THE DRY MATTER AND SOLUBLE SOLIDS CONTENTS OF ONION BULBS AND GLADIOLUS CORMS IN RELATION TO MATURITY AND CURING

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Walter M. Rutherford

1954

This is to certify that the

thesis entitled

The Dry Matter and Soluble Solids Contents of Onion Bulbs and Gladiolus Corms in Relation to Maturity and Curing

presented by

Walter Malcolm Rutherford

has been accepted towards fulfillment of the requirements for

M. S. degree in Horticulture

Major professor

Date May 26, 1954

O-169

THE DRY MATTER AND SOLUBLE SOLIDS CONTENTS OF ONION BULBS AND GLADIOLUS CORMS IN RELATION TO MATURITY AND CURING

By

Walter M. Rutherford

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Horticulture

1954

ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation to Dr. Donald H. Dewey for his encouragement and guidance in the pursuit of this problem, and to Dr. George P. Steinbauer for his assistance in the preparation of the manuscript.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Harvesting at the optimum stage of maturity is extremely important for most horticultural crops. An index of maturity, usually based on changes in physical characteristics such as size, shape, color and firmness, is often available as a guide for the grower. The actual harvest date may be further modified to suit local economic and environmental conditions and the subsequent disposition of the crop.

Harvest maturity for northern-grown, globe type onions is determined by the observation of the condition of tops, the closing of neck tissue, and the drying of outer bulb scales. Regardless of the wide variation in individual observations, these indexes have proven satisfactory for hand harvesting conditions because of the flexibility allowed in choosing the areas to be harvested.

Mechanized harvesting and handling methods have made it impossible to closely follow previous procedures and suggest the need for a fuller understanding of maturity requirements. Further mechanization seems likely because of increased labor costs and competition and increased yields. A lack of flexibility in harvesting with machinery as compared to hand harvesting means that entire fields must be harvested at once. Uniform crop conditions are desirable for machine harvesters in order that harvesting may be quickly and efficiently accomplished. It may mean earlier harvesting when tops are uniformly green, or that perhaps some herbicide could be used to destroy the tops. In such cases, an index based on the stage of development of the bulbs rather than on the conditions of the tops would seem desirable.

Curing under natural conditions is an uncertain procedure since the results are dependent on weather conditions. The use of artificial curing methods in bulk storages gives positive results, and consequently a danger of overcuring. It would seem desirable for the storage operator to be aware of the exact stage of curing for best quality and storage. Present methods of determining the stage of curing appear indecisive, and a dependable estimation is gained only through experience.

Since curing is essentially a drying process, moisture changes should serve as an index. An index based on this factor might also be useful in determining harvest maturity, timing of pre-harvest chemical applications of herbicides or growth regulators, and in estimating certain post-harvest behavior such as shrinkage or storage life.

The gladiolus bulb is similar to the onion bulb only in that proper curing is required for storage. An index should be helpful in determining the proper time of harvest and the right amount of curing for best keeping quality.

Diseases are a serious problem during storage and can be minimized by proper curing and storage under relatively dry conditions. However, excessive moisture loss will adversely affect flower development. A guide to the proper moisture content to be attained by curing and then maintained during the storage period that could be readily and easily applied would be extremely helpful.

The purpose of these studies was to follow the moisture content changes of the onion bulbs and gladiolus corms through the later stages of development, during curing and storage, to relate these changes to the soluble solids content and to ascertain the feasibility of using the soluble solids as an objective index of the changes.

REVIEW OF LITERATURE

Maturity Index

An index of maturity for harvesting purposes is relatively important for a crop that is harvested a long time prior to utilization and receives such post-harvest treatments as ripening, curing, shipping, storage or processing. A reliable index for such crops provides some assurance that the final state of the product will be acceptable. Shoemaker (1952) indicates that optimum harvest maturity of horticultural crops usually depends on several factors, the most useful ones varying with the crop. An ideal index is one that changes uniformly, is easily determined and is self-evident. Expensive, cumbersome or time-consuming methods are not favored for field determinations. Haller (1952) suggests that, while an easily recognizable change must be used as a guide for harvesting, any of the physical and chemical changes during maturation might be established as a standard for harvesting. A number of the more commonly used indexes of maturity for horticultural crops are listed by Shoemaker (1952).

Onions

Determination of a maturity index for onions has been discussed by several authors. Normal maturity of onions, as defined by Magruder _et al_. (1941) occurs under conditions favorable for the gradual softening of the neck tissues. At the same time there is a downward movement of soluble solids from the leaves into the bulb. This causes the outer layers of the bulb to close over the opening to the inner scales and prevents, to a great extent, the entrance of decay organisms and an excessive loss of water. Shoemaker (1952) states that harvest maturity is indicated by a drooping of the tops near the bulb while the tops are still green. Due to a rapid increase in size at this time, resulting from the downward transference of food material to the bulb, best yields are obtained when most of the transfer occurs before harvest. However, because of the presence of "thicknecks", which never mature properly, harvesting is usually started when 90 per cent of the tops are down.

Filman (1952) describes a well-matured bulb as one that is firm, and with typical varietal shape and color. Breaking, rolling down of the tops or cutting the roots did not appreciably hasten maturity. Davis (1943) bases harvest maturity on condition of tops and indicates that lack of uniformity necessitates harvesting when 15 to 25 per cent of the tops have broken over. He contends that ultimate use of the crop, whether storage or fresh market, influences the stage of maturity at which harvest takes place. Jones _et al_. (1944) lists market price, condition of the crop and inclination of the grower as factors influencing actual harvest date. He describes two conditions that serve as guides to harvesting: (1) when 30 to 50 per cent of the tops are down, and (2) when the bulbs have nearly reached their maximum size, but tops are still green.

The authors generally agree that harvest maturity is determined either by the condition of the tops or the size of the bulb. However, it may easily be shown that these conditions are unsuitable under certain circumstances. The condition of the tops may be influenced, for example, by the presence of "thicknecks", which occur from the improper drying of the tops (Magruder, 1941; Shoemaker, 1952; Filman, 1952). If the decision to harvest is influenced by the presence of these "thicknecks", then harvest may be delayed past the optimum period. Onion tops may often by subjected to conditions such as excessive heat, drying winds or insect infestations which cause premature drying of the tops (Shoemaker, 1953; Magruder _et al_., 1941). The size of the bulb as it approaches maximum development is very difficult to determine, and may be influenced by moisture and cultural and fertilizer practices. From these references it would appear that the chemical composition of the bulbs may vary widely at the time they are thought to be mature, if judged according to the above standards. The characteristics recommended for estimating harvest maturity are subject to numerous interpretations, and should not be considered accurate or reliable for all conditions under which onions are grown.

The stage of maturity at which onions are harvested is important in several ways. Shoemaker (1953) concluded that early harvesting resulted in better retention of the outer skins and less sprouting and rooting during the curing period, but the bulbs were softer and more easily bruised. Soft bulbs also resulted from over maturity and excessive curing. Hoyle (1947) reported physiological shrinkage was greatest for onion bulbs harvested when the tops were still upright, intermediate for those harvested when tops were down but still green, and lowest for those harvested when tops were down and dry. In all experiments, less rot and less total loss occurred when the bulbs were harvested with tops down and dry. Boswell (1923) reported that within varieties, early maturing bulbs started growth less readily in storage and were less susceptible to loss from decay than late maturing bulbs. In his experiments, early maturing bulbs were those that first attained a stage of maturity where the tops weakened and fell to the ground. Those were harvested immediately, cured in the field for several days and placed in storage. Late maturing bulbs reached the above stage three or four weeks later and received the same treatment as the early maturing bulbs.

Colby (1945) indicates the presence of a "critical period", starting as maturity is approached and continuing until the tops are completely dried down. Evidently, good curing conditions are required during this period to insure good keeping during storage. The pungency of onion bulbs has been related to the stage of maturity by Platenius and Knott (1935). A peak in pungency is reached just before the tops begin to fall over. When the bulbs remained in the field after this point, their pungency as measured by the volatile sulfur content gradually decreased. Pungency was primarily affected by stage of maturity regardless of climatic conditions.

The degree of curing of onions after harvest and prior to storage has been variable according to the judgement of individual growers. A properly cured onion bulb has not been clearly defined. Shoemaker (1953) describes a well cured bulb as firm and not readily dented by the thumb. Numerous methods have been devised for curing onion bulbs outdoors under natural conditions, and more recently inside using forced air. Davis (1943) advised immediate placement of the bulbs in sacks or slat crates upon topping, followed by several additional days of curing in the field. Jones *et al.* (1944) suggested the method of windrow curing, where the tops remain on the bulbs and provide protection from the sun during curing. The success of the usual methods of outdoor curing depends entirely on weather conditions, and in certain seasons and locations results have been far from suitable.

One means of assuring more positive and dependable results is artificial curing in bulk storage bins. Hoyle (1948) concluded that artificial curing saved time and was highly satisfactory. He reported that bulbs containing green material as a result of mechanical harvesting stored best if artificially cured. Heated air was employed and there was no indication of injury to the bulbs when they received temperatures up to 118°F for as long as 16 hours. Such temperatures may be dangerous since Smith (1944) reported injury to garlic exposed to temperatures of 125°F for more than a few minutes. They concluded that, with garlic, less decay resulted from natural curing at a lower temperature in wire racks than by curing with artificial heat. Boyd and Davis (1954) have suggested the use of heat in forced air curing of Michigan onions, but cautioned against using temperatures over 100°F. At these temperatures there is the danger of excessive drying of the outer scales, resulting in "peelers" of less commercial value. Witzell (1946) reported that onions could be placed in storage earlier and without excessive sprouting by the use of forced air curing.

The changes in the composition of onions in relation to curing were studied by Lorenz and Hoyle (1946). They reported that curing under natural conditions resulted in a loss of weight of both topped and non-topped bulbs. Their results suggested a possible movement of materials from the tops to the bulbs during curing, especially when the tops were partly or completely in the green state at the start of curing. A turgid condition of the tops during curing indicated a possible removal of moisture from the bulbs through the tops.

Successful curing is dependent upon the removal of a certain amount of moisture from the bulbs so that the outer scales serve as a barrier against the entrance or growth of decay organisms. Excessive moisture removal from the whole bulb, however, is economically undesirable because of the loss in weight. The pattern of moisture changes, and of other materials affected by the concentration of water content would seem like a suitable basis for an objective index of the stage of maturity and curing. The rates of water loss during a period of several days following harvest were used by Woodman and Barnell (1937) to determine whether or not a new variety was a good keeper. They found that the bulbs showed a rapid loss of water just prior to harvesting, followed by a period when the moisture content remained practically constant. From this it would seem that determination of moisture content changes might be useful in establishing approaching maturity as well as predicting storage behavior. Foskett and Peterson (1950) studied the relationship of dry weight and sprouting in storage and found minimum sprouting was associated with a high dry matter content; whereas, considerable sprouting resulted with onions of a low dry matter content. Platenius and Knott (1941) suggest that relative pungency is dependent to some extent on dry matter concentration. Jones and Bisson

(1934) stated that varieties considered mild and of poor storage quality have the highest moisture content, while pungent varieties, with good keeping quality are related to low moisture content. While some of the authors refer to the dry weight content of the bulb, this could be determined by measurement of the moisture content.

Moisture changes possibly would serve as a guide to management practices other than harvesting and curing. One of these is the application of pre-harvest chemical sprays. It is known that sprouting in storage can be prevented by the proper application of maleic hydrazide while the tops are still green (Wittwer and Paterson, 1951). Accurate timing is essential since too early application results in hollow, puffy bulbs, and delayed applications are sometimes non-effective in sprout control. Hartman _et al_. (1953) suggest the pre-harvest application of a chemical to cause the outer scales of the bulb to turn brown so that the loss due to "peelers" can be reduced. The use of a herbicide has been suggested for killing the tops in order to provide more uniform harvesting conditions. The value of all these chemicals would depend upon their timely application and an index such as one based on moisture changes would be extremely useful.

Measurement of Moisture Changes

The standard method of measuring moisture changes by

(1934) stated that varieties considered mild and of poor storage quality have the highest moisture content, while pungent varieties, with good keeping quality are related to low moisture content. While some of the authors refer to the dry weight content of the bulb, this could be determined by measurement of the moisture content.

Moisture changes possibly would serve as a guide to management practices other than harvesting and curing. One of these is the application of pre-harvest chemical sprays. It is known that sprouting in storage can be prevented by the proper application of maleic hydrazide while the tops are still green (Wittwer and Paterson, 1951). Accurate timing is essential since too early application results in hollow, puffy bulbs, and delayed applications are sometimes non-effective in sprout control. Hartman *et al.* (1953) suggest the pre-harvest application of a chemical to cause the outer scales of the bulb to turn brown so that the loss due to "peelers" can be reduced. The use of a herbicide has been suggested for killing the tops in order to provide more uniform harvesting conditions. The value of all these chemicals would depend upon their timely application and an index such as one based on moisture changes would be extremely useful.

Measurement of Moisture Changes

The standard method of measuring moisture changes by drying to a constant weight in a vacuum oven is of little practical application for quick determinations in the field. The studies by Carter et al. (1950) to determine methods of ascertaining relative moisture changes of raw sweet corn have shown that the refractive index is rapid, accurate and adaptable to field conditions. Further work by Scott et al. (1945) established a basis for the use of the refractive index in measuring maturity of sweet corn for processing. These workers emphasized the need of a calibration chart for each hybrid, established by a graphical presentation of a large number of determinations of both refractive index and per cent dry weight, as determined by the vacuum oven method. These determinations were made over the normal course of maturation and included samples from numerous locations so that the final curve could be used to convert the refractive index to per cent dry weight for all samples. The authors expressed the opinion that this method provides an index of maturity independent of the moisture content, but related to it by the calibration procedure. The refractive index method was considered superior because it was less affected by extreme weather conditions, and possessed a great advantage in the speed of sample determination.

The refractive index, as discussed by Loomis and Shull (1937) is a rapid method of determining solute concentration. This method is suitable for measuring changes in concentration of any plant solution when the proportions of the various solutes do not vary appreciably. The use of the refractive index in studies of storage, translocation, ripening, etc., is dependent upon comparable methods of extracting the solution to be tested. Uniform pressures will usually give representative samples. Jessop (1939) states that the refractive index is a useful instrument for determining the soluble solids in sugar beets, sugar cane, citrus fruits, berries, etc. A hand press is recommended for expressing the juice.

The refractive index has been used on various crops and products to determine several different factors. Wagner (1940) used the refractive index in determining the sugar content of melons in the field. He found there was a high positive correlation between refractive index and Vitamin C content of the melons. Further uses of the refractive index include selection of varieties, determination of optimum maturity in sugar beets and grapes and quality control in processing industries (Zeiss-Opton, 1946).

The accuracy of the refractive index as compared to other methods has been discussed by several authors. Rygg (1945) reported moisture determinations by means of the refractive index agree within a range of 0.3 to 0.5 per cent with the vacuum oven method. He favored the use of the refractive index for reasons of simplicity and rapidity of determination. Gurley (1946), in work on specific gravity in tomato products, reported the greatest error in refractive index as caused by loss of water through evaporation. Zschabitz (1935) indicated that differences in results between refractometer and drying methods are more pronounced in less ripe fruit and attributed this to the higher acid and lower sugar content of immature fruit.

The refractive index has been suggested as a basis for a working standard in tomato preserves (Piegai, 1939), control analysis of fruit juices during condensation (Riedel, 1949), sugar determination in grape and wine (Francot, 1939; Jaulmes, 1950) and total solids in ice cream and milk products (Konokotina, 1948; Ludington, 1941).

The refractive index has also been used in determination of the dry matter content of the onion bulb. Biryukov (1939) was the first to note this correlation, and favored its use because of the ease and speed of determination and the elimination of the danger of heat decomposition. He reported a difference of approximately one per cent between refractive index and oven dry weight. Mann and Hoyle (1945) used the refractive index in selecting bulbs high in dry matter content for breeding purposes. They reported a significant correlation between the refractive index of the juice expressed from the outer two scales, and the dry weight of the whole bulb. They also indicated that varieties of onions with relatively low refractive index readings had large average bulb size. Foskett and Peterson (1950) in relating dry matter content to storage quality of onions confirmed the existence of a straight line regression between refractive index and per cent dry weight.

Gladiolus

Gladiolus corms are stored through the winter and used for flower production and propagation purposes the following year. They are of relatively high value and require rather exacting curing and storage conditions for maintenance of maximum vitality.

The effect of stage of maturity at harvest upon the subsequent development of the corm has received little attention in the literature. Magie (1952) reported that too rapid drying of immature bulbs resulted in reduction of flower yield. Gould (1953) reported experiments in which late harvesting resulted in a much higher per cent of rotted corms. Other references (Hawker, 1946; Wade, 1945) report more healthy corms from early harvesting.

There have been numerous experiments on the methods of curing. Such conditions as length of the curing period, temperature and relative humidity have received attention. There appears to be two thoughts in respect to the need of moisture removal from the corms. Forsberg (1952) describes a method in which moisture is rapidly removed from the corm to reduce the danger of rotting. Bald (1953) discusses the heat curing method where suberization and wound periderm formation is favored and drying is of secondary importance. The latter method requires a longer curing period and involves maintenance of high temperature and high humidity.

Considerable controversy exists as to the proper temperature required for curing. Forsberg (1952) recommended the use of heat drying and reported satisfactory results after 16 hours at temperatures of 82° to 104°F. However, drying for 16 hours or longer at 120°F resulted in reduced growth. Simmons (1949) indicated that heat drying tended to break dormancy. Gould (1953), upon reviewing the literature on curing treatments for disease control, concluded that warm temperature curing of freshly dug corms reduces decay development. This action is believed to be a result of the formation of suberin and cork cells which serve as a barrier against invading organisms. He lists temperature, length of curing time and relative humidity as factors contributing to the rate of suberization and periderm formation. Experiments conducted in 1947 by Gould indicated that curing at 130°F did not completely destroy the flowering potential, and curing at 80°F for 10 days did not adversely affect flowering. He reported, however, a "so-called heat injury" characterized by a discoloration of the corm after curing for 10 hours at 120°F. Variation in results prompted him to attribute some of the cause to condition of the corms prior to curing. He summarizes this review as follows, "Curing, whether natural or artificial, results in a loss of water, deposition of suberin in certain cells, and formation of cork layers and the abscission layer at the base of the new corm. The latter effect serves to excise the old corm, prevent excessive drying and retard fungous invasion." He suggests an index of curing based on formation of the abscission layer as a practical method. The ease of separation of the new corm from the old would be the principle factor.

A number of experiments have been carried out on temperature and relative humidity through the storage period, and their effect on the corms. The results have been varied, and numerous recommendations have been made. Stuart (1953) reported satisfactory results over a wide range of temperatures, but recommends the range of 40° to 50°F as most satisfactory. Rose et al. (1942) suggested the same range of temperatures with a relative humidity of 70 to 75 per cent. They reported that corms will remain fully dormant at 40°F, but sprouting will occur at 50°F after four to six months. Ample ventilation was stressed as a basic requirement for storage. Lauritzen and Wright (1934) obtained a greater loss in moisture at 32°F than at 40°F, which they attributed to lack of suberization at the lower temperature. They reported complete dormancy at 32°F, rooting at 40°F, and both sprouting and rooting at 50°F. Gould (1953), in his review of storage recommendations, indicated a range of 32° to 50°F as satisfactory.

The effect of relative humidity has been discussed by several authors. Pridham and Ratsek (1932) indicated that humidity in storage had little effect on the flower production, but was related to loss in weight of the corms. Magie (1952) concluded that relative humidity had little effect on the corms, unless it was low enough to cause excessive water loss or high enough to cause rooting. He recommended a relative humidity of 80 to 85 per cent for storage at 40°F. He also stressed the need for good ventilation to prevent injury due to a lack of oxygen.

Stuart (1953) believes that too much emphasis has been placed on the effect of the treatment on disease control, while the effect on subsequent growth and flower development have been largely overlooked. He suggested that future experiments should include the effect of the treatment on the corm and its development, as well as the effect on the disease.

EXPERIMENTAL METHODS

The soluble solids determinations were made with a Zeiss Opton hand refractometer, calibrated in percentage sugar and scaled to 0.5 per cent. The readings were estimated to the nearest 0.2 per cent and were corrected for temperature deviation from 20°C by the temperature adjustment table provided with the instrument.

The percentage dry weight, based on original fresh weight, was calculated by placing weighed samples in moisture dishes in a standard vacuum oven at 70°C and 29 in. of mercury until constant weight. Onion samples required 18 hours to reach a constant weight, while gladiolus corms required 28 hours. The longer time factor required by the latter was attributed partly to the nature of the corm and partly to the larger load in the oven. Samples of both onions and gladiolus were cut into small pieces to facilitate uniform drying.

Onions of the variety Downing Yellow Globe, grown at the Michigan State College muck farm, were used for maturity index determinations. They were grown in the normal manner, and selected from randomized plots in five rows of 300 feet in length. Ten bulbs were harvested from a plot in each of the rows at weekly intervals, from August 5 to September 14, with the exception of the week of September 7. The bulbs were variable in size, but no very small bulbs were used.

The dirt was removed by brushing and the total weight of the plant and the bulb weight alone were determined. Four bulbs from each plot were used for both soluble solids and dry weight determinations. The remainder were used for refractometer readings only. The dry outer scales were removed, and the bulbs were cut laterally midway between the top and the root, so as to yield two parts of nearly equal size. A uniform slice, approximately one-eighth inch in thickness was removed from the cut surface of both parts. The slice from the upper part of the bulb was placed in a hand vegetable juicer and the juice expressed by moderate pressure. The juice from each onion was mixed thoroughly and several drops were placed on the prism of the refractometer. The slice from the lower half was cut into small pieces and placed in moisture dishes for dry weight determination.

The gladiolus corms were of the variety Maid of Orleans, grown commercially on a sandy loam soil three miles north of East Lansing. Random plots were set up in the same manner as with onions. Ten corms were harvested from each of five plots each week. Because of the difficulty encountered in expressing juice from the corms, the largest four corms in each group of ten were used for the soluble solids - per cent dry weight correlations. Harvesting was started on September 23 and continued weekly until November 12.

The corms were cleaned in the laboratory and cut longitudinally to give two nearly equal parts. One part was diced into small pieces into moisture dishes. The juice was expressed from the other part in the vegetable juicer. This juice was thick, creamy yellow in color, and required centrifuging for ten minutes at 2000 rpm before its refractive reading could be determined. This treatment produced a bright, clear yellow liquid. The refractive indexes were determined approximately 15 minutes to one hour after the juice was extracted.

Preliminary determinations of the dry weight and soluble solids changes brought about by curing were made with Ebenezer onions grown at the muck farm. Ten bulbs, harvested August 5, were cured in a 100°F oven, in the greenhouse on an open bench, and outside in the shade. Half of each lot was cured with tops and half with tops removed. Refractometer readings were made on the second and fifth days of curing.

Similar tests were made with Downing Yellow Globe, harvested from the replicated plots on August 11. Lots of ten bulbs were cured at 100°F in the oven, in the greenhouse, in the shade outside and at 40°F in a storage room for 7, 11 and 17 days. Refractometer readings and weight loss calculations were made for each curing period.

Bulbs harvested August 25 were cured with and without tops for one week at the four curing conditions. Refractometer readings and weight loss calculations were made after the curing period. The initial refractometer reading was taken as the average of the 50 bulbs harvested on the same day from the same plots for maturity work. Each lot was composed of 50 bulbs.

The gladiolus corms used for the curing and storage studies were harvested November 11 and separated into three equal lots for curing. They were cured in an unheated shed where the temperature ranged from 35° to 70°F and averaged 50°F, and in 85° and 100°F chambers. The 85°F chamber had an average relative humidity of 60 per cent while the 100°F chamber was higher at 65 per cent. The relative humidity of the shed was not determined.

After two days of curing, one-third of the corms were removed from each location, cleaned and replaced at the original condition for 24 hours. Samples of 20 corms were then taken for dry weight determinations. The remainder were divided into lots of 15 corms each and placed in sealed polyethylene, perforated polyethylene and Kraft paper bags for storage at 32° and 40°F. Duplicate samples were employed for the storage tests. Lots cured for six and eight days were handled and cured in the same manner.

After 18 weeks of storage, all samples were removed for dry weight determinations. Four corms were removed from each bag, and allowed to come to room temperature. The corms were thoroughly dry on the surface before samples were taken. Approximately one-sixth of each corm was used, and the four corms in each lot were combined into one moisture dish.

Statistical Analysis

A standard correlation procedure was used for correlation of per cent soluble solids and per cent dry weight. The 95 per cent area was determined as discussed in Croxton and Cowden (1946). Analysis of variance of curing treatments was determined after Snedecor (1946).

EXPERIMENTAL RESULTS

Onions

The relationship of the per cent soluble solids of the expressed juice of onion bulbs to the per cent dry weight of the bulbs through the harvest season is shown in Figure 1. Highly significant positive correlations occurred for the six harvests made over a period of seven weeks. The correlation values listed in Table I, for the weekly determinations ranged from 0.608 to 0.941. The results obtained at intervals of two weeks were composited and are presented graphically in Figure 2 as a single regression line for the entire harvest period. As true for the individual harvests, the correlation for the whole period is significant at the one per cent level. The lines above and below the regression represent the standard error of estimate. At least 95 per cent of the samples would be expected to fall within the defined area, had additional samples been determined from the same plots. The regressions for two other lots of onions, one of the variety Downing Yellow Globe, harvested from another location at the Michigan State College muck farm and the other of the same variety grown commercially at Stockbridge are included in Figure 2 as lines B and C, respectively. It should be noted that both fall within the standard error established for the regression line of soluble solids and

TABLE I

SOLUBLE SOLIDS AND DRY WEIGHT OF DOWNING YELLOW GLOBE ONIONS

Harvest date	Regression	Average percentage		r Value
		Soluble solids	Dry weight	
Aug. 5	.649X + 5.20	8.16	10.52	.608
11	.864X + 3.12	8.73	10.66	.792
18	.973X + 2.54	9.22	11.51	.884
25	1.004X + 2.57	8.93	11.54	.825
31	.821X + 3.42	9.32	11.07	.780
Sept. 14	.885X + 2.33	9.39	10.64	.941
A	.769X + 4.00	9.02	10.94	.784
B	.965X + 2.78	8.18	10.67	.942
C	1.025X + 1.08	8.91	10.21	.928

A - combined data of four harvest dates at intervals of two weeks.

B - onions from non-experimental plot at Michigan State College muck farm.

C - onions from a commercial planting on muck at Stockbridge, Michigan.

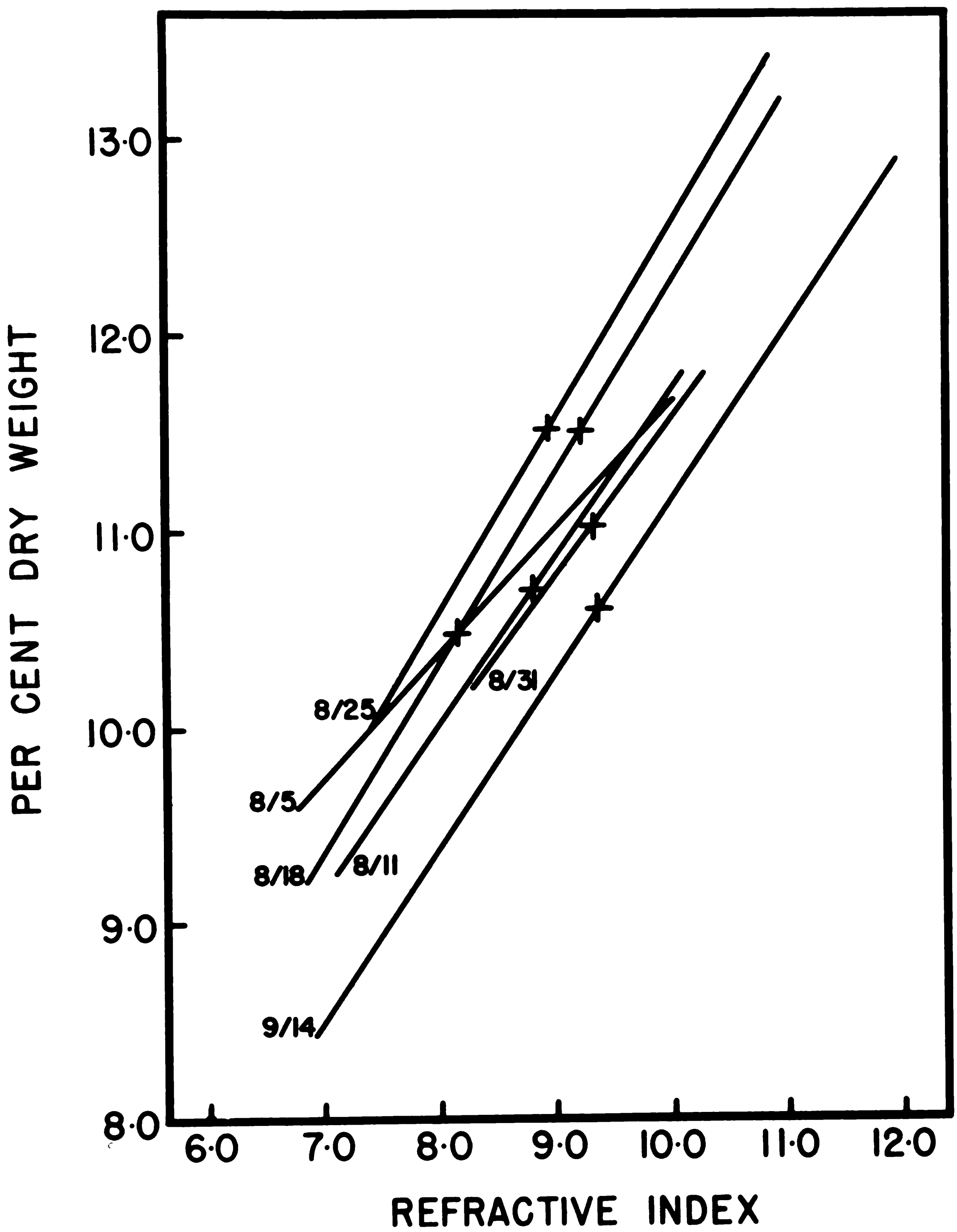

Figure 1. Regression lines of dry weight on refractometer readings of Downing Yellow Globe onion bulbs for six harvest dates.
The refractive index was measured as per cent soluble solids.

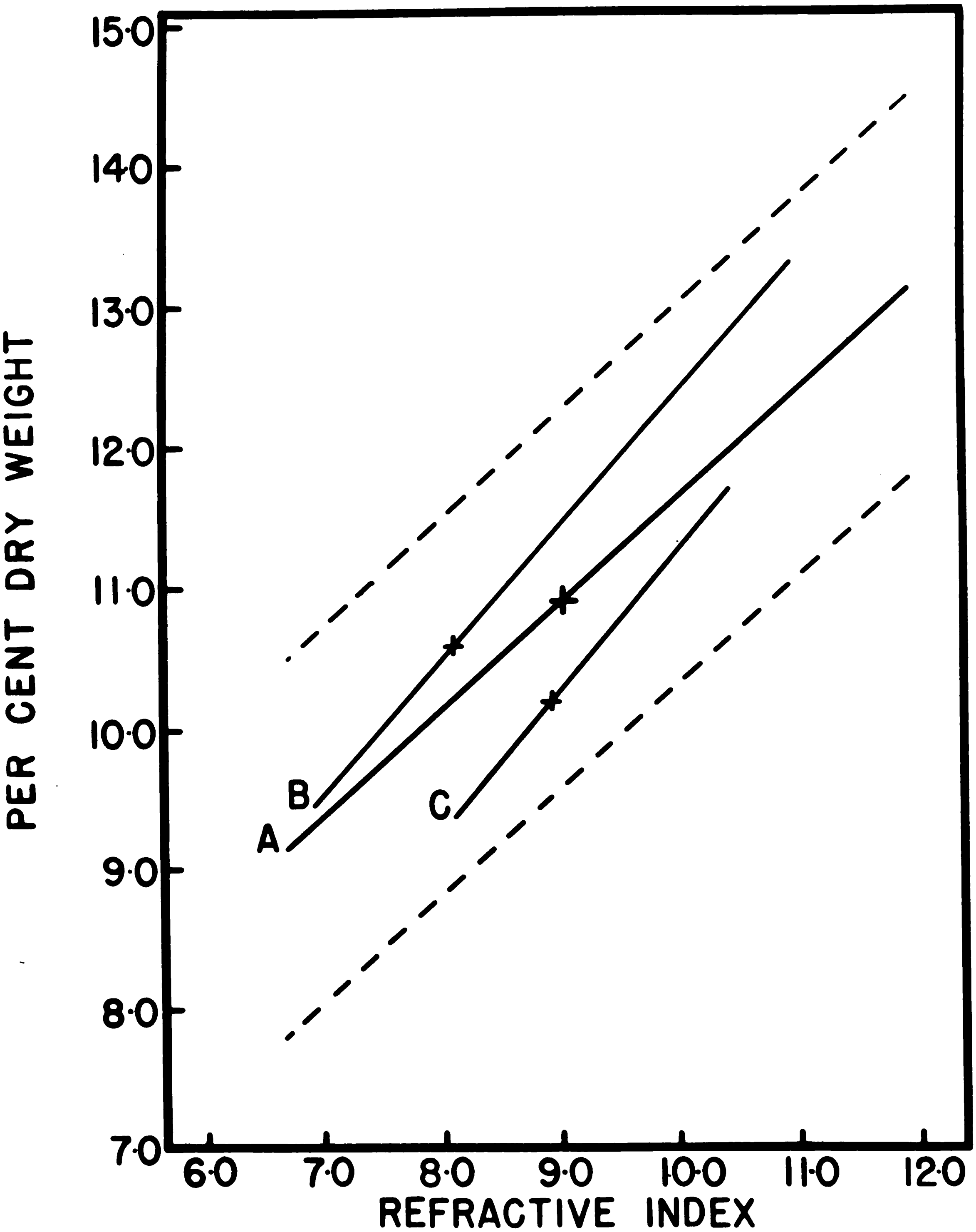

Figure 2. Regression lines of dry weight on soluble solids of Downing Yellow Globe onion bulbs. Line A represents four harvests at intervals of two weeks; line B is for onions harvested from non-experimental plot at Michigan State College muck farm; and line C is for onions from a commercial planting at Stockbridge. The refractive index was measured as per cent soluble solids.

dry weight of the test onions (line A). The actual changes in percentage soluble solids and percentage dry weight from week to week are shown in Figure 3. There was a similar increase of both factors during the early stages of maturity, followed by a more or less levelling off during the period of August 18 to August 25. Following this change, the per cent dry weight decreased markedly the rest of the harvest period. The per cent soluble solids of the 20 samples used for correlation purposes showed a slight increase after the week of August 18-25. A more accurate determination of the weekly changes obtained from lots of 50 bulbs were similar to those from the lots containing only 20 bulbs. The percentages of soluble solids for the larger samples, however, were slightly lower than those of the smaller samples.

The changes in top characteristics were observed through the harvest period. The tops were practically all green at first, had begun to show signs of drying by August 18, and were completely down except for an occasional thickneck on August 25. By August 31 all tops were completely dry.

The r values for bulb size as determined by fresh weights and refractometer readings for six harvest dates are tabulated in Table II. A significant negative correlation of these factors occurred at the first harvest. Thereafter, none were significant, showing that these two factors were not related as determined here. The slight change from negative to positive correlation at the intermediate harvest date should be noted.

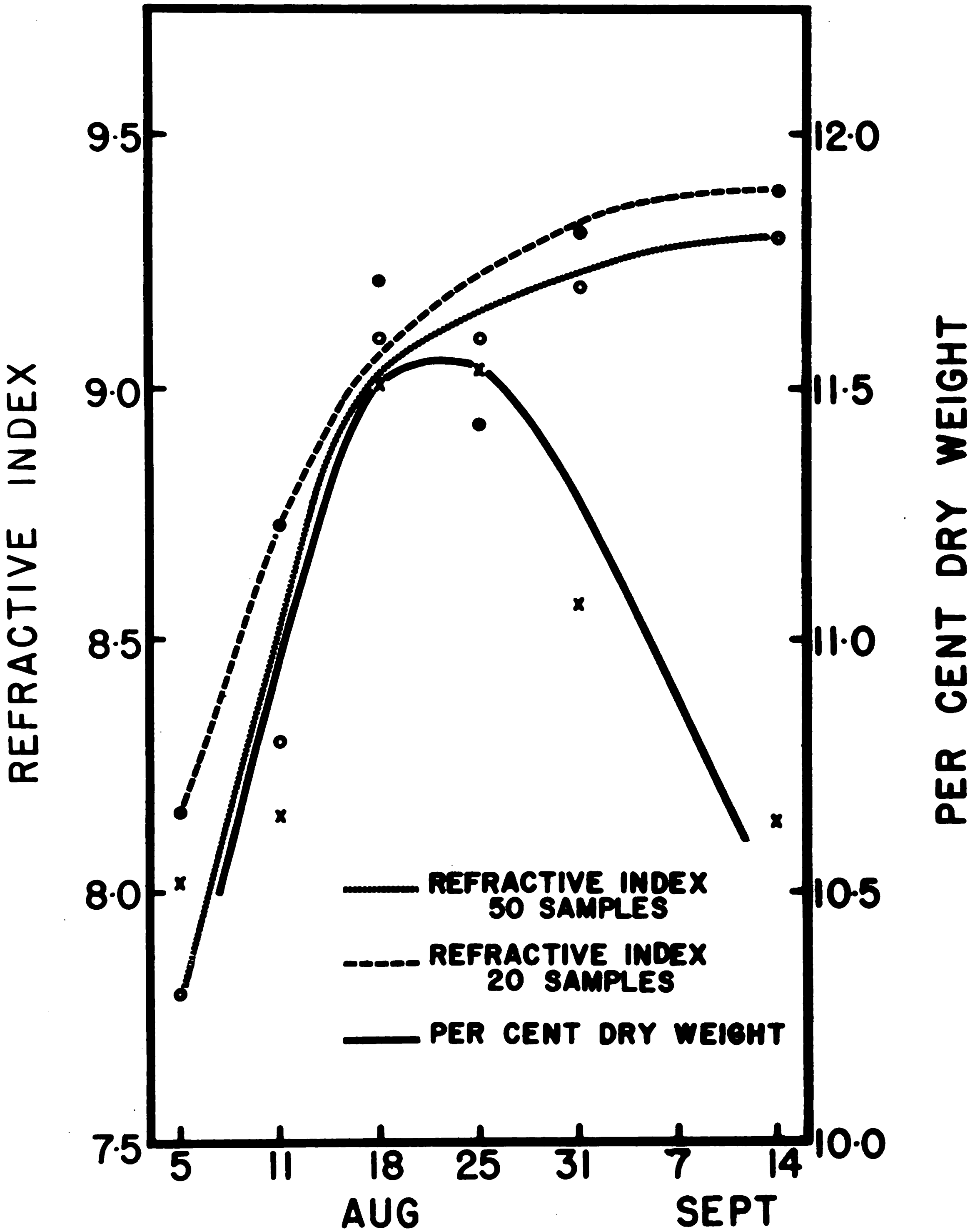

Figure 3. Changes in dry weight and soluble solids of Downing Yellow Globe onion bulbs during maturation.
The refractive index was measured as per cent soluble solids.

TABLE II

CORRELATION OF SOLUBLE SOLIDS AND FRESH WEIGHT FOR DOWNING YELLOW GLOBE ONION BULBS

Date	r Value	Required for significance
Aug. 3	- .307	(50 bulbs)
11	- .154	5% = .273
18	- .017	1% = .354
25	+ .036	
31	+ .012	
Sept. 14	- .225	

Per cent soluble solids determinations were made for onions cured with and without tops. Preliminary tests with the variety Ebenezer, Table III, yielded higher refractometer readings for onions cured with tops than for those cured without tops. This difference was more pronounced after two days of curing than after five days. The refractometer readings for Downing Yellow Globe showed very little difference between curing with and without tops. These results are shown in Table IV. The temperature of curing was of no effect upon the per cent soluble solids cured with and without tops.

The highest average refractometer readings were obtained by curing under natural conditions while the lowest were obtained from curing at 100°F. Comparisons in per cent

TABLE III

REFRACTOMETER READINGS IN PER CENT SOLUBLE SOLIDS OF EBENEZER ONION BULBS AFTER CURING

Duration of curing	Curing condition	Percent soluble solids	
		Without tops	With tops
2 days	100°F oven	9.6	10.6
	Greenhouse	11.0	12.1
	Outside	10.4	10.7
5 days	100°F oven	10.8	11.0
	Greenhouse	11.0	10.9
	Outside	10.0	10.9

TABLE IV

PER CENT SOLUBLE SOLIDS AND PER CENT WEIGHT LOSS OF DOWNING YELLOW GLOBE ONION BULBS AFTER CURING FOR ONE WEEK

	Curing condition			
	40°F	Outside	Greenhouse	100°F oven
Without tops				
Soluble solids (%)	9.15	9.32	9.00	8.98
Weight loss (%)	2.8	2.9	3.8	4.4
With tops				
Soluble solids (%)	9.22	9.42	9.09	8.95
Weight loss (%)	5.4	8.7	10.7	13.6

weight loss of bulbs with and without tops could not be made since the losses from those cured with tops included the loss of the tops as well as moisture losses from the bulbs.

The average per cent soluble solids of 50 bulbs from the same plots at the time of harvest was 9.3. Curing outside resulted in no change from the initial reading, whereas the other curing conditions resulted in reduced percentages of soluble solids.

Additional curing studies with the variety Downing Yellow Globe resulted in no significant differences in refractometer readings between lengths of curing times. These results are shown in Table V. The experimental plan was not designed for analysis of curing temperature.

The per cent weight losses were transposed by the formula angle = arc sin percentage (Snedecor, 1946) for statistical analysis. A significant difference was determined between curing times at the five per cent level. These results are presented in Table VI.

TABLE V

PERCENTAGE SOLUBLE SOLIDS OF DOWNING YELLOW GLOBE ONION BULBS DURING CURING

Duration of curing	Curing condition				
	40°F	Outside	Greenhouse	100°F oven	Average
7 days	8.0	8.5	8.0	7.7	8.1
11 days	8.2	8.4	7.7	8.3	8.2
17 days	7.7	7.7	7.8	7.3	7.6

No significant difference for duration of curing

TABLE VI

PERCENTAGE WEIGHT LOSSES (FRESH WEIGHT) WITH ANGULAR TRANSFORMATIONS FOR TOPPED DOWNING YELLOW GLOBE ONIONS DURING CURING

Duration of curing		Curing condition				
		40°F	Outside	Greenhouse	100°F oven	Mean
7 days	Per cent	3.3	5.9	7.5	12.4	7.3
	Angle	10.47	14.06	15.89	20.62	15.26
11 days	Per cent	3.9	7.0	10.1	18.0	9.8
	Angle	11.39	15.34	18.53	25.10	17.59
17 days	Per cent	4.4	8.0	12.3	21.4	11.5
	Angle	12.11	16.43	20.53	27.56	19.16

Angular $LSD_{.05}$ for duration of curing means = 2.12.

Gladiolus

The correlation values of soluble solids and dry weights for gladiolus corms harvested over a period of eight weeks are summarized in Table VII. A significant correlation value resulted only for the last harvest date. At this time, November 12, the two determinations had a negative correlation that was significant at the one per cent level. It should be noted that there was a change from positive to negative correlation of per cent soluble solids and per cent dry weight as the harvest season progressed.

The average per cent of soluble solids (shown as refractive index) and dry weight at weekly intervals for the entire harvest season are shown in Figure 4. The accuracy of the plotted lines is not known; however, they may suggest the general trend of changes during this period in spite of the extreme variability in both factors from week to week. The percentage dry weights increased for the first six weeks and tended to level off during the last two weeks. Contrary to the results obtained for onions, the per cent soluble solids for gladiolus corms decreased as the plants advanced in maturity.

The per cent dry weight of the gladiolus corms was determined at the completion of the curing treatments and are shown in Table VIII. Statistical analysis of the results

TABLE VII

CORRELATIONS OF DRY WEIGHT AND SOLUBLE SOLIDS FOR MAID OF ORLEANS GLADIOLUS CORMS AT HARVEST

Date	r Value	Number of samples	r Value required for significance
Sept. 23	+ .333	16	5% = .482; 1% = .606 (16 samples)
30	+ .182	20	
Oct. 7	+ .120	20	5% = .433; 1% = .549 (20 samples)
15	+ .383	20	
22	- .033	20	
29	- .056	20	
Nov. 6	- .044	20	
12	- .690**	20	

TABLE VIII

PER CENT DRY WEIGHT OF GLADIOLUS CORMS AFTER CURING

Duration of curing	Curing condition			
	Outside	85°F	100°F	Mean
3 days	28.6	28.8	30.8	29.4
6 days	29.2	29.8	31.4	30.1
8 days	30.6	29.1	30.7	30.1
Mean	29.5	29.2	31.0	29.9

No significant differences between durations of curing.

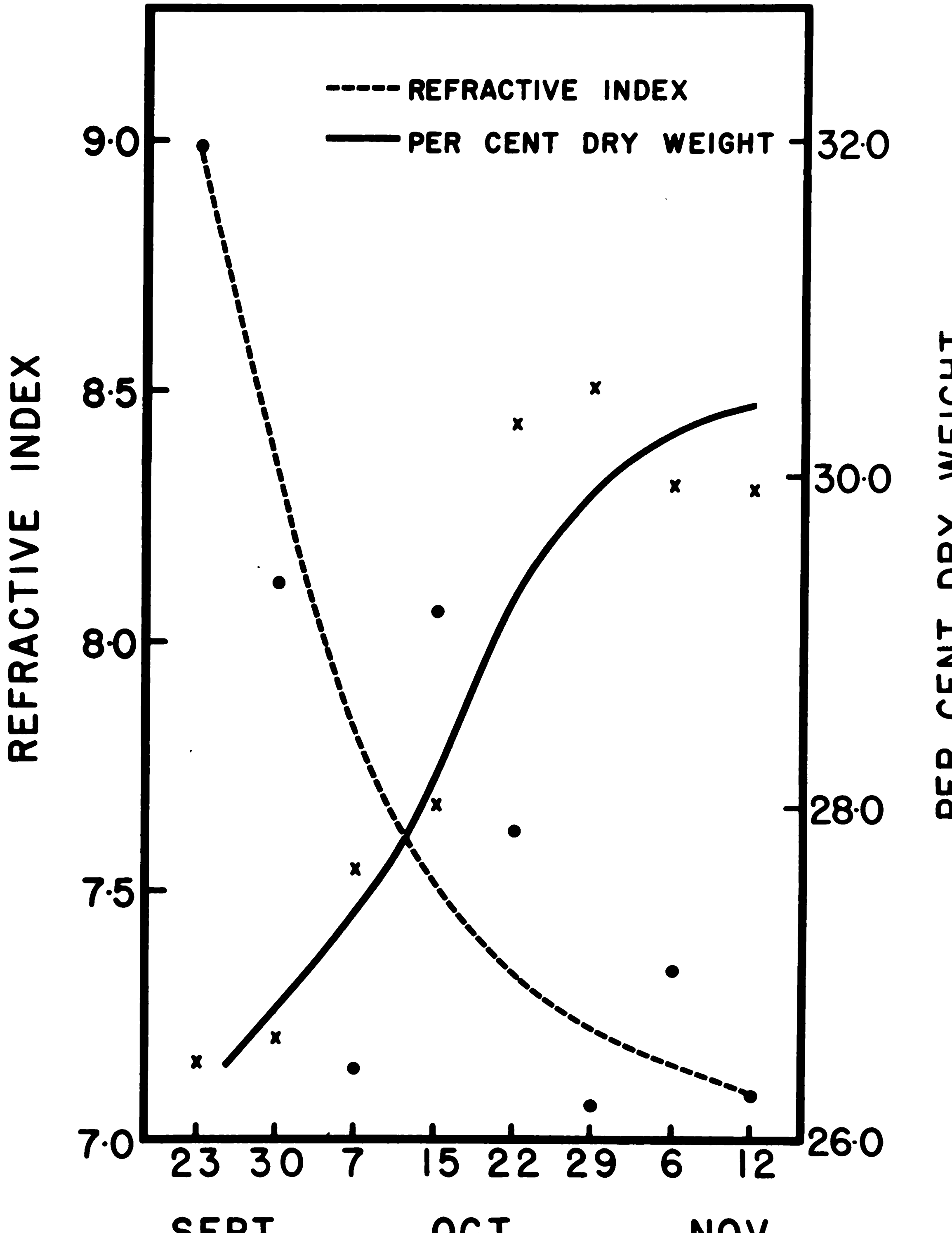

Figure 4. Changes in dry weight and soluble solids of Maid of Orleans gladiolus corms during maturation. The refractive index was measured as per cent soluble solids.

showed there was no significant difference between lengths of curing time. The experimental design prevented the analysis of the results for curing conditions, however, no marked differences were indicated.

The per cent dry weight determinations made after storage for 18 weeks are shown in Table IX. Length of initial curing treatment, storage temperature and type of storage bag showed significant differences in the per cent dry weight. The analysis of variance and the means for these treatments are shown in Tables X and XI.

The length of the curing treatment applied immediately after harvest influenced the per cent dry weight through the storage period. Curing for three days resulted in the lowest per cent dry weight, while curing for six and eight days were significantly higher. There was no significant difference between curing for six and eight days.

A significant difference was found between holding temperatures, with the higher per cent dry weight at the lower holding temperature. The type of bag used for storage was of marked effect upon the per cent dry weight. There was no significant difference between the perforated and sealed polyethylene bags, but the corms held in Kraft paper bags were higher in per cent dry weight than those stored in the other bags by a highly significant amount. A comparison between the per cent dry weight before storage (Table VIII) and after storage (Table XI) indicates that considerable moisture was lost from the corms stored in Kraft paper bags.

TABLE IX

PER CENT DRY WEIGHT OF GLADIOLUS CORMS STORED IN PERFORATED AND NON-PERFORATED POLYETHYLENE BAGS AND KRAFT PAPER BAGS FOR 18 WEEKS

Curing time (days)	Stored at 32°F					
	Perforated		Non-perforated		Kraft	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
			Cured outside			
3	25.7	26.7	27.4	27.9	36.9	32.1
6	28.9	32.2	31.8	29.2	36.2	33.4
8	31.3	30.6	32.4	30.7	34.4	36.6
			Cured at 85°F			
3	28.7	28.7	27.8	30.1	31.9	31.1
6	28.7	32.1	28.3	30.8	37.3	34.1
8	30.8	35.1	27.9	29.9	36.3	34.1
			Cured at 100°F			
3	30.7	29.8	32.1	27.7	33.9	34.4
6	29.8	30.7	30.6	31.4	37.6	34.4
8	28.3	31.6	31.0	32.3	35.1	35.6

TABLE IX (Continued)

Curing time (days)	Stored at 40°F					
	Perforated		Non-perforated		Kraft	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
			Cured outside			
3	26.0	28.6	29.1	28.9	27.8	31.1
6	29.1	29.6	27.4	30.0	31.4	30.7
8	29.3	30.5	30.1	30.0	35.8	37.4
			Cured at 85°F			
3	29.4	29.7	26.5	28.0	31.7	32.9
6	30.9	30.0	30.0	28.8	31.3	33.5
8	30.3	30.4	31.1	29.7	32.4	31.6
			Cured at 100°F			
3	29.8	29.5	28.0	29.0	33.2	33.4
6	32.6	33.1	29.2	29.2	33.4	34.1
8	30.3	29.9	32.6	32.8	33.6	34.0

TABLE X

ANALYSIS OF VARIANCE FOR PER CENT DRY WEIGHT OF GLADIOLUS CORMS AFTER 18 WEEKS OF STORAGE

	D.F.	Sum of squares	Mean square	F
A. Initial curing treatments				
Total for curing	8	129.95		
Total for curing temperature	2	23.47		
Curing time	2	90.61	45.32	11.47*
Error A	4	15.87	3.97	
B. Storage temperatures				
Total for holding	35	193.84		
Total for curing	8	129.95		
Holding temperature	1	26.94	26.94	18.08**
Holding temperature x curing temperature	2	2.15	1.075	--
Holding temperature x curing time	2	2.00	1.00	--
Error B	22	32.80	1.49	
C. Kinds of storage bag				
Total for bags	107	750.77		
Total for holding	35	193.84		
Bags	2	366.89	183.45	68.97**
Bags x curing temperature	4	14.93	3.73	1.40
Bags x curing time	4	3.81	.95	--
Bags x holding temperature	2	11.64	5.82	2.19
Error C	60	159.66	2.66	

*Significant at 5% level
**Significant at 1% level

TABLE XI

MEAN PER CENT DRY WEIGHT OF GLADIOLUS CORMS AFTER 18 WEEKS OF STORAGE

Duration of Curing

Days	Per cent dry weight	$LSD_{.05}$	$LSD_{.01}$
3	29.9		
6	31.4	1.3	
8	32.1		

Storage Temperature

°F	Per cent dry weight	
32	31.6	Significant at 1% level
40	30.7	Significant at 1% level

Storage Container

Kind	Per cent dry weight	$LSD_{.05}$	$LSD_{.01}$
Non-perforated polyethylene	29.7		
Perforated polyethylene	30.0	0.8	1.0
Kraft paper	33.7		

DISCUSSION

The results agree with those of Mann and Hoyle (1945) and Foskett and Peterson (1950) in that the refractometer readings are an accurate and dependable estimate of the per cent dry weight of the onion bulb. In addition the results show that these two factors are correlated throughout the later stages of development and maturity, as the tops changed from the vegetative state to complete desiccation. The regression lines for all harvests were similar in slope with the exception of the first harvest (Figure 1, Table I). It is not known whether this is normal, since only the largest onions were selected at the first harvest in order to obtain a uniform sample of bulbs from each plot. These bulbs likely were more advanced in development, and as shown in Table II a significant correlation (negative) existed for bulb size and soluble solids only at this harvest. Onions more representative of the sizes existing in each plot were selected for sampling at the subsequent harvest.

The regression line for the entire harvest period (Figure 2) was based on the samples selected at intervals of two weeks and determined according to the method suggested by Scott *et al*. (1945) for determining sweet corn maturity. This regression can be considered accurate only for the variety Downing Yellow Globe as grown on one location on muck soil for the season of 1953. Scott et al. (1945) found that once a regression line had been established for a given variety of sweet corn, it remained unchanged despite location and cultural or climatic conditions. However, the regression line for sweet corn was established with samples from a wide range of locations and conditions. The accuracy of the regression line for onions needs further testing, since in 1953 only two other samples were used. Both were of the same variety, grown on muck soil but from different locations. Their regressions did, however, fall within the standard deviations calculated for the onions from the test plots.

It would seem logical, as the case with sweet corn, that each variety would have a distinct regression line. However, Mann and Hoyle (1945) reported an approximate single regression line can be used for all varieties. A difference might also be expected between samples grown on muck and mineral soil, since the availability of moisture influences the dry weight content and soluble solids of certain crops (Allen, 1941). The effect of the growing season could only be determined by testing samples from the succeeding years against the regression line established in 1953.

If it were established that the dry matter content could be used as a basis for harvesting onions it is reasonable, that the refractometer readings would be useful as a quick test for field use. It was thought that instead of developing correlations of dry matter and refractive index for all varieties and conditions, it would be more feasible to follow the changes in refractive index at selected intervals. By reference to Figure 3, it may be seen that there was a similar increase in both factors during the early part of the harvest season with a levelling off between August 18 and 25. These changes, however, occurred simultaneously with a marked change in the condition of the tops. The rapid increases in dry matter occurred as long as the tops remained green and apparently in a state of high photosynthetic activity. Whether or not top breakdown was predicated by the accumulation of dry matter in the bulbs is not known. It is more likely that the condition of the tops was determined primarily by weather and soil conditions rather than by the accumulation of materials in the plant. It is frequently observed that the tops remain green and upright in low spots of the field where soil moisture is most plentiful when the onions in the remainder of the field are in a dry condition.

It has been pointed out by several authors (Shoemaker, 1952; Magruder, 1941) that there is a rapid transfer of carbohydrates from the tops to the bulbs as the tops begin to dry down. Magruder (1941) found there was also a marked increase in bulb size at this time. The combination of these factors, translocation of material from the tops and increase in bulb size, would account for the levelling off of the percentage dry weight of the bulbs between August 18 and 25. The changes in fresh weight of the bulbs in this test were not recorded. Lorenz and Hoyle (1946) cured onions with and without tops attached and found that the percentage dry weight increased during the curing period when the tops were not excised. This was attributed to the loss of water from the bulbs through the intact tops and the movement of solid materials from the tops to the bulbs. Similar results might be expected as the tops dry down in the field before the plants are pulled, but this was not true. Instead the percentage dry matter of the bulbs continually decreased as harvest was delayed (Figure 3). Apparently, the uptake of water through the intact roots was considerable and the relative moisture content of the bulbs increased in spite of the losses of water from the tops and the movement of dry matter into the bulbs.

The slight increases in refractive index measured and presented as per cent soluble solids in Figure 3, during the late maturation period do not agree with the changes in dry weight. Possibly it was caused by a change of insoluble fractions to soluble fractions. Scott _et al_. (1945) found the soluble solids showed little variation when wide fluctuations in other factors occurred.

A lack of significant correlation between bulb size and refractometer readings in these studies are in line with the findings of Mann and Hoyle (1945). It would appear that during the early and late harvest periods the larger bulbs had an average lower percentage soluble solids than for the intermediate harvests. For the commercial application of the refractive index, the size of bulb would be of no significant effect and could be disregarded. The test samples should be selected as representative of the plot, or portion of the field, as the case may be.

The objective of the experiments with curing of onion bulbs was primarily to establish if the refractometer is a suitable method for estimation of the stage of curing, and to determine the effect of different curing conditions on per cent soluble solids. It was thought that a loss of moisture during curing might cause an increase in the soluble solids that could be measured by the refractive index. The loss of moisture was determined by the decrease in total weight of the bulb without consideration of changes in the dry matter content.

The temperature conditions during curing which favor a high rate of water loss would also favor a high rate of respiration, consequently it is not surprising that the lowest refractometer readings during curing were obtained in the greenhouse and in the 100°F constant temperature oven, where the highest weight losses also occurred. If respiration was the only factor influencing the soluble solids content of the bulbs, the highest refractive index would be expected at the lowest temperatures. This was not the case, as the highest refractive index was obtained by curing under natural conditions. This would seem to indicate that intermediate fluctuating temperature conditions favor drying of the outer scales and a minimum loss of water without excessive losses in stored material as a consequence of respiration. It appears that an onion bulb could be cured without a significant change in the refractive index. The loss of moisture would balance the loss of dry weight, so that the per cent dry weight would not be greatly changed. For this reason the refractive index method does not appear suitable for indicating the stage of curing. The refractive index may, however, be of some value in determining the effect of curing treatment on the dry weight of the bulb. This was shown by the experiment in which onions were cured with and without tops. It has been indicated (Lorenz and Hoyle, 1946) that there is a transfer of food material to the bulbs during curing with tops attached. The bulbs cured with tops on had a higher refractive index, indicating this transfer. Differences resulting from curing temperatures or length of curing time may also be indicated by the refractive index. However, the failure to indicate the stage of curing of the onion bulb, definitely limits the practical application of this instrument by the commercial grower.

The experiment conducted with gladiolus corms in 1953 established that the refractive index is not a suitable method for estimating the per cent dry weight. Correlations made between the two factors over the harvest season resulted in a slight change from positive to negative as the season progressed.

The lack of correlation of refractometer readings and dry weight is indicative that the accumulated dry matter in the corm is primarily in the insoluble form, whereas, in the onion bulb the materials are primarily sugars which are soluble. The expressed juice of the corm was not suitable for direct determination of the refractometer readings, and composition changes during the period required for centrifuging, or because of centrifuging, no doubt influenced the readings.

Figure 4 shows that the measurable soluble solids content decreased as the harvest season progressed, whereas the per cent dry weight increased. Such a relationship should not occur as a result of moisture reduction in the corm; more likely there was a change in the dry matter from soluble to insoluble forms as the corms matured or aged.

The increase in per cent dry weight during the first half of the harvest period followed by a levelling off and slight decrease seemed to be associated with the condition and activity of the above-ground portions of the plants. There was an accumulation of dry matter as long as the leaves remained green and turgid.

Changes in soluble solids appear independent of the dry weight changes and seem to be linked more to stage of maturity. The irregularity shown in the decrease of the refractive index may be associated with climatic conditions. A rise in the per cent soluble solids was noted for the harvests of October 15 and November 6, both of which were preceeded by wet, cool weather conditions with low light intensity. Such conditions would cause a decrease in the rates of photosynthesis and food assimilation. Conversion of stored materials from insoluble to soluble forms at these times would account for an increase in soluble solids. There was also a decline in the rate of dry weight increase during these periods that was due to either the decreased elaboration of materials or to the increased water content, or both. The changes in soluble solids cannot, however, be explained on the basis of an increased water content of the corms since a dilution of the juice would be expected.

The influence of the duration of the curing period upon the moisture changes of the corms is not clear. At the end of the curing treatments, there was a slight indication that the least water loss occurred during the shorter curing period, and this was more evident when the percentage dry weights were determined after 18 weeks of storage. Evidently, there were little or no differences in suberin or cork development during curing that markedly influenced moisture losses.

The effect of the holding temperature may be explained on the basis of respiration. Corms held at the higher temperature lost more of the reserve food than those at the lower temperature resulting in the decrease in per cent dry weight. It would appear that the temperature did not affect the rate of moisture loss from the corms which would supposedly be greater at the higher temperature. The relative humidity of the storage rooms was not determined; however, two-thirds of the corms were held in polyethylene bags and similar relative humidities would be expected in these bags at both temperatures. Excessive losses of moisture from gladiolus corms may cause dehydration which would seriously impair the development of the plant when the corm is planted. Polyethylene bags were tested as storage containers which would possibly reduce water losses. Only a slight loss of moisture was noticed from the polyethylene bags, while the corms stored in Kraft paper bags showed signs of desiccation. The slight difference between the sealed and perforated polyethylene bags would seem to favor the use of the perforated bag, since there would be less danger of carbon dioxide injury or damage from a lack of oxygen.

A serious disadvantage for the use of polyethylene bags was the growth of mold on the surface of the corms and a slight amount of root growth, both of which are favored by the high humidity maintained in the bags.

SUMMARY

The problem of determining optimum harvest maturity and stage of curing in the onion and gladiolus suggested a study of moisture changes as measured by per cent soluble solids during maturation and curing. Soluble solids were measured directly in per cent by a hand refractometer and correlated with oven dry weight.

The per cent soluble solids were found to be significantly correlated to per cent dry weight of Downing Yellow Globe onion bulbs for weekly harvests from August 5 to September 14. Both factors increased until the tops showed drying, the soluble solids then became stable, whereas, the dry weight decreased as the tops declined in physiological activity. The refractive index is not suited for estimation of the stage of curing of the onion bulbs, possibly due to a loss of dry matter by increased respiration as well as a loss of water during curing.

The refractometric method is not accurate in the estimation of the per cent dry weight or as a guide to maturity and curing changes of Maid of Orleans gladiolus corms. The transition from positive to negative correlation associated with a decline in per cent soluble solids as the harvest season progressed suggests that reserve carbohydrates are stored in the corm in an insoluble form. In general, an

increase in curing temperature and length of curing time resulted in an increase in per cent dry weight. Corms stored for 18 weeks at 32°F had a higher per cent dry weight than those stored at 40°F. Polyethylene storage containers reduced corm desiccation markedly over paper bags; however, undesireable mold growth and rooting developed at the high relative humidities within the polyethylene bags.

CONCLUSIONS

1. The per cent soluble solids is an accurate guide to the changes in per cent dry weight of Downing Yellow Globe onion bulbs during maturation.
2. The changes in soluble solids and dry weight of the bulbs are primarily dependent upon the condition of the tops.
3. The refractometer readings were not suitable for estimating the stage of curing of the onion bulb.
4. The per cent soluble solids is not an accurate method of measuring the moisture changes in the gladiolus corm.
5. The moisture content of gladiolus corms may be maintained during the storage period by packaging the corms in either perforated or non-perforated polyethylene bags.

LITERATURE CITED

Allen, F. W.

1942. Softening and soluble solids in Bartlett pears as influenced by soil moisture.
Proc. A.S.H.S. 41: 106-112.

Bald, J. G.

1953. Control of disease by heat-curing and dipping of gladiolus corms. I. Wound periderm and extension of lesions.
Phytopathology 43: 141-145.

Biryukov, D. P.

1939. Determination of the content of cry substance in the onion by use of the refractometer. (Russian).
Konservnaya Plodoovoshchnaia Prom. 10(2): 33.
From Chem. Abs. 35: 5205.

Boswell, V. R.

1923. Influence of the time of maturity of onions on the behavior during storage.
Proc. A.S.H.S. 20: 234-239.

Boyd, J. S. and J. F. Davis.

1954. Experimental developments in bulk storage of onions.
Mimeo. Paper presented at Elba, New York.

Carter, G. H., O. E. Olson and J. L. Henry.

1950. Which maturity best fòr raw sweet corn?
Food Packer 31(9): 44-46.

Colby, W. G., C. J. Gilgut and H. M. Yegian.

1945. The culture of set onions in the Connecticut Valley.
Mass. Agr. Exp. Sta. Bul. 424.

Croxton, F. E. and D. J. Cowden.

1946. Applied General Statistics.
New York: Prentice Hall Inc.

Davis, Glen N.

1943. Onion production in California.
Univ. of Calif. Agr. Exp. Sta. Circ. 357.

Filman, C. C. and J. S. Shoemaker.
1952. Onions.
Ontario Dept. of Agr. Bul. 486.

Forsberg, J. L.
1952. Drying gladiolus corms.
Florists' Review 111(2862): 33-34.

Foskett, R. L. and C. E. Peterson.
1950. Relation of dry matter content to storage quality in some onion varieties and hybrids.
Proc. A.S.H.S. 55: 314-318.

Francot, Paul.
1939. Experiments comparing the practical use of a Zeiss Opton refractometer with a Dujardin-Sulleron mustimeter.
Progres agr. vit. 111: 224-229.

Gould, Charles J.
1953. The botrytis disease of gladiolus.
Mimeo. Report Western Wash. Exp. Sta., Puyallup.

Gurley, N. F.
1946. Control of specific gravity of tomato products by use of the Abbe refractometer.
Food Packer 27(9): 39-40.

Haller, Mark H.
1952. Handling, transportation, storage, and marketing of peaches.
U.S.D.A. Bibliographical Bulletin No. 26.

Hartman, John D., D. H. Dewey and F. M. Isenberg.
1953. Report on trip to study methods of harvesting and storaging onions in Mich., Ind., Wisc., Iowa and N.Y.
Mimeo. Paper, Dept, of Hort., Michigan State College.

Hawker, Lillian E.
1946. Diseases of the gladiolus. III. Botrytis rot of corms and its control.
Annals of Applied Biology 33: 200-208.

Hoyle, Burton J.

1947. Storage breakdown of onions as affected by stage of maturity and length of topping.
Proc. A.S.H.S. 50: 353-360.

_______________.

1948. Onion curing - a comparison of storage losses from artificial, field and non-cured onions.
Proc. A.S.H.S. 52: 407-414.

Jaulmes, P.

1950. Density and refraction meters.
Journee vinicole 24(29).
From Chem. Abs. 45: 5062.

Jessop, H. G.

1939. Rapid determination of soluble solids.
Soc. Chem. Ind. Victoria, Proc. 39: 180-183.

Jones, H. A., L. R. Hawthorne and G. N. Davis.

1944. Growing the transplant onion crop.
U.S.D.A. Farmers Bulletin No. 1956.

____________ and C. S. Bisson.

1934. Moisture content of different varieties of onions.
Proc. A.S.H.S. 31: 165-168.

Konokotina, N.

1948. Refractometric determination of soluble solids in ice cream.
Molochnaya Prom. 9(9): 24-26.
From Chem. Abs. 43: 7599.

Lauritzen, J. I. and R. C. Wright.

1934. Factors affecting gladiolus in storage.
Journal Agr. Research 48: 265-282.

Loomis, Walter E. and C. A. Shull.

1937. Methods of Plant Physiology.
New York: McGraw-Hill.

Lorenz, O. A. and B. J. Hoyle.

1946. Effect of curing and time of topping on weight loss and chemical composition of the onion bulb.
Proc. A.S.H.S. 47: 301-307.

Ludington, V. D. and E. W. Bird.
1941. Application of the refractometer in determination of total solids in milk products.
Food Research 6: 421-434.

Magie, Robert O.
1952. Curing and storage of gladiolus bulbs.
North Amer. Comm. Glad. Newsletter No.13.

Magruder, Roy, R. E. Webster, H. A. Jones, T. E. Randall, G. B. Snyder, H. D. Brown and L. R. Hawthorn.
1941. Storage quality of the principal American varieties of onions.
U.S.D.A. Circular No. 618.

Mann, Louis K. and B. J. Hoyle.
1945. Use of the refractometer for selecting onion bulbs high in dry matter for breeding.
Proc. A.S.H.S. 46: 285-292.

Piegai, Aldo.
1939. Refractometric index of tomato preserves.
Ind. ital. conserve 14: 51-56.
From Chem. Abs. 33: 7420.

Platenius, Hans and J. E. Knott.
1935. The pungency of the onion bulb as influenced by the stage of development of the plant.
Proc. A.S.H.S. 33: 481-483.

______________________________.
1941. Factors affecting onion pungency.
Jour. Agr. Research 62(6): 371-380.

Pridham, A. M. S. and J. C. Ratsek.
1932. Growth of gladiolus as affected by storage conditions.
Proc. A.S.H.S. 29: 526-529.

Riedel, L.
1949. Refraction and freezing point of fruit juices in relation to their concentration.
Z. Lebensm -Untersuch u-Forsch. 89: 288-289.
From Chem. Abs. 43: 6752.

Rose, Dean H., R. C. Wright and T. M. Whiteman.
1942. The commercial storage of fruits, vegetables and florist's stocks.
U.S.D.A. Circular No. 278.

Rygg, G. Leonard.
1945. Determination of moisture in dates by means of a refractometer.
Annual Date Growers Inst. 22: 3-4.

Scott, G. C., R. O. Belkengren and E. C. Ritchell.
1945. Maturity of raw sweet corn determined by refractometer.
Food Industries 17(9): 1030-1033.

Shoemaker, J. S.
1952. *General Horticulture.*
New York: J. B. Lippencott Co.

_______________.
1953. *Vegetable Production.*
New York: John Wiley & Sons.

Simmons, S. A.
1949. Research on botrytis corm rot.
North Amer. Comm. Glad. Bulletin No. 17: 93-94.

Smith, H. P., G. E. Altstatt and M. H. Byron.
1944. Harvesting and curing of garlic to prevent decay.
Texas Agr. Exp. Sta. Bulletin No. 651.

Snedecor, G. W.
1946. *Statistical Methods.*
Ames, Iowa: Iowa State College Press.

Stuart, Neil W., J. M. Jenkins, W. G. Cowperwaite, S. S. Woltz and Arthur Bing.
1954. Preliminary report on effects of curing, storage temperature and relative humidity on flowering and corm production of gladiolus.
Gladiolus Magazine 18(1): 47-58.

Wade, G. C.
1945. Botrytis corm rot of the gladiolus - its cause and control.
Proc. Royal Soc. Victoria 57, Parts I and II.

Wagner, L. E., J. C. Hoffman and H. D. Brown.
1940. Correlation between the Vitamin C content and refractive index of muskmelon.
Proc. A.S.H.S. 37: 839-840.

Wittwer, S. H. and D. R. Paterson.
1951. Inhibition of sprouting and reduction of storage losses in onions, potatoes, sugar beets and vegetable root crops by spraying plants in the field with maleic hydrazide.
Mich. Agr. Exp. Sta. Quart. Bul. 34(1): 3-8.

Witzell, S. A.
1946. Design of an onion storage warehouse.
Jour. Amer. Soc. Agr. Engineers 27: 258-260.

Woodman, R. M. and H. R. Barnell.
1937. The connection between the keeping quality of commercial varieties of onions and the rate of water loss during storage.
Annals of Applied Biology 24: 219-235.

Zeiss Opton.
1946. Hand sugar refractometer - directions for use.
Printed in Germany.

Zschabitz, H.
1935. Tomato refractometer in use.
Obst. Gemuse-Verwertungsind 22: 103-104.
From Chem. Abs. 30: 5317.