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EVALUATION AND SELECTION OF CARROT  
BREEDING MATERIAL FOR SUGAR CONTENT,  
DRY MATTER AND SOLUBLE SOLIDS

Thesis for the Degree of M. S.  
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EVALUATION AND SELECTION OF CARROT BREEDING MATERIAL  
FOR SUGAR CONTENT, DRY MATTER AND SOLUBLE SOLIDS

By

BRUCE CHARLES CARLTON

AN ABSTRACT

Submitted to the College of Agriculture, Michigan State University of  
Agriculture and Applied Science in partial fulfillment of  
the requirements for the degree of

MASTER OF SCIENCE

Department of Horticulture

1958

Approved

A handwritten signature in cursive script, appearing to read "C. Peterson", is written over a horizontal line.

Analysis of dried carrot roots for soluble solids, sugars, and dry matter content showed much more variation between individual roots within a variety than between variety means. The extreme ranges within varieties indicate that, through inbreeding and hybridization, it should be possible to develop uniform varieties with levels of dry matter and sugar contents approximating the extremes observed. In individual roots the highest dry matter content observed was 13.3 and the lowest was 7.7 per cent, while total sugars ranged from 6.41 to 1.92, and soluble solids from 9.0 to 4.5 per cent on a fresh weight basis.

Correlation coefficients and regressions show that both dry matter and total sugars can be estimated with reasonable accuracy from soluble solids as determined by the refractometer. By this method, rapid and efficient selection of carrot breeding material for dry matter and total sugars can be accomplished.

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## INTRODUCTION

The State of Michigan produced 1700 acres of carrots in 1957 having a farm value of \$1,034,000 (1). These figures do not nearly express the potential production of carrots in this state, since Michigan has the advantages of suitable climate, large acreages of tillable muck and mineral soils, and nearness to concentrated population centers. In spite of these apparent advantages, the carrot industry is actually declining. Production decreased from 2960 acres (average 1949 to 1954), to 1900 acres in 1956, and further declined to 1700 acres in 1957 (2). At the same time the United States production remained at approximately 80,000 acres throughout this period. What, then, are the reasons for this situation?

The facts are that, at present, Michigan-grown carrots are often of such poor quality that processors prefer to ship carrots from western and southern states rather than to use those grown locally. Sweetness and high dry matter content are two of the most desired features of carrots for processing, and these traits appear to be generally lacking in Michigan-grown carrots. Processors and growers in the State are thus keenly interested in the development of high quality varieties adapted to Michigan conditions, in order to eliminate the need for importing carrots.

As a consequence of these conditions, plant breeders have been encouraged to develop varieties of carrots that can compete with southern

and western products on a quality basis. Fortunately, the discovery of male sterility in the carrot promises a practical means of producing  $F_1$  hybrid varieties which are vigorous and more uniform. This may be accomplished by bringing together the desired characteristics from selected inbred lines.

The objectives of this work were to determine the range of variability in dry matter, soluble solids and sugar content between and within commercial carrot varieties, and to develop methods for the rapid analysis of these characteristics as a basis for selection in the breeding program. This study necessitated a survey of analytical methods for determining sugars, and modification of these methods specifically for rapid and accurate analysis of dried carrot roots from breeding material.

## REVIEW OF LITERATURE

Although studies of sugar and dry matter contents of various plant varieties and tissues have long been common, analytical work of this type as applied to selection of carrots has been comparatively recent. The early work on carrots was primarily concerned with the transformations which the roots undergo while in storage. Hasselbring (6) found that the principal changes taking place in carrots during storage were a conversion of sucrose to reducing sugars and a breakdown of polysaccharides to simple sugars. He also found that these changes occurred more rapidly at higher temperatures, and that an equilibrium was reached during about the first ten weeks of storage. Hasselbring further concluded that the flavor of carrots was determined largely by their natural content of sucrose.

Platenius (12), in the same type of studies, made the interesting discovery that during the storage period sucrose was converted initially to reducing sugars, and the process was later reversed; sucrose increased while reducing sugars decreased. This work led Platenius to studies on the nature of quality in carrots, based on the assumption that quality was controlled largely by physiological processes.

Since sweetness of the carrot root depends on the relative amounts of the various sugars present, tests were made by Platenius (13) for their quantitative identification, based upon the specificity of these sugars on

the time required for osazone formation. His results showed that sucrose constituted almost all of the disaccharides, while glucose made up almost entirely the monosaccharide fraction. Fructose was assumed to be formed as an intermediate during sucrose hydrolysis and was probably converted enzymatically to other carbohydrates immediately. Since sucrose is sweeter than glucose (100 vs. 74.3 relative sweetness), it was concluded that the sweetness of carrot roots was dependent on the sucrose fraction of the total. This supports the theory previously advanced by Hasselbring (6).

Tenderness of carrot roots was considered by Platenius (13) to be proportional to the crude fiber content. In his experiments the percentage of crude fiber remained relatively constant for any given variety harvested at different physiological ages, indicating an inherent potential for tenderness or toughness.

Storage experiments by Platenius (13) showed a rapid increase in total sugars in stored roots early in the storage period, due primarily to hydrolysis of polysaccharides. This increase leveled off after about eight weeks as a result of increased respiration. The percentage of glucose (reducing sugar) increased until January, and then began to decrease while the sucrose (non-reducing sugar) percentage decreased until January, and then began to increase.

Werner (18) reported that there was a larger amount of sucrose compared with reducing sugar in both the xylem and phloem regions of the carrot root throughout the growing season. After about one month of storage the percentage of sucrose in the phloem declined to become less than that of reducing sugars, probably due to increased respiration. After this time sucrose again increased in relation to reducing sugars. Werner also reported that the sweetness rating of carrot roots on a basis of 100 for sucrose and 74 for reducing sugars, was higher in the phloem than in the xylem throughout the growing season. This condition was probably a result of the rapid decrease in xylem sweetness during the period of most rapid root enlargement. Sweetness in both the xylem and the phloem decreased rapidly in storage until November. *total sugars?*

Rygg (15) was concerned with the presence or absence of fructose in carrot roots, since up to this time most investigators, Platenius (13) among them, had found reducing sugars to be composed largely or entirely of glucose. His results showed that fructose was present in quantities closely approaching glucose in Danvers and Imperator varieties stored fifteen days.

Lipton (7) found that variety, soil type, and maturity of carrots affected the sugar content. Carrot roots grown on mineral soil contained 31.3 per cent more sugars on a fresh weight basis than those grown on muck. He suggested that the lower percentage of sugars in muck-grown

carrots may be a result of excessively high levels of fertility, an off-balance of nitrogen and potassium, or high soil temperatures. Lipton's work points out that the best way to express sugar content is on the basis of fresh weight at time of sampling, since that takes into consideration moisture content of the root and thus reflects its actual eating quality.

High dry matter is especially desirable in carrot roots used for processing, since it results in a greater net return per unit weight of raw product. Werner (18) reported that the dry matter percentages of carrots fluctuated throughout the growing and storage seasons in the same manner as the sucrose content. Lipton (7) showed that dry matter, as in the case of sugar content, was affected by soil type, variety and maturity. He found that dry matter content, although of little value in detecting quality, was useful in determining how sugars vary in relation to other constituents, and how changes in water content affect sugar content.

Most of the modern methods for determining sugars are based on the work of Munson and Walker (11) on methods for analysis of reducing sugar. Out of their extensive experiments came the conversion tables for sugars now the official standard for many sugar determinations. Their method of analysis with some modifications, is recognized by the Association of Official Agricultural Chemists.

Waldron et al. (16) in a study of methods, compared Soxhlet extraction with alcohol and water extraction, acid hydrolysis with invertase hydrolysis,

and the gravimetric and volumetric evaluation procedures. Their results were generally in good agreement for all methods. However, with some plant materials, such as spinach and bromegrass, it appeared that some constituents in plants are more soluble in water than in alcohol, and yield reducing sugars more readily when hydrolyzed with acid than with invertase. These results typify the problems likely to be encountered with different methods and different crops when analyzing for sugars.

The use of the refractometer in determining soluble solids has been practiced with many crops. Lutz (8) in comparing refractometer readings with chemically determined sugar contents of several American-type grape varieties, averaging between 11 and 22 per cent sugar, found differences of 1.8 to 2.6 per cent on a fresh weight basis between the two methods. Webster and Cross (17) working with grape juice over a four-year period, found a correlation of  $+0.9247$  between total sugars and refractive index values in 208 samples collected from 40 different varieties of grapes. Porter and Bisson (14) using the refractometer to determine sweetness of watermelons in the field, were able to detect extreme variations in total soluble solids of individual fruits and also composite samples. Their results did not prove that significant differences in total sugar content existed, although fruits with relatively high refractive indices tasted sweeter than those with low readings. They concluded that variations in soluble solids other than sugars existed in watermelons. Brown et al. (3) found a positive correlation of  $+0.626 \pm 0.79$  between good taste and high refractive index for eleven lots of different varieties of carrots grown at different nutritional levels and at different locations.

## MATERIALS AND METHODS

### A. Varieties

Twenty-seven commercial varieties and strains of carrots were planted in a six-replicate yield trial at the Experimental Muck Farm on May 2, 1957. Eleven of these varieties representing the most common types grown in the area were selected for analysis. Line MSU 2710 was a single-row  $S_1$  of Long Chantenay selected especially for its sweet taste. These varieties were field-harvested on September 22, 1957, topped, and ten representative roots from each of the six replications were packed randomly in wire-bottom crates in moist sphagnum moss. The roots were stored at 40°F in a common storage until sampling two weeks later.

### B. Sampling

Samples for analysis were taken over a period of one week from October 7 to October 13, 1957. Composite samples of the eleven varieties were secured by selecting fifteen typical roots at random from the variety. These were washed, dried, and cut into thin (about 1 mm.) slices, amounting to approximately 10 grams from each root, to give a total fresh sample of 150.0 grams per variety. Three of the varieties were sampled at top, middle and bottom of the roots to determine if significant differences in sugar content existed in different parts of the root. All sampling techniques in these experiments

were guided by the necessity of saving as much of each carrot root as possible, so the remnant could be planted for genetic studies and breeding.

Since it was desirable to find single roots high in dry matter and sugar content for breeding purposes, roots of each variety were sampled individually for analysis. Fifteen typical roots were selected at random, washed to remove clinging soil, dried, and sampled. The lower one-half inch of the roots was discarded and approximately 35 grams from the middle portion of each root were cut into thin slices. Sampled roots were tagged and returned to storage until planting in the greenhouse.

#### C. Determination of Dry Matter

Samples were weighed into tared aluminum foil boats and dried immediately at 160° to 170° F in a hot air drying oven for approximately 36 hours before reweighing. No caramelization of sugars was observed under these conditions. Drying was continued until a number of the samples had come to constant weight, at which time they were removed from the oven, allowed to cool a few minutes at room temperature, and weighed to the nearest 0.1 gram. Per cent dry matter was determined by the formula:

$$\frac{\text{Grams Dry Weight}}{\text{Grams Fresh Weight}} \times 100 = \text{Per Cent Dry Matter}$$

#### D. Determination of Soluble Solids

Samples for refractometer analysis were taken by slicing two sections

from the carrot root immediately above those removed for sugar analysis.

These were sealed immediately in Saran Wrap to prevent moisture loss, labeled, and frozen at  $-4^{\circ}\text{F}$  until analyzed.

Samples were removed from the freezer approximately three to four hours before analysis and allowed to come to room temperature. Any moisture condensed on the outside of the wrap was carefully blotted off. The freezing process had softened the tissue sufficiently so that juice could be easily squeezed out by hand. A Bausch and Lomb hand refractometer was used for the analyses, and readings were estimated to the nearest 0.1 per cent. No differences were found in comparing free-run juice with that squeezed out by hand in any given sample. Results are given in per cent total soluble solids expressed as sucrose.

#### E. Preparation of Samples for Sugar Analyses

After the samples were thoroughly dried and weighed, they were ground in a semi-micro Wiley mill through a 20-mesh screen. The mill was thoroughly cleaned by compressed air between samples. The dried samples were ground into labelled two-ounce bottles, mixed thoroughly, and stored until analyzed.

#### F. Determination of Sugars

Since difficulties may arise in attempting to use standard analytical

procedures on materials of diverse natures, it was necessary to prove the suitability of known procedures for analyzing dried carrot roots. Furthermore, since the ultimate purpose of these studies was to permit a comparison of the sugar content of one carrot root with another for selection purposes, a high degree of precision was not required. Attempts were made, therefore, to develop a procedure which would permit making rapid determinations with reasonable precision. The results obtained by the A. O. A. C. method for the determination of sugars were assumed to be the true values for sugar content in the roots and were used as the basis of comparison in this work.

Based on the results of Waldron et al. (16), water-extraction procedure for removing sugars from the tissue, and a hydrolysis~~is~~ period of fifteen minutes in a bath of boiling water were selected for this work. With this modified method it was possible to carry out the entire procedure in one day. The Fehlings reduction of copper gravimetric technique was chosen for the actual determination of sugars, since Waldron et al. (16) showed this procedure to be comparable in precision to the volumetric method.

In an attempt to further simplify the procedure, a number of analyses were made on the same sample with and without the use of lead acetate, which is used to remove proteins and other interfering substances. These analyses showed that, in the case of dried carrot material, the use of lead acetate did not significantly change results when using the modified method developed in

these studies (see Table I). These results agreed with those of MacGillivray et al. (9) on tomatoes, and Morris et al. (10) on grains and other field crops. This phenomenon may result from a lack of interfering substances in certain types of tissue.

Since in almost all cases the value for total sugars determined by the modified method were higher than those determined by the A. O. A. C. method, an attempt was made to discover the cause of these differences. Determinations on the same samples by the A. O. A. C. method, but substituting a fifteen-minute boiling water bath hydrolysis gave values closer to those determined by the A. O. A. C. method than to the modified method. This indicated that the larger values obtained by the modified method were probably a result of the greater solubility of sugars in water as opposed to the alcohol extraction in the A. O. A. C. method. These results conform with those of Waldron et al. (16) mentioned previously.

Since it seemed desirable to determine reducing and non-reducing sugars, as well as total sugars, procedures were also adapted for these determinations. All methods are outlined below:

#### Total Sugars

1. Weigh out 1 gram samples of dried material into 100 ml. volumetric flasks.

2. Place 30 ml. No. 10 Selsa crucibles into 105°C oven, allow to dry at least 3 hours, cool 20 minutes in dessicator, and weigh.

TABLE I

Values for Total Sugars in a Sample of Dried Carrot Roots as Determined  
by the A. O. A. C. and Modified Methods

| Method                                           | Cleared <sup>1/</sup> | Average | Not Cleared | Average |
|--------------------------------------------------|-----------------------|---------|-------------|---------|
| A. O. A. C. Method                               | 37.59                 |         | 39.56       |         |
|                                                  | 37.16                 |         | 39.40       |         |
| (Hydrolyzed overnight<br>at room temperature)    | 37.44                 |         | 38.98       |         |
|                                                  | 38.66                 |         |             |         |
|                                                  | 38.35                 | 37.84   |             | 39.31   |
| A. O. A. C. Method                               | 39.65                 |         | 39.80       |         |
|                                                  | 39.95                 | 39.80   | 40.03       | 39.92   |
| (Hydrolyzed 15 minutes<br>in boiling water bath) |                       |         |             |         |
| Modified Method                                  | 39.71                 |         | 40.08       |         |
|                                                  | 37.27                 |         | 40.55       |         |
|                                                  | 40.53                 |         | 41.64       |         |
|                                                  | 41.20                 |         | 42.10       |         |
|                                                  | 41.75                 |         | 42.63       |         |
|                                                  | 43.18                 |         | 41.90       |         |
|                                                  | 42.63                 |         | 41.78       |         |
|                                                  | 42.70                 | 41.13   | 41.34       | 41.50   |

<sup>1/</sup> Cleared with lead acetate. Excess lead removed with potassium oxalate.

3. Add 50 ml. distilled water to samples, place on hotplate at 98°C for 30 minutes.

4. At the same time set up blank determination of 50 ml. distilled water in 100 ml. flask.

5. Allow to cool, make to volume, and filter through dry Whatman No. 42 quantitative filter paper into 25 ml. Erlenmeyer flasks.

6. Pipette out 40 mls. into 100 ml. volumetric flasks. Add 2 ml. concentrated HCl and hydrolyze in boiling water bath for 15 minutes.

7. Cool, almost neutralize the HCl with 40 per cent NaOH solution, and make to volume.

8. Filter through dry Whatman No. 42 filter paper into 50 ml. volumetric flasks to mark, and transfer to 400 ml. beakers.

9. Add 25 ml. each of alkaline sodium potassium tartrate solution and  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  solution simultaneously.

10. Cover with ribbed watch glass, bring to boil in exactly 4 minutes, and boil for exactly 2 minutes.

11. Filter into a tared Sela crucibles with suction. Wash well with hot distilled water.

12. Dry at least 3 hours at 105°C in a hot air oven, cool in dessicator 20 minutes, and weigh.

13. Calculate per cent invert sugars from Munson and Walker tables.

Sample calculation:

$$1 \text{ gram} \times \frac{40 \text{ ml.}}{100 \text{ ml.}} \times \frac{50 \text{ ml.}}{100 \text{ ml.}} = 0.2 \text{ gram/aliquot}$$

To the grams of  $\text{Cu}_2\text{O}$  determined by weight, subtract the grams of  $\text{Cu}_2\text{O}$  in the blank.

For example:      Grams  $\text{Cu}_2\text{O}$  = .1642      Blank = .0003

Grams - Blank = .1639 grams = 163.9 mg.

Look up values in tables under invert sugar.

162 mg.  $\text{Cu}_2\text{O}$       =      73.9 mg. invert sugar

163.9 mg.  $\text{Cu}_2\text{O}$       =      x mg.      "      "

164 mg.  $\text{Cu}_2\text{O}$       =      74.9 mg.      "      "

Thus, by interpolation

$$\frac{1.9}{2.0} = \frac{x}{1.0}$$

$$2x = 1.9$$

$$x = .95$$

73.9 mg.

.95 mg.

74.85 mg. or .07485 gm invert sugar/.2 g. aliq.

$$\text{For a 1 gm. sample: } \frac{.07485}{.2} \times 100 = 37.43\% \text{ invert sugar}$$

### Reducing Sugars

The procedure for determining reducing sugars is essentially the same as for total sugars, except that hydrolysis is omitted.

Steps 1, 2, 3, 4 and 5 - Same as for total sugars.

6. Pipette out 20 ml. aliquot directly into 400 ml. beaker. Add 30 ml. distilled water. Proceed to step 9.

9, 10, 11, 12. Same as for total sugars.

13. Since only a 20 ml. aliquot was used, the calculations are:

$$1 \text{ gm.} \times \frac{20 \text{ ml.}}{100 \text{ ml.}} = 0.2 \text{ gm/aliquot}$$

Thus, the remaining calculations are identical to those for total sugars.

To determine the per cent sugars on the basis of fresh weight, the calculations are:

$$\text{Per cent sugars} = \frac{(\% \text{ invert sugars/dry wt.}) \times (\% \text{ dry matter})}{100}$$

### Non-reducing Sugars

Since total sugars consist of reducing plus non-reducing sugars, the non-reducing sugar content was obtained by difference.

### G. Statistical Methods

The results of all individual-root determinations were analyzed by analysis of variance. Significance between varieties for dry matter, soluble solids, and reducing sugars was tested by the multiple range test, as outlined by Duncan (4). No difference was considered significant unless it exceeded the 1 per cent level.

For each variety analyzed on an individual root basis the mean ( $\bar{x}$ ), standard deviation ( $S_{\bar{x}}$ ), standard error (S. E.  $\bar{x}$ ), and coefficient of variation (C. V.) were calculated. Regression lines and correlation coefficients were computed to show the relationships between soluble solids and dry matter content and between soluble solids and total sugar content.

## RESULTS

### A. Dry Matter

Dry matter values for composite samples of the eleven varieties and strains of carrots used in these experiments are shown in Table II. Imperator Lot 1027 was highest in dry matter content with 10.8 per cent<sup>1/</sup> and MSU 2710 was lowest with 8.5 per cent. In the three varieties which were sampled in different areas of the root, the dry matter percentage was in all cases highest near the top, intermediate in the middle, and lowest in the bottom portion of the root.

Dry matter contents of individual root samples of the eleven varieties and strains are given in Table III. The variety with the highest dry matter content was Imperator Lot 1027, with a mean of 10.60 per cent, and the lowest was MSU 2710 with 8.22 per cent. The greatest variability in dry matter content within a variety was in Chantenay Lot 1021, which had a range of from 7.7 to 13.3 per cent. The least variability was in MSU 2710, which ranged from 7.1 per cent to 9.1 per cent dry matter. Coefficients of variation of the variety means ranged from a high of 14.3 per cent in Chantenay Lot 1021 to a low of 7.1 per cent in Imperator Lot 1016. The coefficient of variation for all samples in these experiments was 9.8 per cent. The dry matter determinations for eleven varieties were analyzed statistically, and

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<sup>1/</sup> In these varieties in which composite samples were analyzed in three areas of the root, the values determined for the middle portion were chosen as most nearly comparable to those for the other varieties.

TABLE II

Values for Sugars and Dry Matter in Composite Samples of Carrots,  
Expressed as Per Cent of the Fresh Weight at Time of Sampling

| Lot No. | Variety or Strain       | Root Portion | Total Sugars | Reducing Sugars | Non-Reducing Sugars | Dry Matter |
|---------|-------------------------|--------------|--------------|-----------------|---------------------|------------|
| 1002    | Experimental            | Middle       | 4.02         | 1.28            | 2.74                | 9.5        |
| 1007    | Experimental            | Middle       | 4.17         | 0.86            | 3.30                | 10.0       |
| 1015    | R. C. Chantenay         | Top          | 3.57         | 0.58            | 2.99                | 9.3        |
|         | "                       | Middle       | 3.39         | 0.70            | 2.69                | 8.9        |
|         | "                       | Bottom       | 3.35         | 0.90            | 2.45                | 8.6        |
| 1016    | Imperator L. T.         | Middle       | 3.58         | 0.79            | 2.79                | 9.4        |
| 1017    | Gold Spike              | Top          | 3.19         | 0.49            | 2.71                | 9.2        |
|         | "                       | Middle       | 3.22         | 0.96            | 2.26                | 8.9        |
|         | "                       | Bottom       | 2.96         | 0.80            | 2.16                | 8.7        |
| 1018    | Gold Pak                | Middle       | 3.76         | 0.65            | 3.11                | 9.9        |
| 1021    | Chantenay               | Middle       | 3.76         | 1.08            | 2.68                | 8.7        |
| 1022    | Waltham Hicolor         | Middle       | 3.51         | 0.69            | 2.82                | 8.9        |
| 1027    | Imperator L. T.         | Top          | 4.50         | 0.39            | 4.11                | 10.9       |
|         | "                       | Middle       | 4.72         | 0.52            | 4.20                | 10.8       |
|         | "                       | Bottom       | 4.75         | 0.70            | 4.05                | 10.7       |
| 747     | MSU 2710 S <sub>1</sub> | Middle       | 3.18         | 0.81            | 2.37                | 8.5        |
| 1011    | Nantes                  | Middle       | 3.82         | 1.25            | 2.57                | 9.1        |

TABLE III

Dry Matter Content of Carrot Varieties and Strains, Expressed as Per Cent of Fresh Weight at Time of Sampling

| Root No.           | Lot Number of Variety or Strain |            |            |            |            |            |            |            |            |                    | 1027 <sup>1/</sup> |
|--------------------|---------------------------------|------------|------------|------------|------------|------------|------------|------------|------------|--------------------|--------------------|
|                    | 1002                            | 1007       | 1015       | 1016       | 1017       | 1018       | 1021       | 1011       | 747        | 1022 <sup>1/</sup> |                    |
| 1                  | 8.7                             | 9.7        | 8.0        | 10.1       | 8.9        | 12.0       | 10.5       | 9.6        | 7.2        | 9.2                | 9.9                |
| 2                  | 8.9                             | 10.0       | 9.1        | 9.4        | 9.1        | 10.3       | 9.4        | 9.4        | 8.5        | 9.8                | 10.5               |
| 3                  | 10.2                            | 9.0        | 7.2        | 8.3        | 8.6        | 10.5       | 9.3        | 9.9        | 9.0        | 8.2                | 10.4               |
| 4                  | 8.0                             | 9.7        | 8.4        | 10.4       | 8.6        | 10.0       | 13.3       | 8.7        | 8.3        | 9.7                | 11.5               |
| 5                  | 8.8                             | 9.0        | 8.2        | 10.0       | 7.5        | 8.8        | 10.1       | 9.3        | 7.8        | 9.7                | 12.4               |
| 6                  | 11.1                            | 10.3       | 9.2        | 9.9        | 8.5        | 9.8        | 8.5        | 8.7        | 7.9        | 9.2                | 10.9               |
| 7                  | 9.6                             | 10.6       | 10.9       | 8.6        | 9.0        | 10.2       | 7.7        | 10.3       | 8.6        | 9.9                | 10.1               |
| 8                  | 10.3                            | 10.7       | 8.8        | 9.1        | 9.5        | 8.5        | 9.4        | 8.9        | 7.2        | 9.3                | 10.3               |
| 9                  | 8.7                             | 9.7        | 8.2        | 10.2       | 8.2        | 9.7        | 8.9        | 8.4        | 8.5        | 7.4                | 9.4                |
| 10                 | 9.4                             | 9.7        | 7.9        | 9.0        | 9.5        | 10.5       | 9.4        | 12.4       | 8.7        | 10.2               | 10.7               |
| 11                 | 10.4                            | 12.6       | 8.5        | 10.6       | 10.4       | 9.1        | 8.7        | 8.8        | 7.1        |                    |                    |
| 12                 | 8.7                             | 9.4        | 8.5        | 9.5        | 8.9        | 10.5       | 8.5        | 9.1        | 9.1        |                    |                    |
| 13                 | 9.5                             | 12.0       | 8.6        | 9.7        | 9.3        | 11.0       | 8.3        | 9.3        | 8.4        |                    |                    |
| 14                 | 10.2                            | 10.6       | 9.8        | 9.9        | 7.3        | 9.7        | 10.1       | 9.4        | 8.6        |                    |                    |
| 15                 | 10.0                            | 10.5       | 9.3        | 10.4       | 9.9        | 9.9        | 8.4        | 7.7        | 8.6        |                    |                    |
| Mean ( $\bar{x}$ ) | 9.50                            | 10.23      | 8.70       | 9.68       | 8.88       | 10.03      | 9.35       | 9.33       | 8.22       | 9.26               | 10.60              |
| $S_{\bar{x}}$      | $\pm 0.86$                      | $\pm 1.00$ | $\pm 0.89$ | $\pm 0.69$ | $\pm 0.83$ | $\pm 0.87$ | $\pm 1.34$ | $\pm 1.06$ | $\pm 0.64$ | $\pm 0.86$         | $\pm 0.84$         |
| S.E. $\bar{x}$     | $\pm 0.22$                      | $\pm 0.26$ | $\pm 0.23$ | $\pm 0.18$ | $\pm 0.21$ | $\pm 0.23$ | $\pm 0.35$ | $\pm 0.27$ | $\pm 0.17$ | $\pm 0.27$         | $\pm 0.26$         |
| C. V.              | 9.1%                            | 9.8%       | 10.2%      | 7.1%       | 9.3%       | 8.7%       | 14.3%      | 11.4%      | 7.8%       | 9.3%               | 7.9%               |

<sup>1/</sup> Only 10 samples available.

the results of a multiple range test are presented in Table IV.

Since one objective of this study was to develop rapid and efficient means of selection for dry matter and sugar content, the relationship between soluble solids, as determined by the refractometer, and dry matter content was investigated. A highly significant correlation coefficient of +0.816 was found between refractometer reading and dry matter percentage. A similar relationship has been previously determined for onions by Foskett and Peterson (5).

A regression of dry matter on soluble solids (Figure 1) showed a standard deviation from the regression line of  $\pm 0.454$  per cent, indicating that the dry matter content of carrot roots can be predicted with a reasonable degree of accuracy from the refractometer reading.

#### B. Soluble Solids

The results of refractometer analyses of individual root samples of the eleven varieties and strains of carrot roots are given in Table V. The variety means varied from 6.1 to 7.2 per cent soluble solids. The multiple range test is presented in Table VI. In general, the Chantenay types contained the lowest percentages of soluble solids, with Gold Spike, Nantes, Waltham Hicolor, and Gold Pak intermediate. Imperator and the experimental types were highest in the range.

In soluble solids, roots of Red-cored Chantenay Lot 1015 varied from

TABLE IV

Multiple Range Test for Significance of Per Cent Dry Matter  
Between Carrot Varieties and Strains

| Variety<br>or Strain | Lot<br>Number | Mean  | Stat. <sup>1/</sup><br>Sig. |
|----------------------|---------------|-------|-----------------------------|
| MSU 2710             | 747           | 8.22  |                             |
| Red-cored Chant.     | 1015          | 8.70  |                             |
| Gold Spike           | 1017          | 8.88  |                             |
| Waltham Hicolor      | 1022          | 9.26  |                             |
| Nantes               | 1011          | 9.33  |                             |
| Chantenay            | 1021          | 9.35  |                             |
| Experimental         | 1002          | 9.50  |                             |
| Imperator            | 1016          | 9.68  |                             |
| Gold Pak             | 1018          | 10.03 |                             |
| Experimental         | 1007          | 10.23 |                             |
| Imperator            | 1027          | 10.60 |                             |

Coefficient of Variation<sub>OL</sub> = 9.8%

S. E.  $\bar{x}$  =  $\pm 0.074\%$

<sup>1/</sup> Means not spanned by a continuous line differ at the 1% level;  
e. g., the mean 9.26 differs from 8.88, but not from 9.33, etc.

Figure 1. Regression of dry matter content of carrot roots on soluble solids.

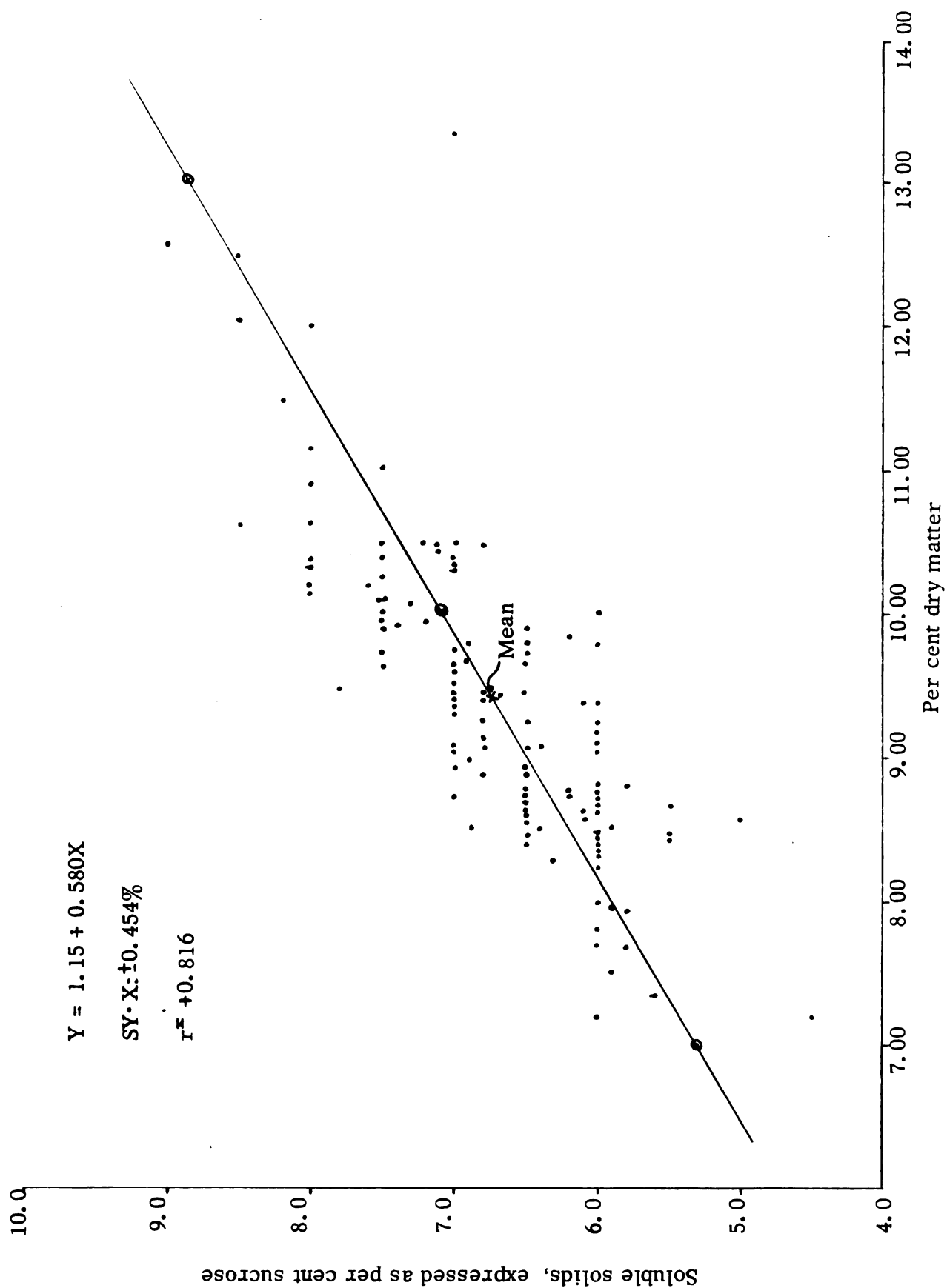


TABLE V

Soluble Solids of Carrot Varieties and Strains, Expressed as Per Cent Sucrose<sup>1/</sup>

| Root No.                          | Lot Number of Variety or Strain |           |           |           |           |           |           |           |           |                    |                    |  |
|-----------------------------------|---------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------------------|--------------------|--|
|                                   | 1002                            | 1007      | 1015      | 1016      | 1017      | 1018      | 1021      | 1011      | 747       | 1022 <sup>2/</sup> | 1027 <sup>2/</sup> |  |
| 1                                 | 6.5                             | 6.5       | 6.0       | 8.0       | 7.0       | 8.5       | 6.8       | 7.0       | 6.0       | 6.0                | 6.5                |  |
| 2                                 | 7.0                             | 6.0       | 7.0       | 6.5       | 6.8       | 7.0       | 6.1       | 7.0       | 6.9       | 6.9                | 7.4                |  |
| 3                                 | 8.0                             | 6.0       | 4.5       | 6.2       | 6.5       | 7.0       | 6.8       | 7.5       | 6.9       | 6.0                | 7.0                |  |
| 4                                 | 6.0                             | 7.0       | 6.5       | 7.1       | 6.5       | 7.0       | 7.0       | 7.0       | 6.3       | 6.7                | 8.2                |  |
| 5                                 | 6.5                             | 6.0       | 6.0       | 7.1       | 5.9       | 5.8       | 7.3       | 7.0       | 6.0       | 6.9                | 8.5                |  |
| 6                                 | 8.0                             | 7.5       | 6.5       | 7.5       | 6.5       | 6.2       | 6.4       | 6.0       | 5.9       | 6.0                | 8.0                |  |
| 7                                 | 7.5                             | 8.0       | 8.0       | 6.0       | 6.5       | 6.3       | 5.8       | 8.0       | 6.5       | 7.4                | 7.5                |  |
| 8                                 | 7.5                             | 7.5       | 6.0       | 6.5       | 6.9       | 5.9       | 6.8       | 6.5       | 5.1       | 7.0                | 7.0                |  |
| 9                                 | 6.5                             | 6.5       | 6.0       | 7.2       | 6.0       | 6.9       | 6.8       | 6.0       | 6.0       | 5.6                | 6.8                |  |
| 10                                | 7.0                             | 7.5       | 5.8       | 7.0       | 6.9       | 7.2       | 6.0       | 8.5       | 6.2       | 7.6                | 7.5                |  |
| 11                                | 8.0                             | 9.0       | 6.0       | 8.5       | 6.0       | 6.8       | 5.5       | 6.0       | 5.1       |                    |                    |  |
| 12                                | 6.0                             | 7.0       | 5.5       | 7.8       | 6.5       | 7.1       | 6.0       | 6.0       | 6.4       |                    |                    |  |
| 13                                | 7.0                             | 8.0       | 5.0       | 7.0       | 7.0       | 7.5       | 6.0       | 6.5       | 6.0       |                    |                    |  |
| 14                                | 7.5                             | 7.0       | 6.0       | 7.5       | 5.6       | 7.0       | 7.5       | 6.5       | 6.1       |                    |                    |  |
| 15                                | 7.5                             | 7.5       | 6.5       | 7.5       | 7.2       | 7.0       | 5.5       | 6.0       | 6.1       |                    |                    |  |
| Mean ( $\bar{x}$ )                | 7.1                             | 7.1       | 6.1       | 7.2       | 6.5       | 6.9       | 6.4       | 6.8       | 6.1       | 6.6                | 7.4                |  |
| S <sub><math>\bar{x}</math></sub> | $\pm 0.7$                       | $\pm 0.9$ | $\pm 0.8$ | $\pm 0.7$ | $\pm 0.5$ | $\pm 0.7$ | $\pm 0.6$ | $\pm 0.8$ | $\pm 0.5$ | $\pm 0.7$          | $\pm 0.6$          |  |
| S.E. $\bar{x}$                    | $\pm 0.2$                       | $\pm 0.2$ | $\pm 0.2$ | $\pm 0.2$ | $\pm 0.1$ | $\pm 0.2$ | $\pm 0.2$ | $\pm 0.2$ | $\pm 0.1$ | $\pm 0.2$          | $\pm 0.2$          |  |
| C. V.                             | 10%                             | 13%       | 13%       | 10%       | 8%        | 10%       | 9%        | 12%       | 8%        | 11%                | 8%                 |  |

<sup>1/</sup> As determined by Bausch and Lomb hand refractometer.<sup>2/</sup> Only 10 samples available.

TABLE VI

Multiple Range Test for Significance of Per Cent Soluble Solids<sup>1/</sup>  
Between Carrot Varieties and Strains

| Variety<br>or Strain | Lot<br>Number | Mean | Stat. <sup>2/</sup><br>Sig. |
|----------------------|---------------|------|-----------------------------|
| MSU 2710             | 747           | 6.1  |                             |
| Red-cored Chantenay  | 1015          | 6.1  |                             |
| Chantenay            | 1021          | 6.4  |                             |
| Gold Spike           | 1017          | 6.5  |                             |
| Waltham Hicolor      | 1022          | 6.6  |                             |
| Nantes               | 1011          | 6.8  |                             |
| Gold Pak             | 1018          | 6.9  |                             |
| Experimental         | 1002          | 7.1  |                             |
| Experimental         | 1007          | 7.1  |                             |
| Imperator            | 1016          | 7.2  |                             |
| Imperator            | 1027          | 7.4  |                             |

Coefficient of Variation = 10.1%

S. E.  $\bar{x}$  =  $\pm 0.055\%$

<sup>1/</sup> As determined by Bausch and Lomb hand refractometer.

<sup>2/</sup> Means not spanned by a continuous line differ at the 1% level,  
e. g., the mean 6.4 differs from 6.1, but not from 6.5.

4.5 to 8.0 per cent. Gold Spike Lot 1017, the least variable, ranged from 5.6 to 7.2 per cent. MSU 2710 also showed a small amount of variability, ranging from 5.1 to 6.9 per cent soluble solids. The coefficient of variation for the total population was 10.1 per cent.

The extremes for soluble solids in these experiments were 4.5 per cent in a root of Red-cored Chantenay and 9.0 per cent in a root from Experimental Lot 1007. This range does not represent the maximum, however, since refractometer readings on 400 individual carrot roots selected in the breeding project at Michigan State University ranged from 4.5 to 11.0 per cent soluble solids.

### C. Sugars

The values obtained for the determination of sugars in composite samples of eleven varieties and strains of carrot roots are given in Table II. Varieties ranged between 3.18 and 4.72 per cent total sugars, 0.52 and 1.28 per cent reducing sugars, and 2.26 and 4.20 per cent non-reducing sugars among the tested varieties.

Four of these varieties were analyzed for sugars on an individual root basis and the results are summarized in Table VII. Variety means for total sugars ranged from 3.83 per cent in Imperator Lot 1027 to 3.33 per cent in Gold Pak Lot 1018, and individual root extremes were 6.41 per cent in a root of Nantes and 1.92 per cent in a root from Gold Pak. There was no

TABLE VII

Sugar Content of Carrot Roots, Expressed as Percent of the Fresh Weight at Time of Sampling

|                   |            | Nantes (Lot 1101) |            |         | Imperator (Lot 1016) |            |            | Gold Pak (Lot 1018) |            |            | Imperator (Lot 1027) <sup>1/</sup> |            |            |
|-------------------|------------|-------------------|------------|---------|----------------------|------------|------------|---------------------|------------|------------|------------------------------------|------------|------------|
|                   |            | Total             | Red        | Non-red | Total                | Red        | Non-red    | Total               | Red        | Non-red    | Total                              | Red        | Non-red    |
|                   |            | Sugars            | Sugars     | Sugars  | Sugars               | Sugars     | Sugars     | Sugars              | Sugars     | Sugars     | Sugars                             | Sugars     | Sugars     |
| 4.08              | 0.39       | 3.69              |            |         | 4.68                 | 0.23       | 4.45       | 5.33                | 0.00       | 5.33       | 3.12                               | 0.48       | 2.64       |
| 4.76              | 1.65       | 3.11              |            |         | 3.68                 | 0.77       | 2.91       | 3.74                | 0.29       | 3.45       | 3.79                               | 0.23       | 3.56       |
| 3.63              | 0.69       | 2.94              |            |         | 2.64                 | 1.15       | 1.49       | 3.32                | 0.00       | 3.32       | 3.86                               | 0.75       | 3.11       |
| 2.59              | 1.13       | 1.46              |            |         | 3.96                 | 0.79       | 3.17       | 3.85                | 0.65       | 3.20       | 5.00                               | 0.27       | 4.73       |
| 3.51              | 0.77       | 2.74              |            |         | 3.95                 | 0.25       | 3.70       | 2.54                | 0.56       | 1.98       | 4.49                               | 0.95       | 3.54       |
| 2.23              | 0.82       | 1.41              |            |         | 3.11                 | 0.98       | 2.13       | 2.96                | 0.00       | 2.96       | 3.47                               | 0.44       | 3.03       |
| 4.56              | 0.73       | 3.83              |            |         | 2.47                 | 0.38       | 2.09       | 3.17                | 0.39       | 2.77       | 3.44                               | 0.61       | 2.83       |
| 3.51              | 0.82       | 2.69              |            |         | 3.58                 | 0.33       | 3.25       | 1.92                | 0.61       | 1.31       | 3.17                               | 0.60       | 2.57       |
| 2.94              | 0.51       | 2.43              |            |         | 3.97                 | 0.36       | 3.61       | 3.24                | 0.15       | 3.09       | 3.56                               | 0.88       | 2.68       |
| 6.41              | 0.67       | 5.74              |            |         | 3.12                 | 0.98       | 2.14       | 3.13                | 0.00       | 3.13       | 4.39                               | 1.20       | 3.19       |
| 3.26              | 1.17       | 2.09              |            |         | 4.44                 | 0.52       | 3.92       | 3.01                | 0.76       | 2.25       |                                    |            |            |
| 3.63              | 0.62       | 3.01              |            |         | 3.21                 | 0.17       | 3.04       | 4.02                | 0.64       | 3.38       |                                    |            |            |
| 2.16              | 0.97       | 1.19              |            |         | 3.65                 | 0.25       | 3.40       | 3.61                | 0.05       | 3.56       |                                    |            |            |
| 3.41              | 0.26       | 3.15              |            |         | 3.88                 | 0.49       | 3.39       | 3.07                | 0.09       | 2.98       |                                    |            |            |
| 2.82              | 1.06       | 1.76              |            |         | 4.04                 | 0.40       | 3.64       | 3.00                | 0.20       | 2.74       |                                    |            |            |
| Mean( $\bar{x}$ ) | 3.57       | 0.82              | 2.75       |         | 3.63                 | 0.54       | 3.09       | 3.33                | 0.29       | 3.03       | 3.83                               | 0.64       | 3.19       |
| S $\bar{x}$       | $\pm 1.10$ | $\pm 0.35$        | $\pm 1.16$ |         | $\pm 0.62$           | $\pm 0.32$ | $\pm 0.81$ | $\pm 0.76$          | $\pm 0.28$ | $\pm 0.88$ | $\pm 0.62$                         | $\pm 0.31$ | $\pm 0.64$ |
| S. E. $\bar{x}$   | $\pm 0.28$ | $\pm 0.09$        | $\pm 0.30$ |         | $\pm 0.16$           | $\pm 0.08$ | $\pm 0.17$ | $\pm 0.20$          | $\pm 0.07$ | $\pm 0.23$ | $\pm 0.19$                         | $\pm 0.10$ | $\pm 0.20$ |
| C. V.             | 30.8%      | 42.7%             | 42.2%      |         | 17.1%                | 59.3%      | 26.2%      | 22.8%               | 97.0%      | 29.0%      | 16.2%                              | 48.4%      | 20.1%      |

<sup>1/</sup> Only 10 samples available.

difference in total sugar content between varieties. However, Nantes Lot 1011 showed a greater coefficient of variation than the other three varieties for total sugars. The least variability was observed in Emperor Lot 1027. The coefficient of variation for all samples collectively was 23 per cent. A regression of total sugars soluble solids showed a standard deviation from the regression line of  $\pm 0.546$  per cent. The correlation coefficient of  $+0.751$  (Figure 2), indicates that total sugars can be estimated from the refractometer reading.

Reducing sugar content determined from composite samples of all eleven varieties ranged from 0.52 to 1.28 per cent. Individual root samples of the four varieties showed extremes in reducing sugars ranging from 0.00 per cent in a root of Gold Pak to 1.65 per cent in a root of Nantes. The multiple range test for reducing sugars is presented in Table VIII. The most variable variety in reducing sugar content was Gold Pak, with a coefficient of variation of 97.0 per cent. The least variable was Nantes, with a coefficient of 42.7 per cent (Table VII). The coefficient of variation for all samples was 55.5 per cent.

In single roots of Nantes, the most variable of the four varieties sampled, non-reducing sugars ranged from a high value of 5.74 to a low of 1.19 per cent. Emperor Lot 1027 was the least variable in non-reducing sugars, showing a coefficient of variation of 20.1 per cent as compared to 42.2 per cent for Nantes. The coefficient of variation for all samples was 30.7 per cent.

Figure 2. Regression of total sugars on soluble solids in carrot roots.

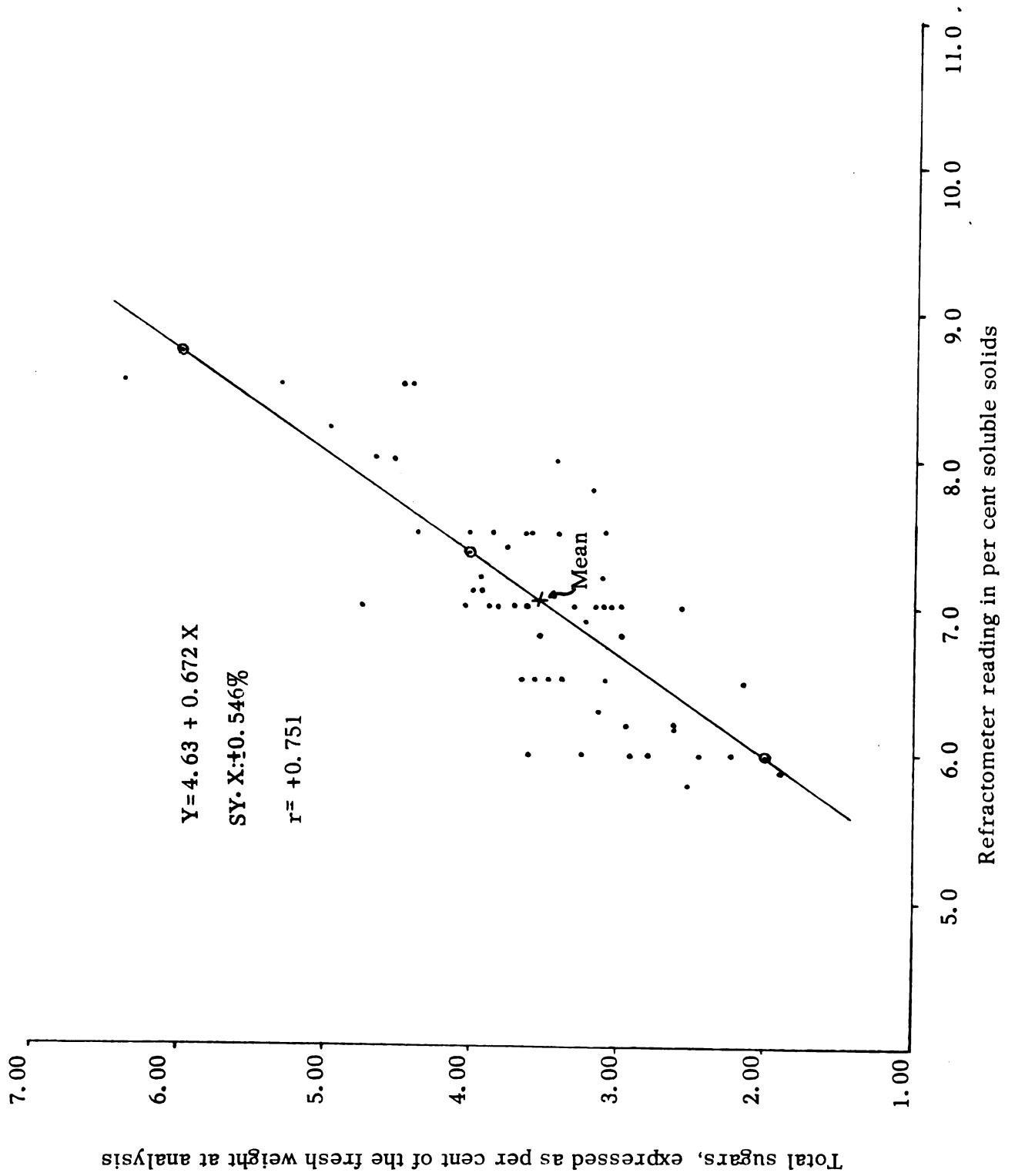


TABLE VIII

Multiple Range Test for Significance of Per Cent Reducing Sugars  
Between Carrot Varieties and Strains

| Variety   | Lot Number | Mean | Stat. <sup>1/</sup><br>Sign. |
|-----------|------------|------|------------------------------|
| Gold Pak  | 1018       | 0.29 |                              |
| Imperator | 1016       | 0.54 |                              |
| Imperator | 1027       | 0.64 |                              |
| Nantes    | 1011       | 0.82 |                              |

Coefficient of Variation = 55.5%

S. E.  $\bar{x}$  =  $\pm .043\%$

<sup>1/</sup> Means not spanned by a continuous line differ significantly;  
e. g. , 0.54 differs from 0.29, but not from 0.64.

## DISCUSSION AND CONCLUSIONS

### A. Dry Matter

Dry matter content of a number of composite samples of carrot varieties ranged from 8.5 to 10.8 per cent. The varieties having the lowest percentage dry matter were the Chantenay strains, primarily used for processing, while Nantes, Waltham Hicolor, and Emperor Lot 1016 were intermediate. Two market types, Emperor Lot 1027 and Gold Pak, and the experimental strains were highest. Some of the market types were high in dry matter and some processing types were low. This is the reverse of what would be expected, since processing carrots should be high in dry matter to increase net yield of the processed product and market types should be succulent.

The means of individual root analyses for most of the eleven varieties and strains of carrots approximated the values obtained for the composite samples, indicating that the sampling techniques for the two different determinations were comparable. The extremes in dry matter content of 13.3 and 7.1 per cent are important to the plant breeder because they indicate the levels of dry matter content that can be achieved through inbreeding and hybridization. The fact that in these experiments the least variable variety in dry matter content was MSU 2710, an  $S_1$  inbred, shows that uniformity can be improved by inbreeding.

In the three varieties analyzed at top, middle, and bottom of the root, the dry matter percentages in all cases were highest in the top, intermediate in the middle, and lowest in the bottom portion of the roots. This might be expected in the mature root, since the upper portions of the carrot contain a higher percentage of differentiated cells than the lower portions.

Differences in dry matter were observed between varieties. Although not analyzed by replications as such, samples of all varieties except MSU 2710 were taken at random from a six-replicate yield trial. The variation between varieties indicates that definite genetic differences exist in dry matter content.

The correlation coefficient of +0.816 between dry matter and soluble solids shows that as soluble solids increase there is a proportional increase in dry matter. The regression line computed for these factors demonstrates that, through the use of the refractometer, dry matter content of carrot roots can be estimated with an acceptable degree of accuracy from the standpoint of making selections in a breeding program. Actual dry matter content can be estimated by using the regression formula presented in Figure 1. Large numbers of samples can thus be rapidly analyzed with the refractometer, rather than by the slower process of determining dry matter content by weighing.

## B. Soluble Solids

Variety means varied from 6.1 to 7.2 per cent, a difference of only 1.1 per cent. These data would seem to put limitations of the effectiveness of the hand refractometer used in these experiments, since readings could be estimated only to the nearest 0.1 per cent. However, means differing by as little as 0.2 per cent were significant at the 1 per cent level of probability.

Variability ranges up to only 3.0 per cent within varieties might suggest that total soluble solids do not vary as greatly as dry matter content in carrot roots. By comparing the coefficients of variation for the two, however, it is evident that the variability is approximately the same. Variety means also ranked in about the same order for total soluble solids as they did for dry matter content.

For the plant breeder the extreme readings for individual roots of 4.5 to 9.0 per cent soluble solids are important, because with this range of variability it is possible to develop uniformly high or uniformly low lines by means of inbreeding and selection. In an assortment of inbred lines and open pollinated selections used in the carrot breeding project at Michigan State University refractometer readings were observed up to 11.0 per cent soluble solids. Such high values present the possibility of developing varieties having soluble solids and dry matter content higher than any now available, simply by working with selections from present varieties.

### C. Sugars

The sugar determinations for composite samples of carrots show that reducing sugars comprise a small fraction of the total sugar content; in most cases less than one-fifth. The means of the four varieties analyzed for total sugars did not differ. This might lead one to the conclusion that little genetic variability exists between varieties. However, as evidenced by the relatively high standard deviations of each of the varieties, this conclusion would be misleading.

The extreme ranges of 6.41 and 1.92 per cent total sugars point out the possibility of obtaining varieties with total sugar content at, or even exceeding, these extremes. The correlation coefficient and regression of total sugars on soluble solids shows that total sugar content, as well as dry matter, can be estimated from the refractometer reading by using the regression formula.

Reducing sugars were more variable both between and within varieties as compared to total and non-reducing sugars. Although some of the variability is undoubtedly genetic in nature, the difficulties in duplicating results experienced with some samples would seem to be of a technical nature. Probably most of the observed variability in reducing sugar content between varieties was due to laboratory techniques rather than to genetic factors. The fact that Nantes, the variety varying most in total sugar content, was

the least variable in reducing sugars suggests that some varieties were more susceptible to these laboratory errors than others.

Non-reducing sugars followed the same pattern as total sugars in the four varieties analyzed. This might be expected since non-reducing sugars constitute by far the greatest fraction of the total sugar content. The higher coefficient of variation for non-reducing sugars than for total sugars is probably due to calculating non-reducing sugar content by subtracting reducing sugars from total sugars, thus reflecting the great amount of unexplainable variation in reducing sugar content.

A comparison of sugar determinations shows that agreement was not good in all cases between composite samples and the means of individual root samples. Since all sugar analyses were duplicated and precision was in most cases 0.5 per cent on the basis of the dry weight samples, there seems to be no good explanation for this discrepancy. One possibility is that sampling error in the analysis of composite samples was high and in the same direction as the error in precision, resulting in the generally lower mean values based on individual root samples.

## SUMMARY

The objectives of this study were to determine the range of variability in dry matter and sugar contents within and between varieties of carrots, and to develop methods for rapid analysis of these constituents for selection purposes. This necessitated a study of methods for sugar determination and modification of these methods specifically for the dried carrot roots used in this experiment.

Dry matter analyses showed extremes between varietal means of 10.8 per cent for Emperor Lot 1027 and 8.5 per cent for MSU 2710. Within a single variety, roots of Chantenay Lot 1021 varied from 7.7 per cent to 13.3 per cent dry matter. The extremes observed for single roots were 13.3 per cent in a root of Chantenay, and 7.1 per cent in a root of MSU 2710. Soluble solids, as determined by the refractometer, varied from a mean of 7.4 per cent in Emperor Lot 1027 to 6.1 in MSU 2710. The greatest variability in soluble solids for a single variety occurred in Red-cored Chantenay, roots of which ranged from 4.5 to 8.0 per cent. Individual-root extremes were 9.0 per cent in Experimental Lot 1007, and 4.5 per cent in Red-cored Chantenay. Among varieties, total sugar content varied from 4.72 per cent in a composite sample of Emperor Lot 1027 to 3.18 per cent in a similar sample from MSU 2710. Within varieties the greatest variability was in Nantes Lot 1011, roots of which ranged from 2.23 to 6.41

per cent total sugars. The extremes observed for individual roots in these experiments were a high of 6.41 per cent total sugar in a root of Nantes and a low of 1.92 in a root from the variety Gold Pak. Reducing sugars were extremely variable, both within and between varieties. Non-reducing sugars followed closely in the pattern of total sugars and did not differ significantly between varieties.

Dry matter and total sugar content were correlated with soluble solids as determined by the refractometer. Regressions computed from these data demonstrate that, by means of the refractometer, both dry matter and total sugars can be estimated with a degree of accuracy that is satisfactory for root selection in a breeding program.

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