A Study of Hybrids Between Sugar Beets and Mangel Wurzels With Reference to Color Factors and Sugar Content

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A STUDY OF HYBRIDS BETWEEN SUGAR BEETS AND MANGEL WURZELS
WITH REFERENCE TO COLOR FACTORS AND SUGAR CONTENT

by

Boyd Berrey

A thesis submitted in partial fulfillment of the requirements
for the degree of

Master of Science

in

School of Agriculture

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Approved:
ACKNOWLEDGMENT

I wish to express appreciation to Dr. F. V. Owen for valuable suggestions which led to the selection and completion of this problem.

Boyd Berrey
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INTRODUCTION

Preliminary unpublished work at the Salt Lake City Laboratory of the Division of Sugar Plant Investigations, Bureau of Plant Industry, United States Department of Agriculture, indicates that beets showing the \( Y \) color factor \((9)\) were larger than sugar-beet types recessive for this color factor \((Y Y)\). It was suggested to the writer that an investigation be made to determine whether or not yield and sugar content were correlated with color factors in beets. Linkages between the \( R \) and \( Y \) color factors have been reported by Keller \((9)\), and the results indicate a close linkage between color factors \( R \) and \( Y \), with about 7.5 percent recombinations. Abegg \((1)\) has found linkage between the \( R \) color factor and the factor \( B \) for annual habit with a crossover percentage of about 15.5 percent.

Unpublished data from the Division of Sugar Plant Investigations indicate several additional color factors in the \( R Y B \) linkage group.

Yield and sugar analysis, as related to presence and absence of the \( R \) factor, have been studied by Nuckols \((10)\). Nuckols' studies were made from a commercial variety and plants recessive for the red color \((\text{genotype } R R)\) were separated from plants with red hypocotyls \((\text{genotypes } R r \text{ and } R R)\) at thinning time. He reports no significant difference between the 2 color classes in yield or sugar content. Since these data were taken from a commercial variety of beets by thinning to color classes, no critical information was secured regarding possible genetic linkages; but satisfactory data were secured showing \( R \) color to be as good as the other as far as production of sugar is concerned.
In the present study hybrids were made between a sugar beet and a mangel wurzel. The sugar beet was a high sugar type and of genetic constitution \( R^+ Y \) for color. The mangel wurzel was a high yield and low sugar type and of genetic constitution \( r r y y \) for color. A large \( F_2 \) population resulting from hybrids between the sugar beet and the mangel made possible a critical study of the association of the \( R \) and \( Y \) color factors with yield and sugar analysis.
GENETIC MATERIAL

The $F_1$ and $F_2$ populations studied in this paper were taken from the cross between a high testing sugar beet and the golden tankard mangel, a commercial variety. The cross was made by Dr. F. V. Owen at the Salt Lake City Laboratory of the Division of Sugar Plant Investigations, Bureau of Plant Industry, United States Department of Agriculture, in 1935.

For an understanding of this paper it is necessary to give a detailed description of parental plants, $F_1$ and $F_2$ hybrids, and methods of recording data.

The Mangel Wurzel Parent. The mangel wurzel parental seed was from the golden tankard variety and came from the Johnson Seed Company of England. The seed was obtained through a retail store of Salt Lake City in 1933. A single plant (number 269) grown from this seed was selected for the hybridization work here described. This plant was selected for a typical expression of the $Y$ factor (9) with an abundance of orange or rich, yellow pigment in the more prominent veins of the leaf and petiole, as well as in the epidermis and flesh of the root. Plants with the $Y^r$ (9) factor with the pigment chiefly restricted to the root were also found in this variety of golden tankard, but care was taken to avoid such plants in the present study. The parental golden tankard, plant number 269, was recessive for the $R$ factor for red hypocotyl color. Its genotypic constitution for color was $rrY^rY$. 
Sugar Beet Parent. Clone 138 was the sugar-beet parent. This clone was a high sugar type selected from the curly-top resistant strain 2167 in 1933. Strain 2167 was a high sugar variety, and for this reason high sugar selections within the variety were not difficult to make. Clone 138 was selected for extremely high sugar percentage. With regard to color factors considered, clone 138 possessed the dominant red hypocotyl color and was of genotypic constitution \( R r Y y \). The heterozygous constitution, \( R r \), was known from breeding behavior. Clone 138 was strongly self-sterile, which was a convenience in hybridization work.

In comparing parental types with \( F_1 \) and \( F_2 \) hybrid generations it was necessary to choose a variety to represent clone 138. It was recognized that clone 138 may have been heterozygous for factors affecting yield and sugar percentage and the same probably applied to sister plants that might be selected from strain 2167. As a practical choice, however, a hybrid involving clone 138 was selected to represent the sugar-beet parent. This was strain 744, which represented the \( F_2 \) generation of clone 138 \( \times \) clone 139. Clone 139 was a sister plant to clone 138 with similar origin, and the strain 744 was a well-proved high sugar variety, believed to represent clone 138 fairly well.

\( F_1 \) Generation. The \( F_1 \) plants were obtained by pollinating clone 138 with pollen from plant 269 of the golden tankard variety. Paper bags were exchanged to effect the pollination. The hybrids could be easily recognized as quickly as they were germinated, due to the presence of the \( Y \) factor from the golden tankard which increased the development of red and yellow pigment. Only the \( F_1 \) plants resulting from hybrids with the single golden tankard plant 269 were studied in \( F_2 \), but 3 similar hybrids to sister plants of 269 were utilized in comparing \( F_1 \) plants with the parental types and \( F_2 \) generation.
**F₂ Generation.** The F₂ generation was obtained by growing 52 F₁ plants in a field isolation in the vicinity of Salt Lake City in 1936. The 52 F₁ plants chosen were of genotypic constitution \( RRYY \); and F₁ plants of constitution \( RrYy \), due to heterozygous condition \( (Rr) \) of clone 138, were discarded. A quantity of 516 grams of F₂ seed was obtained from the 52 F₁ plants.
FIELD PLANTINGS AND METHODS OF RECORDING DATA

Parental Types Compared with \( F_1 \) and \( F_2 \). A field near Salt Lake City on the farm of G. Kasworm was selected in 1938 to give a rough comparison of parental types with \( F_1 \) and \( F_2 \) generations. The field was chosen because of its fertility and uniformity of soil, and particular care was taken to secure the best possible fertilization, soil preparation, and cultural care. A yield of approximately 30 tons per acre of commercial sugar beets adjoining the test field reflected the degree of soil fertility. Damage from the curly-top disease was negligible in this test field. This was fortunate because when curly-top becomes severe, as it frequently does in the vicinity of Salt Lake City, it is not possible to grow the golden tankard variety of mangel wuzels satisfactorily.

Two 75-foot rows of the mangel parent were planted adjacent to 2 rows of strain 744 representing the high sugar parent, and a single row of 86 plants from 3 \( F_1 \) progenies adjoined the 2 rows of strain 744. Five rows of the \( F_2 \) progeny then adjoined the row of \( F_1 \) plants. The rows were 20 inches apart, and the plants were spaced approximately 11 inches within the rows. Due to lack of replication, means between the parents and the \( F_1 \) and \( F_2 \) plants can be compared only roughly, but individual plant records were taken to portray the nature of the variability in each case (figure 1). Detailed records were taken from 30 plants of the golden tankard parent, 30 plants of the strain 744 sugar-beet parent, 86 plants of the three \( F_1 \) progenies, and 250 plants from the \( F_2 \) progeny.
F₂ Plants. The most extensive data for the F₂ population were secured in 1937 plantings made in March at 3 different locations in Salt Lake County, Utah. The reason for 3 plantings was to escape the curly-top disease, if possible. Only a small amount of curly-top resistance was expected in these F₂ plants, and severe curly-top exposure would have defeated the purpose of the experiment. By having 3 plantings it was hoped that 1 of the 3 might escape the disease. Fortunately, the disease was not a serious factor in any of the 3 locations. The plantings were located on the Hill Brothers’ farm at Granger, the J. T. Brinthurst farm at Taylorsville, and the Mary B. Chatwin farm at Murray. The beets were planted in rows 20 inches apart and thinned to approximately 11 inches in the row. Thinning was done at random with regard to plant color, i.e., the color of the plant was disregarded in the thinning operation. The plantings were made in fields where good yields of commercial beets were secured. Careful attention was given to cultural care by the respective farmers.
Color Classes. Four distinct color classes were observed in the F2 population with phenotypes $RY$, $RY$, $rY$, and $rY$ (9). These color classes were as follows: (1) $RY$ (red beet), epidermis of root medium to dark-red, flesh of root predominantly light-red; (2) $RY$, white root and red hypocotyl, the red color in hypocotyl often very faint; (3) class $rY$ (yellow beet), with epidermis of the root lemon-yellow to orange, distinct yellow pigment in veins of petioles and blades; (4) class $rY$, with white root and yellow or nearly white hypocotyl. Considerable variability in intensity of color was noted in $RY$ and $rY$ groups, but classification into the 4 classes was easy.
METHODS OF RECORDING DATA

Data From Individual Plants. In harvesting the beets from the field 10 plants were dug consecutively in the row to facilitate recording of data. At the time of digging each beet was numbered with an indelible pencil, and records were taken for color class, height of crown above soil surface, and curly-top grade. Records for weights and chemical analysis were made later in the laboratory. The beets were topped in the field, with the crown intact, the same as mother beets are prepared for storage with leaves cut at the base of the petioles. Each beet was examined and placed in its particular class, R Y, R X, F X and F Y, as previously described. Records were taken for each beet. The beets were then stored in a cool root cellar for a few days before the laboratory work could be done.

Measurements. A measurement in centimeters was taken of the height of the crown of each beet above the soil surface previous to digging.

Curly-top Grade. The beets are given a curly-top rating on grades ranging from 0 to 3. Grade 0 plants showed no curly-top; grade 1 plants showed slight symptoms; grade 2 plants showed the disease rather well-developed; grade 3 plants were badly injured by the disease.

Weight of Roots. The beets were taken to the laboratory in Salt Lake City, where they were washed. Weights of individual beets, including crown and beet root were recorded in grams.
Sucrose Percentage. Each beet was tested for sucrose percentage by the Sachs Le Docte cold water digestion method (5).

Coefficient of Apparent Purity. The coefficient of apparent purity was obtained by dividing the sucrose percentage by the percent total solids. The percent total solids was taken from the dipping refractometer reading as described by Bachler (2).

Specific Electrical Resistance. Specific electrical resistance was obtained from an electrical resistance reading made under a constant temperature of 20° C. at the same time that the refractometer reading was made. A flow-through cell, made by Myron Stout, Assistant Physiologist, Division of Sugar Plant Investigations, Bureau of Plant Industry, United States Department of Agriculture, was used to make these readings. The cell constant used throughout all experiments was 0.23593. Specific electrical resistance was obtained by multiplying the reciprocal of the cell constant by the observed resistance reading. The specific electrical resistance was preferred to the more customary reading expressed as specific electrical conductance. The specific electrical conductance involves the use of a fraction or decimal point and is less convenient for this reason.
EXPERIMENTAL RESULTS

Histograms of the sucrose percentages of the parents in the cross studied and the $F_1$ and $F_2$ generations are presented in figure 1. It can be seen from this figure that the $F_1$ and $F_2$ populations tend to bridge the space on the percent sucrose scale between the low-testing mangel parent (golden tankard) and the sugar parent (strain number 744).

The $F_2$ population is shown to include a somewhat wider range in sucrose percentage with a more gradual slope toward the sugar parent in comparison to the $F_1$. This may be partly due to the larger $F_2$ population which would naturally include a wider range of variation.
Figure 1. Sucrose percentage of golden tankard mangel wurzel parent, 26 plants; sugar beet parent strain no. 744, 30 plants; the F₁ generation, 86 plants; and the F₂ generation, 250 plants.
Means were calculated for the 2 parents and the $F_1$ and $F_2$ generations. These means are given in table 1 for rough comparison. The 2 hybrid populations seem to be very nearly alike in all factors studied. The high crown and the high yield of the mangels in comparison with the sugar beet is characteristic of the mangel type beet with the $Y$ factor.
Table 1. Data from the 2 parents, the sugar beet strain No. 744 and the golden tankard mangel wurzel, compared with the $F_1$ and $F_2$ populations grown in 1938

<table>
<thead>
<tr>
<th>Strain 744, representing the sugar beet parent</th>
<th>Number of plants</th>
<th>Percent sucrose</th>
<th>Coefficient of apparent purity</th>
<th>Specific electrical resistance</th>
<th>Beets per acre</th>
<th>Average root weight</th>
<th>Height of crown above soil surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golden Tankard Mangel Wurzel</td>
<td>29</td>
<td>7.48</td>
<td>75.44</td>
<td>626</td>
<td>49.8</td>
<td>1359</td>
<td>15.2</td>
</tr>
<tr>
<td>Three $F_1$ populations</td>
<td>86</td>
<td>12.69</td>
<td>82.79</td>
<td>700</td>
<td>55.2</td>
<td>1736</td>
<td>9.4</td>
</tr>
<tr>
<td>$F_2$ population</td>
<td>250</td>
<td>12.71</td>
<td>82.99</td>
<td>774</td>
<td></td>
<td>1311</td>
<td>9.1</td>
</tr>
</tbody>
</table>
A detailed study was made of the 3 color classes, $R_Y$, $r_Y$, and $R_Y$, in 1937, and as a check on these data 250 plants from seed of the same $F_2$ population were studied for comparison in 1938. Roughly, these data follow rather well the earlier studies in 1937.

These means are given in table 2. No standard errors were calculated since the writer was interested only in a rough check on the 1937 data.

The main difference appears in weight of roots which is somewhat higher in class $r_Y$ (yellow beet) than in the other 2 classes.
Table 2. Data from 3 color classes in $F_2$ population of 250 plants grown in 1938

<table>
<thead>
<tr>
<th>Color class</th>
<th>Number of plants</th>
<th>Percent sucrose</th>
<th>Coefficient of apparent purity</th>
<th>Specific electrical resistance</th>
<th>Average root weight</th>
<th>Height of crown above soil surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV</td>
<td>121</td>
<td>12.51</td>
<td>82.79</td>
<td>754</td>
<td>1284</td>
<td>9.5</td>
</tr>
<tr>
<td>(Red beet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HY</td>
<td>51</td>
<td>11.77</td>
<td>81.25</td>
<td>705</td>
<td>1470</td>
<td>10.2</td>
</tr>
<tr>
<td>(Yellow beet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>By</td>
<td>78</td>
<td>13.63</td>
<td>84.43</td>
<td>850</td>
<td>1248</td>
<td>7.7</td>
</tr>
<tr>
<td>(White root, red hypocotyl)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The mean and standard errors of the 4 color classes from an F₂ population of 1299 plants grown in 1937 are given for comparison in table 3. No standard errors were calculated for the total recessive class \( r_{Y} \) (white hypocotyl, white root), since only 4 individuals were found among the 1299 plants taken, due to the \( R_{Y} \) and \( r_{Y} \) linkage groups.

As shown by table 3, color class \( R_{Y} \) (white root, white hypocotyl) is considerably higher in percent sucrose and purity, but lower in height of crown above the soil surface than the other 3 classes; however, due to the small number of individuals involved, little emphasis can be placed on this class, except to say that results similar to these would be expected had larger numbers been available for study. Color class \( R_{Y} \) (white root, red hypocotyl) is second highest in percent sucrose, apparent purity, and electrical resistance, and next lowest in weight of roots and height of crown; class \( r_{Y} \) (yellow beet) is the exact opposite, being the second lowest in sucrose percentage, purity, and electrical resistance, yet highest in weight and height of crown above the soil surface; while the red beet (\( R_{Y} \)) takes the intermediate position with respect to the factors mentioned.

The effect of the \( Y \) color factor is shown by the way these 3 color types align themselves with respect to the 5 characters under observation. Whenever the \( Y \) factor appears in a color type, there is a tendency toward lower sugar and purity, but higher root weight and higher crowns of individual beets above the soil surface.
Table 3. Data from color classes of $F_2$ population of 1299 plants grown in 1937

<table>
<thead>
<tr>
<th>Color class</th>
<th>Number of plants</th>
<th>Percent sucrose</th>
<th>Coefficient of apparent purity</th>
<th>Specific electrical resistance</th>
<th>Average root weight</th>
<th>Height of crown above soil surface (Cm)</th>
<th>Curly-top grade 0 to 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{HY}$</td>
<td>694</td>
<td>12.025±0.109</td>
<td>82.23±0.212</td>
<td>673.5±6.595</td>
<td>937±26.5</td>
<td>8.7±0.114</td>
<td>1.1±0.072</td>
</tr>
<tr>
<td>$(\text{Red beet})$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{FY}$</td>
<td>275</td>
<td>11.378±0.137</td>
<td>80.86±0.178</td>
<td>646.4±10.190</td>
<td>974±46.1</td>
<td>8.9±0.191</td>
<td>1.1±0.119</td>
</tr>
<tr>
<td>$(\text{Yellow beet})$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{FY}$ (White root white hypocotyl)</td>
<td>4</td>
<td>15.765</td>
<td>89.735</td>
<td>983.4</td>
<td>750</td>
<td>6.0</td>
<td>1.25</td>
</tr>
<tr>
<td>$\text{FY}$</td>
<td>326</td>
<td>13.047±0.119</td>
<td>83.59±0.394</td>
<td>752.4±11.903</td>
<td>903±36.4</td>
<td>7.6±0.156</td>
<td>1.1±0.109</td>
</tr>
<tr>
<td>$(\text{White root red hypocotyl})$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mean difference, standard error of mean difference, and \( t \) values were calculated for the 3 color classes for a total population of 1295 plants. Fisher's tables of \( t \) values for measuring significant differences were used for comparing mean differences. These data are presented in table 4.

The highly significant \( t \) value for sucrose percentage between \( R_Y \) vs. \( F_Y \) in favor of the former, verifies the previously expressed belief that one or more genetic factors for sugar are linked with the color factor \( F \), and that the \( Y \) color factor is associated with a depressing effect on percent sucrose. The somewhat smaller, though highly significant, \( t \) value for the comparison \( R_Y \) vs. \( F_X \), adds still more evidence of the above stated relationship. The influence of the \( Y \) factor is seen in the comparison \( R_Y \) vs. \( F_Y \), in the smaller \( t \) value when \( Y \) occurs in both classes being compared. The fact that the comparison is significant indicates the linkage of the factors for sugar with the \( R \) color factor.

The highly significant \( t \) values for percent purity in the comparison \( R_Y \) vs. \( F_Y \) agree with the fact shown from analysis, that beets with the \( Y \) color factor contain considerable total solids that are not sugar. The high \( t \) value calculated from the comparison \( R_Y \) vs. \( F_Y \) can be explained on the basis that high purity is associated with high sugar content.

Height of crown of beets is seen to be associated with the presence of the \( Y \) factor as is shown by the comparison \( R_Y \) vs. \( R_Y \) and by the highly significant \( t \) values for the comparison \( R_Y \) vs. \( F_Y \).
No significant difference between means of the 3 classes were measured in this experiment for root weight.

The highly significant $t$ values calculated from the comparisons $R_Y$ vs. $R_Y$ and $R_Y$ vs. $R_Y$ show the depressing effect of the $X$ factor on the specific electrical resistance as is indicated in table 3. In the comparison $R_Y$ vs. $R_Y$ the low $t$ value when $Y$ occurs in both classes being compared indicates the depressing effect of the $Y$ factor on specific electrical resistance.
Table 4. Data from color classes in \( F_2 \) population of 1295 plants grown in 1937

<table>
<thead>
<tr>
<th>Color classes compared</th>
<th>Differences with standard error of differences and t values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent sucrose</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| \( \text{RY} \)  
(White root red hypocotyl)  
vs. \( \text{rY} \)  
(Yellow beet) | \( 1.022 \pm 0.163 \) | \( 1.363 \pm 0.447 \) | \( 78.889 \pm 13.608 \) | \( 55.657 \pm 44.977 \) | \( 1.107 \pm 0.193 \) |
| \( \text{rY} \)  
(White root red hypocotyl)  
vs. \( \text{rY} \)  
(Yellow beet) | \( 1.663 \pm 0.182 \) | \( 2.731 \pm 0.452 \) | \( 106.603 \pm 15.669 \) | \( 70.305 \pm 58.726 \) | \( 1.223 \pm 0.247 \) |
| \( \text{Ry} \)  
(White root red hypocotyl)  
vs. \( \text{rY} \)  
(Yellow beet) | \( 0.643 \pm 0.176 \) | \( 1.566 \pm 0.276 \) | \( 27.106 \pm 12.136 \) | \( 17.146 \pm 53.156 \) | \( 0.121 \pm 0.222 \) |

\( t = \text{difference divided by standard error of difference, and t values greater than 3 are considered significant.} \)
An idea as to the variability within the 3 color classes may be obtained from table 5, which includes standard deviation and standard errors for the 6 factors under question. The high standard deviation for root weight indicates this factor to be a rather highly variable one. Specific electrical resistance, percent sucrose, apparent purity, and height of crown above soil surface are shown to be considerably less variable.
Table 5. Data from color classes in \( F_2 \) population of 1295 plants grown in 1937

<table>
<thead>
<tr>
<th>Color class</th>
<th>Number of plants</th>
<th>Percent sucrose</th>
<th>Coefficient of apparent purity</th>
<th>Specific electrical resistance</th>
<th>Average root weight</th>
<th>Height of crown above soil surface</th>
<th>Curly-top grade 0 to 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( rY ) (Red beet)</td>
<td>694</td>
<td>2.879±0.077</td>
<td>5.582±0.150</td>
<td>175.789±4.665</td>
<td>696.95±18.70</td>
<td>3.033±0.081</td>
<td>1.983±0.058</td>
</tr>
<tr>
<td>( rY ) (Yellow beet)</td>
<td>275</td>
<td>2.280±0.072</td>
<td>2.947±0.126</td>
<td>169.019±7.206</td>
<td>764.56±32.60</td>
<td>3.161±0.135</td>
<td>1.874±0.085</td>
</tr>
<tr>
<td>( rY ) (white root red hypocotyl)</td>
<td>326</td>
<td>2.145±0.084</td>
<td>7.109±0.278</td>
<td>214.952±8.418</td>
<td>656.74±25.72</td>
<td>2.825±0.111</td>
<td>1.970±0.077</td>
</tr>
</tbody>
</table>
A graphic representation of percent sucrose and root weight for the 3 color classes is given in figure 2. The significant $t$ values recorded in table 4 for percent sucrose between color classes can readily be seen in figure 2. Also, the low $t$ values below significance for root weight are shown in figure 2.
Figure 2. Weight and sucrose percentage of the 3 color classes, representing 694 plants of $RY$ class, 275 plants of $RY$ class, and 326 plants of $ry$ class.
DISCUSSION

The chief purpose of this study was to determine the effect of the \( Y \) color factor on size and sugar content of beets. The material used contained both the \( Y \) and the \( R \) color factors, and a relatively close linkage in the repulsion phase was found, with approximately 12.5 percent crossing-over between \( R \) and \( Y \). These 2 factors in combination (\( R + Y \)) gave rise to a red beet with a red hypocotyl and red root, and the absence of both \( R \) and \( Y \) gave the double recessive yellow hypocotyl, white root type. When \( Y \) occurs and \( R \) is absent, a yellow beet with yellow hypocotyl and yellow root is the result. When \( R \) occurs in the absence of \( Y \) the result is a beet with red hypocotyl and a white root. The \( Y \) factor occurs in mangel beets both with and without the \( R \) factor. In the case of the golden tankard mangel used for a parent of hybrids studied in this paper, the \( R \) factor was absent and consequently all the roots were yellow and of genotypic constitution \( R X Y Y X \).

A German scientist, Marggraf, and Achard, his student, are accredited with starting the great sugar-beet industry as we know it today (6). Their work began in 1747 when Marggraf discovered that sugar extracted from cultivated species of the beet family was identical with cane sugar. Achard coined the name "sugar beet" for his selections made from mixed stock of mangel wurzel being grown by peasant farmers for feeding livestock.

Historical records (6) indicate that these early cultivated varieties of beets consisted of mixed red, white and yellow roots; and some of them, therefore, contained the \( Y \) color factor.
Considerable evidence has been supplied by the tables given here indicating the $X$ color factor to be associated negatively with sugar percentage, coefficient of apparent purity, and specific electrical resistance and positively associated with height of the beet crown. Nuckols (10) reported from a study of a commercial variety of sugar beets that there was no significant difference between yield and sugar content of beets with or without the $R$ factor for red hypocotyl color. The $Y$ factor, which of course was not present in the commercial variety of sugar beets studied by Nuckols, seems to be the color factor most concerned in producing an effect on yield and sugar content. Unpublished work at the Salt Lake City Laboratory of the Division of Sugar Plant Investigations of the Bureau of Plant Industry, United States Department of Agriculture, indicates that most color factors retard growth. The $Y$ factor appears to be a notable exception and plants with this factor may have remarkable vigor.

Continued work needs to be done to determine if the $Y$ color factor alone is responsible for this phenomenon of increased yield and decreased percentage of sugar, or if growth factors on the same chromosome and closely linked to $Y$ are responsible. One reason for elimination of the $Y$ factor from commercial sugar-beet varieties may be the injurious effect of the pigment on the factory processes of extracting sugar. On the other hand, if low sugar and low purity are produced by the physiological action of the $Y$ factor, it is not surprising that this factor has been eliminated from commercial sugar-beet varieties.
SUMMARY

The color factor \( Y \) responsible for development of yellow pigment in *Beta vulgaris* L. was found to be associated with a large root of low sugar percentage. In an \( F_2 \) population resulting from a hybrid between a sugar beet and the golden tankard variety of mangel wurzel a negative association between the color factor \( Y \) and sugar percentage was observed. Yellow or red beets with the \( Y \) factor were slightly larger, and their roots grew higher above the surface of the soil than recessives (\( YY \)) with white roots. The yellow and red beets were lower in coefficient of apparent purity indicating the presence of a higher proportion of solids which were not sucrose. The yellow and red beets were also lower in specific electrical resistance, indicating the presence of more inorganic salts and particularly those which ionize readily and are harmful in the process of extracting beet sugar. Extremely high statistical odds were secured for the differences in sucrose percentages and other analysis as a result of analyzing separately 1549 \( F_2 \) plants. Further work will be required to determine whether these correlations represent genetic linkages between the \( Y \) color factor and factors for root size and sucrose percentage or whether the \( Y \) factor alone is responsible for a difference in developmental processes which affects sucrose percentage and related analysis.
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