Effect of Spacing on Seed, Protein, and Oil Production of Four Okra Varieties[1]

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ABSTRACT

The yield of okra seed of several varieties was measured as affected by spacing during summer and winter planting. Winter plantings were stunted by short day length but two varieties, Evergreen Velvet and White Velvet, were partially adapted to the winter season. During summer plantings the variety Clemson Spineless outyielded other varieties in seed, oil, and protein yields. A major factor in superior yields was a high seed per pod yield. In addition, this variety yields well at high population densities. The optimum population densities were calculated by quadratic regression. For high-yielding varieties, optimum densities are 6–8 plants per square meter. The protein and oil yields obtained compare favorably with those of other protein and oil producing crops of the tropics.

INTRODUCTION

Interest in okra as a seed crop yielding protein and oil has been stimulated by Karakoltsides and Constantinides (9), who pointed out the previously unrecognized potential of this vegetable.

Okra appears to be a very desirable crop for the tropics. It is widely adapted and in some areas, such as Brazil, so trouble-free that it is considered a crop that always pays for the effort of planting it. Okra can be produced even during the rainy season, when other grains are very difficult to grow. The seeds of okra are produced in abundance and in some varieties are held in the pod for long periods without shattering. The seeds are easy to harvest, clean, and store, by simple as well as large-scale techniques. They can be milled and sifted to provide a useful meal or extracted with water, and protein and oil can be precipitated by simple techniques (11). As a crop for small and for large scale production, okra seed merits study.

Most studies of okra production concern only the harvest of the immature green pod used as a vegetable. Techniques for production of the vegetable are so different from those for the production of seeds that the former studies need no review here. In Louisiana about 2240 kg/hectare (2000 lb) per acre has been considered a good yield (12).

It is easily observed that during summer months okra plants tend to grow to fit the space allotted to them. Plants with as much as a meter of growing space become very large and bear many pods. As spacing

decreases, the size of plant decreases, as does its fruit production. There-fore, two distinct tendencies can be seen. As plant population density increases, fruit yield increases, but yield per plant decreases. Abregts and Howard (1) found that in okra fields harvested for green fruits, yields increased on a double logarithmic scale for plant population of 16, 32 and 64 plants/m². Nevertheless, a limit to yield might be expected at densities where yield per plant decreases with increased plant density at the same rate that yield increases with increased number of plants.

In India, yields of dried seed of the variety Pusa Sawani increased as space between plants decreased from 60 through 45 to 30 cm (6). Plants could be picked twice for green pods without reducing subsequent seed production. June plantings were more productive than earlier plantings. Apparently optimum densities for maximum seed production were not reached.

The studies reported here were made to find appropriate densities for okra seed production in the hot tropics of Puerto Rico.

MATERIALS AND METHODS

Seed production was studied in two experiments in Coto clay soil, an acid Oxisol (pH about 5.5) in Isabela, Puerto Rico. The first experiment was planted November 27, 1977, an off-season planting date, and consisted of eight commercial varieties: Dwarf Green Long Pod, Clemson Spineless, Red River, Perkin's Spineless, White Velvet, Red Okra, Pusa Sawani, and Evergreen Velvet. Each plot consisted of a single row 3.05 m long (10 ft.). Plants were established by direct seeding and thinning at 23 cm (9 in) and 30.5 cm (12 in) intervals. Each variety-distance combination was replicated three times.

Plants were observed for mature height, capsule length, capsule type, capsules per plant, and grams of seed per plant. The yield was extrapo-lated to estimated yield per hectare.

For the second planting, July 11, 1978, four commercial varieties were used: Evergreen Velvet, Red Okra, White Velvet, and Clemson Spineless. Each plot was 3.7 m wide wide and 4.6 m long (12 × 15 ft). The spacing within plots varied as follows:

Plot number	Space between rows, cm (in)	Space between plants in row, cm (in)	Areas/plant M²	Ft²
1	46 (18)	23 (9)	.10	1.12
2	61 (24	23 (9)	.14	1.50
3	91.5 (36)	23 (9)	.21	2.25
4	122 (48)	23 (9)	.28	3.00
5	46 (18)	30.5 (12)	.14	1.50
6	61 (24)	30.5 (12)	.19	2.00
7	91.5 (36)	30.5 (12)	.28	3.00
8	122 (48)	30.5 (12)	.37	4.00
9	46 (18)	46 (18)	.21	2.25

Plot number	Space between rows, cm (in)	Space between plants in row, cm (in)	Areas/plant M^2	Ft^2
10	61 (24)	46 (18)	.28	3.00
11	91.5 (36)	46 (18)	.42	4.50
12	122 (48)	46 (18)	.56	6.00
13	46 (18)	61 (24)	.28	3.00
14	61 (24)	61 (24)	.37	4.00
15	91.5 (36)	61 (24)	.56	6.00
16	122 (48)	61 (24)	.74	8.00

The plantings were made as a randomized split block design with four replications. Thus, there were 256 individual plots, each 16.73 m² (180 ft²).

In spite of these careful preparations, germination was often poor and stands were seldom what was expected. Therefore, the actual numbers of plants surviving to flowering stage were counted and from these counts, actual populations per hectate were calculated.

Plants of the second planting were left in the field until the majority had matured all seed pods (December 7). Plant height was measured three times during the growing season and capsule lengths were measured once. Dry capsules were harvested as necessary and were further dried by exposure to the sun. The seeds were separated from the capsule, and the two fractions were weighed.

The data were subjected to analysis of variance with respect to principal varietal differences. Data were also analyzed by regression of weight of seeds on actual population. This technique permitted graphical comparisons of varieties as well.

The okra plants were grown without irrigation. Actual rainfall and maximum and minimum temperatues follow:

	Rainfall (mm)	Maximum temperature (C)	Minimum temperature (C)
July	126	30.0	21.1
August	236	30.6	21.6
September	182	30.0	20.6
October	130	30.0	23.9
November	56	28.9	20.6
December	8	29.4	20.6

Samples of seed from the plots were tested for protein by AOAC methods (7) and for oil by techniques of the American Oil Chemists' Society (2).

RESULTS

The first planting of okra, made near the beginning of the season of short day lengths (winter), was stunted normally due to the short-day response of all varieties. Nevertheless, varietal differences were apparent. Table 1 gives the characteristics of the plants, the yields, and the

estimated yields per hectare of seeds. Particularly impressive were the varieties Evergreen Velvet and White Velvet. These varieties are slow to develop, but plants become larger and are heavy bearers. They can be considered possible winter varieties for Puerto Rico. The capsules of Evergreen Velvet were the largest, but those of White Velvet were the smallest. Seed yields were about equal for the two cultivars, but they responded differently to the two spacings (table 1). Total yields were very good considering that the planting was off-season. The standard variety Clemson Spineless did not yield well during the winter season. The horn or nondehiscent capsule type found in the two velvet varieties was observed to be superior for seed production purposes, for it holds the seed

TABLE 1.—*Seed yields and other characteristics of eight okra seed varieties in off-season (winter) plantings*

Variety	Spacing	Plant height	Capsule length	Capsule type[1]	Actual yield	Extrapolated Yield
	Cm	*M*	*Cm*		*G/plant*	*Kg/hectare*
Evergreen Velvet	23	.80	18	ND	578	830
	30.5	.67	18	ND	719	1032
Pusa Sawani	23	.48	15	D	428	614
	30.5	.69	15	D	294	422
Red Okra	23	.73	18	ND	347	498
	30.5	.87	16.5	ND	280	402
White Velvet	23	1.04	11	ND	837	1201
	30.5	1.10	13	ND	524	752
Red River	23	.86	13	ND	319	457
	30.5	.82	13	ND	279	400
Clemson Spineless	23	.78	15	D	465	667
	30.5	.70	15	D	310	445
Dwarf Green Long	23	.56	14	D	492	706
	30.5	.60	14	D	406	583
Perkin's Spineless	23	.79	13	ND	512	735
	30.5	.57	11	ND	298	428

[1] D = dehiscent; ND = not readily dehiscing.

on the plant for a long period of time and shelters the seed from frequent wetting in light showers.

Most plants reached only about 1 m of height, 40 to 60% of the height expected in summer planting. Capsules were somewhat shorter than those from comparable summer plantings (see table 2 for comparable data).

For all cases except Evergreen Velvet, seed yield was reduced at the 30.5 cm spacing as compared to the 23 cm spacing. Average seed yield at 30.5 cm spacing was 558 kg/hectare, compared to 713 kg/hectare for the 23 cm spacing. Thus, increasing population density by 33% increased seed yield by 28%. Optimum spacing for maximum seed yields for winter plantings is probably less than 23 cm between plants.

Tables 2 and 3 show differences in cultivars observed in the summer planting. Table 3 shows those characteristics that were subject to analysis of variance. Significant differences were found in each characteristic. The highest seed yield per plot was in the variety Clemson Spineless, yet this variety had neither more plants per plot nor capsules per plot. The lowest seed yield per plot was in White Velvet, the variety with the largest population, yet with the fewest capsules per plot. The amount of seed in all varieties represented 52–54% of the weight of the capsules (seed and chaff).

Table 2 gives characteristics of individual plants. Plants were much taller and capsules were slightly longer in the summer than in the winter

TABLE 2.—*Differences in plant characteristics of four okra varieties during the summer planting*

Variety	Mature height	Capsule length	Capsules/ plant	Weight of seeds/ plant	Weight of chaff/ plant	Weight of seeds/ capsule
	Cm	*Cm*		*g*	*g*	*g*
Evergreen Velvet	288	22.1	21.4	85	79	3.99
Red Okra	151	22.8	12.1	59	53	4.88
Clemson Spineless	147	19.2	14.7	85	77	5.79
White Velvet	247	15.6	10.5	42	36	4.26

TABLE 3.—*Differences on a plot basis of selected characteristics of four okra varieties in the summer planting*

Variety	Plants per plot	Capsules per plot	Weight of seed	Weight of chaff
			Kg/plot	*Kg/plot*
Evergreen Velvet	36.47 b[1]	780 a	3.11 b	2.88 b
Red Okra	52.77 a	639 ab	3.12 b	2.82 b
Clemson Spineless	49.86 a	732 ab	4.24 a	3.83 a
White Velvet	57.35 a	603 c	2.44 c	2.07 c

[1] Means followed by the same letter(s) do not differ significantly at (P = .05).

planting. Seed yields per plant were much higher in Clemson Spineless and Evergreen Velvet than in the other two varieties. Clemson Spineless had relatively few capsules with a high seed weight, while Evergreen Velvet had many capsules, but with fewer seeds per capsule. Seeds per capsule does not appear to be closely related to the length of the capsule. These data help explain Clemson Spineless high plot yields, which are clearly related to high seed yields per capsule.

Table 4 gives the seed yields of the four cultivars, extrapolated from plot yields to ton/hectare. Although population size varied by a factor of 11, seed yields varied by a factor of about 3. This can be explained from the observation that plants are larger and produce more capsules when

populations are low. Thus, as populations increase in size, plants are stunted, but up to a point yields may still increase.

The relationship between population size and seed yield can thus best be studied by regression. Because varieties differ in response to population size, this regression is best calculated separately for each variety. Furthermore, because two opposing tendencies influencing seed production occur, i.e., increase of total seed yield with increased plant density, and decrease of seed yield per plant with increased plant density, the relationship between seed production and density would not be expected to be linear over all population densities.

Regression analysis showed that yields of seed are related to plant densities by a quadratic relationship. Table 5 gives the regression equations best relating yield to plant density. The statistical probability of

TABLE 4.—*Range of seed yields (tons/hectare) of four okra varieties during the summer planting*

Variety	Seed yield			Calculated for optimum population
	Low	Mean	High	
Evergreen Velvet	0.64	1.84	3.26	2.30
Red Okra	.98	1.87	2.92	2.26
Clemson Spineless	1.18	2.54	4.00	3.33
White Velvet	.54	1.46	2.45	1.88

TABLE 5.—*Quadratic regression of seed weight on number of plants per plot*

Variety	Regression equation	P	r
Evergreen Velvet	$WS = 1.0337 + 0.0877 \, (PPP) - 0.000658 \, (PPP)^2$	.0121	.63
Red Okra	$WS = 1.6371 + 0.0408 \, (PPP) - 0.000194 \, (PPP)^2$	.0956	.60
Clemson Spineless	$WS = 2.3832 + 0.0501 \, (PPP) - 0.000196 \, (PPP)^2$	.0246	.64
White Velvet	$WS = 0.3985 + 0.0575 \, (PPP) - 0.000300 \, (PPP)^2$	.008	.60

this relationship is given in the probability column, and because it is less than .05 in all cases but that of the cultivar Red Okra, it signifies that the data fit this hypothesis. The correlation coefficients of actual data with the theoretical curves are given in the final column. These correlations are fairly high. It is supposed that yields are also influenced by other factors such as microclimate, soil fertility, drainage, etc., so higher correlations are not expected.

Figure 1 shows curves of the seed yields that can be expected for the four varieties. Three of the four curves are similar in shape although they differ in height. That of Evergreen Velvet is completely different and may reflect a basic physiological difference. The curves all reach a broad maximum that suggests that seed yields will be about the same for populations that differ considerably. For example, the curve suggests that
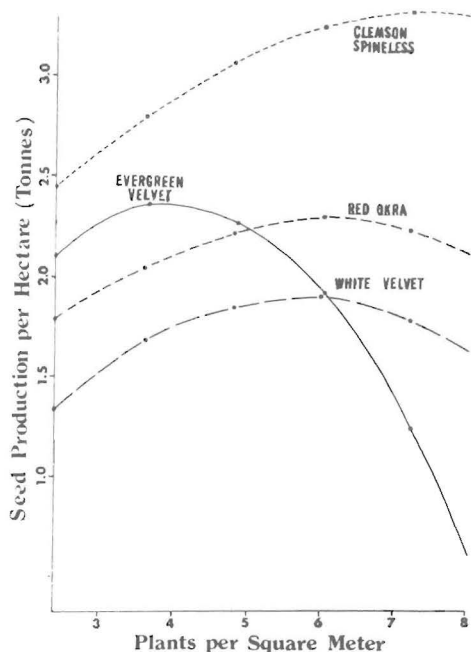
FIG. 1.—Seed yield of four okra varieties planted at the Isabela Substation July, 1978.

TABLE 6.—*Populations and spacings expected to maximize seed yields of four varieties of okra*

Variety	Approximate optimum population per hectare	Suggested spacing (cm)	
		Optimum	Practical
Evergreen Velvet	36,000	53 × 53	28 × 100
Red Okra	60,000	41 × 41	17 × 100
Clemson Spineless	72,000	37 × 37	14 × 100
White Velvet	60,000	41 × 41	17 × 100

maximum seed yields can be obtained in the case of Clemson Spineless with 6 to 8.6 plants per meter (58,000–86,000 plants/hectare).

Table 6 gives the optimum populations per hectare, as calculated from regression analysis, and also appropriate spacings. Clemson Spineless, the highest yielding variety, is the variety that can tolerate the closest spacing. Yields predicted on the basis of optimum population are compared to lowest, mean, and high yields in table 4. Highest yields actually obtained were higher than those predicted from the regression analysis because such analysis is based on average, not on extremes.

Table 7 shows the contents of oil and protein measured in seeds of the

four varieties. These represent measurements of the seed actually harvested from the plots. No attempt has been made to evaluate the effect of plant density on the oil and protein content of the seed itself.

The actual percentage of oil and protein were extrapolated to production per hectare at the optimum populations, as calculated from the

TABLE 7.—*Content oil and protein yields (kg/hectare) of four okra varieties based on calculated yields for optimum population, and on highest plot yields*

Variety	Measured content percent		Protein		Oil	
	Protein	Oil	Optimum Population	Best plot	Optimum population	Best plot
Evergreen Velvet	18.43	20.5	423.9	600.8	471.5	668.3
Red Okra	19.37	24.3	437.8	565.6	549.2	709.6
Clemson Spineless	19.72	24.1	657.7	788.8	802.5	964.0
White Velvet	20.98	19.8	394.4	514.0	372.2	485.1

TABLE 8.—*Protein production in kg/hectare of some important crop plants, as compared to okra*

Crop group	Species or variety	Kg/ha protein	Source
Okra	Clemson Spineless	658	These experiments
	White Velvet	394	These experiments
	Evergreen Velvet	424	These experiments
	Red Okra	438	These experiments
Cereals	Maize	504	Kaul (9)
	Wheat	752	Kaul (9)
	Buckwheat	480	Dendy et al. (5)
	Quinoa	160	Dendy et al. (5)
	Teosinte	168	Dendy et al. (5)
Pulses or legumes	Mung bean	200	Kaul (9)
	Red gram	348	Jeswani (8)
	Urd bean	338	Jeswani (8)
	Bambarra groundnut	160	Dendy et al. (5)
	Cowpea	330	Dendy et al. (5)
	Lupin	350	Dendy et al. (5)
Oil seeds	Safflower	435	Betschart et al. (3)
	Sunflower	195	Betschart et al. (3)
	Soybean	750	Circle and Smith (4)
	Sesame	180	Betschart (3)
	Castor	175	Betschart et al. (3)
Vegetables	Potato	412	Kaul (10)
	Pumpkin seed	235	Dendy et al. (5)
	Melon seed	70	Dendy et al. (5)
	Green kale	600	Shepherd (14)
	Edible pod mung bean	632	Munger[3]
	Cabbage	444	Munger[3]

[3] Munger, H., 1979. Personal communication.

regression equations, and the highest producing plot observed. Values per best plot were always higher than values calculated for optimum populations. Clemson Spineless was again the most productive variety.

Yields of protein expected from optimum populations of okra are compared with yields reported from various other crops (table 8). This comparison shows that okra seed can yield as much protein per hectare as almost all important protein crops of the world. Its protein production per hectare is definitely excelled only by that of wheat and soybean.

Table 9 compares the average oil production of okra varieties in this experiment to that of other oil-producing crops. The African oil palm is recognized to be a superior source of oil, far outranking all other sources. However, okra seed appears to be an excellent oil source, capable of yielding at least as much oil as other important oil crops of the temperate zone and the tropics.

TABLE 9.—*Average oil production in kg/hectare of some important crop plants as compared to okra (means per experiment)*

Species or variety	Kg/ha oil	Source
Okra		
Clemson Spineless	612	These experiments
White Velvet	289	These experiments
Evergreen Velvet	377	These experiments
Red Okra	454	These experiments
Coconut	600	Ochse et al. (13)
Oil palm	2200	Ochse et al. (13)
Soybean	300	Betschart et al. (3)
Sunflower	450	Betschart et al. (3)
Safflower	600	Betschart et al. (3)
Sesame	360	Betschart et al. (3)
Peanut	360	Ochse et al. (13)
Flaxseed	225	Betschart et al. (3)
Castor	485	Betschart et al. (3)

DISCUSSION

In this first experiment to determine effects of spacing on seed, protein, and oil production of okra in Puerto Rico, it has been clearly shown that the average production of protein and oil is comparable or superior to protein and oil production of traditional crops of the temperate zone and the tropics. It must be concluded that okra seed is a potentially important protein and oil crop for the tropics.

The comparison of varieties showed that some are much more productive than others. Furthermore, varieties vary in response to different population densities. The yield of the most productive varieties is highest at population densities of six or more plants/m^2. In the testing of existing varieties or the development of new varieties, close spacing should be the

rule in order that potentially productive varieties have the opportunity to demonstrate their usefulness.

RESUMEN

El rendimiento de semilla de quimbombó se midió con respecto a la influencia del espaciamiento entre plantas en siembras de verano e invierno. El crecimiento de las siembras en invierno se retardó en los días cortos, pero dos variedades se destacaron como aptas para esa estación: Evergreen Velvet y White Velvet. En verano la variedad Clemson Spineless rindió mejor que otras en términos de semilla, aceite y proteína. Un factor importante asociado con sus altos rendimientos fue sus numerosas semillas por vaina. Esta variedad rinde bien cuando la siembra es bien densa. Las densidades de siembra óptimas se calcularon a base de regresión cuadrática. De 6 a 8 plantas por m² es la mejor densidad para las variedades de altos rendimientos. Los rendimientos de proteína y aceite comparan muy favorablemente con los de otros cultivos de trópico.

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