Inheritance of Certain Characters in Okra (Hibiscus Esculentus L.).

Abdul Jabbar Jasim

Louisiana State University and Agricultural & Mechanical College

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INHERITANCE OF CERTAIN CHARACTERS IN OKRA (HIBISCUS ESCULENTUS L.)

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy in

The Department of Horticulture

by

Abdul Jabbar Jasim
B.S., Kansas State University, 1958
M.S., University of Arizona, 1964
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ABSTRACT

This investigation was conducted to study the mode of inheritance of such characters as leaf shape, plant height, pod color, pod spinesness and pod shape in okra (*Hibiscus esculentus* L.).

Seven parental lines of okra, Louisiana Green Velvet, Gold Coast, Clemson Spineless-11, Clemson Spineless-15, Campbell Soup Co. 48-1 (C-48-1), Campbell Soup Co. 48-2 (C-48-2) and P.I. 204545-1 were used in this study.

Seeds of the parents were planted in the late spring of 1964 at the Louisiana Agricultural Experiment Station. When the plants were in bloom direct and reciprocal crosses were made to obtain F$_1$ seeds.

Emasculature, crosses, backcrosses and self-pollination were made by hand.

In the early spring of 1965, seeds of the F$_1$ hybrids and selfed seeds of the original parents were planted. When the plants bloomed, the F$_1$ hybrid plants were selfed to obtain F$_2$ seed. They were also backcrossed to both respective parents.

In the late summer of 1965, seeds of F$_2$ and backcross generations were sown to study the segregating generations. The F$_2$ and backcrossed progenies were classified according to the mode of segregation of each contrasting character. Inheritance of each
character was determined by comparing the ratio obtained in the F₂ and backcross progenies with the expected Mendelian ratios.

Chi-square was used to measure the fit of the observed values to the expected ratios.

Leaf shape was studied in the cross of C-48-1 (cut leaf) x La. G.V. (lobed leaf). The cut leaf character was found to be completely dominant over lobed leaf in the F₁, and a sharp segregation of 3 cut : 1 lobed was obtained in the F₂. The data obtained from the backcrosses confirmed the hypothesis that only one pair of factors was concerned in leaf shape.

Plant height was studied in cross of Louisiana Green Velvet (tall) with Gold Coast (dwarf). The height of the F₁ was intermediate and the F₂ gave tall, intermediate and dwarf plants in the ratio of 1:2:1. The breeding behavior of the backcrosses confirmed the F₂ segregation, indicating that plant height was governed by one pair of genes.

Pod color was investigated by crossing C-48-2 (white pod), with Gold Coast (green pod). White was dominant as all F₁ plants had the same pod color as the white parent. The F₂ and test cross data showed a clear 3 white pods : 1 green pod and 1:1 segregation, respectively. Evidently, there is a single major gene difference for pod color.
Pod spininess was studied by crossing Clemson Spineless-11 (spineless) with P.I. 204545-1 (spiny). The F₁ pods were intermediate in spininess. Progeny in the F₂ were classified in the ratio of 1:2:1, the middle class being like the F₁. The backcross progenies confirmed that pod spininess was monogenically inherited.

Pod shape was studied in the cross of Clemson Spineless-15 (angular) x La. G.V. (round). There was a blending of both characters in the F₁ generation (angular-round), the pods were angular at the top and round at the base. Experimental results obtained indicated in the F₂ population a fit to the expected ratio of 12 angular-round : 3 angular : 1 round. Further analysis of the same segregating population showed that the F₂ progeny had a better fit to the expected ratio of 11 angular-round : 4 angular : 1 round. The backcross behavior confirmed the F₂ hypothesis of the digenic nature of segregation with epistasis being involved in the production of the observed phenotypes.
INTRODUCTION

Okra has not been the subject of much genetic study in the world as compared to other vegetable crops such as tomatoes, potatoes, and sweet potatoes. Some useful genetic data have been obtained by a few workers (9, 14, 15, 26, 48).

Okra (Hibiscus esculentus L.), belongs to the Malvaceae family and its importance as a vegetable is referred to by several workers (4, 5, 36, 39, 52, 54). These workers relate that the production of this crop for processing and fresh market is rapidly increasing due to an increase in demand.

Varieties of okra differ in their morphological characters. Differences in shape, color and spininess of the pods are important criteria used in judging the economic importance of varieties. Other characters such as leaf shape and plant height are plant characteristics that affect the ease with which the pods are harvested.

Breeders are continually striving to improve the more important economic characters of okra. Furthermore, the breeder must know certain basic facts about the nature of inheritance of characters in okra in order to enhance the development of improved varieties.

The okra plant possesses many heritable characters which are visible in the subsequent generations after hybridization. Expression of some of these characters are qualitative in nature. A
qualitative character is controlled by a few factors, and the progeny can be separated into distinct classes following certain Mendelian ratios.

This investigation involved the genetic analysis of leaf shape, plant height, pod color, pod spininess and pod shape in okra.
REVIEW OF LITERATURE

Thompson and Kelly (46) in writing about the history of okra declared that either Africa or Asia could be the place of origin. They stated that this vegetable was known by the Spanish Moor and was used by the Egyptians in the twelfth or thirteenth century. Okra is mentioned as having been grown in Philadelphia in 1748 and was listed by Jefferson in 1781 as being grown in Virginia.

Purewal and Randhawa (30) concluded that okra had its origin in Tropical Africa.

Certain observations were made by Woodroof (53) and he reported that the okra plant is a half woody, semi-fibrous annual propagated by seeds. It has an upright habit of growth. The leaves are borne alternately, with petioles from six to twelve inches long. The venation is palmate with margins varying from slightly wavy to very deeply lobed.

Other observations were made by Purewal and Randhawa (30), and Woodroof (53) from which they reported that the flower buds of okra arise in the axils of each leaf above the sixth to twelfth basal leaves.

McGinty and Barnes (22) noted that except for a few nodes (6-8) at the base of the plant, a flower bud occurs normally at each node on both the central stem and branches.
Woodroof (53) concluded that the crown of the stalk consists of several undeveloped leaves and flowers with as many as ten undeveloped flowers in a single crown. As the stem elongates the lowermost flower buds develop into flowers, one at a time. Never does more than one flower appear on a single stem the same day. On the other hand McGinty and Barnes (22), and Purewal and Randhawa (30) showed that more than one flower was observed on the same stem during the same day.

The flower has been described by Bailey (2) and others (30, 53). They reported that the blossoms are about three inches in diameter and resemble upturned bells. They are bright yellow in color with a tinge of crimson color at the base. The corolla has five petals, with stamens in a truncate tube and is five-toothed at the summit. The anthers are reniform and one-celled; the ovary is 5- to 7-celled and the pistil has five styles.

Thompson and Kelly (46) and others (41, 52) concluded that okra is a tender plant and grows best in hot weather. It should be planted on moderately well drained soils. For fresh market, earliness is desirable so it should be planted as early as possible in the spring. The seed is usually sown about 4 to 8 pounds per acre. Okra seed is drilled in rows 3 1/2 to 4 feet apart, and the plants are later thinned to stand 12 to 18 inches apart in the row. The seeds can be planted or drilled by planter or it may be dropped in hills by hand to a depth of 1/2 to 1 inch deep.
Commercial fertilizer is needed for best yield and quality of okra. The Louisiana recommendations for okra in 1960 were as follows: 300 to 600 pounds of 6-12-6 per acre plus 15 to 30 pounds of nitrogen as side-dressing if necessary to get good growth on alluvial soils. On hill soils apply 400 to 800 pounds of 5-10-10 or 4-12-8 plus 15 to 30 pounds nitrogen per acre. On terrace soils use 400 to 800 pounds of 6-12-6 per acre plus 15 to 30 pounds of nitrogen as a side-dressing if necessary (1).

Wilson, Cox and Montelaro (52), and Spivey, Woodard and Woodward (41) found that cultivation is necessary on young plants in order to keep the surface loose and free of weeds. After the plants are grown little cultivation is necessary.

Woodroof (53) stated that the fruit of okra is the seed pod with its contents. There is one pod with each blossom.

Boswell (4) and others (39, 52) found that the okra pod usually reaches a very good stage for eating in 4 to 6 days after the flower opens. One or two days delay beyond this stage will yield pods that are tough and of poor quality.

According to Culpepper and Moon (7) the eating quality was rather high at the 4-day stage (from blossoming), increased to the 6-day stage, then slowly declined to the 10- or 12-day stage, after which the pods became so fibrous as to be unsuited for table use.
Boswell (4) reported that okra pods in the edible stage contain about 90 per cent water, 2 per cent protein, 7 per cent carbohydrates and 1 per cent minerals.

McGinty and Barnes (22) observed that the hairs which are found upon okra plants are multicellular and obviously arise from epidermal cells. The spines are single cells with thick walls. The hairs, but not the spines, can be seen within the flower bud, sometime in advance of blooming.

Thompson and Kelly (46) concluded that okra varieties may be classified on the basis of plant size, pod shape, and pod color. The dwarf types grow to a height of 3 to 4 feet, while the tall types may be 6 to 8 feet tall. All of the popular varieties have spineless pods in the fresh-market stage, and the range in pod color among the varieties is from creamy white to dark green. Many varieties produce pods with prominent ridges, while a few produce smooth pods.

Wilson, Cox and Montelaro (52), working in Louisiana, reported that the yield of okra seed per acre may range from 300 to 600 pounds of dry seed for hill soils and from 600 to 1,000 pounds on Red River soils and from 1,000 to 2,000 pounds on Mississippi alluvial soils. The earlier the okra is planted, the higher the yields will generally be.

Thompson and Kelly (46) and Wilson, Cox and Montelaro (52) found that in commercial plantings average yields of 3 to 5 tons of pods should be produced per acre.
There are relatively few reports on inheritance of characters in okra.

Srivastava (42) noted that okra flowered singly in leaf axils and the flowers were hermaphroditic. Flower buds took about 22 days for full development while stigma receptivity was found to be of a very short duration and was maximal on the day of anthesis.

Venkataramani (49) concluded that it took the flower of okra 20 to 22 days to reach maximum size from bud initiation; the anthers dehisced soon after the corolla opened and the stigma was receptive while the flower remained opened. Also cross-pollination was more usual than self-pollination under field conditions.

Purewal and Randhawa (30) reported that okra flowers were mostly self-pollinated but the possibility of cross-pollination can not be ruled out in view of the fact that okra flowers are frequently visited by insects. They observed that honey bees and black ants were the most common visitors. They also noted that natural cross-fertilization in okra varied from 4.0 to 18.75 per cent with the average being 8.75 per cent.

Purewal and Randhawa (30) found that the stigma was definitely not receptive 20 hours before the normal opening of the flower, but it was receptive as soon as the flower opened.

Popoff (29) reported that okra was mainly self-pollinated, but insects do visit the flowers and cross-pollination may occur.
Purewal and Randhawa (30) stated that the pollen grains of okra were bright yellow, large, spherical with thick conical spines which were round at the base and tapered at the end. The pollen grains usually adhere together due to the secretion of an oily substance from the exine.

Purewal and Randhawa (30) concluded from their studies that pollen grains were shed about 10 to 15 minutes after the opening of the flowers and it took another five to ten minutes for all the anthers of a single flower to dehisce. The anthers on the top dehisced first followed by those underneath. These workers also observed that the okra pollen grains germinated on the stigmatic surface five minutes after being deposited. The fast growing pollen grain tubes reached the ovules in about two hours after pollination, the per cent of fruit setting was 23 while after three hours it was 52 per cent and after six hours fruit set increased to 96 per cent. These data indicated that the time lapsing between pollination and fertilization in okra is very short.

Venkataramani (49) indicated that fruit curling may be the result of uneven pollen deposition on stigmatic lobes.

Srivastava (42) found that pollen grains of okra were round in shape; fertile grains were relatively larger than sterile grains. Pollen fertility was optimal between 6:30 and 8:30 a.m. A 15 per cent sugar solution was found to be the most suitable medium for pollen germination.
Purewal and Randhawa (30) stated that the okra pollen grains were successfully germinated in artificial medium of 1 per cent agar plus 55 per cent sucrose at room temperature. The germination started 30 minutes after the pollen grains were placed on the media.

Balerdi (3) concluded that the two best artificial media for germinating okra pollen were 1) 2 per cent agar, 30 per cent sucrose in distilled water, and 2) 2 per cent agar, 30 per cent sucrose plus adding a 100 ppm solution of calcium nitrate to complete the volume.

In 1956 Kuwada (19) studied the effect of artificial media on pollen germination. Comparisons were made between the germination on artificial media of two species and an interspecific hybrid of okra pollen (*Hibiscus esculentus, Hibiscus manihot* and an amphidiploid hybrid between the two). The response of the pollen of the hybrid was similar to that of *H. esculentus* and both were more adaptable to the media than *H. manihot*. For the latter the best medium had 7 per cent agar and 20 per cent glucose but the germination only exceeded 90 per cent when the stylar tissue from any of the 3 species was added to the medium.

Venkataramani (49) stated that pollen grains remained viable for about 144 hours at 0 degree C. over calcium chloride, but lost viability in 24 hours at 30 degrees C.

Teshima (43), Tezima (44), and Ustinova (47) made crosses between *H. esculentus* L. and *H. manihot*. The cross only succeeded
completely dominant to shallow lobing. Segregation in the F₂ and backcross populations, and in the F₃ and backcross progenies showed monofactorial inheritance.

Deshpande (8) stated that lobed leaves were dominant to entire leaves in *Hibiscus cannabinus* and that the inheritance of this character was unifactorial.

Ustinova (47) crossed *Hibiscus esculentus* with *Hibiscus manihot*. The F₁ was intermediate with respect to leaf shape.

Mendiola (25) stated that juvenile leaves of *Hibiscus rosa-sinensis* may and may not be lobed, and that the presence of lobes was dominant with one single gene pair involved in the inheritance of leaf shape.

Mendiola and Capinpin (24) reported that the result of an observation on a number of F₂ seedlings would tend to indicate that dwarfness was a recessive character in *Hibiscus rosa-sinensis* L.

Miller and Wilson (26) made a study on plant height in which seven crosses involving tall and dwarf okra plants were observed. In every case the height of the F₁ plants was intermediate to that of the two parent strains. In the F₂ generation of each of these seven crosses the observed ratio was 1:2:1 for tall, intermediate and dwarf plants. The segregation showed a single factor difference between tall and dwarf okra plants.

Venkataramani (48) reported that the F₁ plants were intermediate between their parents with respect to height of okra plants.
Kalra and Padda (14) investigated the inheritance of fruit hairiness in okra by crossing variety 77 (prickly hair) x variety B 13 (nonhairy). The fruit surface of the F₁ was hairy but not so prickly as that of variety 77, indicating the absence of complete dominance. In the F₂, the segregation was observed to be in the ratio of 1 with prickly hair : 2 with smooth hair : 1 nonhairy, which indicated a single gene difference between the parents. Similar observations were made by Ustina (47) in the F₁ of an interspecific cross, *Hibiscus esculentus* x *Hibiscus manihot*.

Miller and Wilson (26) observed that some spineless varieties produced fruits with spines during the late growing season so definite conclusions on the mode of inheritance was not made.

Erickson and Couto (9) crossed an okra accession which was homozygous for completely yellow external petal surface with an accession homozygous for an external basal reddish blotch. The F₁ plants in the crosses between the two types were blotched, but the coloring was less intense than in the reddish parent. The F₂ and test cross gave ratios of 1:2:1 and 0:1:1, respectively. Red basal blotch was incompletely dominant to yellow, with a single gene pair involved.

Richharia (33) reported that pink external basal petal color was inherited as a simple dominant character over yellow.

Kalra and Padda (15) found that purple color on both sides of the petal base was monogenically dominant over purple color on the
inside of the petal base, while purple petal venation was found to be monogenically dominant over yellow petal venation. Also purple calyx color was monogenically dominant over green.

Erickson and Couto (9) crossed okra that had solid red stems and petioles with green plants. Red was dominant, with all F₁ plants being the same color as the red parent. In the segregating F₂ and test cross populations, three distinct phenotypes were recorded. In addition to all-red and all-green plants, several green plants appeared with considerable pigmentation on the petioles. Evidently, red color differed from green by two dominant genes for pigmentation: one gave a red stem and petiole, and the other affected the petiole only. As plants carrying both dominants could not be positively distinguished from those having only the one for red stem and petiole, the postulated F₂ segregation was 12:3:1, and the test cross 2:1:1. Their observed segregation was in close agreement with this hypothesis.

Venkataramani (48) noted that dark green plant color was dominant to light green. He also concluded that greenish red plant coloration in general was dominant to greenish. Apparently, these characters were not further analyzed to determine the number of genes involved.

Sanyal and Dutta (35) found that yellow petals in Hibiscus cannabinus was dominant over white and dependent on a single gene. They also pointed out that red stigma was dominant over white and monogenically inherited.
Joyner and Pate (13) contended that purple petal spot in kenaf was dominant to the absence of such a spot in kenaf, and dependent on a single gene.

Erickson and Couto (9) crossed an extremely late flowering type of okra with an early type. Earliness was dominant as $F_1$ plants began fruiting with the early parent. The $F_2$ and test cross data showed a clear 3:1 and 1:1 segregation, respectively. Evidently, there was a single major gene difference.

Raman and Ramu (31) found that hybrids obtained in crosses involving four varieties of *Hibiscus esculentus* flowered earlier than their parents while a few showed superiority in number or weight of fruits.

Venkataramani (48) observed hybrid vigor in crosses of six varieties of okra. The $F_1$ hybrids flowered as early as, or earlier than, the early flowering parent, and in general produced more fruits per plant and higher total yields than the parents.

Raman (32) observed hybrid vigor from crosses between okra varieties. Some hybrids also showed early flowering, early maturity and high individual fruit weight.

Joshi, Singh and Gupta (11) crossed six varieties of okra and compared them with their parents for several characters, such as height, fruit size and the number and weight of fruit per lot. Thirteen of 29 combinations gave a greater weight of fruit per lot than the
respective higher yielding parents while ten yielded less than the parents with lower yields. The increase in fruit number was responsible for the increase in yield. The variety Long White Darbhanga was the best in combining ability; its cross with Pusa Makhmali giving 51.3 per cent more yield than Pusa Makhmali. Crosses with 5-edged and 8-edged fruits resulted in hybrids with higher yields than those within the 8-edged or 5-edged group.

Kuwada (20) stated that the progeny from a cross of \textit{H. esculentus} \( \Phi \) x \textit{H. manihot} \( \delta \) was more fertile than the reciprocal combination and pollen-tube growth was more rapid in the direct cross. Fruit number was higher in the F\textsubscript{1} of the direct cross than in the reciprocal.

Ustinova (47) noted hybrid vigor from a cross between \textit{H. esculentus} and \textit{H. manihot}. The F\textsubscript{1} was superior to both parents in respect to greater thickness and length of the stems, length of internodes, and size of leaf blades. Backcrossing led to sterility in both the F\textsubscript{1} and the F\textsubscript{2} plants.

Singh, Chakravarti and Kapoor (38) described a hybrid which resulted from \textit{Hibiscus esculentus} x \textit{Hibiscus ficulneus}. Hybrid vigor was displayed in increased height and branching and in greater number of fruits though the hybrid was sterile. The stem color, fruit size, dehiscence of fruit and time of flowering of the hybrid were intermediate between the parents.
Leake (21) crossed two species of Indian cottons (Gossypium indicum, and Gossypium arboreum) one of which has a deeply and narrowly lobed leaf and the other a shallowly and broadly lobed leaf. The first generation plants were intermediate and the second generation segregated in a 1:2:1 ratio of narrow-lobed, intermediate and broad-lobed plants.

Shoemaker (37) studied the crosses of okra-leaf type with normal leaf in Upland cotton and reported intermediate leaf lobation and a 1:2:1 ratio of okra-leaf, intermediate lobation, and normal leaf in the F₂ generation.

McLendon (23) made crosses with two forms of Upland cotton; one deeply and narrowly lobed ("okra-leaf" type) and the other shallow and broad lobed. The F₁ generation was intermediate for these characters, and the F₂ generation segregated into a 1:2:1 ratio which was easily observed. Similar results were noted by Peebles and Kearney (28). When they crossed an "okra-leaf" form of Acala cotton with the normal broad leafed form, the F₁ was intermediate between the narrow-lobed and the broad-lobed parents. The F₂ generation segregated into a 1:2:1 ratio. The segregation in the F₂ was so clear-cut that there was no difficulty whatsoever in classifying any of the individuals by inspection in the field.

Ware (51) confirmed Peebles and Kearney's work in crosses between okra leaf plants, and a deep-cleft-leaf type with normal leaf
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plants. In the F₁ generation the plants were intermediate in leaf shape, that is, the cleft in the leaf was about one-half as deep as with the pure okra leaf type. In the F₂ generation from selfed F₁ plants a modified monohybrid 1:2:1 ratio occurred. This ratio was 1 okra leaf : 2 intermediate : 1 normal leaf.

Santhanam (34) reported that a crinkled leaf mutant was crossed with a normal parental form to study possible heterotic effects. The F₁ exhibited partial dominance for the character crinkled leaf and included plants with leaves possessing an intermediate degree of crinkling. The F₂ segregated in the proportion 1 crinkled : 2 intermediately crinkled : 1 normal. Plants with normal or crinkled leaves bred true in the F₃ but plants possessing leaves with an intermediate degree of crinkling again segregated in the ratio 1:2:1. Plants with crinkled leaves were taller, had a higher fresh and dry weight and possessed a larger number of nodes than the normal plants.

McLendon (23) crossed green and red-leaf types in Upland cotton. He found an intermediate development of red pigment in the first generation plants and plant color ratio in the second generation of 1 deep red : 2 intermediate : 1 full green.

Ware (50) found in crosses between the red-leaf and green-leaf strains of Upland cotton, that the F₁ was intermediate in color and a 1:2:1 ratio of red : intermediate, and full green was shown in the F₂.
Patel and Patel (27) found that the results of crosses between two cotton types, pale green leaf and normal-green, indicated that the pale green chlorophyll deficient was monogenic and recessive, with the F₁ being an intermediate, dilute green color. Reciprocal differences were observed. Progeny color was influenced by the color of the female parent.

Carver (6) reported green hirsute dominant to white hirsute in *Gossypium hirsutum* crosses, with a ratio in the F₂ of 19 green : 6 white. The same author stated that brown seed hirsute was dominant to white giving 79 brown : 24 white in the F₂. These results indicated that both green and brown hirsuteness differed from white by a single pair of genes.

McLendon (23) working with Upland and Sea Island cotton in Georgia found that in all his crosses between brown and white hirsute types he obtained an F₁ having all brown hirsute types. He obtained similar results when he crossed green and white. He did not ascertain any ratio for the F₂ generation of such crosses, but there was a wide range of variation in the color of the hirsute in the F₂ generation.

Kearney (16) in a study of Holdon (*G. hirsutum*) x Pima (*G. barbadense*) found that the mean fiber length of the F₁ approached the mean of the longer fiber (Pima) parent, while the F₂ gave a unimodal and nearly symmetrical curve, indicating that several factors governed the character.
Kottur (18) studied the inheritance of staple length in a cross between two pure lines of *G. herbaceum* (Dharwar No. 1) and *G. neglectum* variety Rosea. Dharawar No. 1 had a staple length ranging from 22 to 36 mm with an average of 28 mm and Rosea had a 12 to 24 mm range and 18 mm as the average length. The staple length of the F₁ generation approached closely the length of the long parent but was not quite equal to it. This indicated partial dominance of longer staple over shorter staple in these two types of cotton. The behavior of the cross in the F₂ generation indicated the staple length was not controlled by simple inheritance.

Thadani (45) made interspecific crosses between Sea Island and Upland varieties of cotton; long and short staple types, respectively. In the F₁ generation he found that long fiber was partially dominant over short fiber in all crosses. It was not possible to investigate the F₂ generation of some of the crosses on account of a high degree of sterility. In others the ratio obtained varied in several crosses so that no theoretical ratio could be suggested. It appeared that length was governed by multiple factors.

Fletcher (10) stated that long lint was dominant over short lint.

McLendon (23) in crosses between Egyptian long and Upland short, got F₁ population ranging between intermediate and long. In the F₂ the parental forms reappear with indications of segregation into a 3:1 ratio. McLendon's data, however, were not convincing.
McLendon (23) reported that in a cross between Sea Island and Upland cotton, the tall stem was dominant to short stem; "branched" (at the base) was dominant to "unbranched" (at the base), and "late maturity" seems to be dominant to early maturity.

Khadilkar (17) crossed a dwarf mutant in *Neglectum verum* cotton with normal pure strains N.R. 5 and B. XXI. The data obtained indicated that dwarf habit behaved as a recessive to normal and was dependent upon single pair.
MATERIALS AND METHODS

Seven pure lines of okra, *Hibiscus esculentus* L., Louisiana Green Velvet, Gold Coast, Clemson Spineless-11, Clemson Spineless-15, Campbell Soup Co. 48-1 (C-48-1), Campbell Soup Co. 48-2 (C-48-2) and P.I. 204545-1 were used in this study. A brief description of each is given below.

**Louisiana Green Velvet**

This variety was developed by the Louisiana Agricultural Experiment Station. The plants are vigorous, tall and branching, reaching a height of 7.5 to 8 feet. The petioles are long and the leaves lobed, pods are smooth, light green, round and straight. Mature pods are 7 to 8 inches long and three-fourths inch in diameter.

**Gold Coast**

This dwarf variety was also developed by the Louisiana Agricultural Experiment Station. Gold Coast reaches a height of 3 1/2 to 4 feet. The leaves are lobed with long petioles. Pods are short, round in shape, smooth and dark green in color. Mature pods are from 3 to 4 inches in length and about 1 inch in diameter.

**Clemson Spineless-11**

This pure line is a selection from Clemson Spineless which was developed by the South Carolina Agricultural Experiment Station.
This uniform spineless line has a plant height of 4 to 5 feet and cut leaves, with pods about 7 inches long at maturity. The pods are very smooth and spineless, green, semi-angular and straight.

**Clemson Spineless-15**

This pure line is a selection from Clemson Spineless which was developed by the South Carolina Agricultural Experiment Station. In general the plants grow to a height of 5 feet. Petioles of this line are long and the leaves cut, making the pods easily accessible for harvest. The pods are very smooth, free of spines, green, very angular and straight.

**Campbell Soup Co. 48-1 (C-48-1)**

This pure line was obtained from the Campbell Soup Company and has been kept pure by self-fertilization for many generations. The plant height is approximately 6 feet. The leaves are deeply cut with long petioles. Mature pods are 7 to 8 inches long. The pods are smooth round, very slender and green.

**Campbell Soup Co. 48-2 (C-48-2)**

This pure line was obtained in the same manner as C-48-1. Plants of this line grow to a height of about 6 feet. The leaves are cut in shape. Mature pods are 7 inches long. The pods are round, smooth, slender but white in color.
P.I. 204545-1

This line was also selected by this station from P.I. 204545 and kept pure by self-fertilization for many generations. It is a very spiny plant, reaching a height of 6 feet. The leaves are semi-cut in shape. The pods are thick, greenish white, semi-angular and very spiny.

All above varieties and lines of okra were used as parents for studying the mode of inheritance of leaf shape, plant height, pod color, spininess of the pod and pod shape.

The parental seeds were planted on May 14, 1964 on a silt loam soil at the Louisiana Agricultural Experiment Station, Baton Rouge, La. Three seeds were planted per hill, the hills being 12 inches apart on 3 1/2 foot rows. Once the stand was established, the plants were thinned to only one plant per hill. Recommended cultural practices were followed.

During the summer of 1964 direct and reciprocal crosses of different parents were made in the field when the plants were in bloom to obtain the $F_1$ seeds. The direct and the reciprocal crosses were as follows.

**Leaf Shape**

Campbell Soup Co. 48-1 (C-48-1) x Louisiana Green Velvet (cut leaf) (lobed leaf)
Louisiana Green Velvet x Campbell Soup Co. 48-1 (C-48-1)
Plant Height

Louisiana Green Velvet x Gold Coast
(tall) (dwarf)
Gold Coast x Louisiana Green Velvet

Pod Color

Campbell Soup Co. 48-2 (C-48-2) x Gold Coast
(white pod) (green pod)
Gold Coast x Campbell Soup Co. 48-2 (C-48-2)

Spininess of the Pod

Clemson Spineless-11 x P.I. 204545-1
(spineless pod) (spiny pod)
P.I. 204545-1 x Clemson Spineless-11

Pod Shape

Clemson Spineless-15 x Louisiana Green Velvet
(angular pod) (round pod)
Louisiana Green Velvet x Clemson Spineless-15

Emasculation, crosses, backcrosses and self-pollinations were
made by hand using the following technique.

Since the okra flower bears both pistillate and staminate parts,
it was necessary to remove the stamens from the flower of the plant
to be used as the female before the anthers dehisced. The emascula-
tions were made between 4 and 7 p.m. on flower buds which were to
open the next day. This was also the best stage for selfing. All
self-pollinations were made by bagging the buds with number 1 paper
bags which were securely fastened around the peduncle with paper
clips. The selfed flowers were then tagged. The emasculated
flower buds were covered with paper bags, which were held in place
by paper clips. The emasculation of the large flowers of okra is relatively easy as the ovary is large with the style, one-half to one inch long, which is surrounded by a sheath upon which the pollen sacs are located. This sheath was pierced with the thumb nail near the base and the entire sheath was slit. The sheath covered with the pollen sacs was then removed by peeling it from around the ovary and style. Care was exercised not to injure the style which protrudes through the hollow central cylinder of the staminal column.

Flower buds, which were emasculated the previous afternoon, were pollinated the next morning between 8 and 11 a.m. The paper bag covering the emasculated flower was removed and the desired anthers were rubbed against each lobe of the stigma. After pollination the flower was rebagged to prevent the random deposition of foreign pollen. After approximately 5 days the bags were removed. Small white tags were used for all crosses so as to distinguish the hybridized from the selfed flowers, which were identified by a yellow tag.

The F₁ seeds of the crosses and selfed seeds of the original parents were harvested during August, 1964. The seed from each cross was placed in separate bags. Each bag was marked according to the identification tag found on each flower. Seeds were stored in cold storage at 35 degrees F until planted during the spring of 1965.
Spring Planting of F1 Hybrids and Parental Seeds - 1965

The F1 seeds from each cross and the selfed seeds of the original parents were planted in separate rows at the same location on April 12, 1965. When the plants bloomed, the F1 hybrid plants were selfed to obtain the F2 seed. They were also backcrossed to both parents to study the segregation in backcross generations.

The following F1 selfings and backcrosses were made:

**Leaf Shape**

Campbell Soup Co. 48-1 (C-48-1) x Louisiana Green Velvet, F1-selfed (cut leaf) (lobed leaf)

Louisiana Green Velvet x Campbell Soup Co. 48-1 (C-48-1), F1-selfed

C-48-1 x (C-48-1 x La. G.V.), F1-backcrossed.

La. G.V. x (C-48-1 x La. G.V.), F1-backcrossed.

**Plant Height**

Louisiana Green Velvet x Gold Coast, F1-selfed (tall) (dwarf)

Gold Coast x Louisiana Green Velvet, F1-selfed.

La. G.V. x (La. G.V. x G.C.), F1-backcrossed.

G.C. x (La. G.V. x G.C.), F1-backcrossed.

**Pod Color**

Campbell Soup Co. 48-2 (C-48-2) x Gold Coast, F1-selfed (white pod) (green pod)

Gold Coast x Campbell Soup Co. 48-2 (C-48-2), F1-selfed

G.C. x (C-48-2 x G.C.), F1-backcrossed.

C-48-2 x (C-48-2 x G.C.), F1-backcrossed.
**Spininess of the Pod**

Clemson Spineless-11 x P.I. 204545-1, F₁-selfed.  
(spineless pod)  (spiny pod)  
P.I. 204545-1 x Clemson Spineless-11, F₁-selfed

Clemson Spineless-11 x (Clemson Spineless-11 x P.I. 204545-1),  
F₁-backcrossed.

P.I. 204545-1 x (Clemson Spineless-11 x P.I. 204545-1),  
F₁-backcrossed.

**Pod Shape**

Clemson Spineless-15 x Louisiana Green Velvet, F₁-selfed  
(angular pod)  (round pod)  
Louisiana Green Velvet x Clemson Spineless-15, F₁-selfed

Clemson Spineless-15 x (Clemson Spineless-15 x La. G.V.),  
F₁-backcrossed.

La. G.V. x (Clemson Spineless-15 x La. G.V.), F₁-backcrossed.

Data were taken on leaf shape, pod color, pod spininess and  
pod shape in each F₁ plant. On August 20, 1965, height measure-  
ments in centimeters from ground level to the top of the terminal bud  
were made on parents and F₁ stalks of the respective crosses.  

Seeds for the F₂ and backcross plantings were harvested as  
soon as the F₁ and backcrossed pods were dry.

**Fall Planting of F₂ and Backcross Segregating Generations**

By growing the segregating generations in the early fall of  
1965 a period of one year was saved. Therefore, the F₂ and back-  
cross seeds for different crosses were available from the spring  
planting of 1965.
Seeds of the F$_2$ and backcrosses were sown on August 1, 2, and 3, 1965 in the same field. Also the F$_1$ and the selfed seeds of the original parents were planted, along with the F$_2$ and backcrosses, in order to provide means for making comparisons. The seed of each F$_2$ and backcross generation was planted on three 90-foot rows spaced 3 1/2 feet apart. Three seeds were planted per hill. The hills were 12 inches apart. When the plants reached the approximate height of 4 inches, they were thinned to only one plant per hill. Weeds were controlled by the usual methods of cultivation. A sprinkler irrigation system was used to water the field during prolonged dry periods especially in the fall.

The plants of each F$_2$ and backcrossed progeny were classified according to the mode of segregation. When the plants were killed by frost on November 30 height measurements in centimeter from ground level to tip of terminal bud were made on all stalks of the respective progenies. The measurements of the parent strains and their hybrids were tabulated in intervals of ten centimeters for convenience of presentation.

For all segregating generations the observed data were classified according to the expected groups and the deviations of the observed numbers from the calculated numbers were determined. The Chi-square value was computed, and the corresponding probability value obtained.
The Chi-square ($X^2$) test for goodness of fit was made by subjecting the data to the following formula:

$$X^2 = S \frac{(O-C)^2}{C},$$

where

- $S$ = summation
- $O$ = observed value
- $C$ = expected value

Statistical analyses were made according to Snedecor (40).
RESULTS

Inheritance of Leaf Shape

The inheritance of leaf shape was studied in the cross of C-48-1 (cut leaf) x Louisiana Green Velvet (lobed leaf). The leaf shape classifications of the parents and F₁ hybrids are shown in Table I. Cut leaf was dominant, with all F₁ plants being the same leaf shape as the cut leaf parent. The reciprocal cross showed this same simple Mendelian dominance of cut leaf. The complete dominance of cut leaf is illustrated in Plate 1.

Table I. Leaf shape classification of parents and F₁ hybrids.

<table>
<thead>
<tr>
<th>Parental Cross</th>
<th>Number of Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cut Leaf</td>
</tr>
<tr>
<td>Campbell Soup Co. 48-1 (C-48-1)*</td>
<td>20</td>
</tr>
<tr>
<td>Louisiana Green Velvet**</td>
<td>38</td>
</tr>
<tr>
<td>C-48-1 x La. G.V., F₁</td>
<td>20</td>
</tr>
<tr>
<td>La. G.V. x C-48-1, F₁</td>
<td>18</td>
</tr>
</tbody>
</table>

*Cut leaf
**Lobed leaf

The F₁ hybrids which resulted from a cross between C-48-1 and Louisiana Green Velvet were selfed to study the F₂ progeny as to segregation for leaf shape. The F₁ plants were also used in back-crosses to each parent. Frequency distributions for leaf shape in the
Plate 1. Leaf shape segregation: left, C-48-1 (cut leaf); center, F₁ hybrid; right, Louisiana Green Velvet (lobed leaf).
F₂ population are shown in Table II. The F₂ generation segregated into a ratio of three cut leaf to one lobed leaf plants. Plants from the reciprocal cross gave the same segregating ratio, cut leaf being completely dominant.

In the backcross of the F₁ to the cut leaf parent the plants of the entire progeny possessed the cut leaf character. Also the backcross of the F₁ to the lobed leaf parent gave a 1:1 ratio. Plants in the F₂ and backcross progenies segregated as expected assuming complete dominance of the cut leaf characters shown in Table II.

Genetic ratios of plants as to leaf shape in the cross and backcross progenies of C-48-1 x Louisiana Green Velvet were analyzed statistically. In testing the assumption of a simple monofactorial character, the chi-square (X²) value of 0.666 was obtained for the F₂ generation. With one degree of freedom this probability falls between 0.25-0.50. The chi-square value for the reciprocal cross was 0.056 (Table II) and this also, with one degree of freedom, has a probability value of 0.75-0.90. This indicates that the deviation of the observed values from the theoretical values is not significant in both chi-square tests, and therefore suggests the genetic behavior of this character is controlled by one pair of genes with complete dominance.

The results of segregating ratios of backcrossed progenies are presented in Table II. The backcross of the F₁ to the cut leaf parent resulted in progeny with all cut leaf plants. When the F₁ was
Table II. Frequency distribution of $F_2$ and backcross progenies of okra into different leaf shape classes.

<table>
<thead>
<tr>
<th>Parental Cross</th>
<th>Number of Plants</th>
<th>Expected Ratio</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cut Leaf</td>
<td>Lobed Leaf</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Campbell Soup Co. 48-1 (C-48-1)* x Louisiana Green Velvet**, $F_2$</td>
<td>155</td>
<td>45</td>
<td>200</td>
<td>3:1</td>
</tr>
<tr>
<td>Louisiana Green Velvet x Campbell Soup Co. 48-1 (C-48-1), $F_2$</td>
<td>162</td>
<td>52</td>
<td>214</td>
<td>3:1</td>
</tr>
<tr>
<td>C-48-1 x (C-48-1 x La. G.V.), $F_1$-backcrossed</td>
<td>215</td>
<td>215</td>
<td></td>
<td></td>
</tr>
<tr>
<td>La. G.V. x (C-48-1 x La. G.V.), $F_1$-backcrossed</td>
<td>104</td>
<td>97</td>
<td>201</td>
<td>1:1</td>
</tr>
</tbody>
</table>

*Cut leaf
**Lobed leaf
backcrossed to the lobed leaf parent a 1:1 ratio with a chi-square value of 0.244 was obtained. This value, with one degree of freedom, has a probability that lies between 0.50-0.75 which indicates a good genetic fit.

These data show conclusively, that the difference between cut leaf and lobed leaf in okra is controlled by a single pair of genes. Cut leaf shape was completely dominant.

**Inheritance of Plant Height**

Inheritance of plant height was studied with plants representing the parental varieties, F₁, F₂ and backcross generations of a cross between Louisiana Green Velvet (tall) and Gold Coast (dwarf) and its reciprocals. The height of Louisiana Green Velvet plants varied from 200 to 230 cm and the mean height was 214.50 cm. The height of Gold Coast plants ranged from 100 to 130 cm and the mean height was 120 cm.

F₁ plants in the progenies of a cross and reciprocal cross of the above varieties were intermediate in height between the two parents. The average height of the F₁ plants of the cross (La. G.V. x G.C.) was 167.78 cm and the average height of the F₁ plants of the reciprocal cross was 167.00 cm. The F₁ mean was therefore at the midway point between the parental means. These data are shown in Table III.
Table III. Frequency distribution of parents and F$_1$ progenies of okra into different plant height classes for a cross between Louisiana Green Velvet (tall) and Gold Coast (dwarf).

<table>
<thead>
<tr>
<th>Parental Cross</th>
<th>Height of Plants in Centimeters</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
<th>160</th>
<th>170</th>
<th>180</th>
<th>190</th>
<th>200</th>
<th>210</th>
<th>220</th>
<th>230</th>
<th>240</th>
<th>Total</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold Coast*</td>
<td></td>
<td>7</td>
<td>11</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Louisiana Green Velvet**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>38</td>
</tr>
<tr>
<td>La. G.V. x G.C., F$_1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>13</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G.C. x La. G.V., F$_1$</td>
<td></td>
<td>2</td>
<td>8</td>
<td>17</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Dwarf  
** Tall
Okra plants in the F₂ generation consisted of individuals of varying heights. The plant height was measured in centimeters from the ground level to the top. The results showed that the progenies were sharply divided into three distinct groups (Table IV). The three separate groups were classed as tall, intermediate, and dwarf. The number of plants in each group of the cross La. G.V. x G.C. were 59 tall, 137 intermediate and 62 dwarf with a mean height of 215.08, 167.81, and 121.12 cm, respectively. The number of plants for each group of the reciprocal cross were 74 tall, 132 intermediate and 65 dwarf with a mean height of 214, 168.07 and 120.46 cm, respectively.

The plants in the progeny of the backcross to the tall parent gave two distinct classes (Table IV); there were 139 plants with a mean height of 167.91 cm which was similar to the F₁ and 127 plants with a mean height of 214.96 cm which was similar to the tall parent. On the other hand the backcross to the dwarf parent also gave two distinct classes. The totals of 137 plants with a mean height of 167.15 cm and 130 plants with a mean of 119.92 cm were similar to the dwarf parent. Based on ratios obtained in the F₂ and backcross generations monofactorial inheritance with absence of dominance is suggested for plant height. Chi-square values (Table IV) further suggest that the difference between tall and dwarf height in okra is controlled by one pair of genes.
Table IV. Frequency distribution of F\textsubscript{2} and backcross progenies of okra into different plant height classes.

<table>
<thead>
<tr>
<th>Parental Cross</th>
<th>Number of Plants</th>
<th>Expected Ratio</th>
<th>X\textsuperscript{2}</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tall</td>
<td>Intermediate</td>
<td>Dwarf</td>
<td>Total</td>
</tr>
<tr>
<td>Louisiana Green Velvet* x Gold Coast**, F\textsubscript{2}</td>
<td>59</td>
<td>137</td>
<td>62</td>
<td>258</td>
</tr>
<tr>
<td>Gold Coast x Louisiana Green Velvet, F\textsubscript{2}</td>
<td>74</td>
<td>132</td>
<td>65</td>
<td>271</td>
</tr>
<tr>
<td>La. G.V. x (La. G.V. x G.C.), F\textsubscript{1}-backcrossed</td>
<td>127</td>
<td>139</td>
<td></td>
<td>266</td>
</tr>
<tr>
<td>G.C. x (La. G.V. x G.C.), F\textsubscript{1}-backcrossed</td>
<td>137</td>
<td>130</td>
<td></td>
<td>267</td>
</tr>
</tbody>
</table>

*Tall
**Dwarf
Inheritance of Pod Color

A cross between C-48-2 (white pods) and Gold Coast (green pods) produced F₁ plants with white pods. The same was true for the reciprocal cross. The data as shown in Table V indicate complete dominance of the character for white pod color. The color of the pods of the parents and F₁ hybrids is shown in Plate 2.

Table V. Pod color classification of parents and F₁ hybrids.

<table>
<thead>
<tr>
<th>Parental Cross</th>
<th>Number of Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campbell Soup Co. 48-2 (C-48-2)*</td>
<td>20</td>
</tr>
<tr>
<td>Gold Coast**</td>
<td>25</td>
</tr>
<tr>
<td>C-48-2 x G.C., F₁</td>
<td>20</td>
</tr>
<tr>
<td>G.C. x C-48-2, F₁</td>
<td>18</td>
</tr>
</tbody>
</table>

*White pod
**Green pod

The F₂ generation of the selfed F₁ hybrids produced a segregating ratio of three white pod plants to one green pod. The backcross of the F₁ to the green pod parent produced plants with a genetic ratio of 1 green pod : 1 white pod. The backcross of the F₁ plants to the white pod parent gave a progeny of plants whose pods were all white. Furthermore, the segregation in the F₂ and backcross progenies were clear cut. The segregation data pertaining to the F₂ and the backcross
Plate 2. Pod color segregation: left, C-48-2 (white pod); center, $F_1$ hybrid; right, Gold Coast (green pod).
Table VI. Frequency distribution of F₂ and backcross progenies of okra into different pod color classes.

<table>
<thead>
<tr>
<th>Parental Cross</th>
<th>Number of Plants</th>
<th>Expected Ratio</th>
<th>X²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>White Pod</td>
<td>Green Pod</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Campbell Soup Co. 48-2 (C-48-2)* x Gold Coast** , F₂</td>
<td>152</td>
<td>56</td>
<td>208</td>
<td>3:1</td>
</tr>
<tr>
<td>Gold Coast x Campbell Soup Co. 48-2 (C-48-2), F₂</td>
<td>148</td>
<td>56</td>
<td>204</td>
<td>3:1</td>
</tr>
<tr>
<td>G.C. x (C-48-2 x G.C.), F₁-backcrossed</td>
<td>108</td>
<td>95</td>
<td>203</td>
<td>1:1</td>
</tr>
<tr>
<td>C-48-2 x (C-48-2 x G.C.), F₁-backcrossed</td>
<td>220</td>
<td>220</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*White pod
**Green pod
progenies are summarized in Table VI. These data suggest that pod color is monofactorially inherited. Chi-square data for F₂ and backcross generations further substantiate this hypothesis.

**Inheritance of Spininess of the Pod**

In order to study this character a cross between Clemson Spineless-11 (spineless pods) and P.I. 204545-1 (spiny pods) was made. The data in Table VII show that F₁ plants had an intermediate amount of spines on the pods. Reciprocal crosses produced plants with the same pattern of spines on the okra pods.

Table VII. Classification of parents and F₁ plants for pod spininess.

<table>
<thead>
<tr>
<th>Parental Cross</th>
<th>Number of Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spineless Pod</td>
</tr>
<tr>
<td>Clemson Spineless-11*</td>
<td>25</td>
</tr>
<tr>
<td>P.I. 204545-1**</td>
<td>30</td>
</tr>
<tr>
<td>Clemson Spineless-11 x P.I. 204545-1, F₁</td>
<td>20</td>
</tr>
<tr>
<td>P.I. 204545-1 x Clemson Spineless-11, F₁</td>
<td>15</td>
</tr>
</tbody>
</table>

*Spineless pod
**Spiny pod

The plants of the F₂ progenies segregated into three classes, with a ratio of 1 spineless : 2 intermediate : 1 spiny pod. Half of the plants were intermediate, like the F₁ generation. The spineless pods in the F₂ progeny resembled those of Clemson Spineless-11 and the spiny ones
resembled those of P.I. 204545-1. The backcross of the F₁ to the spineless parent showed a ratio of 1 spineless : 1 intermediate pod plant. However, in the F₁ backcross to the spiny pod plant a ratio of 1 intermediate : 1 spiny pod plants was observed. This suggests a monohybrid type of segregation with absence of dominance (Table VIII).

Since this character appeared to be influenced to some degree by the environment and error in human measurement, the inheritance of this character is not very clear cut as shown by the chi-square values in Table VIII, although the observed and calculated values show a goodness of fit.

The analysis of segregating ratio of the F₂ filial generation in the cross of Clemson Spineless-11 x P.I. 204545-1 gave a chi-square of 3.830. The probability (P) value for the chi-square of 3.830 and with 2 degrees of freedom was 0.10-0.25. The chi-square value for segregation of the progeny of the reciprocal cross was 2.790 and with 2 degrees of freedom it has a probability of 0.10-0.25. Therefore the figures obtained fit a 1:2:1 ratio indicating that the inheritance of pod spininess is governed by a single pair of genes with the absence of dominance of the spiny pod character.

The monohybrid inheritance for the F₂ is further confirmed by the observation of backcross plant progenies. The chi-square value of 2.630 was obtained and with one degree of freedom the probability lies between 0.10-0.25 when the backcross was made to the spineless
Table VIII. Frequency distribution of F₂ and backcross progenies of okra into different pod spininess classes.

<table>
<thead>
<tr>
<th>Parental Cross</th>
<th>Number of Plants</th>
<th>Expected Ratio</th>
<th>X²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spineless Pod</td>
<td>Intermediate Pod</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Clemson Spineless-11* x P.I. 204545-1**, F₂</td>
<td>43</td>
<td>98</td>
<td>62</td>
<td>203</td>
</tr>
<tr>
<td>P.I. 204545-1 x Clemson Spineless-11, F₂</td>
<td>53</td>
<td>136</td>
<td>70</td>
<td>259</td>
</tr>
<tr>
<td>Clemson Spineless-11 x (Clemson Spineless-11 x P.I. 204545-1), F₁-backcrossed</td>
<td>89</td>
<td>112</td>
<td>201</td>
<td>1:1</td>
</tr>
<tr>
<td>P.I. 204545-1 x (Clemson Spineless-11 x P.I. 204545-1), F₁-backcrossed</td>
<td>114</td>
<td>91</td>
<td>205</td>
<td>1:1</td>
</tr>
</tbody>
</table>

*Spineless pod
**Spiny pod
parent. On the other hand the genetic ratio of the progeny of the backcross to the spiny parent gave a chi-square value of 2.850 and the probability of goodness of fit falls between 0.10-0.25.

The segregation obtained from each backcross satisfied the expected ratio of 1:1 and thus confirmed the postulate that one pair of genes is involved.

Inheritance of Pod Shape

This character was studied in the cross of Clemson Spineless-15 (angular) x Louisiana Green Velvet (round), and its reciprocal. The two characters appeared in a distinctly peculiar form in the F1 generation. There was a blending of both characters since the pods were angular at the top and round at the base. The degree of pod angularity on the same pod ranged from one rib occurring only at the pod tip to another rib extending near the pod base. This pattern of blending was also noted in the reciprocal cross. The pod shape classes of the parents and F1 hybrids are presented in Table IX. Pod shape variations of the parents and F1 hybrids are shown in Plate 3.
Plate 3. Pod shape segregation: left, Louisiana Green Velvet (round pod); center, F$_1$ hybrid; right, Clemson Spineless-15 (angular pod).
Table IX. Pod shape classification of parents and $F_1$ hybrids.

<table>
<thead>
<tr>
<th>Parental Cross</th>
<th>Number of Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angular</td>
</tr>
<tr>
<td>Clemson Spineless-15*</td>
<td>30</td>
</tr>
<tr>
<td>Louisiana Green Velvet**</td>
<td>38</td>
</tr>
<tr>
<td>Clemson Spineless-15 x Louisiana Green Velvet, $F_1$</td>
<td>19</td>
</tr>
<tr>
<td>Louisiana Green Velvet x Clemson Spineless-15, $F_1$</td>
<td>28</td>
</tr>
</tbody>
</table>

*Angular pod  
**Round pod

The $F_1$ of the Clemson Spineless-15 and Louisiana Green Velvet cross was selfed to study the segregation in the $F_2$ progeny. Backcross progenies were obtained by crossing the $F_1$ hybrid to each parent. In the $F_2$ generation, three types of plants were obtained, namely, angular-round, angular and round as shown in Table X. The plants of the $F_2$ progeny were calculated to segregate into three classes as follows: 12 angular-round, similar to the $F_1$ generation to 3 angular, like the angular parent to 1 round, like the round pod parent. Another calculated $F_2$ progeny was 11 angular-round : 4 angular : 1 round. In the backcross to the angular pod parent the calculated ratio was 1 angular-round : 1 angular and the backcross to the round pod parent was calculated to be 3 angular-round : 1 round pod plant.
Table X. Frequency distribution of $F_2$ and backcross progenies of okra into different pod shape classes.

<table>
<thead>
<tr>
<th>Parental Cross</th>
<th>Number of Plants</th>
<th>Expected Ratio</th>
<th>$X^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Clemson Spineless-15</em> x Louisiana Green Velvet**, $F_2$</td>
<td>Angular-round 157, Angular 55, Round 16, Total 228</td>
<td>12:3:1</td>
<td>4.871</td>
<td>0.05-0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11:4:1</td>
<td>0.286</td>
<td>0.75-0.90</td>
</tr>
<tr>
<td><em>Louisiana Green Velvet x Clemson Spineless-15</em>, $F_2$</td>
<td>Angular-round 139, Angular 49, Round 14, Total 202</td>
<td>12:3:1</td>
<td>4.44</td>
<td>0.10-0.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11:4:1</td>
<td>0.1926</td>
<td>0.90-0.95</td>
</tr>
<tr>
<td>*Clemson Spineless-15 x (Clemson Spineless-15 x Louisiana Green Velvet), F$_1$-backcrossed</td>
<td>Angular-round 94, Angular 115, Total 209</td>
<td>1:1</td>
<td>1.055</td>
<td>0.25-0.50</td>
</tr>
<tr>
<td>*Louisiana Green Velvet x (Clemson Spineless-15 x Louisiana Green Velvet), F$_1$-backcrossed</td>
<td>Angular-round 146, Angular 62, Total 208</td>
<td>3:1</td>
<td>2.564</td>
<td>0.10-0.25</td>
</tr>
</tbody>
</table>

*Angular pod
**Round pod
The observed and calculated ratios were then compared for goodness of fit by means of $X^2$ and $P$ (Table X).

To test these assumptions in the $F_2$ generation a fit was obtained to the expected 12:3:1 ratio ($X^2 = 4.871, P = \text{slightly less than } 0.10$). In the reciprocal the observed and the calculated values were also in agreement as shown in Table X.

In the analysis of the segregating population of the $F_2$ progeny a better fit to the expected ratio of 11:4:1 ($X^2 = 0.286, P = 0.75-0.90$) was obtained. In the reciprocal cross a very close fit to the expected ratio of 11:4:1 was found. The deviations between the observed and expected values were not significant.

The breeding behavior of the backcrosses confirmed the $F_2$ data. The results showed that, when the $F_1$ was backcrossed to the angular pod parent, the ratio of 1 angular-round, similar to the $F_1 : 1$ angular, like the angular pod parent ($X^2 = 1.055, P = 0.25-0.50$) gave a good fit to the expected 1:1 ratio. Whereas, the backcross to the round parent segregated into 3 angular-round : 1 round as expected ($X^2 = 2.564, P = 0.10-0.25$). The results of the $F_2$ and backcross progenies led to the conclusion that pod shape is controlled by two pairs of genes.
DISCUSSION

Inheritance of Leaf Shape

Data used in studying leaf shape were obtained by crossing C-48-1 (cut leaf) with Louisiana Green Velvet (lobed leaf). It was concluded that cut leaf in okra was a simple Mendelian dominant over the lobed leaf character.

The homozygous dominant may be represented by the letters LL, the homozygous recessive by ll and the heterozygous condition by Ll. Data supporting the foregoing conclusions were obtained by studying plants from selfed, crossed and backcrossed progenies.

Analyses of these data showed that the observed values were close to the predicted ratio for one pair of factors.

If the above is true the following genetic complex would be possible:

- LL x LL should give 100 per cent cut leaf plants.
- LL x ll should give 100 per cent cut leaf plants.
- Ll x Ll should give a ratio of 3 cut leaf to 1 lobed leaf plants.
- LL x Ll should give 100 per cent cut leaf plants.
- ll x Ll should give a ratio of 1 cut leaf plant to 1 lobed leaf.
- ll x ll should give 100 per cent lobed leaf plants.

Results obtained by cross-pollination of the cut leaf line with the lobed leaf line supported the assumption that the cut leaf character
is a simple Mendelian dominant over lobed leaf. The F\textsubscript{1} plants had the same leaf shape as the pure line C-48-1 (cut leaf). The F\textsubscript{2} segregated on a 3:1 basis. The backcrosses confirmed the results of the F\textsubscript{2} segregation.

These results are similar to those of Venkataramani (48), who observed that deep lobing was completely dominant over shallow lobing. The F\textsubscript{2} and backcross data suggested a monogenic control of this character. Joyner and Pate (13) and Deshpande (8) found that deep lobing was dominant to shallow lobing in kenaf.

However, Kalia and Padda (15) worked with okra in India and reported that the F\textsubscript{1} plants were intermediate in leaf shape between deep lobed and shallow lobed parents. They declared that the mode of segregation in the F\textsubscript{2} was 1:2:1 with leaf shape being controlled by a single gene. Their work agreed with that of Ustinova (47), who obtained an interspecific hybrid, *Hibiscus esculentus* x *H. manihot*. This hybrid F\textsubscript{1} was intermediate in respect to leaf shape.

Cotton researchers (21, 23, 28, 37, 51) also found that the F\textsubscript{1} plants were intermediate in leaf shape when a parent having deep-narrow lobes was crossed to a parent having leaves that were shallow and broad lobed. They found the ratio in the F\textsubscript{2} to be 1:2:1.

It should be added that in the present work the F\textsubscript{1} was as uniform as the cut leaf parent, C-48-1.
Inheritance of Plant Height

It is evident from this study that a unit factor difference was present between Louisiana Green Velvet (tall) x Gold Coast (dwarf).

The tall parent type may be represented by the factor TT. Gold Coast (dwarf), on the other hand may be represented by the allelomorph tt. The $F_1$ and the other heterozygotes in the $F_2$ and backcross progenies should be intermediate in plant height and must therefore be Tt, the $F_2$ segregation being 1 TT:2 Tt:1 tt. In the backcross the segregation would be 1 Tt:1 TT when the $F_1$ was backcrossed to the tall parent and 1 Tt:1 tt when the $F_1$ was backcrossed to the dwarf parent.

The results obtained in the cross of tall to dwarf plants showed that the height of plant was controlled by one pair of genes. The $F_1$ plants obtained were intermediate in height. The $F_2$ plants segregated on a 1:2:1 basis. The backcross to both parents confirmed the results of the $F_2$ segregation.

These data indicated a monohybrid segregation of tall to dwarf plants and were in agreement with the results recorded by other workers (26, 48).

Different results were found in cotton by McLendon (23), and Khadilkar (17). The former reported that in a cross between Sea Island and Upland cotton, the tall stem was dominant to the short stem. While the latter crossed a dwarf mutant in Neglectum verum cotton with a normal pure strain. He concluded that dwarf habit behaved as recessive to normal and was dependent upon a single pair of genes.
Mendiola and Capinpin (24) found that dwarfness was recessive in *Hibiscus rosa-sinensis* L.

**Inheritance of Pod Color**

A monofactorial mode of inheritance has been observed between plants with white pod (C-48-2). This character may be represented by the factor WW and plants with green pod, Gold Coast, may be represented by ww. No intermediate color in the different generations were observed. In all crosses the distinction was always sharp and clear cut.

The resulting hybrid F₁ (Ww) was like the white pod parent. Thus the white pod condition was dominant over the green. The results from the self-pollination of the F₁ flowers produced plants which bore either white or green pods and a statistical examination showed that they occurred in the ratio of three of the dominant to one of the recessive forms, or 3W to 1w. While the backcross of the F₁ to the recessive parent showed a 1 white to 1 green ratio, in the backcross to dominant parent (C-48-2) all the plants had white pods.

The plants showing the dominant character (white) were all precisely similar in external appearance.

The explanation of this example based on the phenomena is offered by Mendel. The two kinds of gametes of the F₁ plants carry W and w in equal numbers, then when union of the gametes occurs in fertilization to form a new individual, there are two types of gametes, but four ways by which these gametes combine as WW, Ww, wW and
ww. Because of the dominance of W the Ww class cannot be distinguished from the WW class, thus the W masks the appearance of w, therefore the phenotypic ratio was 3 plants with white pods to 1 plant with green pods. The homozygous classes WW, white and ww, green, breed true because the germ cells carry only W and w genes, respectively. A backcross of the F₁ (Ww) with the Gold Coast variety (the recessive parent) gave an equal number of dominant and recessive types. In the F₁ the gametes are produced in equal numbers, 1W:1w and they united with the w gametes of the recessive Gold Coast and gave Ww and ww plants in the proportion of 1:1. In the second case the backcross to the pure dominant parent gave all dominant individuals (white pods); since the F₁ (Ww) when crossed to the dominant parent (WW) gave the genotypes of WW, Ww, WW, and Ww.

**Inheritance of Pod Spininess**

A monofactorial mode of inheritance was observed in pod spininess in the cross of Clemson Spineless-11 (spineless) with P.I. 204545-1 (spiny pods).

After testing the data statistically, it was noted that the deviation of the F₂ from the 1:2:1 ratio and the deviation of the backcross from 1:1 ratio were such as to allow the conclusion that the mode of inheritance of pod spininess in *Hibiscus esculentus* was governed by one pair of genes. The absence of the spines on the pods may be represented by the homozygous aa and the presence of spines by the symbol AA.
The scheme of inheritance would be:

1. Parents
   - Spineless aa  Spiny AA

2. F1 generation
   - Intermediate Aa

3. F2 generation
   - Spineless aa, Intermediate Aa and Spiny AA

4. Backcrosses
   - Spineless aa, Intermediate (to the spineless parent)
   - Spiny AA, Intermediate (to spiny parent)

The spineless and the spiny parents always breed true. The intermediate plants, when selfed gave a ratio of 1 spineless : 2 intermediate : 1 spiny pods.

Whether the spines character was carried in the female or the male plant made no difference in the character transmission.

**Inheritance of Pod Shape**

From the results obtained in the cross of Clemson Spineless-15 (angular) with Louisiana Green Velvet (round) and its reciprocal, the inheritance of fruit shape showed that in the F1 the fruit exhibited a peculiar type of blending of both characters. The fruits were angular at the top and round at the base. It appeared from the results found in the F2 and backcross progenies that the angular and round parents differed by two pairs of genes. The fruits are completely angular when both pairs...
of the dominant genes are present together in a homozygous condition. The presence of both pairs of the recessive genes caused the fruits to be round. The angular parent may be represented by AABB and the round pod parent by aabb. The F₁ plants would have the genetic constitution AaBb for pod shape.

The segregations obtained in the F₂ as well as in the backcross generations are given below:

<table>
<thead>
<tr>
<th>F₂ genotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 AABB</td>
</tr>
<tr>
<td>2 AABb</td>
</tr>
<tr>
<td>2 AaBB</td>
</tr>
<tr>
<td>4 AaBb</td>
</tr>
<tr>
<td>1 AAbb</td>
</tr>
<tr>
<td>2 Aabb</td>
</tr>
<tr>
<td>1 aaBB</td>
</tr>
<tr>
<td>2 aaBb</td>
</tr>
<tr>
<td>1 aabb</td>
</tr>
</tbody>
</table>

Backcross to Clemson Spineless-15 (angular)

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 AABB</td>
</tr>
<tr>
<td>1 AABb</td>
</tr>
<tr>
<td>1 AaBB</td>
</tr>
<tr>
<td>1 AaBb</td>
</tr>
</tbody>
</table>

Backcross to Louisiana Green Velvet (round)

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 AaBb</td>
</tr>
<tr>
<td>1 Aabb</td>
</tr>
<tr>
<td>1 aaBb</td>
</tr>
<tr>
<td>1 aabb</td>
</tr>
</tbody>
</table>
The expected ratio of 12:3:1 can be explained by assuming that any $F_2$ plant with $A$ in the homozygous condition and in combination with either the homozygous or heterozygous $B$ gives angular shape.

When $A$ is in the heterozygous form or $a$ is in the homozygous condition in combination with $BB$ or $Bb$ angular-round pod shape is obtained. In addition to this any homozygous $A$ combined with homozygous $bb$ also gives angular-round like the $F_1$ plants.

The combination of $aa$ with $bb$ gives round as the round parent.

An expected ratio of 11:4:1 can be explained by the fact that $F_2$ plants homozygous for one pair of genes, $AA$ in combination with $B$ or $b$ gives angular pod shape like the angular parent, while any heterozygous $A$ in combination with $BB$, $Bb$ or $bb$ gives angular-round. In addition to this any homozygous recessive combined with homozygous or heterozygous $B$ also gives angular-round shape. Only plants which are homozygous for both pairs of recessive genes will be round.

Regarding the backcross to the angular parent, any plant homozygous dominant for one of the genes for angular ($AA$) will be angular. All heterozygous for these genes will be angular-round like the $F_1$.

Regarding the backcross to the recessive parent (round), all plants with the heterozygous $Aa$ combined with $Bb$ or $bb$ and the homozygous $aa$ with the heterozygous $Bb$ gives angular-round pods like the $F_1$ plants. Only plants which are homozygous recessive for both pairs will be round.
Grouping together the various genotypes according to their phenotypic expressions two phenotypic ratios are possible: 12 angular-round : 3 angular : 1 round, and 11 angular-round : 4 angular : 1 round.

When the F₁ was backcrossed to the angular parent, a 1 angular : 1 angular-round was obtained. The F₁ backcrossed to the round parent gave a 3 angular-round : 1 round ratio.

These results presented above lead to the conclusion that there is a digenic difference between the angular and round pod character.

This suggests that the gene for angular pod is epistatic to the gene for round pod.

Miller and Wilson (26) and Kalia and Padda (14) reported inheritance in respect to pod shape. They crossed angular and round podded type of okra. The F₁ gave a typical type of blending with the upper part of the pod being angular and the lower part round. In the F₂ a ratio of 15:1 was obtained. They postulated that two pairs of genes controlled pod shape. However, they obtained this 15:1 ratio by grouping pods of angular shape with pods like the F₁. They classified this F₁ as intermediate.
SUMMARY

A study was made over a three-year period of the mode of inheritance of five okra characters: leaf shape, plant height, pod color, pod spininess and pod shape. The method used consisted of crossing pure line parents that differed widely in these characters and studying the F₁, F₂, and backcross generations in comparison with the parents.

Crosses between C-48-1 (cut leaf) and Louisiana Green Velvet (lobed leaf) showed that cut leaf was completely dominant over lobed leaf. The segregation frequency in the F₂ and backcross generations showed that leaf shape was inherited on a monofactorial basis.

Inheritance of plant height was studied in the cross of Louisiana Green Velvet (tall) with Gold Coast (dwarf). It was found that this character was qualitative in nature. The heterozygous F₁ was intermediate in height to the parent strains. Segregation in the F₂ was 1 tall, 2 intermediate, 1 dwarf. The breeding behavior of the backcrosses confirmed the F₂ segregation, indicating that plant height was governed by one pair of genes.

Pod color character was studied by crossing Campbell Soup Co. 48-2 (C-48-2), white pod, with Gold Coast, green pod. White was dominant as all F₁ plants had the same pod color as the white pod parent. The mode of segregation in the F₂ was 3 white : 1 green pod.
In the backcross to the green pod parent the ratio was 1:1, while the backcross to the white pod parent all the plants produced pods of a white color. It was concluded that the inheritance of pod color was governed by a single pair of genes.

Inheritance of pod spininess was calculated from crosses involving Clemson Spineless-11 (spineless) with P.I. 204545-1 (spiny). Pods from F₁ plants between the two types were intermediate in spines. The F₂ and test cross gave ratios of 1:2:1 and 1:1, respectively. This indicated a monogenic nature of segregation for this character.

Pod shape was studied by crossing Clemson Spineless-15 (angular) x Louisiana Green Velvet (round). The F₁ showed an unusual blending of the two shapes in all pods, followed by a dihybrid ratio of 12:3:1 or 11:4:1 for angular-round, angular and round shapes, respectively, in the F₂ generation. The digenic nature of pod shape in this cross was confirmed in the backcross generations. The round and angular pod parents in this cross thus differed from each other by two pairs of genes.
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AUTOBIOGRAPHY

Abdul Jabbar Jasim was born on March 3, 1927 in Amarah, Republic of Iraq.

He received his primary and secondary education in Iraqi public schools. He entered the Agricultural high school in Abu-Ghraib, Baghdad in September, 1946, graduating in June, 1949.

From 1949 to 1954 he was employed by the Ministry of Agriculture in the Horticulture Experiment Station in Baghdad. In August, 1954 he was picked by the Government of Iraq to study Horticulture in the United States of America. In the fall of the same year, he entered Kansas State University, Manhattan, Kansas and received his Bachelor of Science in Horticulture in June, 1958. He then returned to work in the same Experiment Station in Baghdad until 1962; in this year he was married to Samira M. Kaisi.

In August, 1962 he was sent again to study Horticulture in the United States of America. He entered the Graduate School of the University of Arizona, Tucson, in September, 1962 and received a Master of Science degree in Horticulture in January, 1964. In the spring of 1964 he entered Louisiana State University and is now a candidate for the degree of Doctor of Philosophy in the Department of Horticulture.
EXAMINATION AND THESIS REPORT

Candidate:  Abdul Jabbar Jasim

Major Field:  Horticulture

Title of Thesis:  Inheritance of Certain Characters in Okra (Hibiscus esculentus L.)

Approved:

[Signature]
Major Professor and Chairman

[Signature]
Dean of the Graduate School

EXAMINING COMMITTEE:

[Signature]

[Signature]

[Signature]

Date of Examination:

December 7, 1966