CORRELATION OF YIELD, VINE WEIGHT AND EARLINESS IN WATERMELON, *CITRULLUS VULGARIS* SCHRAD

by

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INTRODUCTION

Watermelon (Citrullus vulgaris Schrad.) is one of the top ten commercial truck crops in this country. The plant has been cultivated in America since 1629 (10) and for over 4,000 years in tropical Africa, the place of its origin (9). The commercial production and shipping of fresh melons to distant markets is much more extensive in the United States than anywhere in the world (25). Since the melon's introduction into this country, tremendous improvements in its shipping, cultural and edible qualities have been made.

To continue this improvement, additional basic information is needed concerning its many quantitative and qualitative characters. Although all watermelon varieties are considered to belong to one species, the variation of characters is considerable and complex (17). Many watermelon characters such as rind color, thickness and toughness; seed number, color and size; and flesh color, texture, flavor and sugar content have been studied. Most of the genetic research and breeding have been related to the inheritance of resistance and development of varieties resistant to fusarium wilt (Fusarium oxysporum f. niveum) and anthracnose (Colletotrichum lagenarium).

But in spite of the long time and wide spread cultivation of this crop, the genetic relationship between most watermelon characters has not been thoroughly analyzed. Correlation studies are hindered by environmental influences and by the time required to mature an adequate number of melons. It is a difficult plant species to work with because of the necessity of relatively large row and plant spacing, which results in a large land area required for an experiment. In terms of production per acre and per man-hour, watermelon is reported to be one of the least efficient vegetable crops (13).

This relative inefficiency is associated with yield, vine weight, and earliness of maturity. Discovering and proving the relationship between these three characters would provide useful information for future breeding operations. This thesis presents the results of a study made for the purpose of gathering such information.

REVIEW OF LITERATURE

Collins (3) claimed that nearly all successful breeding has been made possible by the fact that correlations exist. He suggested that the existence of "types" of plants must mean that there are many individuals that possess nearly the same combination of characters, and this is exactly what correlation implies.

Conner (4) emphasized that correlation data dealing with biological material should have the most careful analysis, giving much consideration to the causal agencies. Often these causitive factors are related to a series of cellular reactions which are manifested as correlated characters. The operation of causal factors on character expression is influenced not only by environment but also by genetic factors. These include the degree of linkage, homozygosity, dominance and interaction as well as the number of segregating gene pairs.

Poole and Grimball (18) estimated the number of gene pairs segregating for watermelon fruit weight in the F_2 population of a cross between Northern Sweet (about 3.2 kilos) and Dove (about 8.0 kilos) to be 25. This estimate was based solely on the skewness of F_2 data. They also estimated the number of gene pairs segregating for fruit weight in the backcross to Northern Sweet to be 12. They speculated that Dove was heterozygous for weight genes. Multifactor determination of weight prevented their making linkage estimates. Fruit weight and fruit shape were found to be significantly correlated in some crosses and backcrosses, but not in others. Chung (2) estimated the number of incompletely dominant gene pairs segregating for fruit weight in F_2 populations of a cross between Crimson Sweet (28.61 pounds) and Sugar Baby (6.37 pounds) to be 4. He also found that the fruit weight frequency distributions showed the typical mode of inheritance of quantitative characters.

Weetman (24) found that small size of mature fruit seemed to be dominant over large fruit, if data for fruit weight were plotted arithmetically. If they were plotted logarithmically, the genes for size seemed to lack dominance and had proportional and cumulative effects.

Porter's (19, 20) work indicates that inbreeding does not cause decrease in number of fruits or total yield. He found that inbreeding tended to isolate lines which produce either larger or smaller fruit than the commercial variety. Inbreeding appeared to increase homozygosity of the genes responsible for the factors controlling fruit growth rate.

In a study with cantaloupe (Cucumis melo var. reticulatus Naud.) cultivar PMR 45, R. M. Davis and co-workers (6) demonstrated that rate of fruit growth is faster initially. Early environmental conditions had a dominant effect on final fruit weight. Major field to field differences in fruit weight appeared to be related to variations in the causal factors related to initial fruit growth.

Davis and co-workers (6) also studied the time required for maturation of fruit of the cantaloupe cultivar PMR 45. Over a wide range of environmental conditions, the mean time lapse from the 2-3 inch size fruit to full-slip, allowing a correction factor of 5 to 7 days, was found to be nearly constant from field to field. Parris (17) suggested that earliness in watermelon may be associated with the ability of a variety to thrive under a wide range of environmental conditions.

Mohr's (15) genetic studies indicate that inheritance of the short-internode character is on a monofactorial basis. In the F_2 population from a cross of Bush Desert King with the weakly vegetative Sugar Baby variety, Mohr (16) observed extreme differences in vegetative growth among the plants segregating for short-internode. With inbreeding, he was able to establish short-internode lines with uniform vegetative growth. Porter (20) reported that selfing long-internode lines for 6 generations resulted in uniformity of vegetative growth and did not reduce the average vegetative vigor. Watts (23) reported that in some cases low vegetative vigor characterized glabrous plants derived from irradiated Sugar Baby watermelon seed. When not present in normal sibs, low vegetative vigor was not transmitted to outcross F_1 populations or to the normal F_1's of sib-matings.

Cunningham (5) found that the setting of watermelon fruit tended to check the terminal vegetative growth. After a time, the plants tended to start setting fruit again, so that cyclic setting occurred. This became less pronounced as the plants grew older.

McCollum's (14) experiments with cucumber indicated that the development of fertilized fruits caused a depression in vegetative growth. Decreases in vine growth due to parthenocarpic fruit development and to the early development of fertilized fruits later removed were much less significant than those caused by the production and continued development of normal fruits. McCollum suggested that fruit development was not the primary factor limiting growth, since parthenocarpic fruits did not produce the characteristic inhibitive effects. He postulated that the causal agent was a vine growth retarding substance produced by the young embryos.

It must be concluded that neither the relationship nor the causal influences or modes of inheritance have been definitely established for any of these three watermelon characters: fruit weight, vine weight, or days for maturation.

MATERIALS AND METHODS

The primary purpose of this study was to determine the direction, magnitude, and meaning of the correlations between yield, vine weight, and earliness in watermelon, Citrullus vulgaris Schrad. Two commercial watermelon varieties, Crimson Sweet and New Hampshire Midget, were used as the parent lines, designated P_1 and P_2 respectively. The F_1, F_2, BC_1 (backcross to Crimson Sweet) and BC_2 (backcross to New Hampshire Midget) were also studied.

The seeds, provided by Dr. C. V. Hall, were planted in peat pots in the greenhouse, and later the seedlings were transplanted to the field at Ashland Horticulture Farm in 1968. A spacing of 10 feet within the row, 8 feet between the rows and 9 hills per row with a randomized block design of four replications was used. The total population of 504 plants was distributed in the following proportion: 36 plants for each parent and the F_1, 72 plants for each backcross, and 252 plants for the F_2. Fertilization, irrigation, and other cultural practices in the greenhouse and the field were uniform.

Collection and Recording of Data

The date of opening of every female flower on each plant was recorded and the flower was tagged. Tagging was continued until each plant had set-on at least one fruit. Ripeness was judged from bottom rind color, thumping sound and appearance of rind surface. When the first melon on each plant reached maturity, the entire plant was harvested. All fruits were picked from the vine. The number of mature melons was recorded and their weight in grams was determined. The vines were placed in sacks, oven-dried and weighed, the dry weight being recorded as "vine weight." The number of days from fruit set to harvest was calculated, corrected, and recorded as "earliness." Corrections were made by adding or subtracting days depending on degree of ripeness when the melons were cut. A melon was judged as "ripe" if it had crisp flesh with a relatively high sugar content and a pleasant ("ripe") flavor, as well as a dull green rind color. A melon was judged as "very over ripe" if its flesh was not at all crisp, its sugar content was relatively very low, and its flavor was completely deteriorated. Intermediate degrees of ripeness were judged as either "slightly over ripe" or "over ripe." A melon was judged as "very under ripe" if its flesh was only slightly pink but very crisp, its sugar content was relatively very low, its flavor was bitter ("green"), and its rind was a bright shiny color. Intermediate degrees of ripeness were judged as either "slightly under ripe" or "under ripe." Correction factors for each degree of ripeness are presented below in Table 1. The average weight of the mature melons from each plant was calculated. Melons were split open to verify maturity and the average mature melon weight for each plant was recorded as "yield."

Table 1. Correction factors for earliness.

Degree of ripeness	days
Very under ripe	+6
Under ripe	+4
Slightly under ripe	+2
Ripe	0
Slightly over ripe	-2
Over ripe	-4
Very over ripe	-6

Statistical Analysis

The Pearson or product-moment method was used to calculate correlation coefficients. The value of this coefficient (r) is equal to the mean of the sum of the z-score products for the X and Y pairs of characters. The algebraic definition of the correlation coefficient is stated below:

$$r = \frac{\sum \left(\frac{X-Mx}{Sx}\right)\left(\frac{Y-My}{Sy}\right)}{N}$$

The symbols used in this equation represent the following statistical terms:

r= correlation coefficient

X= individual X-scores

Mx=mean of the x-scores

Y= individual Y-scores

My=mean of the Y-scores

Sx = standard deviation of the x-scores

Sy = standard deviation of the Y-scores

N = total number of individuals

The regression equations were calculated by the least squares estimation procedure. The general regression equation for finding the predicted Y from X is given below:

$$Y = bX - bMx = My$$

The value of b is determined by the following equation:

$$b = \frac{\Sigma (X - Mx)(Y - My)}{\Sigma (X - Mx)^2}$$

EXPERIMENTAL RESULTS

Yield

Analysis of variance of yield data summarized in Table 2 reveals that differences due to lines are highly significant at the 5 per cent level, and those among blocks are non-significant. Frequency distribution histograms of fruit weight for each of the lines are shown in Figs. 1, 2, and 3. The mean weight of Crimson Sweet fruits is 9.693 kg., while that of New Hampshire Midget is only 1.076 kg.

The F_1 and F_2 means are 4.095 and 4.197 kg. respectively, both about intermediate between the two parents. The BC_1 mean is 4.453 kg. and the BC_2 mean is 3.867, both closer to their respective backcross parents. The higher variances obtained for the P_1 and BC_1 are presumed to be due to the larger fruit weights. Because of genes segregating for fruit weight, the

F_2 variance is much higher than for any of the other lines.

Table 2. Analysis of variance of yield.

Source	DF	SS	MS	F
Blocks	3	0.250	0.083	0.512
Lines	5	194.250	38.850	239.398
Error	15	2.426	0.162	
Total	23	196.926		

Vine Weight

Analysis of variance of the vine dry weight data is presented in Table 3. Differences due to lines are highly significant at the 5 per cent level. Differences among blocks are non-significant. The mean dry vine weight of the Crimson Sweet parent is 1.661 kg., whereas the mean dry vine weight for New Hampshire Midget is .614 kg. The F_1, F_2, BC_1 and BC_2 means are 1.046, 1.040, 1.402, and .852 kg. respectively. Histograms showing the distribution of vine dry weight for the 6 lines are shown in Figs. 4, 5, and 6. These histograms show the typical mode of inheritance of quantitative characters.

Table 3. Analysis of variance of vine weight.

Source	DF	SS	MS	F
Blocks	3	0.043	0.014	0.538
Lines	5	2.840	0.568	21.846
Error	15	0.387	0.026	
Total	23	3.270		

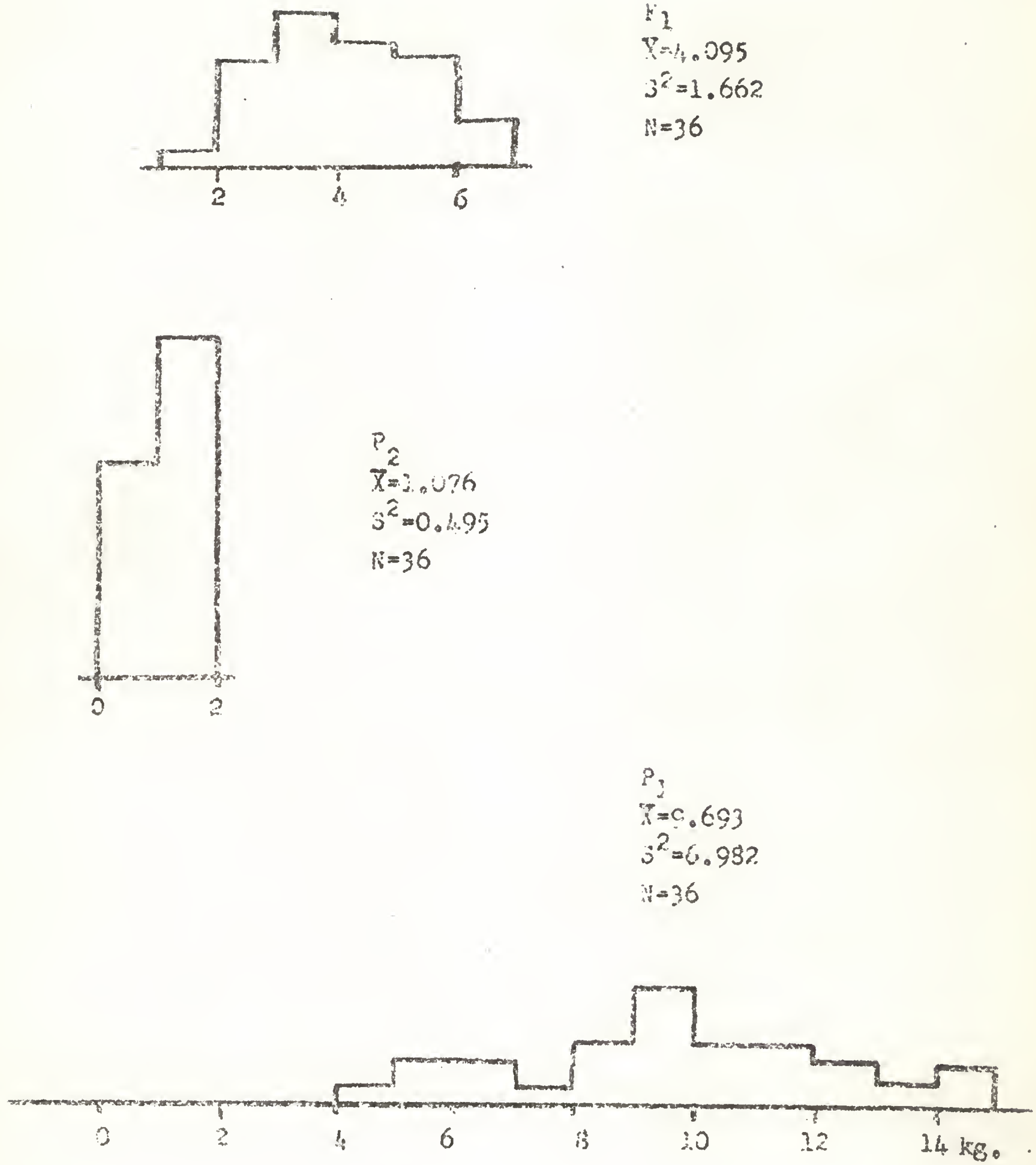

Fig. 1. Frequency distribution of yield in parents and F_1.

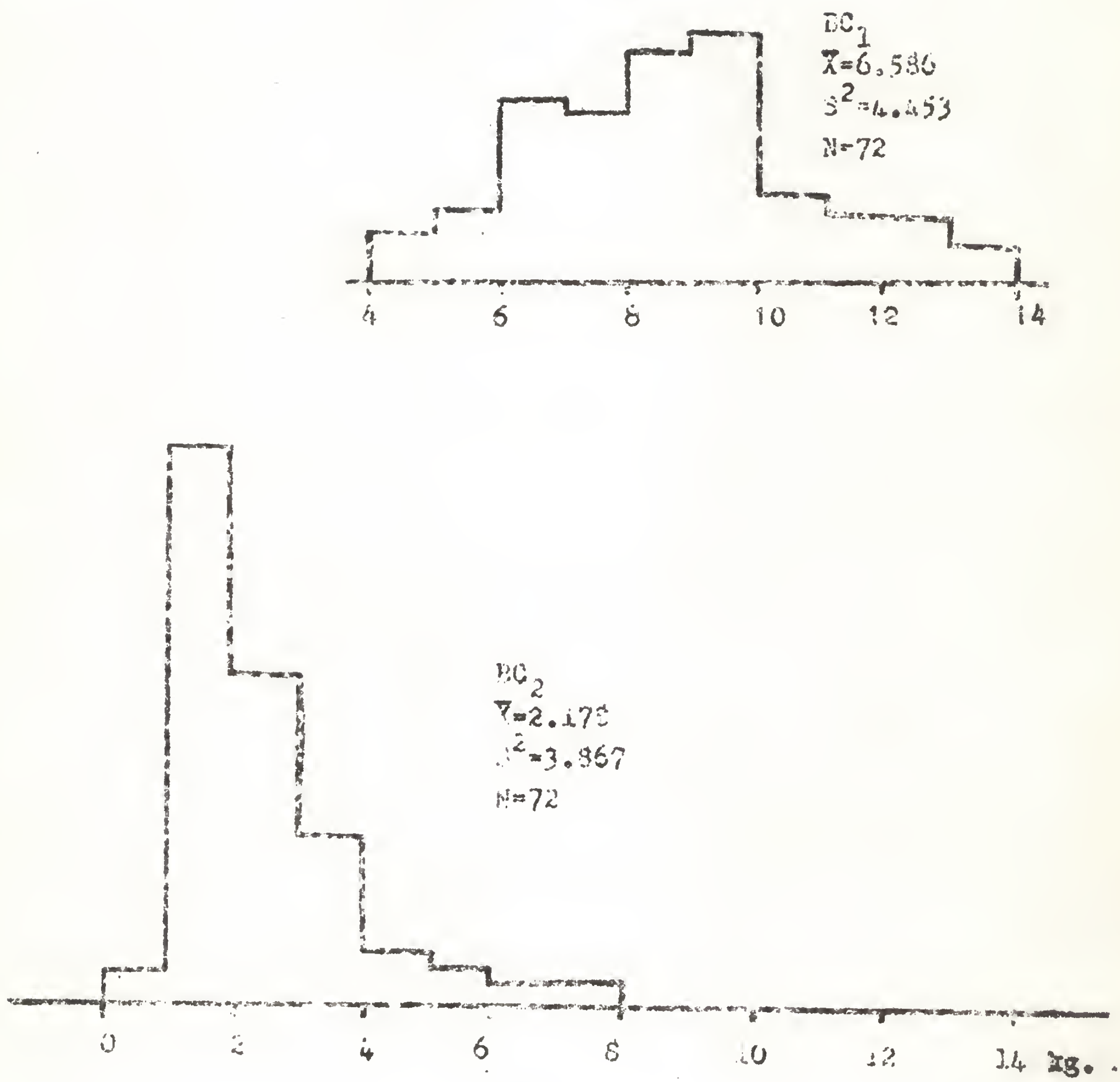

Fig. 2. Frequency distribution of yield in BC_1 and BC_2.

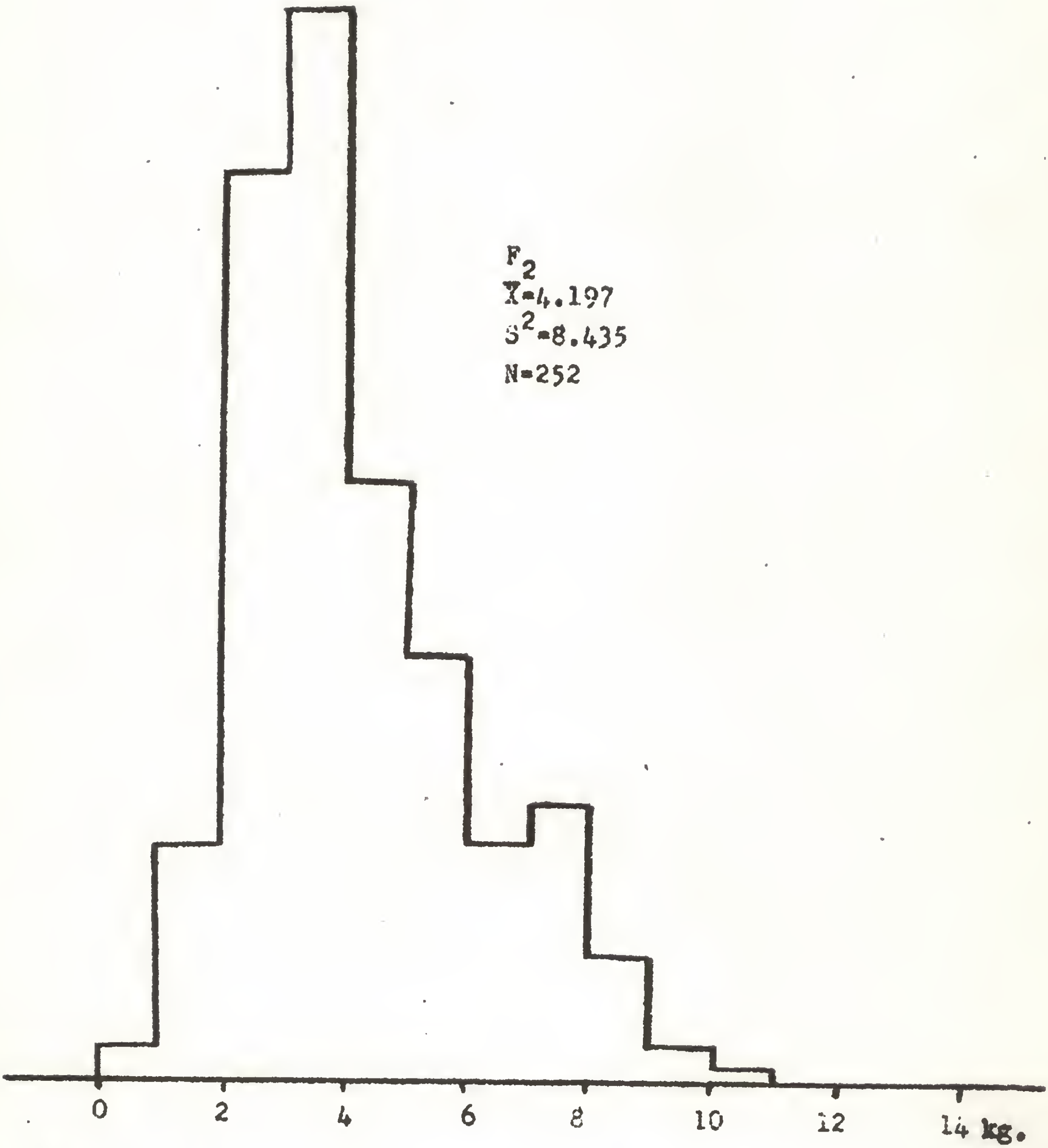

Fig. 3. Frequency distribution of yield in F_2.

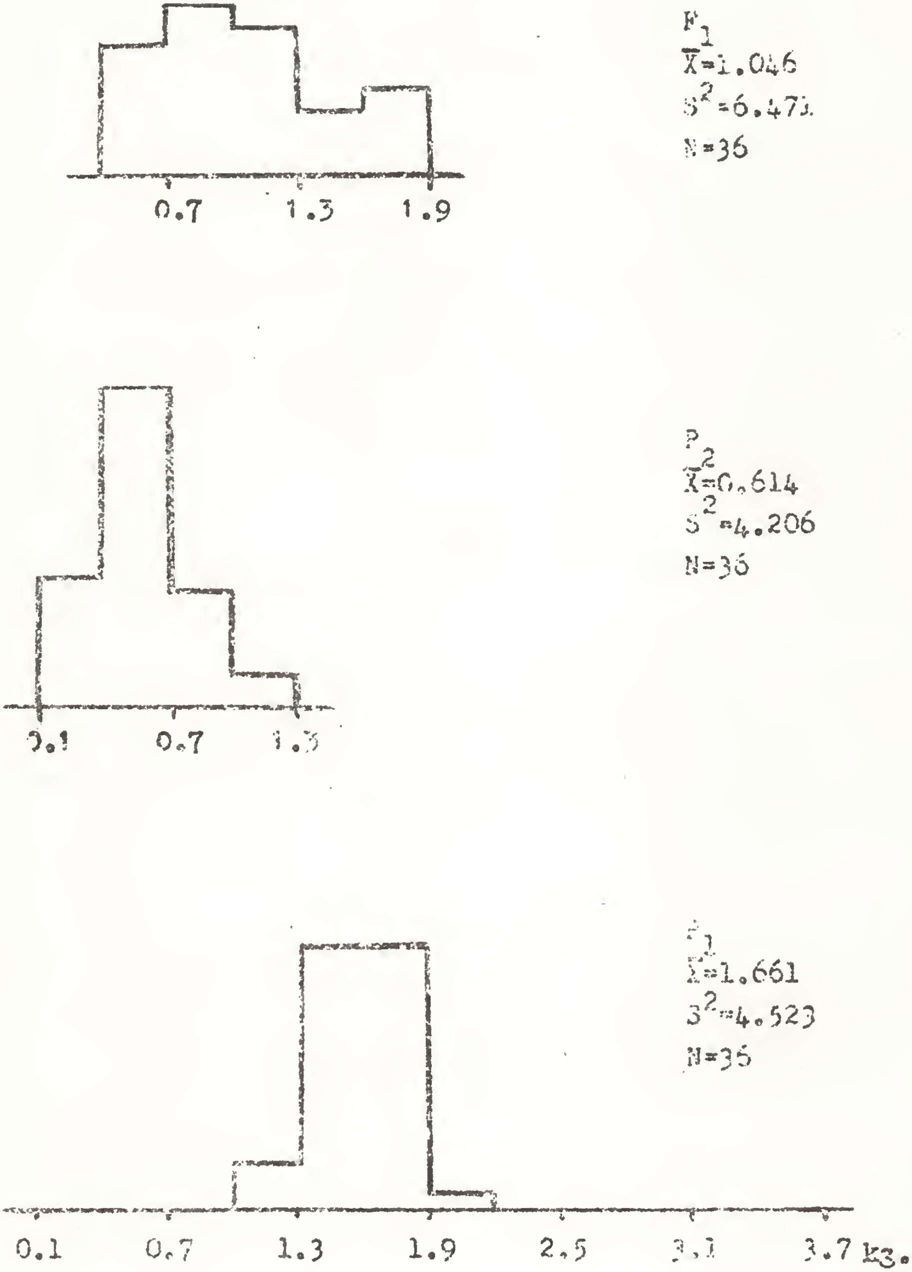

Fig. 4. Frequency distribution of vine weight in parents and F_1.

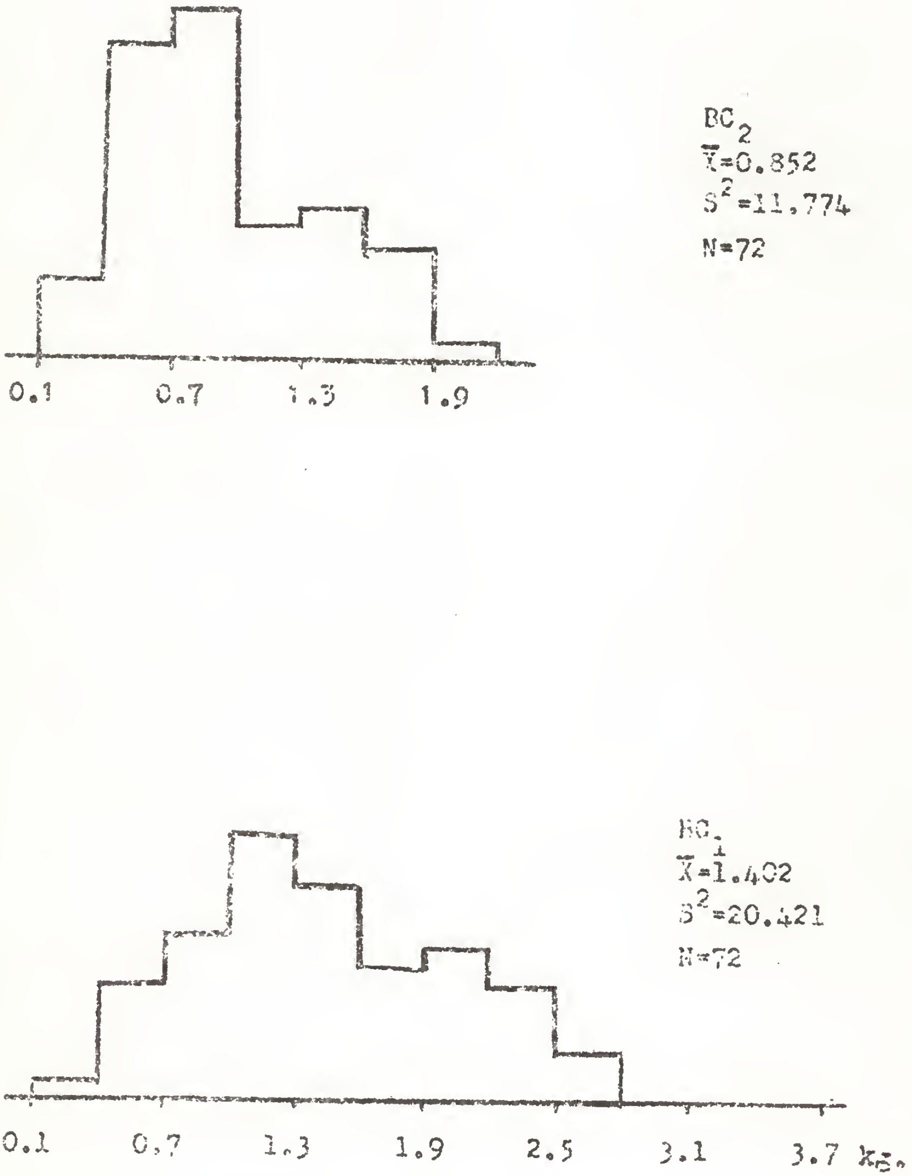

Fig. 5. Frequency distribution of vine weight in BC_1 and BC_2.

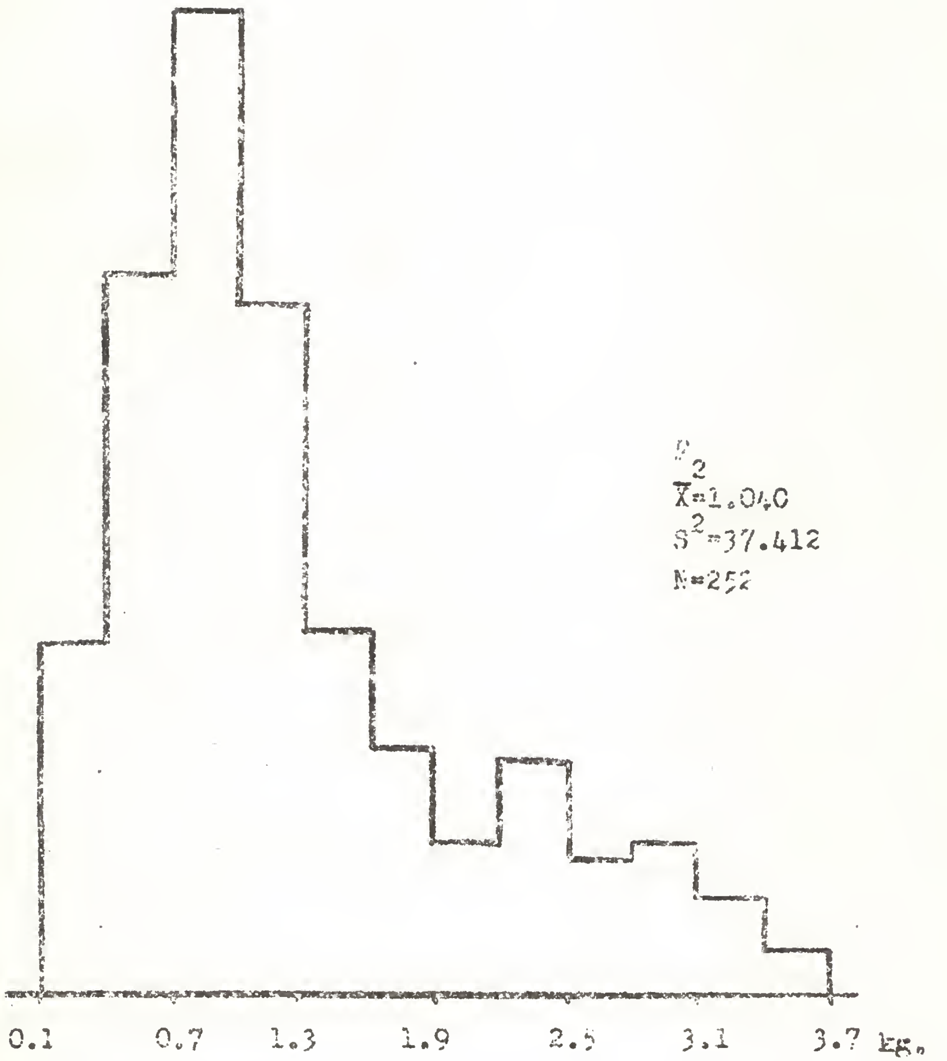

Fig. 6. Frequency distribution of vine weight in F_2.

Earliness

Analysis of variance of data for the number of days for maturation (Table 4) shows significant differences between lines at the 5 per cent level. The differences due to blocks are only very slightly significant at the 5 per cent level. The observed value of the inverted beta (F) distribution is 5.439 which is slightly greater than the table value, $F=5.41$ with 3 and 5 degrees of freedom. Significant differences between blocks may have been a result of later harvest of some of the plants in replications 3 and 4. Since differences between blocks were not significant for either mature fruit weight or dry vine weight, delayed harvest was probably not the cause of significant differences observed. A more likely explanation would be the use of inaccurate correction factors. Days were added or subtracted depending on the degree of ripeness of the mature fruit. This was not a precise correction method and depended to a large extent on the consistency of the experimenter's judgment. Considerable experimental error may have resulted due to variation in correction factors used on the plants of the 4 replications. Considering this explanation along with the fact that differences were only slightly significant, it seems reasonable to believe that there were no actual differences between the blocks. Histograms for each of the 6 lines are shown in Figs. 7 and 8. Crimson Sweet had a mean number of days to maturation of 35.86, whereas that of New Hampshire Midget was 26.82. The means of the F_1, BC_1

and BC_2 are 34.35, 35.29 and 28.38 days respectively. The F_2 mean is 33.60 days, and the distribution is skewed in the direction of Crimson Sweet. The F_2 variance is high and individuals in the population cover the entire range of the parents which indicates a segregation of genes governing days for maturation.

Table 4. Analysis of variance of earliness.

Source	DF	SS	MS	F
Blocks	3	46.163	15.388	5.439
Lines	5	307.874	61.574	21.765
Error	15	42.435	2.829	
Total	23	396.472		

Correlation Between Yield and Vine Weight

The correlation coefficients between yield and dry vine weight for each of the six lines are summarized in Table 5. The linear correlation for Crimson Sweet and BC_1 was negative and significant at the 10 and .1 per cent levels respectively. Plants with high yield tended to have a lower dry vine weight than plants with lower yield. All the other lines had positive correlations, which means that plants with high yields tended to have higher dry vine weights than plants with lower yields. The correlation coefficient for New Hampshire Midget was significant at the 1 per cent level whereas that of BC_2 and F_1 were both significant at the .1 per cent level. The F_2 correlation

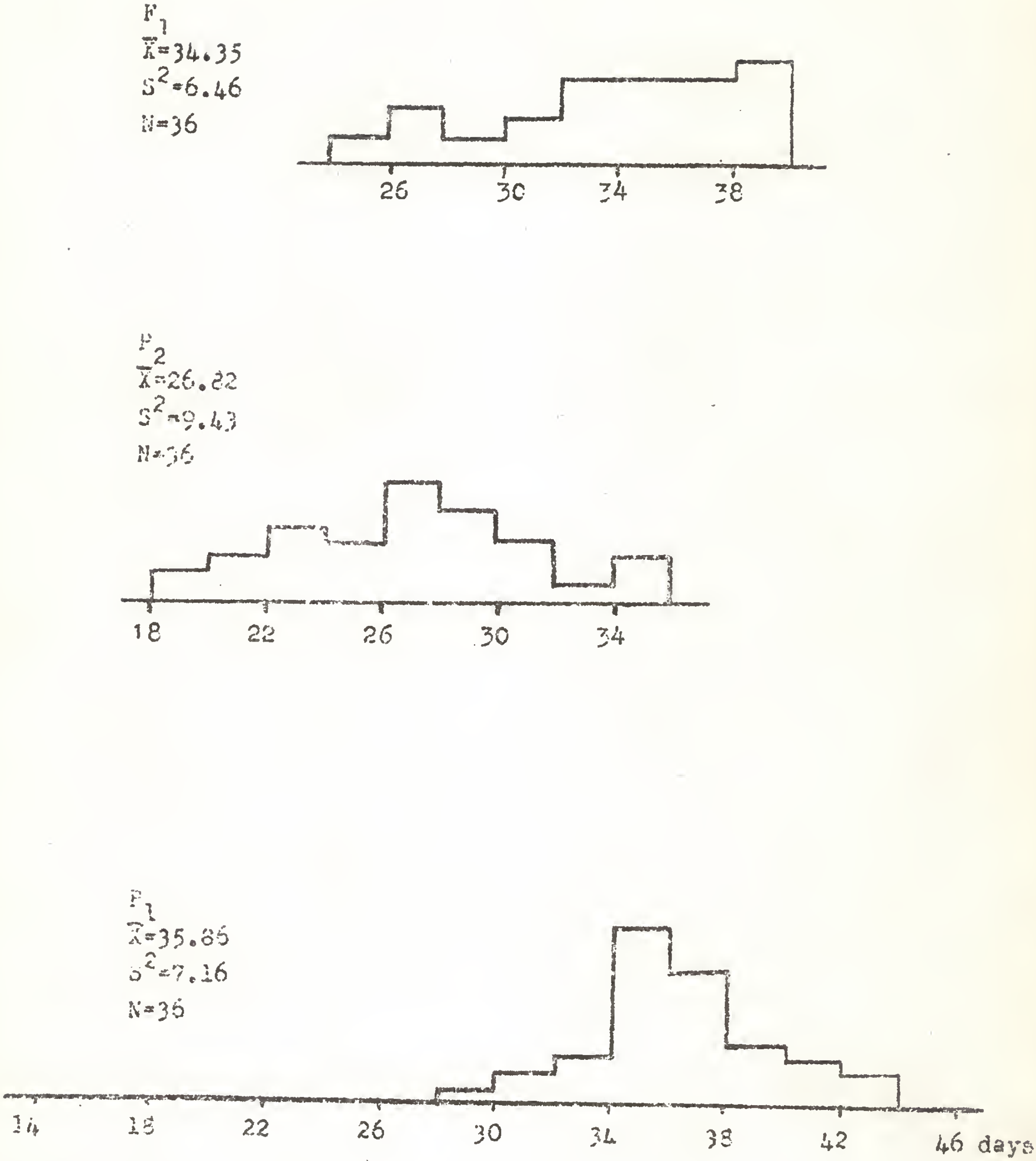

Fig. 7. Frequency distribution of earliness in parents and F_1.

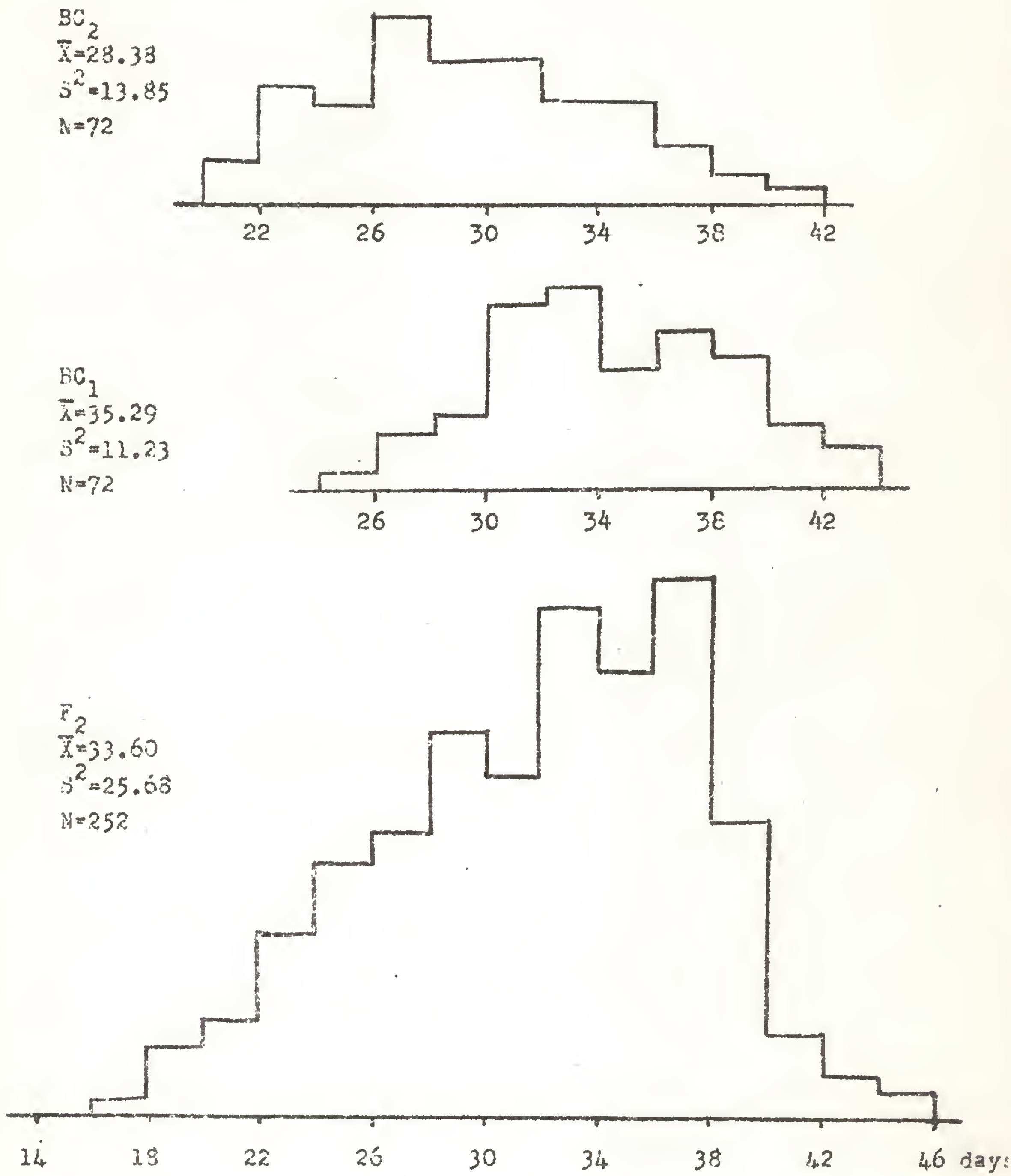

Fig. 8. Frequency distribution of earliness in BC_1, BC_2 and F_2.

was significant at the 2 per cent level. Regression equations and lines for each of the six genetic lines are shown in Table 6 and Fig. 9 respectively.

Table 5. Correlation between yield and vine weight.

Lines	P_1	P_2	F_1	F_2	BC_1	BC_2
Correlation	-.3130	.4888	.5527	.9383	-.5254	.9833
DF	34	34	34	250	70	70
Significance	.1	.01	.001	.02	.001	.001

Table 6. Relation of vine weight to yield.

Lines	Regression equations
P_1	$Y = -.2628X + 4.2083$
P_2	$Y = 2.0831X - 1.6279$
F_1	$Y = 1.0907X - 3.4204$
BC_1	$Y = -1.1252X + 8.8124$
BC_2	$Y = 1.7158X - 2.8851$
F_2	$Y = 1.9761X - 7.2539$

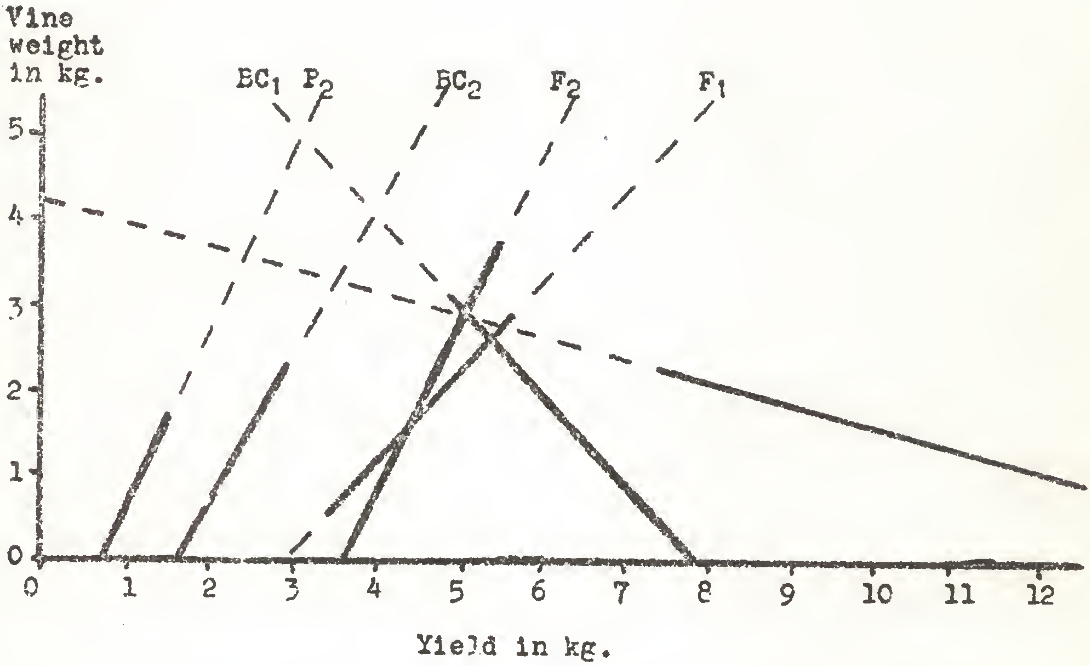

Fig. 9. Regression lines relating vine dry weight to yield.

Correlation Between Earliness and Yield

Table 7 summarizes the correlations between earliness and yield for each of the six lines. The linear correlation between these characters was significant at the 10 per cent level for Crimson Sweet but non-significant for New Hampshire Midget. The F_1 and BC_2 correlations were both negative and significant at the .1 per cent level. The F_2 and BC_1 correlations were both positive and significant at the 2 per cent level. Fig. 10 shows the regression lines and Table 8 shows the regression equations for all of the watermelon lines.

Table 7. Correlation between earliness and yield.

Lines	P_1	P_2	F_1	F_2	BC_1	BC_2
Correlation	.2768	.2159	-.6042	.6159	.2859	-.4732
DF	34	34	34	250	70	70
Significance	.1	*	.001	.02	.02	.001

* non-significant at 10 per cent level.

Table 8. Relation of yield to earliness.

Lines	Regression equations
P_1	$Y = .2732X - .1040$
P_2	$Y = .0493X - .2462$
F_1	$Y = -.3064X + 14.6198$
BC_1	$Y = 1.8003X - 56.9466$
BC_2	$Y = -.2500X + 9.2730$
F_2	$Y = .3529X - 7.6604$

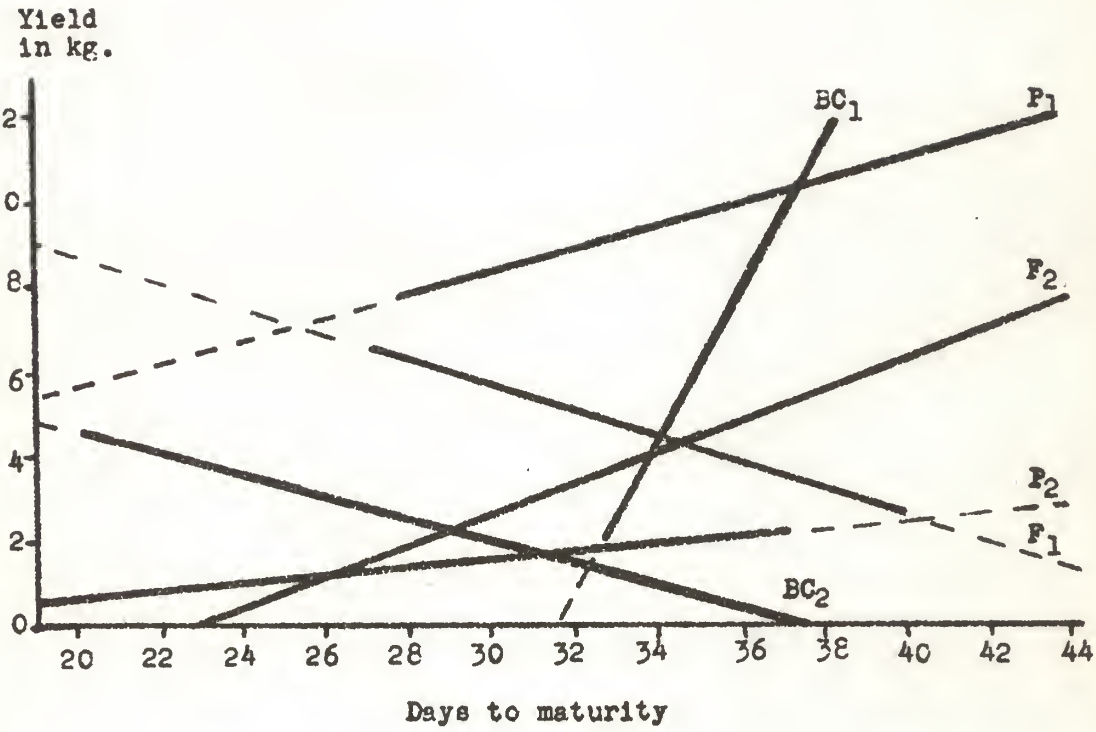

Fig. 10. Regression lines relating yield to earliness.

Correlation Between Vine Weight and Earliness

The correlation between dry vine weight and earliness of maturity of these characters were non-significant at the 10 per cent level for either Crimson Sweet or BC_2. New Hampshire Midget and the F_2 both had positive correlations which were significant at the 5 and 2 per cent levels, respectively. The F_1 and BC_1 were both negative and significant at the .1 per cent level. Correlation coefficients between these two characters are summarized in Table 9. Regression equations and lines for all genetic lines are shown in Table 10 and Fig. 11, respectively.

Table 9. Correlation between vine weight and earliness.

Lines	P_1	P_2	F_1	F_2	BC_1	BC_2
Correlation	-.2003	.3558	-.8637	.8361	-.90393	.1234
DF	34	34	34	250	70	70
Significance	*	.05	.001	.02	.001	*

* non-significant at 10 per cent level.

Table 10. Relation of earliness to vine weight.

Lines	Regression equations
P_1	$Y = -.2416X + 36.2634$
P_2	$Y = .3646X + 26.5961$
F_1	$Y = -.8629X + 35.2525$
BC_1	$Y = -.6700X + 35.3840$
BC_2	$Y = .1338X + 28.2660$
F_2	$Y = .6927X + 32.8796$

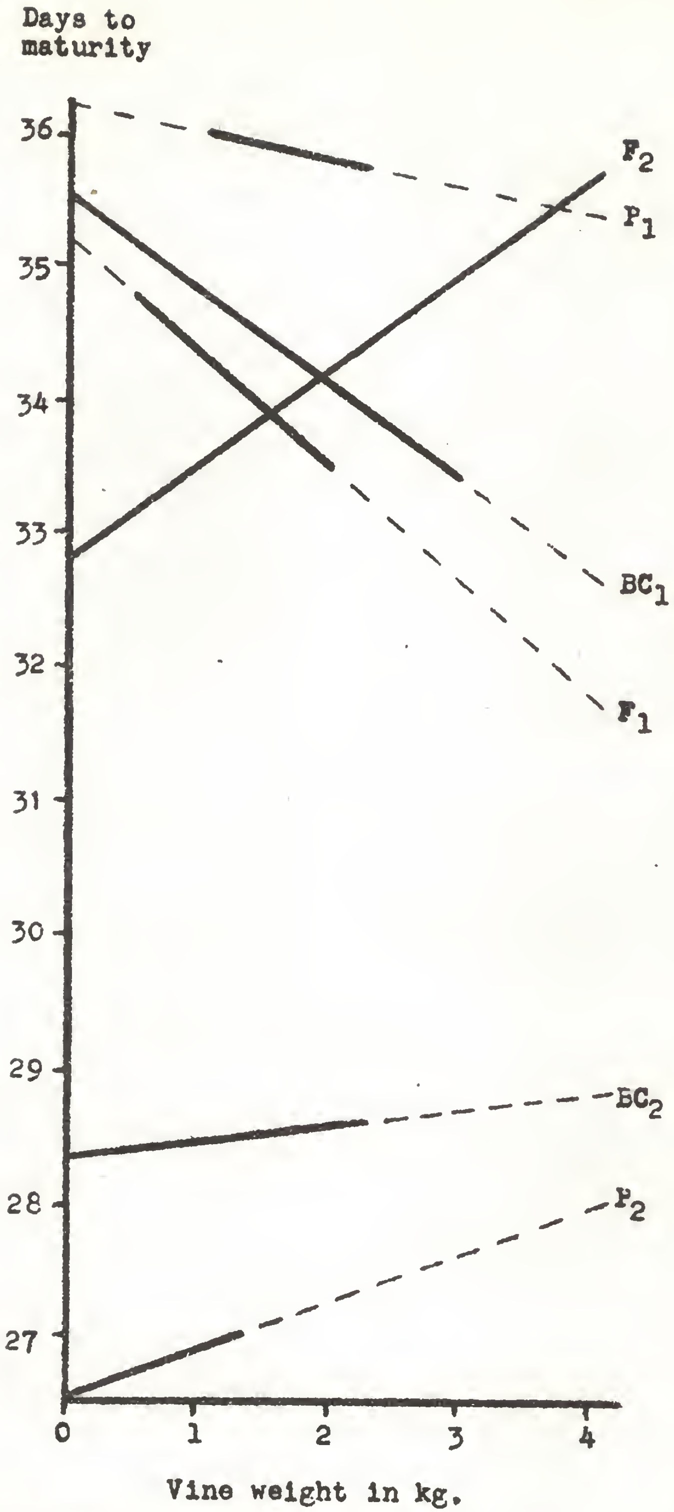

Fig. 11. Regression lines relating earliness to vine weight.

DISCUSSION

In general, quantitatively inherited characters are assumed to be controlled by the cumulative action of many genes, each of which produces a small effect. The frequency distribution histograms for yield, vine weight and earliness (Figs. 1 through 8) show the typical attributes of quantitatively inherited characters. The cumulative action of genes involved influenced the relationship between these characters. The relationship or degree to which these characters varied together was measured by the correlation coefficient, which has a value from zero (no correlation) to -1 or +1 (perfect negative or positive correlation). This means that the correlation coefficient measures the degree to which a linear regression line or equation relating the two characters can summarize the trend in a scatter plot or dot diagram. The closer the absolute value of a correlation coefficient is to 1, the closer the data approximate a linear regression relationship. Steel and Torrie (22) pointed out that a linear relation is often a reasonably good approximation for a non-linear relation provided the values of the independent variable do not cover too wide a range.

Yield and Vine Weight

The correlation coefficients relating yield and vine weight were all significant at the 10 per cent level or less. Slope of the regression equation for Crimson Sweet is negative and that for BC_1 is also negative but closer to 1. The regression equations for New Hampshire Midget, BC_2 and F_2 all have negative slopes approximately equal to 2. Slope of the F_1 is also negative but it is closer to 1.

If the close parallelism of New Hampshire Midget and the segregating F_2 generation regression lines indicates similar causal factors, then this may suggest that the genes governing the expression of these factors are recessive in Crimson Sweet and dominant in New Hampshire Midget. The causal factors may be vegetative growth retarding substances produced by the fertilized egg similar to the situation in cucumber suggested by McCollum (14).

The quantitative inheritance of fruit weight observed by Chung (2), and the apparent dominance of small fruit size over large fruit size reported by Weetman (24) are consistent with the findings in this study.

In addition to dominance, complementary gene action might be involved as it apparently was in Khambanonda's (11) study of fruit size in red pepper. Epistatic gene action similar to that found in corn yield study by Bauman (1) may also be involved.

Vine Weight and Earliness

The correlation coefficients relating vine weight to earliness for Crimson Sweet and BC_2 were non-significant at the 10 per cent level while those for the remaining lines were significant at the 5 percent level or less. The regression equations for New Hampshire Midget and BC_2 appear to be similar in that they both have slopes that are positive, y-intercepts that are close together and regression lines that nearly parallel. These similarities may suggest similar causative factors, even though the BC_2 correlation was non-significant.

The Crimson Sweet, BC_1 and F_1 regression equations seem to be similarily related except that they all have negative slopes. This too may indicate similar causal factors. However, the correlation coefficient for Crimson Sweet was non-significant.

The regression line for the segregating F_2 generation is positive like those of New Hampshire Midget and BC_2, but its y-intercept is closer to those of Crimson Sweet, BC_1 and F_1.

Earliness and Yield

The correlations between earliness and yield were significant at the 10 per cent level for all lines except New Hampshire Midget. The F_1 and BC_2 lines were negatively correlated and had nearly parallel regression lines. Crimson Sweet and the F_2 were positively correlated and had nearly parallel regression lines. The slope of the BC_1 regression line was positive and nearly equal to 2. These findings may indicate some similarity of causative factors for F_1 and BC_2 lines or for Crimson Sweet and F_2 but no definite conclusions can be made.

SUMMARY

The relationship between yield, vine weight and earliness was determined by calculating correlation coefficients and regression equations and comparing the values obtained for the commercial varieties: Crimson Sweet and New Hampshire Midget and the F_1, F_2, BC_1 and BC_2 of these varieties.

Yield was measured as the average weight of the mature fruits per plant. Vine weight was measured as the total dry weight for each plant minus the mature and immature fruits and the root system. Earliness was measured as the total number of days required for fruit maturation or the days from fruit set to harvest plus or minus a correction factor depending on the degree of ripeness.

The results of this study show that vine weight decreases with an increase in yield to a greater extent in BC_1 than in Crimson Sweet (negative correlations). Vine weight increases with an increase in yield to about the same degree in New Hampshire Midget, BC_2 and F_2 (positive correlations). In the F_1 vine weight increases to a lesser degree with each increase in yield. The close parallelism of the New Hampshire Midget and the segregating F_2 generation regression lines may indicate similar causative factors responsible for the two correlations. If this is true, then genes controlling the expression of these factors appear to be recessive in Crimson Sweet and dominant in New Hampshire Midget.

Vine weight and earliness was found to increase together (positive correlation) for New Hampshire Midget and the F_2

while one increased as the other decreased (negative correlation) in the BC_1 and F_1. The correlations were non-significant in Crimson Sweet and the BC_2 population.

Positive correlations (both characters increased together) between earliness and yield were found for Crimson Sweet, BC_1 and F_2. The correlations were negative (one increased while the other decreased) in the F_1 and BC_2 and were non-significant in New Hampshire Midget.

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CORRELATION OF YIELD, VINE WEIGHT AND EARLINESS IN WATERMELON, CITRULLUS VULGARIS SCHRAD

by

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ABSTRACT

With increased interest in the development of high yielding, improved quality, small fruited varieties of watermelon, Citrullus vulgaris, Schrad., additional information concerning the inheritance and correlation of certain quantitative characters is needed. Notwithstanding the long time and wide spread cultivation of this crop, the relationships between most watermelon characters have not been determined.

In 1968 the relationships between yield, earliness, and vine weight were studied in Crimson Sweet and New Hampshire Midget and the F_1, F_2, BC_1 and BC_2 generations. Correlation coefficients and regression equations were calculated.

The results of this study showed that yield and vine weight are negatively correlated in Crimson Sweet and BC_1 and positively correlated in New Hampshire Midget, F_1, F_2 and BC_2. The regression lines relating vine weight to yield showed general similarities between Crimson Sweet and BC_1, between New Hampshire Midget and BC_2, and between F_1 and F_2.

Vine weight and earliness were negatively correlated in Crimson Sweet, F_1 and BC_1 and positively correlated in New Hampshire Midget, F_2 and BC_2. The correlation coefficients were non-significant at the 10 per cent level for Crimson Sweet and BC_2. The regression lines relating yield to earliness showed similarities in slopes of the F_1 and BC_2 and of Crimson Sweet and F_2.

Earliness and yield were negatively correlated in the F_1 and BC_2 and were positively correlated in Crimson Sweet, New Hampshire Midget, F_2 and BC_1. The correlation coefficient for New Hampshire Midget was non-significant at the 10 per cent level. The regression lines relating earliness to vine weight showed general similarities between New Hampshire Midget and BC_2 and between Crimson Sweet, BC_1 and F_1 which were overlapped by the F_2 regression line.