiber weight, differences were consistent and fairly large. Inbreds 6 and 7, which were the most productive in the F_1 nursery, were not available for F_2 comparisons; diameter, fiber percentage, and fiber yield were particularly high in those two inbreds and their progenies.

The results of the two methods of demonstrating heritability are comparable. Date of first flower in the F_2 nursery shows little heritability by either method. However, the F_2 stem diameter measurements showed little heritability in table 11, but they have relatively high r^2 value (table 10). In other variables in the two nurseries, both heritability estimates and high and low comparisons give strong evidence of heritability.

DISCUSSION

In selecting lines for a composite variety, two characteristics are of primary importance—high fiber yield of the inbred and uniform flowering date of both the inbred and progenies that result from intercrossing. A third characteristic is cross-compatibility; incompatible lines would be eliminated when crosses were first being made, but would not have the disastrous effect on a composite that low fiber yield or variation in flowering date would have. Most of the other variables considered—diameter, height, percent fiber, and fiber weight per sample—are components of yield. Other variables, which are not included in this bulletin and which would exclude a line from consideration, are tendency to lodge, branch, or produce unusually large or small seeds and, most of all, susceptibility to disease.

The inbreds chosen for this study of differences and inheritance provide good examples of lines whose performance would exclude them from consideration for use in a single composite variety: The differences in maturity dates—the earliness of parents 0 and 3 and the lateness of parent 6—the shortness and the low fiber percentage of parent 0, and above all the low fiber yield of parents 0 and 4.

Otherwise desirable inbreds would also be eliminated from consideration if incompatibility were found when the original crosses were made. Such incompatibility would affect the composition of the first few subsequent generations of a composite variety and would also have the same effect on inbreeding in the composite as would a reduction in the number of component lines.

It can be expected that inbred lines of kenaf that would be considered for a composite variety will have had relatively little, if any, testing for combining ability, since kenaf has traditionally been handled on the basis of inbred lines. The much higher variances for g.c.a. than for s.c.a. found in this study are in agreement with the findings of Sprague and Tatum (*12*). They found that previously tested and selected lines of corn showed higher s.c.a. than g.c.a. variances in nearly all cases. The untested lines they studied showed a higher g.c.a. in about half of the combinations.

Also according to Sprague and Tatum (*12*) and Matzinger and Kempthorne (*10*), g.c.a. and s.c.a. measure different types of gene action. G.c.a. variances measure additive effects; s.c.a. variances measure nonadditive effects. Thus, from the point of view of the plant breeder who is testing inbreds for use in a composite variety, g.c.a. gives the information that will help him to select lines that would perform well in a composite. Strictly from the point of view of logic, it would follow that in a composite variety, any one line will be crossed with all the other lines at random, and the number of times that a specific combination occurs would make the performance of that particular cross relatively unimportant. If, on the other hand, the plant breeder is looking for single- or double-cross combinations, both g.c.a. and s.c.a. information helps him to find the lines with a combination of additive and nonadditive effects necessary to obtain maximum production.

In working with material like kenaf about which little is known concerning inheritance, the knowledge of combining ability gained in this study gives a firm basis for eliminating undesirable types or selecting the ones that are most promising. In putting together any such set of randomly selected lines, the plant breeder can expect the general results to be similar to those reported here, but they may be of different magnitudes. However, performance of the individual lines, as indicated by their g.c.a. estimates, can be expected to differ from the results that would be obtained with another set of inbreds. Thus, the g.c.a. and the s.c.a. *mean squares* (for all lines taken together) may be considered on the basis of having been random selections of lines from a population. But the combining-ability *estimates* for the various individual inbred lines and combinations cannot be considered on the basis of randomly selected variables, and inferences can be made on that basis only about the individual lines in the sample—not about a population that they might represent.

In order to make maximum use of the high combining-ability potential, cross-pollination must be encouraged. With compatible lines that bloom at the same time, as much as 25-percent natural crossing in kenaf should be readily attained, and under ideal conditions more than that much should be possible. Some kenaf breeders believe that varieties differ in susceptibility to natural crossing. This should be checked. Jones and Tamargo (*7*) found as much as 23.76-percent natural crossing between lines that were selected only on the basis of marker genes and without providing supplemental bee population. Lower percentages were found among lines that bloomed at different times. Furthermore, their results were based on plants in alternate rows, and crossing was not so extensive as it would have been if the plants had been surrounded by contrasting types, as they would be in a composite variety. In a limited supplemental experiment, Jones and Tamargo found that, with alternate plants, the amount of natural crossing was increased more than 50 percent—from 11.07 percent in alternate rows to 18.32 with alternate plants.

On the basis of 25-percent natural crossing and the estimated heterosis effects in the F_1 plants of 44 percent in fiber weight per sample found in this study (table 9, column 4), a theoretical advantage of a composite of lines is an increase of about 11 percent. Furthermore, part of this increased vigor or productivity would continue into the

F_2 generation, although the amount of increase there would be small. Preliminary tests on one or two composite varieties have not supported this estimate.

Even on the assumption that 25-percent crossing would occur, there would also be a large amount of inbreeding. For this reason, if for none other, the lines selected must be good producers as inbreds.

Another important reason for requiring inbreds that are productive and have other desirable agronomic characteristics is the consistent relationships between parent and progeny performance, especially as to fiber percentages and yield. The good performance of the high × high parents in diameter, percent fiber, and fiber weight, as given in table 11, is in agreement with the findings reported by Hayes and Johnson (*2*) for corn. However, the high × low performers in corn were relatively better than those in kenaf. This difference may be attributed to the fact that the high and low parent lines of kenaf were selected entirely on the basis of inbred performance; the corn inbreds were selected on the basis of top cross performance.

Diversity of origin within adaptation limits should normally produce a maximum of hybrid vigor, but with the material used in this study it was less important than good performance of the inbred. Yield differences had been observed earlier, but these inbreds had not been evaluated on the basis of the more specific variables studied here. Some of the differences found in this study were of considerable magnitude—much greater than had been expected, even though the inbreds were chosen on the basis of differences.

From a practical point of view in kenaf breeding, this close relationship between inbred performance and progeny performance greatly simplifies the selection of inbreds for a composite. Yield tests of hybrid progenies prior to the bulking of the inbred lines are not necessary. The tests that are required in the F_1 and F_2 generations can be made by observation and from field notes.

Although the tests that must be made on hybrid progenies are simple compared to yield tests, they are nonetheless important. Salvadorian, the variety from which several of the inbreds used in this study came, is a composite variety and a fairly successful one. Possibly natural selection has improved it. More recent attempts to develop composite varieties (usually called synthetic varieties by kenaf breeders) have not met with success, usually because of segregation in flowering dates. The inbred components of these recent composites have not been tested as hybrid combinations, nor probably had the components of Salvadorian, but no records are available on its development. It has been assumed that Salvadorian was a fortunate accident. Findings in this study emphasize the importance of examining F_1 and F_2 behavior of all combinations of inbred lines before they are put together as a composite variety. This is especially clear in the findings on maturity, as indicated by date of flowering. Here, wide segregation was found in some F_2 progenies whose parents had flowering dates as inbreds that did not differ enough to eliminate them from consideration.

One of the inbred lines and some of its progenies shed buds early in the season. The date that flowering would have occurred if buds had not fallen might have been earlier than that shown. It would not have been later, since the method used to estimate these dates was based on a comparison of buds and bud scars with buds and flowers of apparently normal plants in the same progeny.

The shedding of buds in the hybrid progenies as well as in the inbreds is a characteristic that needs basic study. An important question is whether or not the fiber becomes lignified and brittle if the plant drops buds and continues to grow. The fiber does develop these poor characteristics as the plant continues to flower and mature seed. It is not known, however, whether the same physiological processes are initiated and continued if the buds drop before the flowers open; but it has been, for the purpose of this discussion, arbitrarily and tentatively assumed that either the lignification does not occur during bud shedding or the process is greatly retarded. If this assumption is true, the shedding of buds would have the same effect as late maturity. However, until more is known about the relationship of bud shedding to fiber quality, inbreds that shed buds or produce offspring that shed buds should be avoided in selecting lines for a composite variety.

Another aspect of flowering date to be considered in selecting lines for a composite variety is kenaf's strong photoperiodic response; the flowering behavior of the spring-planted crop shows little relation to that of the summer planting. In the former, the seed is planted during short days, and the date of first flower depends on factors other than day length; in summer plantings, which bloom in the fall, the date of first flower is limited by day-length effects as well as by other less tangible factors. In this study progenies of the pure Javanese line (parent 0) were among the latest in the spring nursery (table 3), but the earliest of all in the summer nursery (table 4). The pure Javanese line has another unusual characteristic; inbred 0 and several of its progenies continued to bloom in the spring, long after other inbreds and their progenies had stopped because of long days. Thus, the Javanese line seems to be less sensitive to day length than the Salvadorian.

Day-length response is an indication that flowering date of the Javanese types is controlled by different genetic factors than is the Salvadorian. However, segregation was no wider in the F_2 generation in a cross between Salvadorian and inbred progenies of J × S types than in crosses between Salvadorian lines.

In kenaf, neither earliness nor lateness per se is always undesirable. It is desirable to have at least one reasonably early- and one late-maturing variety. For efficient use of harvesting and processing machinery, producers should be able to start their harvesting on an early-maturing type and to extend their harvest by the use of late-maturing types. Thus, more than one composite would need to be developed. A type such as might be developed from inbreds from the late-maturing segregates of this study would supplement the earlier maturing Salvadorian variety.

In evaluating lines for a composite from the standpoint of yield, one of two methods may be used; actual yields may be determined or yields may be estimated from diameter-height measures and plant count. Both were explored in this experiment.

Diameter and height were studied primarily as indicators of vigor and yield. The dry weight of the 15-inch stem samples was also determined, but the correlation of 0.97 between stem-sample weight and diameter indicated that the density of the various types being studied was sufficiently consistent that there was no advantage in reporting both diameter and weight. In other words, they were essentially measurements of the same thing—vigor. Stem-sample weight was used for calculating percent dry fiber. However, since diameter measurements can be readily determined without processing the stems, they are more useful generally for estimating yield. Thus, diameters were studied in more detail and were reported under results. For this, more sampling and testing need to be done. By measuring stem diameters and plant height and by determining the stand prior to harvesting and processing samples, it should be possible to accumulate data that would give a reasonably accurate estimate of yields of total plant material, and perhaps of fiber yield, without cutting the plants. This study shows that on the basis of present knowledge, diameter, height, and plant-count information is satisfactory for estimating yields in early-generation testing within a given experiment. Dr. S. D. Chaudhuri, a jute specialist from Pakistan, stated that jute researchers use a similar method of plot evaluation, but make diameter measurements about midway between the ground and the top of the plant rather than at a predetermined height, as in this study.

It is essential that kenaf grow tall in order to produce well and to be suitable for harvesting and processing by methods now employed. However, since most varieties that are being grown commercially or are being used in kenaf breeding programs grow fairly tall if conditions are favorable and since there is a close relationship between yield and height, data on height have not been given much attention in recent breeding programs.

If kenaf is harvested and processed by a combine-type harvester (now in the development stage), high fiber content is important only as it affects yield. However, with present methods of handling, a high fiber percentage is especially important, because the stems are moved to a central area for processing, and thus a low fiber percentage means moving greater amounts of unsalable material.

Fiber percentages are greatly affected by moisture content of the stems, which varies with stage of maturity, atmospheric humidity, and soil moisture at the time of harvest. Therefore, in evaluating fiber percentages of an inbred, this variation can be minimized by using dry weights of the stems or by adjusting the green weights to a constant-moisture basis after actual moisture determinations have been made on the samples.

An estimate of yield based on fiber weight per sample, height, and plant count is considered far more reliable than plot totals when there are such wide differences in number of plants per plot as in the F_1 nursery of this study. Generally speaking, however, such an estimate is more subject to error than plot totals would be. In fact, if it had been recognized at the time of harvest that yield estimates would be wanted later, all plants in the F_2 nursery would have been sampled even if they had made an abnormal-type growth due to injury or had been abnormally small. Then plot totals would have been more reliable than estimates calculated from components.

In selecting inbreds for use in a composite variety, considerable expense may be saved if selections and eliminations are made in this order:

1. Inbred performance. Select inbreds with similar maturity dates and with the good yield and agronomic characteristics sought for any variety.

2. Compatibility. Eliminate lines that are not generally cross-compatible.

3. F_1 performance. Eliminate F_1 progenies by visual examination, taking out lines that produce progenies apparently lacking in vigor, differing in maturity, susceptible to disease, or otherwise undesirable.

4. F_2 performance. Make observations similar to those for F_1 progenies, paying particular attention to range of maturity and disease susceptibility.

The actual combination of the composite material may be accomplished by bulking the seed either from the inbreds or from the F_1 hybrids. The simplest and, with kenaf, the most practical method is to bulk an equal quantity of seed from each of the inbred lines being considered. This method has the additional advantage of providing a considerable quantity of seed in a short time. In the second method, the F_1 hybrids between all the lines finally selected for the inbreds may be made and this seed bulked. In either case, equal quantities of seeds should be included from each line or each cross. The result should be essentially the same. The material should be grown in isolation to avoid cross-pollination with undesirable types, but cross-pollination among the selected material is essential if the advantage of heterosis is to be obtained. Since natural crossing is dependent on insect pollination, insects should be kept plentiful. For example, hives of bees located in or around the seed field would be desirable.

Seed increases and seed production should be limited to late summer and fall plantings in Florida unless the flowering habits of the inbreds and the hybrid combinations have been studied in different photoperiods and found to be satisfactory on the basis outlined for maturity date. Otherwise, seed produced in the spring nursery might completely upset the balance of lines in a composite variety.

Though several researchers are working to develop kenaf lines that can be composited as a variety, nothing has been found in the literature or in this experiment that proves the advantage of the composite versus the inbred. However, the good performance of the original Salvadorian composite variety as compared to the highest yielding selections taken from it as well as the F_1 heterosis found in this study cannot be overlooked.

Before a firm case can be made for the use of kenaf composites versus kenaf inbreds as varieties, extensive comparisons must be made between inbreds and actual composites developed as described in this bulletin.

SUMMARY

Inheritance as related to selection of inbred lines of kenaf for composite varieties was studied in a diallel-cross analysis of data from nine lines of kenaf grown in Palm Beach County, Fla. The more critical variables studied were date of first flower, stem diameter, plant height, percent fiber, and fiber weight.

In making the original crosses, incompatibility between some of the inbred lines was found. Such incompatibility between any two lines would immediately eliminate one of them from consideration in a composite variety.

Also, wide segregation in flowering date was found in some of the crosses between lines, which as inbreds had bloomed at the same time. Thus, it is essential that all combinations of inbreds be tested in hybrid combinations through the F_2 generation to avoid the serious consequence of segregation in maturity date.

For fiber yield and yield components—stem diameter, plant height, and percent fiber—this study showed that the high-producing inbred lines invariably resulted in high-yielding offspring and, conversely, that the low-yielding lines produced low-yielding offspring.

Fairly strong hybrid vigor was evidenced in the F_1 generation, but little was found in the F_2 generation. As indicated by fiber yield per sample, production was increased by 44 percent over the inbred lines in the F_1 generation. In the F_2 generation, only slight and relatively unimportant increases were noted.

Variances were found relatively much higher for general than for specific combining ability in the lines included in this study.

In general, this analysis shows that heritability of the variables studied is high. High × high, high × low, and low × low inbreds produced high, intermediate, and low progenies, respectively. Further evidence of high heritability of the factors considered was demonstrated by high correlation between means of inbred lines and progeny array means. The high heritability found and other evidence of the close relationship between performance of inbreds and hybrid progenies clearly demonstrate that extensive studies of yield or of the various yield components in hybrid progenies are not necessary. Only a careful observation is needed during tests on such factors as date of flowering to avoid including lines that, though good performers as inbreds, perform badly in hybrid combinations. No such lines were found in this study.

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