July 31, 1970

To the Graduate Council:

I am submitting herewith a dissertation written by Charles William Marr, entitled "An Investigation of Several Physical and Chemical Factors Associated with Chilling Injury in Stored Sweetpotato Cultivars." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Agricultural Plant and Soil Science.

Homer D. Smengle
Major Professor

We have read this dissertation and recommend its acceptance:

[illegible]

Henry H. Finlong

David L. Coffey

Gordon E. Hunt

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

AN INVESTIGATION OF SEVERAL PHYSICAL AND CHEMICAL FACTORS ASSOCIATED WITH CHILLING INJURY IN STORED SWEETPOTATO CULTIVARS

A Dissertation

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

---

by

Charles William Marr

August 1970

ACKNOWLEDGMENTS

The author is greatly indebted to Dr. H. D. Swingle, Department of Horticulture, for his advice, criticism, and support during the experimentation and manuscript preparation for this study. The author also expresses appreciation to Dr. B. S. Pickett, Head, Department of Horticulture, for his encouragement and support of this research, as well as the constructive review of the manuscript.

The author expresses special appreciation to the following:

To Dr. David L. Coffey, Department of Horticulture, and Dr. Gordon Hunt, Department of Botany, for their review of the manuscript and encouragement during the period of graduate study.

To Dr. Henry Fribourg, Department of Agronomy, for his review of the manuscript and his constructive suggestions for its improvement.

To Dr. Bernadine Meyer, Department of Food Science, and the staff of the Food Science Laboratory for their assistance in the baking tests of this study.

To The University of Tennessee Computing Center for use of the equipment for statistical analysis of these data.

To The University of Tennessee Agricultural Experiment Station and the Department of Horticulture for their financial support during the period of study.

The author is deeply indebted to his wife, Joyce, for her patience, support, and encouragement during the period of graduate study.

926882

ABSTRACT

The objective of this research was to evaluate the effect of chilling temperatures on the appearance of raw roots of selected sweetpotato cultivars and on the color and flavor of baked roots of these same cultivars. Cultivars selected to give a range of chilling injury susceptibility were NC-212, NC-240 (Jewel), L-4-73, and Centennial. Storage temperatures of 35° F, 45° F, and 55° F for weekly durations up to six weeks were used. This was followed by a one week holding period at 70° F previous to examination. Non-cured and cured roots were evaluated for visual appearance, specific gravity, intercellular space, dry matter content, tissue pH, ascorbic acid content, and chlorogenic acid content.

Roots of the NC-212 cultivar were less susceptible to chilling injury as measured organsleptically. NC-240 (Jewel), L-4-73, and Centennial followed in order of their "resistance" to chilling injury. NC-212 did not develop the characteristic dark discoloration following chilling temperature storage. Pithiness in NC-212 often prolonged storage following 35° F storage suggests that this cultivar is not immune to chilling injury.

Specific gravity, intercellular space, and percentage dry matter were only slightly influenced by temperature treatments. Tissue pH decreased then increased in non-cured Centennial roots over the six week period. Tissue pH was reduced in cured Centennial roots with low temperature treatment. The reduction of pH was delayed in NC-212 cultivar at low temperature storage.

Ascorbic acid content decreased more rapidly in Centennial than in NC-212 at low temperature storage in both cured and non-cured roots but curing tempered the ascorbic acid contents reduction. Chlorogenic acid did not increase in NC-212 at any temperature treatment but did increase in Centennial roots at 35°F and 45°F for both cured and non-cured roots.

Little consistent relationship, cultivar to cultivar, was observed between appearance and any of the other variables measured.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
II.	REVIEW OF THE LITERATURE	3
	History	3
	General Considerations of Chilling	4
	Physiological Effects of Chilling	6
	Symptoms of Chilling in Raw and Baked Roots	9
	Specific Quality Factors	10
	Specific gravity	10
	Intercellular space	10
	Dry matter	11
	Tissue pH	11
	Ascorbic acid	12
	Chlorogenic acid	13
III.	METHODS AND MATERIALS	15
	Preparation and Handling	15
	General procedures	15
	Screening tests, 1968	16
	Storage tests, 1969	16
	Non-cured roots	16
	Cured roots	17
	Prolonged post-treatment storage test, 1969	18
	Baking tests	18

CHAPTER PAGE

Non-cured roots 18
Cured roots 19
Organoleptic Procedures 19
Analytical Procedures 20
Specific gravity 20
Intercellular space in tissues 20
Dry matter content 21
Tissue pH 21
Ascorbic acid 21
Chlorogenic acid 22
Analyses of Data 22
IV. RESULTS 23
Organoleptic Determinations 23
Raw non-cured roots 23
Raw cured roots 25
Baked non-cured roots 28
Baked cured roots 32
Prolonged post-treatment storage - raw roots 35
Root Specific Gravity 36
Non-cured roots 36
Cured roots 39
Intercellular Space 39
Non-cured roots 39
Cured roots 41

CHAPTER PAGE

Dry Matter Content 44
Non-cured roots 44
Cured roots 46
Tissue pH 46
Non-cured roots 46
Cured roots 46
Ascorbic Acid 50
Non-cured roots 50
Cured roots 53
Chlorogenic Acid 56
Non-cured roots 56
Cured roots 60
Interrelationships 63
V. DISCUSSION 66
Organoleptic Determinations 66
Specific Gravity 70
Intercellular Space 72
Dry Matter Content 73
Tissue pH 74
Ascorbic Acid 75
Chlorogenic Acid 77
Interrelationships 78
General and Physiological Implications 78
VI. SUMMARY 85
LITERATURE CITED 88
VITA 95

LIST OF TABLES

TABLE PAGE

1. Influence of Three Temperature Treatments on Four Cultivars of Non-Cured Sweetpotato Roots as Measured by a Visual Chilling Injury Rating Scale 24

2. Influence of Three Temperature Treatments on Four Cultivars of Cured Sweetpotato Roots as Measured by a Visual Chilling Injury Rating Scale 27

3. Flavor Differences of Four Non-Cured Sweetpotato Cultivars Stored at Three Temperatures as Determined by Taste Panel Evaluations 30

4. Color Differences for Four Cultivars of Non-Cured Sweetpotatoes at Three Storage Temperatures as Determined by Taste Panel Evaluations 31

5. Flavor Differences in Four Cultivars of Cured Sweetpotatoes at Three Storage Temperatures as Determined by Taste Panel Evaluations 33

6. Color Differences of Four Cultivars of Cured Sweetpotatoes at Three Storage Temperatures as Determined by Taste Panel Evaluations 34

7. Visual Chilling Injury Ratings of Four Cultivars of Cured Sweetpotato Roots Held Nine Weeks After Temperature Treatments 37

8. Influence of Temperature on the Specific Gravity of Four Cultivars of Non-Cured Sweetpotatoes 38

TABLE PAGE

9. Influence of Temperature Treatments on the Intercellular Space of Four Cultivars of Non-Cured Sweetpotatoes 40

10. Influence of Temperature Treatments on the Intercellular Space of Four Cultivars of Cured Sweetpotatoes 43

11. Influence of Temperature Treatments on Percentage Dry Matter Content of Four Cultivars of Non-Cured Sweetpotatoes . . . 45

12. Effect of Three Temperature Treatments on the pH of Four Cultivars of Non-Cured Sweetpotatoes 47

13. Effect of Three Temperature Treatments on the pH of Four Cultivars of Cured Sweetpotato Roots 49

14. Influence of Three Temperature Treatments on the Ascorbic Acid Content of Four Cultivars of Non-Cured Sweetpotatoes 52

15. Influence of Three Temperature Treatments on Ascorbic Acid Content of Four Cultivars of Cured Sweetpotatoes 55

16. Effect of Three Temperature Treatments on the Chlorogenic Acid Content of Four Cultivars of Non-Cured Sweetpotatoes 58

17. Effect of Three Temperature Treatments on the Chlorogenic Acid Content of Four Cultivars of Cured Sweetpotatoes . . 61

18. Linear Correlation Coefficients by Cultivar for Visual Chilling Injury Observed During Storage Tests of Cured and Non-Cured Sweetpotatoes 64

LIST OF FIGURES

FIGURE PAGE

1. Influence of Duration of Storage Temperature on Four Cultivars of Non-Cured Sweetpotatoes as Measured by Visual Chilling Injury Ratings 26
2. Influence of Duration of Storage Temperature on Four Cultivars of Cured Sweetpotatoes as Measured by a Visual Chilling Injury Rating Scale 29
3. Influence of Duration of Storage Temperature on the Intercellular Space of Two Cultivars of Non-Cured Sweetpotatoes 42
4. Influence of Duration of Storage Temperature on the pH of Two Cultivars of Non-Cured Sweetpotatoes 48
5. Influence of Duration of Storage Temperature on the pH of Two Cultivars of Cured Sweetpotatoes 51
6. Influence of Duration of Storage Temperature on the Ascorbic Acid Content of Two Cultivars of Non-Cured Sweetpotatoes 54
7. Influence of Duration of Storage Temperature on the Ascorbic Acid Content of Two Cultivars of Cured Sweetpotatoes . . . 57
8. Influence of Duration of Storage Temperature on the Chlorogenic Acid Content of Two Cultivars of Non-Cured Sweetpotatoes 59
9. Influence of Duration of Storage Temperature on the Chlorogenic Acid Content of Two Cultivars of Cured Sweetpotatoes 62

CHAPTER I

INTRODUCTION

Per capita consumption of sweetpotatoes has steadily decreased for the past thirty years (68). This decline may be partially due to diversity in the diet of the population.

A larger percentage of the sweetpotatoes produced in the United States is now being canned or processed. Sweetpotato production for canning has increased during the past ten years despite the overall decrease in production (2). Sweetpotatoes are one of the most nutritious vegetables available (68). The sweetpotato could serve an important role in meeting future needs for balanced nutrition and increased food production.

One severe limitation of sweetpotato production and storage in temperate areas is the injury that occurs to this tropical root at above freezing temperatures. It is possible for chilling to occur in a temperature range from 1 to 10°C (49). Numerous research workers have dealt with this problem to describe its effects, to note chemical and physical changes that accompany it, or to prevent its occurrence. However, the problem, despite all that is known about it, still exists. Solving the problem or isolating a specific causal factor would be desirable. It may be advantageous to establish chilling susceptibility and quality changes that occur in order to be able to minimize the chilling effects associated with currently grown cultivars and handling procedures. The first phase of this investigation proposed to establish the degree

chilling injury in non-cured and cured raw and then in baked roots of sweetpotato cultivars as evidenced by color and flavor changes after storing at low temperatures. The second phase of the study was concerned with the influence of these same curing and temperature treatments on specific gravity, intercellular space, dry matter content, tissue pH, ascorbic acid content, and chlorogenic acid content of roots. These will be collectively referred to in the text as "quality" factors. The final phase of the investigation was to determine whether a relationship existed between chilling injury as measured in the first phase and each of the six quality factors studied.

Throughout this text the term cultivar is used for consistency and simplicity. It is recognized that breeding lines or clones are represented; but the more common term, cultivar, has been used.

CHAPTER II

REVIEW OF THE LITERATURE

I. HISTORY

The sweetpotato (Ipomea batatas (L.) Poir.), a member of the Convolvulvaceae or morning glory family, was first cultivated in the tropical Americas and the Pacific Islands. Early explorers to these areas found them being grown and were responsible for their spread to the far East and Europe (8). The first evidence of sweetpotatoes being used in a temperate climate region occurred in primitive tribes of New Zealand. There the primitive storage procedures were first practiced in a ritual-like manner.

The sweetpotato was introduced to the United States in the mid 1600's. The curing process, essential for producing periderm or callus tissue over areas where breaks in the skin have occurred, was reported in Europe in the early 1500's; however, not until 1852, was curing by heat recommended as a storage practice (8). Hasselbring and Hawkins (21), in the early 1900's, were among the first to study respiratory storage changes in sweetpotatoes. They reported a small amount of reducing sugars present in sweetpotatoes compared to "cane" sugars when starch was converted. "Cane" sugar is accumulated after harvest in sweetpotatoes over a wide range of temperatures as contrasted to storage organs of other species that convert starch at low temperatures only (22).

II. GENERAL CONSIDERATIONS OF CHILLING

Physiological chilling injury is not limited to sweetpotatoes. The general symptoms in most susceptible fruits and vegetables are surface and internal discoloration, pitting, susceptibility to decay, and failure to ripen properly (59). Plank (60), in a simplified explanation of the complex mechanism of chilling injury, theorized that two cell reactions were involved. One reaction leads to an accumulation of a poison while the other leads to its removal. An imbalance in these reactions would cause a poisoning agent to accumulate and manifest itself as chilling injury. It is difficult to separate the various observed changes in chilled roots to determine if a change in certain metabolic functions may begin a series of reactions all relating to one another. There is a possibility that the initial stage of the chilling injury process may be more of a physical phenomenon involving permeability of intercellular membranes (59).

Lauritzen (46), in an early study of chilling in sweetpotatoes, noted that prolonged exposure from -2°C to 9°C may result in increased fungal infection as well as in internal discoloration and sprout inhibition.

Kimbrough and Bell (34) established that 50°F appears to be the critical temperature below which chilling injury symptoms could occur provided the exposure was of sufficient length. Lutz (53) indicated chilling sensitivity was greatly reduced by proper curing. In another report (54) he indicated that injury could occur after two days exposure at 32°F or four days exposure at 40°F in non-cured roots or ten days at 32°F or twenty-one days at 40°F in cured roots, when roots were examined

sixteen weeks after exposure. Other cases of chilling injury susceptibility have been reported in the literature (10, 72, 73, 74).

In addition to temperature conditions involved in chilling, cultivar differences have been reported by several authors.

Lewis and Morris (48) noted chilling injury at 50°F constant storage temperature in a study of several varieties of sweetpotatoes. Differential varietal responses were observed with chilling symptoms occurring after one to two months of storage at 50°F for most varieties tested.

Kushman and Deonier (40) in a study of three varieties, reported 50°F temperatures resulted in injury symptoms after about thirteen weeks. Minor cultivar differences were noted but they concluded that all then popular cultivars were subject to chilling injury. In another study with Porto Rico variety (39) they noted that lateness of harvest increased chilling injury. Keeping quality was not associated with ascorbic acid or sugars although sugars were high in roots that did not keep well.

Cooley, Kushman, and Smart (9), in a study of six cultivars, noted differences were observed for potatoes stored at 50°F for five months. Storage temperatures of 55°F or greater were found to be necessary for prolonged storage. Fontenot (18) suggested that cultivar chilling injury responses may be due to differences in periderm activity.

In summarizing the studies related to chilling injury in storage, it is generally agreed that the degree of chilling is dependent on the time of temperature exposure as well as the difference between chilling temperature and subsequent storage temperature. Chilling injury can occur in storage under chilled conditions but the most rapid evidence of

injury occurs after exposure to warmer temperatures after chilling exposure. It is generally agreed that there are some varietal differences in chilling injury susceptibility but there are no varieties that are resistant. Most of the work has dealt with chilling conditions present throughout prolonged storage. Only a few studies such as the one by Fontenot (18) considered chilling injury after prolonged storage preceded by a short cold exposure. It is generally agreed that, although the curing process is not fully understood (25), it results in less susceptibility to chilling injury (54).

III. PHYSIOLOGICAL EFFECTS OF CHILLING

Physiological changes induced by chilling injury have been studied by numerous workers. The metabolic sequence that is altered by chilling may produce a number of chemical and physical changes which may have occurred indirectly as a result of the chilling injury mechanism or of some other chemical or physical change so induced.

Lewis (47) observed cessation of cytoplasmic streaming in chilled sensitive plants, indicating that a true cellular component interferrence does exist.

The effect of chilling injury on respiration has been used as an indication of physiological effects in chilling sensitive plants (6). After exposure to chilling temperatures, many plants sensitive to chilling exhibit a sudden increase in carbon dioxide evolution. Such a response has been noted in cucumbers (13, 14), citrus fruits (12), and sensitive vegetables including sweetpotatoes (3). This increased carbon dioxide evolution is not present in chilled non-sensitive plant species (12).

Kushman and Deonier (40) reported that respiration rates increased with duration of the holding period and degree of change in chilling and storage temperature when sweetpotatoes were exposed to chilling temperature followed by storage at non-chilling temperatures. This was unrelated to changes in sugar content (3, 21).

Barry and Patterson (5) indicated that water absorption of sweetpotato tissue is influenced by variety and by chilling temperature, indicating a possible membrane permeability chilling response. Lieberman, Craft, Audia, and Wilcox (50) demonstrated increased ion leakage from chilled sweetpotato tissue.

Chilling injury effects on mitochondria have been investigated by several authors in an effort to explain chilling injury in greater detail. Chloroplast membrane injury and mitochondrial membrane injury have been demonstrated with low temperature exposure of isolated cellular particles (23, 24). Lyons, Wheaton, and Pratt (55) noted that the flexibility of the mitochondrial membrane, as influenced by concentrations of unsaturated fatty acids, enables chilling resistant plant mitochondria to function at low temperature. Schichi and Uritani (63) observed sweetpotato roots stored at 0°C reached a point where respiratory oxygen uptake was greater after which a rapid decline in respiration was observed. An accompanying decline on dinitrophenol stimulating effect was noted as this occurred. Mitochondrial destruction or membrane inactivation was thought to be involved. Minamikawa, Akazawa, and Uritani (56) concluded that the P/O ratio remained constant and that protein nitrogen of mitochondria remained constant, indicating no degradation of structure or change in cofactor composition occurred in sweetpotato mitochondria.

Another report bears similar evidence (1). Lieberman noted ion leakage from chilled tissues, as well as decline in oxidative and phosphorylative activity of sweetpotato tissue, after prolonged chilling (50).

Mitochondrial injury by phenols was suggested by Lieberman and Biale (49) and this injury theory indicated that certain phenolic substances may be responsible for mitochondrial malfunctions. In a normal active cell the oxidation of polyphenols must be coupled to a system that reduces the quinone formed. Ascorbic acid may function in this capacity. Ascorbic acid decreases would result in quinones building up in cells and causing mitochondrial damage. Thus, Lieberman and Biale (49) proposed a mechanism to relate several chemical factors to oxidative and phosphorylative activity.

In a subsequent study, Lieberman, Wilcox, and Craft (51) observed chlorogenic acid content buildup accompanying ascorbic acid decreases in chilled and non-chilled sweetpotato roots. A high correlation was observed between ascorbic acid decline and chlorogenic acid buildup in root tissues. Minamikawa et al. (56), however, have shown that phenolic compounds did not increase but mitochondrial respiratory activity and DNP-stimulated respiratory activity increased in chilled sweetpotato tissues.

Further evidence of the influence of these compounds will be discussed later in this chapter. The physiological sequences that influence the concentrations of these two compounds and cellular activities is not fully explained.

IV. SYMPTOMS OF CHILLING IN RAW AND BAKED ROOTS

Several reports have described the visual chilling injury symptoms (46, 34, 54). Disease susceptibility and internal darkening are the most prevalent in prolonged storage of chilled sweetpotatoes (46). The general term, internal breakdown, is often used to describe the general shrinkage, discoloration, and decay. It is often difficult to distinguish physiological breakdown from the point where disease organisms promote tissue breakdown. Lewis and Morris (48) indicated varietal differences in observed internal tissue color. Their work, however, dealt with older cultivars and was based on prolonged storage under chilling conditions.

Discoloration of raw tissue follows through to the baked product as reported in an early observation by Lutz (54). He established that exposure for a few days to chilling temperatures caused discolorations in the baked roots. Curing appeared to increase slightly time exposure necessary for discoloration to appear.

Kushman and Hoover (41) reported poor appearance scores for puree made from flakes of chilled roots. Actual color values was not associated with the chilling but poor appearance was thought to be due to the darkening discoloration. Hughes and Swain (29, 30) indicated that chlorogenic acid was responsible for this darkening in Irish potatoes.

Kushman and Deonier (38) reported baking quality, as measured by flavor evaluation, to be poor in roots held at 50°F for thirteen weeks. Roots held at 60°F, or at 50°F with intermittent warming periods, had better baking quality.

Intercellular space values are not direct indications of respiration rate since volume losses may result in intercellular space reductions (44). General agreement has been noted between intercellular space and the observed pithiness of the root tissue (44).

Dry Matter

Dry matter content has been mentioned previously in an interrelationship with specific gravity of tissue in a report by Kushman et al. (36). They reported that dry matter content of sweetpotatoes was much higher than for other carbohydrate-containing vegetables. Varietal differences in dry matter content have been observed, as well as differences in dry matter losses over storage time, for different cultivars (37). Although there is an overall loss of dry matter in storage, the percentage dry matter of sweetpotato tissue has been shown to change very little regardless of the storage condition (44). This was reported, however, under unchilled conditions where normal respiratory processes were functioning. Although not indicative of total dry matter, soluble solids and total sugar as dextrose were found to increase in storage (27).

In a study of several commercial varieties, Scott and Matthews (65) noted varietal differences in dry matter, starch, and sugar content.

Tissue pH

The pH of sweetpotato tissue was found by Schichi and Uritani (63) to increase when the roots were held at 32°F. Hyde and Morrison (31) reported decreases in pH associated with low temperature storage of potatoes. Freebarin (19) speculated that, if changes in mitochondrial activity could not explain the increased respiratory rates of chilled

tissues, changes in organic acids could produce such a response. Up to 40 per cent increases in certain organic acids were noted in chilled tissues of certain plant species.

Weimer and Harter (70) reported a pH range of 5.0 to 6.0 in sweetpotatoes. Kushman and Hoover (41) indicated that 6.30 was the initial pH with variations from 6.12 to 6.27 in the Goldrush variety under 60°F storage temperature. The pH of chilled tissue was found to decrease at first then increase over a constant pH for non-chilled roots (41). They speculated that varietal differences in pH could be associated with varietal chilling sensitivity. They also indicated that the reversal of the pH from reduced to increased values as storage time progressed tended to occur about the time that chilling symptoms developed. The rise in pH was theorized to be related to the "break point" where chilling injury becomes irreversible when the roots were returned to warm temperatures.

Ascorbic Acid

Ascorbic acid has been mentioned already in discussion of a general mechanism for ascorbic acid and chlorogenic acid relationships in chilled tissues. Kushman and Deonier (39) indicated ascorbic acid apparently was not related to keeping quality. Ezell, Wilcox, and Crowder (16) reported the loss of ability to synthesize carotenoids as a sensitive measure of chilling injury. Ezell and Wilcox (15) also reported 50 per cent losses of ascorbic acid in storage.

Lieberman and Biale (49) proposed a mechanism for ascorbic acid-polyphenol metabolism. Miller and Heilman (58) observed that ascorbic acid was destroyed as the first phase of chilling injury in pineapple.

Doby (11) in citing the work of several authors, indicated that ascorbic acid may serve as the terminal oxidase in some plant systems. The functioning of this system in sweetpotato tissue, as well as the relationship that this oxidase system may serve with other oxidase systems, is not completely understood.

Kruger (35) described the role of ascorbic acid as being involved in hydroxylation reactions of the phenolase system. Ascorbic acid appears to be the reducing agent in direct reaction with the enzyme. Reduction of ascorbic acid content interferes with the utilization of chlorogenic acid, a phenolase substrate. Lieberman et al. (51) noted decreases in ascorbic acid in chilled roots, with concurrent increases in chlorogenic acid. Barry (4) reported ascorbic acid decreased markedly in curing; then, when exposed to chilling storage conditions (5°C), ascorbic acid increased initially and in time declined. After a time period the ascorbic acid in tissues in the chilling temperature gradually decreased to the level of the unchilled tissue. This would appear to be contrary to Lieberman et al. (31), since no similar pattern was noted for the chlorogenic acid present.

Chlorogenic Acid

Phenol oxidases are able to transfer electrons to oxygen. In injured cells, polyphenol oxidases can react with phenolics to form quinone structures. These quinones can be further oxidized to form the dark substances observed in certain tissues (62). Chlorogenic acid, a phenolic, has been shown to increase oxygen uptake and carbon dioxide evolution of sweetpotato tissue (61), and was shown to be an uncoupling agent in phosphorylation activities of the cell (1).

The synthesis of chlorogenic acid in higher plants is thought to be from phenylalanine through cinnamic acid (20). The role of chlorogenic acid in decay organism resistance has been disputed (20, 26, 66, 69), but Harborne (20) indicates that oxidation of chlorogenic acid or subsequent metabolism may be involved in susceptibility to decay organisms. Tissue darkening is thought to involve oxidation and polymerization of chlorogenic acid (51) in sweetpotatoes as well as in Irish potatoes (28, 29).

Increases of chlorogenic acid in roots during chilling storage have been reported by several authors (51, 4, 48). Barry (4) confirmed the role of chlorogenic acid as an uncoupling agent but observed no direct chlorogenic acid-ascorbic acid correlation. He suggested the possibility of another role of chlorogenic acid as a respiratory substrate.

Fontenot (18), in short-term low temperature exposures followed by prolonged storage, indicated he found no effect of storage temperature on chlorogenic acid content. He observed clonal chlorogenic acid content differences in several clones tested. He noted that there was apparently no relation between chlorogenic acid and keeping quality, since "poor keepers" and "good keepers" were found to have similar chlorogenic acid contents. After up to six days exposure to cold (35°F) roots of the Centennial variety showed no increases in chlorogenic acid content nor did they have increased chlorogenic acid content when cured and stored for prolonged period. He suggested that chlorogenic acid may serve as a respiratory substrate, confirming Barry's mention of the possibility (18).

CHAPTER III

METHODS AND MATERIALS

I. PREPARATION AND HANDLING

General Procedures

Sweetpotato roots used for this study were grown on The University of Tennessee Plant Sciences Farm, Knoxville, during the 1968 and 1969 growing seasons. Roots were dug on October 15, 1968, and on October 8, 1969. Non-cured roots were under the various treatments shortly after harvest. The others were cured at 85°F and 90 per cent relative humidity for seven days immediately following harvest. They were then stored at temperatures between 55°F and 60°F until subjected to appropriate treatment procedures.

Uniform U. S. number one grade roots were selected for all experiments in this investigation.

Temperature treatments selected for holding of roots for various time periods were 55°F, 45°F, and 35°F. Storage chamber temperatures were maintained within a range of $\pm$1°F.

Curing was found to delay chilling effects on raw color, baked color, and flavor by Lutz (54). The times of chilling temperatures required to influence these factors in his experiment were used as guides in establishing the storage duration.

In order to secure a range of susceptibility to chilling injury preliminary screening experiments were conducted whereby varieties were rated for visual chilling symptoms.

Screening Tests, 1968

Ten cultivars were screened for chilling susceptibility in a factorial arrangement of treatments in a completely randomized experiment with three individual root samples removed at weekly intervals for six weeks. On October 15, 1968, approximately thirty uniform roots of each of the ten cultivars were placed in chambers held at the three storage temperatures. The cultivars used in this experiment were Goldrush, Julian, Centennial, Rose Centennial, NC-212, NC-240 (later released and named Jewel), L-3-130, L-4-73, L-4-186, and L-4-261. After removal from the temperature treatments the roots were allowed to remain at 70°F for one week and examined. (This holding period will be referred to as the post-treatment period.) The roots were washed and cut longitudinally. Each root was rated for visual symptoms of chilling injury on a one to five rating scale. A rating of one represented no symptoms present and a rating of five represented severe injury which would render the roots unusable. From this test four cultivars were selected that represented a range of susceptibility, NC-212 and NC-240 showed fewer chilling injury symptoms. Centennial was among the most sensitive and L-4-73 was intermediate or average in susceptibility. These four cultivars were used in the storage tests.

Storage Tests, 1969

Non-cured roots. The four varieties at three storage temperatures were studied in a factorial arrangment of treatments in a completely randomized experiment with five roots removed at weekly intervals for six weeks. On October 10, 1969, approximately one bushel each of NC-212,

Prolonged Post-Treatment Storage Test, 1969

In this test approximately one-half bushel of sweetpotatoes of each of the four cultivars used in the previous test was selected from cured roots held in storage. On December 12, 1969, these were placed at 35°F, 45°F, and 55°F temperatures as described in the procedure for non-cured roots. A five-root sample was removed after one week and after two weeks exposure to the temperature treatments. The roots were then placed at 70°F and stored for nine weeks. After nine weeks storage, the same determinations were made as in the two previous tests.

Baking Tests

Non-cured roots. Approximately one-half bushel of non-cured roots of each of the four varieties of sweet potatoes described previously was placed in the three temperature treatments on October 29, 1969. These roots were removed after ten days and held at 70°F for seven days. A three-root sample from each treatment was then removed, washed, and baked in a kitchen oven. Roots were baked at a temperature of 350°F for one hour. One longitudinal slice of each root was used for color evaluation. The skins were then removed and the three roots blended with a portable mixer before organoloptic evaluation. An experienced panel of eight members evaluated root slices for color and the puree for flavor. A one to six rating scale was used with a rating of one being poor and six being excellent. During the flavor evaluation, color of the blended product was masked to prevent color from influencing flavor evaluation. Presentation of samples to panel members was randomized and a three digit random number code identified each sample. Mean scores of panel members were reported.

In raw roots, darkened coloration, internal breakdown, and pithiness were combined into a rating of visual observation of chilling injury appearance (53). In baked roots, darkened color and undesirable flavors by organoliptic determinations were considered as evidence of chilling injury (54). Determinations were made by a rating scale ranging from no detectable influence to unacceptable appearance, color, or flavor.

III. ANALYTICAL PROCEDURES

Specific Gravity

Specific gravity was measured by first weighing one-half of an individual root to the nearest one-tenth gram. The root was then placed in a one-liter beaker of water and the water displaced by the root collected. The volume of water was measured to the nearest ml. Specific gravity or weight per unit volume was then calculated.

Intercellular Space in Tissues

The determination of air space in tissue was modified from the methods of Kushman and Pope (42). One half of an individual longitudinally-cut root was weighed to the nearest one-tenth gram and the volume determined by displacement of water as described in the specific gravity procedure. The roots were submerged in water in a vacuum dessicator. A vacuum was drawn on the dessicator for one hour until no increase in weight was observed. The roots were then removed and surface-dried. The roots were reweighed, and the difference between the original weight and the water filled root weight was recorded. Volume was redetermined and the intercellular space calculated as change in weight minus change in volume and expressed as milliliters of water per 100 ml of root tissue.

Dry Matter Content

A central area of an individual longitudinally cut raw root was used for this determination. A 20 to 40 g section was cut from the root, weighed to the nearest one-hundredth gram, and dried in a forced air oven at 70°C for seventy-two hours. The dry matter was calculated as per cent by weight.

Tissue pH

Fifty grams from the central area of two longitudinally-cut roots were blended with 100 ml. of distilled water for three minutes. The pH was measured with a Beckman pH glass electrode meter. Duplicate samples were measured.

Ascorbic Acid

Ascorbic acid content was determined by the decolorization of 2,6-dichlorophenolindophenol dye by extracted ascorbic acid. The method followed was modified from a method by Loeffler and Pointing (52). A composite sample of 50 g of raw frozen sweetpotato tissue was removed in semiradial section of an individual longitudinally-cut root. This was blended with 350 ml or 1 per cent metaphosphoric acid for five minutes. Approximately 50 ml of the resulting homogenate was then centrifuged to remove the solids. The supernatant was then filtered through Whatman #42 filter paper to further clarify the solution. Duplicate samples of 1 ml of each solution was then added to 9 ml of indophenol dye solution. After twenty seconds, the transmittance at 520 mμ was read on a Beckman DU Spectrophotometer. This reading was compared to a standard ascorbic acid concentration curve (52).

Chlorogenic Acid

Chlorogenic acid determinations were made on similar sections of frozen sample roots. The method of Lieberman (49) was used in making these determinations. One-hundred grams of tissue were blended with 150 ml of 95 per cent ethanol for 10 minutes. After filtration through Whatman #1 filter paper, a 3 ml aliquot was removed and brought to 250 ml with 50 per cent ethanol. The transmittance of this solution was read at 330 mμ in a Beckman DU spectrophotometer and the concentration of chlorogenic acid calculated from an Emax value of 19,700 at this wavelength (30).

IV. ANALYSES OF DATA

The data from these experiments were statistically analyzed with an analysis of variance. The $p > .05$ level of significance was used to determine significant differences. When significant differences were detected, means were separated by Duncan's Multiple Range Test. Correlations were determined for the various dependent variables measured. All analyses of data were carried out on an IBM 360/65 computer system at The University of Tennessee Computing Center, utilizing statistical library programs adapted to the parameters of these experiments.

CHAPTER IV

RESULTS

The results of these experiments are presented in the following tables and figures for the variables measured. Overall varietal and storage temperature responses as well as their interaction for the six-week duration in both cured and non-cured roots are presented.

Responses at each time period sampled are presented for the 30°F and 55°F treatments only and for the NC-212 and Centennial cultivars. The data indicated that the other temperature and cultivars produced intermediate responses.

I. ORGANOLEPTIC DETERMINATIONS

Raw Non-Cured Roots

Cultivars showed significant differences in chilling symptoms. Lower temperatures increased chilling injury ratings. The interaction between temperature and cultivars was also significant as shown in Table 1. NC-212 had less visual chilling injury over the temperature range than any of the other varieties. Increasing susceptibility to temperature was exhibited by NC-240, L-4-73, and Centennial, respectively. Over the entire six-week period NC-212, and to a lesser extent NC-240, did not show appreciable symptoms of chilling injury even after the last sampling period. By the third week NC-212 did have an apparent pithiness or sponginess of the tissue. Centennial, and to a lesser extent L-4-73, had tissue darkening develop at 35°F and 45°F as is generally observed in

TABLE 1. Influence of three temperature treatments on four cultivars of non-cured sweetpotato roots as measured by a visual chilling injury rating scale.*

Cultivar	TEMPERATURE 35°F	45°F	55°F	Cultivar Means
NC-212	1.86cd**	1.36de	1.14e	1.45c
NC-240	2.93b	2.07c	1.14e	2.05b
L-4-73	3.21b	2.14c	1.213	2.19b
Centennial	3.93a	3.00b	1.64cde	2.86a
Temperature Mean	2.98a	2.14b	1.29c	

*Rating scale 1 = no injury to 5 = severe injury. Each rating mean of seven weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

chilling injury. Lower ratings for NC-212 and NC-240 were influenced by the failure of these cultivars to develop the characteristic darkening discoloration as a symptom of chilling injury. The pithiness that was developed in these two cultivars appeared as small spaces uniformly throughout the flesh and did not develop in localized areas or "pockets."

Chilling injury ratings, taken weekly from each storage treatment as shown in Figure 1, increased with duration of storage. Each point represents the mean of the three storage temperatures. Chilling injury gradually increased in Centennial as time increased up to the fourth week; whereas, NC-212 did not show signs of significant chilling injury until after the fourth week. L-4-73 and NC-240 were much alike at each duration period. Non-cured Centennial roots at 55°F showed a slight darkening discoloration after four weeks.

Raw Cured Roots

Visual chilling injury ratings for cured roots are presented in Table 2. The relationships for cultivars, temperature treatments, and their interactions were similar to those found for non-cured roots. Since these experiments were not conducted concurrently and cured roots were stored for a period before the temperature treatments were applied, no statistical measure between cured and non-cured experiments was attempted. It is obvious that chilling injury symptoms for all cultivars and temperature treatments were reduced by the curing treatment. Cultivar differences existed, with NC-212 showing the least chilling injury. The lower temperature treatments resulted in greater chilling injury. Again, the interaction between temperature and cultivars exhibited by NC-212, and to a lesser extent NC-240, were less sensitive to the two colder

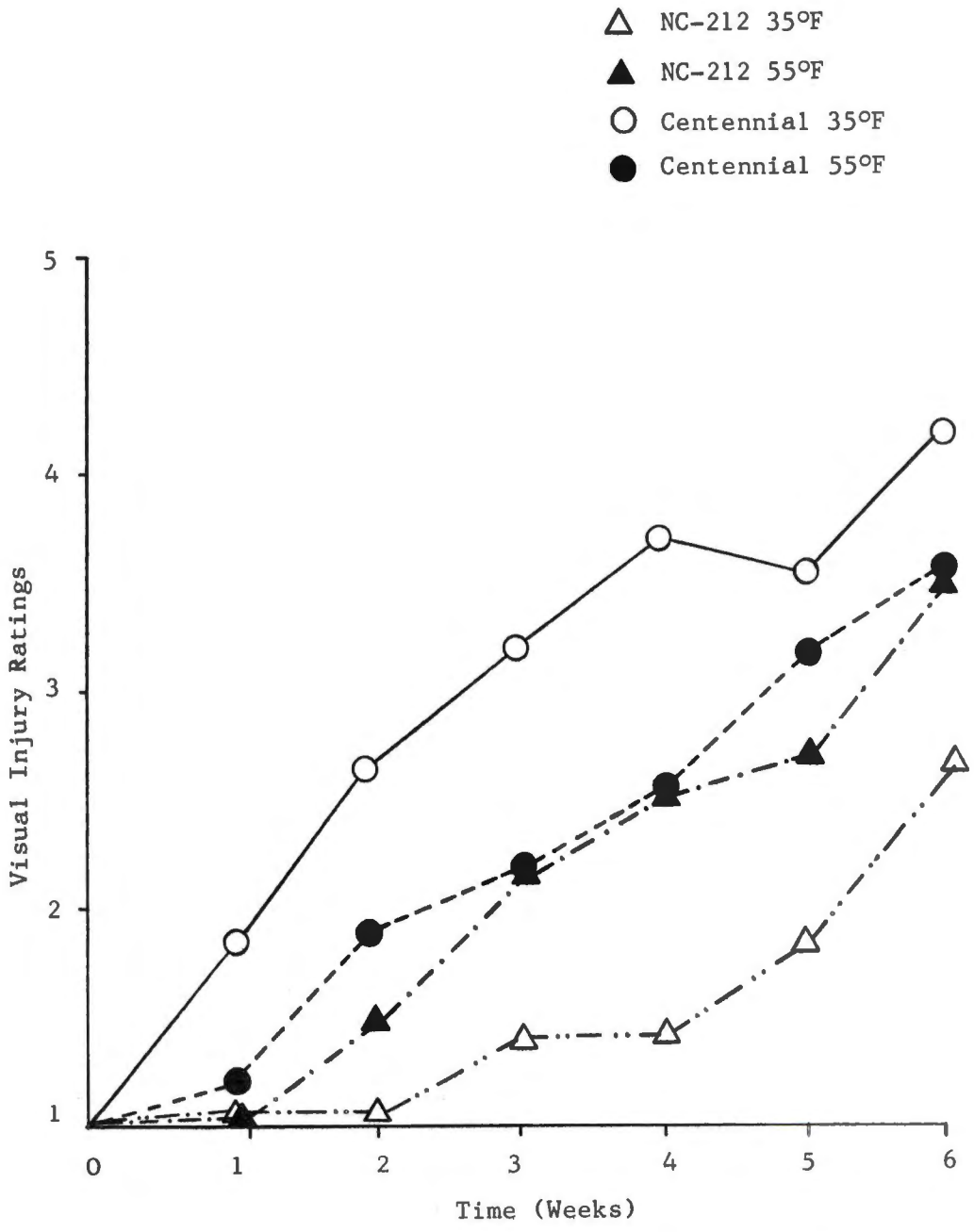

Figure 1. Influence of duration of storage temperature on four cultivars of non-cured sweetpotatoes as measured by visual chilling injury ratings.

TABLE 2. Influence of three temperature treatments on four cultivars of cured sweetpotato roots as measured by a visual chilling injury rating scale.*

Cultivar	TEMPERATURE			Cultivar Means
	35°F	45°F	55°F	
NC-212	1.00e**	1.00e	1.00e	1.10c
NC-240	2.29c	1.79d	1.00e	1.69b
L-4-73	3.14ab	2.78b	1.00e	2.31a
Centennial	3.29a	2.14cd	1.29e	2.34a
Temperature Means	2.43a	1.93b	1.07c	

*Rating scale 1 = no injury to 5 = severe injury. Each rating mean of seven weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

temperature treatments, than the other cultivars. Similar observations on the discoloration and pithiness differences of the cultivars to those found in the non-cured roots were noted.

Chilling injury ratings with increasing duration of temperature treatments for the cured roots are illustrated in Figure 2. As in the non-cured roots, injury to Centennial increased initially, while that of NC-212 remained at a low level throughout the experiment. In the cured roots, however, L-4-73 was not similar to NC-240, but after the first week of treatment behaved more like Centennial. During this time NC-240 maintained a slight indication of chilling injury. Again, these values are the mean of the 35°F, 45°F, and 55°F with increases in injury during each duration time period being due to the lower temperature treatments only. No chilling injury symptoms were observed in the roots of any variety at the 55°F temperature treatment.

Baked Non-Cured Roots

The baking tests of non-cured roots after storage at the three temperature treatments for ten days followed by the seven-day post-treatment holding period consisted of organoleptic flavor and color evaluations. The results of these tests are presented in Tables 3 and 4.

There were cultivar flavor differences, NC-240 and Centennial being rated higher than L-4-73 or NC-212. No over all differences in flavor due to temperature treatments were noted in Table 3. The flavor score of Centennial was lower at the 35°F storage treatment while those for NC-240 and L-4-73 were relatively unaffected by temperature treatment. Flavor ratings for all treatments were generally low, indicating that the panel was critical of flavor in these non-cured roots.

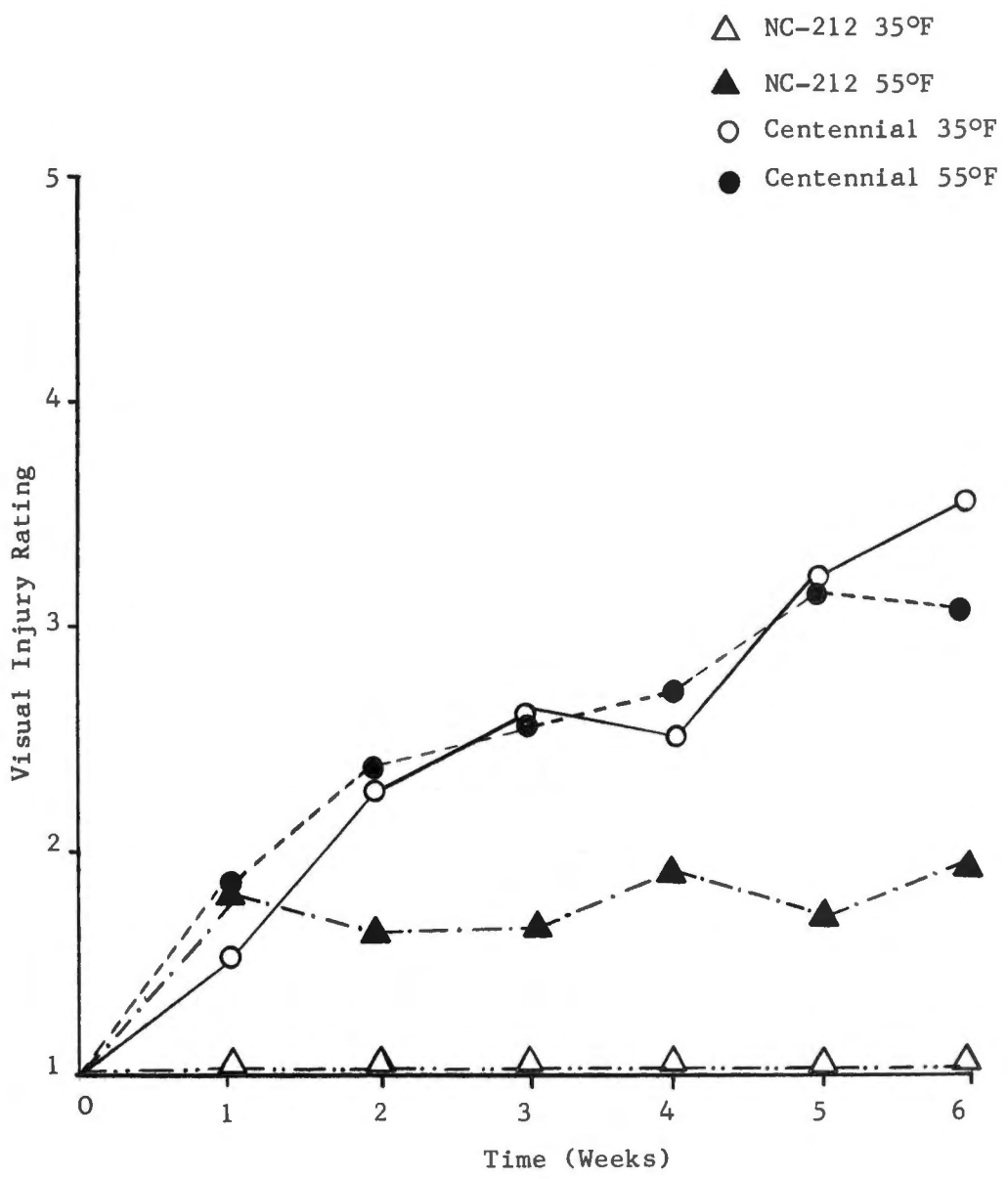

Figure 2. Influence of duration of storage temperature on four cultivars of cured sweetpotatoes as measured by a visual chilling injury rating scale.

TABLE 3. Flavor differences of four non-cured sweetpotato cultivars stored at three temperatures as determined by taste panel evaluations.*

Cultivar	TEMPERATURE 35°F	45°F	55°F	Cultivar Means
NC-212	2.12cd**	1.50d	1.25d	1.62c
NC-240	3.12ab	3.00ab	3.12ab	3.08a
L-4-73	1.87cd	2.00cd	1.75cd	1.87c
Centennial	1.75cd	3.25a	2.75abc	2.58b
Temperature Means	2.13a	2.44a	2.22a	

*Rating scale 0 = very poor, 6 = excellent.

**Means followed by a common letter are not significantly different at $p > .05$.

TABLE 4. Color differences for four cultivars of non-cured sweet-potatoes at three storage temperatures as determined by taste panel evaluations.*

Cultivar	TEMPERATURE 35°F	45°F	55°F	Cultivar Means
NC-212	2.62c**	2.42c	2.51c	2.58b
NC-240	3.01bc	3.17b	3.97a	3.39a
L-4-73	1.51d	0.42e	1.25d	1.06c
Centennial	0.59e	0.12e	0.25e	0.32d
Temperature Means	1.93a	1.79a	2.00a	

*Rating scale 0 = very poor to 6 = excellent.

**Means followed by a common letter are not significantly different at $p > .05$.

Color differences in the non-cured roots are presented in Table 4. Color differences among cultivars were pronounced. Centennial and L-4-73 rated low in color appearance while NC-212 and NC-240 each improved with low temperature treatments in color rating scores, respectively. As was the case for flavor, no root color differences were observed due to storage temperature treatments. A significant interaction between cultivars and temperatures was noted. Centennial was poor in color at all storage temperatures. NC-212 was similar in color at all storage temperatures. NC-240 decreased in color rating at the two colder temperatures. L-4-73 had a poor color at the 45°F temperature treatment only. As was true for flavor evaluations, over all poor ratings for color were given by the panel for these non-cured roots.

Baked Cured Roots

Storage duration at the various temperature treatments for the cured roots was four weeks instead of ten days as was used in the non-cured roots. Evaluations were made after a seven-day post-treatment holding period. Color and flavor evaluations for cured roots are presented in Tables 5 and 6.

Cultivar flavor differences were present in the cured roots (Table 5). NC-240 was preferred, but the roots of other cultivars were more similar than the non-cured cultivar roots. A significant reduction in flavor was noted at the lower temperature treatments. A significant cultivar-temperature interaction was observed. NC-212 was similar in flavor at all storage temperatures. Both NC-240 and L-4-73 roots were reduced in flavor by storage at temperatures lower than the 55°F storage

TABLE 5. Flavor differences in four cultivars of cured sweetpotatoes at three storage temperatures as determined by taste panel evaluations.*

Cultivar	TEMPERATURE 35°F	45°F	55°F	Cultivar Means
NC-212	3.60bc**	3.26de	3.93abc	3.60ab
NC-240	3.33cd	4.07abc	4.67a	4.02a
L-4-73	2.73e	3.73bc	3.80bc	3.42b
Centennial	2.80de	2.73e	4.13ab	3.22b
Temperature Means	3.18c	3.45b	4.13a	

*Rating scale 0 = very poor to 6 = excellent.

**Means followed by a common letter are not significantly different at $p > .05$.

TABLE 6. Color differences of four cultivars of cured sweetpotatoes at three storage temperatures as determined by taste panel evaluations.*

Cultivar	TEMPERATURE 35°F	45°F	55°F	Cultivar Means
NC-212	3.80bcd**	3.27cde	3.80bcd	3.62a
NC-240	2.40f	5.00a	4.33ab	3.91a
L-4-73	2.33f	4.07bc	4.51ab	3.64a
Centennial	2.40f	3.00def	2.87ef	2.76b
Temperature Means	2.73b	3.83a	3.88a	

*Rating scale 0 = very poor to 6 = excellent.

**Means followed by a common letter are not significantly different at $p > .05$.

treatment. The flavor of Centennial roots was sharply changed by storage at 35°F and 45°F as compared to the 55°F treatment. A generally more acceptable flavor was noted for the cured roots by panel members.

Color evaluations for the cured roots are presented in Table 6. Cultivars here were more similar in color than the non-cured roots. Centennial had a lower color value than the other cultivars. A lower color rating was given to roots of the 35°F storage treatment than to either of the other two. NC-212 and Centennial were unaffected by temperature treatments, while L-4-73 and NC-240 reached lower color values at the coldest temperature treatment. Panel members rated color more acceptable in the cured roots than in the non-cured roots.

In some of the L-4-73 cultivar stored at 35°F and, to a lesser extent in the Centennial cultivar at this same temperature, a textural abnormality appeared in the baked product. Although roots were cooked to a uniform internal temperature, there were areas of hard tissue in the baked root. These hard areas appeared in a mottled pattern in cross sections of these baked roots, since they were lighter in color than the softer tissue. These areas appeared to be uncooked and were noted as lumps in the mashed product presented to the panel members. This was observed in both the non-cured and cured roots. This was observed only in roots from the 35°F storage treatment.

Prolonged Post-Treatment Storage - Raw Roots

Although the general purpose of these experiments was to evaluate chilling injury after a short post-temperature holding period at 70°F, a secondary experiment was designed to evaluate these same cultivars

held at the same temperature treatments for a one- and two-week period followed by a nine-week post-treatment holding period. Visual chilling injury ratings for this experiment with cured roots are presented in Table 7.

Chilling injury cultivar differences were noted between Centennial and the other cultivars. Chilling injury was greatest at the 35°F storage temperature. A significant interaction indicated that generally Centennial was more temperature susceptible than the other cultivars. In this experiment, as in the non-cured roots, there was a tendency for the Centennial roots at the 55°F storage treatment to develop a dark discoloration. NC-212 at the 35°F storage treatment developed pronounced pithiness that appeared as a honeycombed interior, rather than as a fine sponginess throughout the tissue. However, in this experiment as was the case in the former trials, NC-212 did not develop discoloration to any degree even after the prolonged post-treatment holding period.

II. ROOT SPECIFIC GRAVITY

Non-Cured Roots

Specific gravity was significantly different in the four cultivars studied. NC-212 was considerably lower in specific gravity than the other cultivars. No significant storage temperature effect on specific gravity was observed (Table 8). A cultivar-temperature interaction was present.

There was no significant interaction between cultivars and treatments for storage time periods. Specific gravity of all cultivars

TABLE 7. Visual chilling injury ratings of four cultivars of cured sweetpotato roots held nine weeks after temperature treatments.*

Cultivar	TEMPERATURE 35°F	45°F	55°F	Cultivar Means
NC-212	1.68c**	1.00e	1.00e	1.22b
NC-240	1.33d	1.00e	1.00e	1.11b
L-4-73	1.50cd	1.00e	1.00e	1.17b
Centennial	3.33a	2.50b	1.67c	2.50a
Temperature Means	1.96a	1.37b	1.17b	

*Rating scale 1 = no injury to 5 = severe injury. Each rating mean of three weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

and temperature treatments tended to first decrease and then increase after removal from storage.

Cured Roots

Specific gravity in cured roots differed in the cultivars studied as it did in the non-cured roots. The same relationship existed among the cultivars in the cured roots, with NC-240 having the greatest specific gravity and NC-212 having the least. No significant temperature or cultivar-temperature interaction differences were observed.

At each period of temperature treatment there were no significant differences observed in the cured roots for any of the cultivars or storage temperatures studied.

When cured roots were held for one and two weeks in the temperatures specified and then for the prolonged holding period, specific gravity generally tended to decrease for all cultivars with the one- and two-week temperature treatments, respectively. Only in Centennial stored at 35°F for two weeks and followed by nine weeks of the post-treatment holding period was the specific gravity increased over any of the other varieties or temperature treatments.

III. INTERCELLULAR SPACE

Non-Cured Roots

The intercellular space measurements of non-cured roots is presented in Table 9. A similar intercellular space was noted for all cultivars. Intercellular space was greatest in roots from the 45°F storage treatment, followed by the 55°F and 35°F storage treatments,

TABLE 9. Influence of temperature treatments on the intercellular space of four cultivars of non-cured sweetpotatoes.*

	(Ml per 100 ml of Tissue Volume)			
	TEMPERATURE			
Cultivar	35°F	45°F	55°F	Cultivar Means
NC-212	7.21abc**	7.82ab	6.82bc	7.28a
NC-240	5.43d	7.99ab	7.20abc	6.87a
L-4-73	5.79cd	8.46a	7.68ab	7.31a
Centennial	6.76c	7.94ab	7.35ab	7.36a
Temperature Means	6.30c	8.05a	7.26b	

*Mean of seven weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

respectively. A significant cultivar-temperature interaction was present. NC-212 tended to maintain a greater level of intercellular space at the 35°F storage treatment than the other cultivars.

Intercellular space volumes for NC-212 and Centennial roots only at 35°F and 55°F storage treatments are presented in Figure 3 for each duration of temperature treatment. The NC-212 roots at both storage temperatures maintained a fairly uniform intercellular space level throughout the test. Centennial roots at 55°F increased and Centennial at 35°F first increased, decreased sharply, and increased toward the end of the storage period. The sharp decrease in the intercellular space of Centennial roots at 35°F after the first two weeks of temperature treatment may reflect a sudden loss of tissue volume, rather than indicating changes in respiratory activity. Dry matter content was greater in roots of this treatment about this same time and specific gravity increases also were noted. However, this change appeared more abrupt than could be accounted for by the other observed changes.

Cured Roots

Intercellular space measurements of cured roots are presented in Table 10. Intercellular space differences were observed among the four cultivars. No cultivar differences were noted in the non-cured roots. Greatest intercellular space was observed in NC-212 and the least in NC-240. Intercellular space was least at the lowest temperature treatment and was greatest at the 45°F storage treatment, as was the case for the non-cured roots. NC-212 and Centennial maintained a similar level of intercellular space at all temperature treatments. The other two cultivars were affected by the temperature treatments.

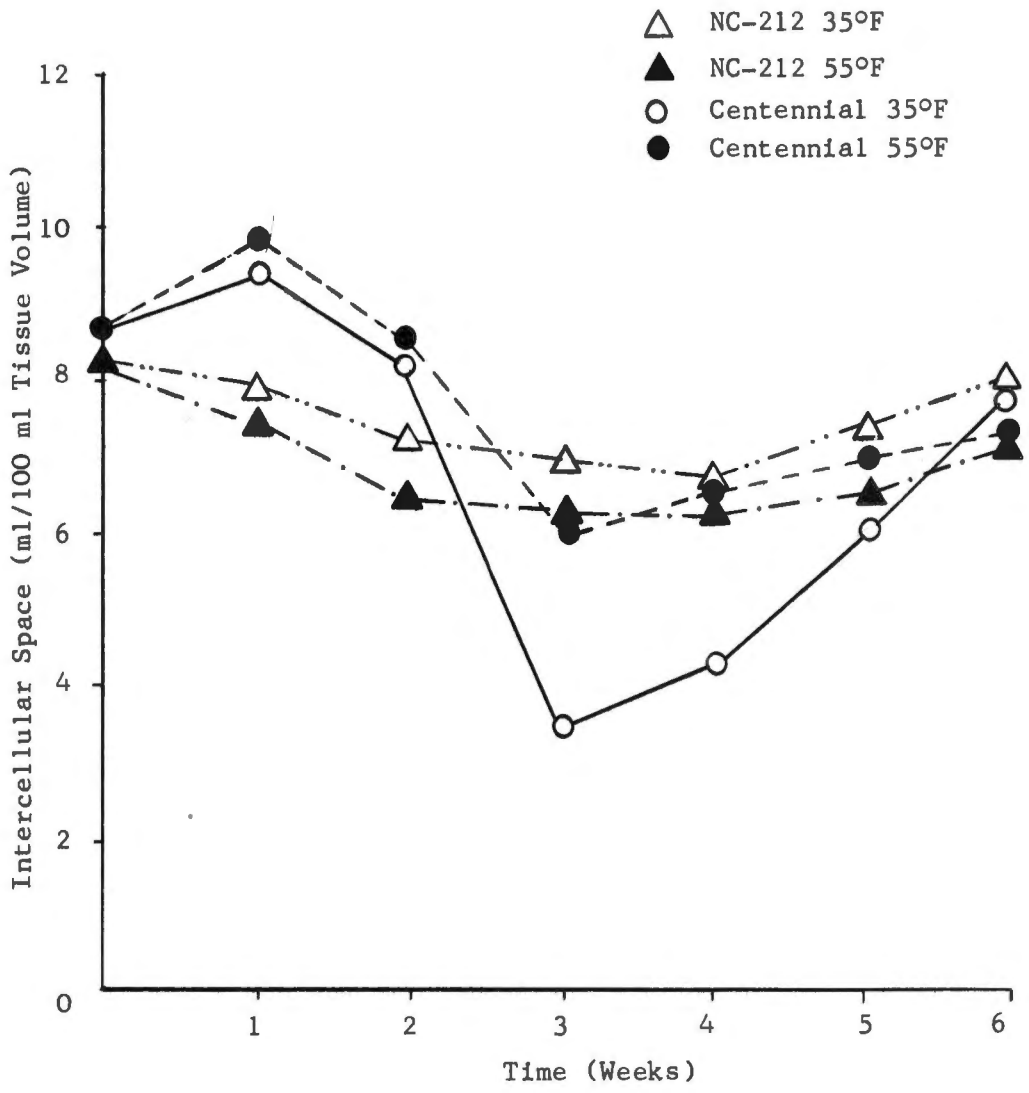

Figure 3. Influence of duration of storage temperature on the intercellular space of two cultivars of non-cured sweetpotatoes.

TABLE 10. Influence of temperature treatments on the intercellular space of four cultivars of cured sweetpotatoes.*

	(Ml per 100 ml of Tissue Volume)			
	TEMPERATURE			
Cultivar	35°F	45°F	55°F	Cultivar Means
NC-212	22.72a**	20.96ab	20.82ab	21.66a
NC-240	15.10d	18.44c	17.51bcd	17.02c
L-4-73	16.18cd	2.082ab	19.66ab	18.88b
Centennial	18.26bcd	20.46ab	20.34ab	19.70b
Temperature Means	18.18b	20.14a	19.08ab	

*Mean of seven weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

There were no significant cultivar-temperature interactions for NC-212 and Centennial stored at 35°F and 55°F, regardless of treatment period. Intercellular space increased with length of treatment for all cultivars and temperatures.

In the prolonged post-treatment holding test, the intercellular space of cured roots have all cultivars increased with one week temperature treatment. After the two-week temperature treatment followed by the prolonged post-treatment period, there was a decrease in intercellular space in Centennial roots at 35°F. This may account for the increase in the specific gravity in this cultivar and treatment earlier noted.

IV. DRY MATTER CONTENT

Non-Cured Roots

The dry matter content observed in the non-cured root experiment is presented in Table 11. Pronounced differences in percentage dry matter were observed. The dry matter content for NC-212 was approximately two-thirds that of Centennial. Slight differences in dry matter content were observed due to storage temperature treatments. Dry matter was highest in roots given the 35°F storage treatment. A significant cultivar-temperature interaction was also present. NC-212 roots were unaffected by temperature treatment while roots of Centennial stored at 35°F contained the highest percentage dry matter. The other cultivars were similar in response to the NC-212 roots.

When examined at the end of each storage period, no significant interaction of cultivars and temperatures was noted. Percentage dry matter decreased over all cultivars and temperatures with length of storage treatment.

TABLE 11. Influence of temperature treatments on percentage dry matter content of four cultivars of non-cured sweetpotatoes.*

Cultivar	TEMPERATURE 35°F	45°F	55°F	Cultivar Means
NC-212	19.96e**	19.40e	19.21e	19.52d
NC-240	30.21bc	29.21c	29.98c	29.47b
L-4-73	27.54d	26.86d	27.01d	27.13c
Centennial	32.13a	30.40bc	30.92ab	31.15a
Temperature Means	27.46a	26.46b	26.53b	

*Based on mean of seven weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

Cured Roots

In the cured roots, only significant differences among cultivars were observed similar to those in the non-cured roots.

V. TISSUE pH

Non-Cured Roots

Unlike many of the previously reported factors, pH of the non-cured roots was similar in all cultivars studied (Table 12). At the 35°F storage temperature, there was a decrease in pH for all varieties. Cultivars responded to temperature treatments in a similar manner to each other.

Also, there were significant pH changes with durations of storage (Figure 4) only for NC-212 and Centennial roots at the 35°F and 55°F treatments. NC-212 and Centennial roots at 55°F maintained a fairly constant pH throughout the experiment. Centennial roots at 35°F decreased in pH after a one-week storage. After about the third week, the pH of roots from this same treatment reversed and began to increase. NC-212 roots maintained a constant pH until after the fourth week when a sharp decrease in pH was observed.

Cured Roots

The pH of cured sweetpotato roots is presented in Table 13. As was the case in the non-cured roots, there were no differences among cultivars. A reduction in pH was measured in the 35°F storage treatment. The four cultivars responded in a similar manner to the temperature treatments over the entire experiment.

TABLE 12. Effect of three temperature treatments on the pH of four cultivars of non-cured sweetpotatoes.*

Cultivar	TEMPERATURE 35°F	45°F	55°F	Cultivar Means
NC-212	6.0a**	6.1a	6.2a	6.1a
NC-240	5.9a	6.2a	6.2a	6.1a
L-4-73	5.8a	6.1a	6.1a	6.0a
Centennial	6.0a	6.2a	6.2a	6.1a
Temperature Means	5.9b	6.1a	6.2a	

*Mean of seven weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

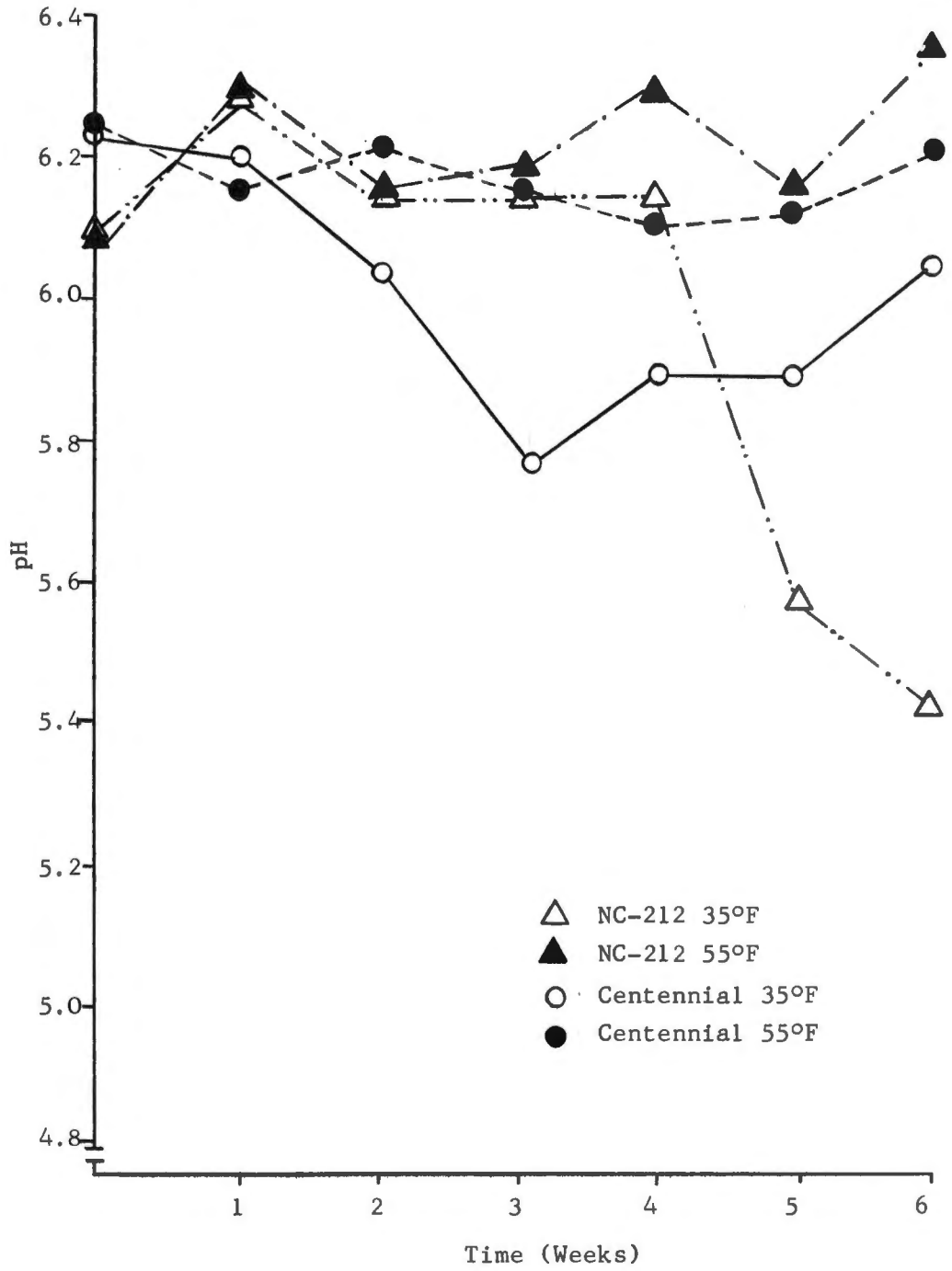

Figure 4. Influence of duration of storage temperature on the pH of two cultivars of non-cured sweetpotatoes.

TABLE 13. Effect of three temperature treatments on the pH of four cultivars of cured sweetpotato roots.*

Cultivar	TEMPERATURE 35°F	45°F	55°F	Cultivar Means
NC-212	6.0a**	6.1a	6.0a	6.0a
NC-240	5.8a	6.1a	6.1a	6.0a
L-4-73	5.7a	6.1a	6.1a	6.0a
Centennial	5.7a	6.2a	6.1a	6.0a
Temperature Means	5.8b	6.1a	6.1a	

*Mean of seven weekly time periods.

**Means having common letters are not significantly different at $p > .05$.

When each temperature treatment period was considered, however, it appears that temperature means were not a satisfactory indication of the changes that occurred in the roots. As shown in Figure 5, Centennial roots stored at 35°F maintained a constant pH until after the third week, when a marked decrease in pH occurred. NC-212 at this same storage temperature maintained about the same pH throughout the experiment. At the 55°F storage treatment Centennial roots had an increasing pH until after about the fourth week when the pH began to decrease slightly. NC-212 maintained a more constant pH at this temperature with a slight increasing trend noted until the fifth week duration of temperature treatment.

In the cured roots that were held for nine weeks after one and two weeks of temperature treatment, there were no significant differences in pH observed for overall storage temperatures. Even in the Centennial roots treated for two weeks at 35°F and stored nine weeks at 70°F, the pH was 5.9.

VI. ASCORBIC ACID

Non-Cured Roots

The ascorbic acid content of non-cured roots is presented in Table 14. Differences in ascorbic acid for the cultivars studied were observed. The ascorbic acid content of Centennial was high while that of NC-212 was low. Ascorbic acid content was influenced by temperature treatment. Reduction of ascorbic acid content occurred at the 35°F storage treatment. Cultivars responded differently to the storage temperatures. The ascorbic acid content of roots of NC-212 was unaffected by

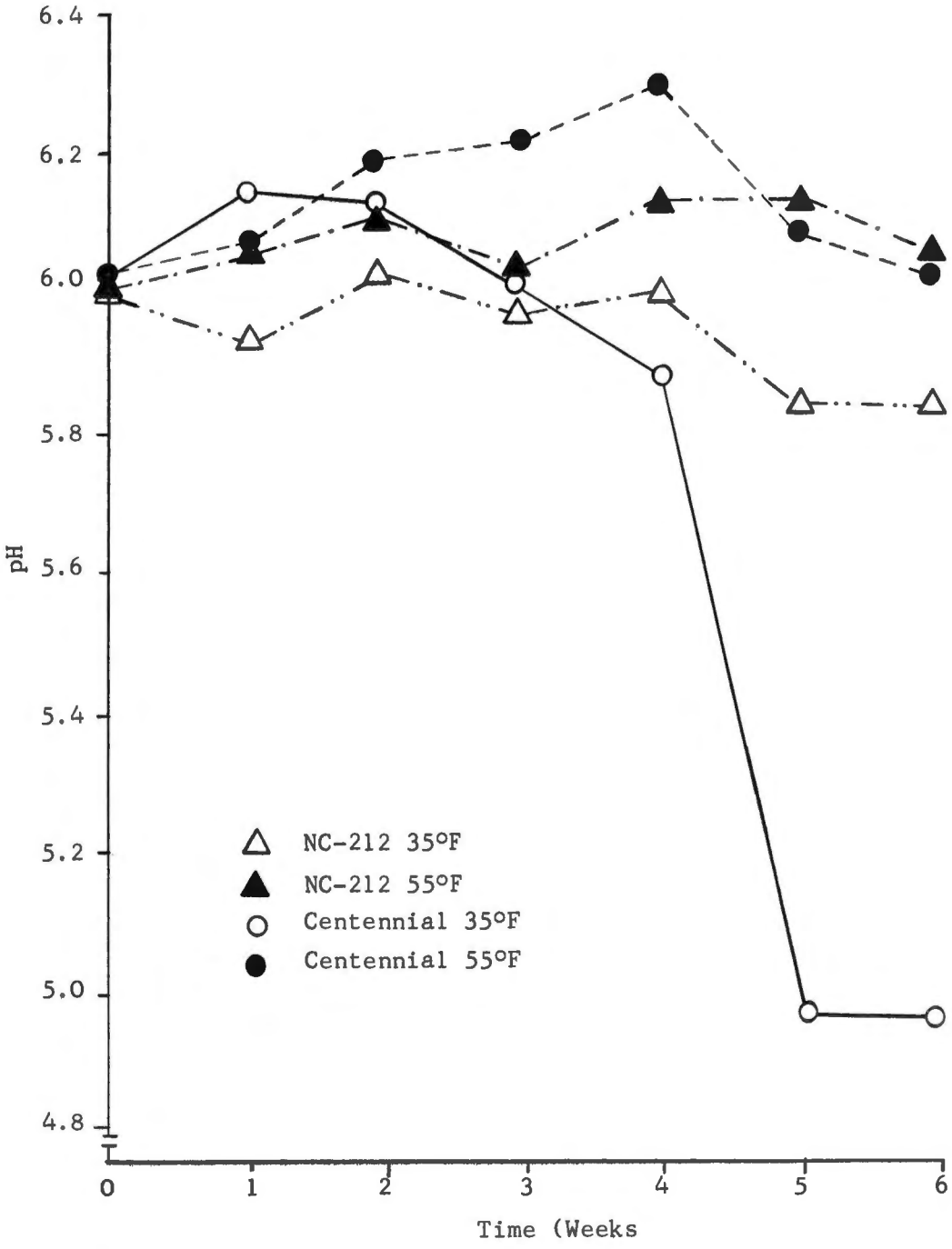

Figure 5. Influence of duration of storage temperature on the pH of two cultivars of cured sweetpotatoes.

TABLE 14. Influence of three temperature treatments on the ascorbic acid content of four cultivars of non-cured sweetpotatoes.*

	(Mgs Ascorbic Acid per 100 g Fresh Weight)			
	TEMPERATURE			
Cultivar	35°F	45°F	55°F	Cultivar Means
NC-212	24.28bc**	25.97bc	26.10bc	25.45c
NC-240	24.95bc	31.47b	31.76b	29.39ab
L-4-73	21.62c	28.06bc	32.06b	27.25bc
Centennial	20.72c	32.53b	40.87a	31.37a
Temperature Means	22.89b	29.51a	32.70a	

*Mean of seven weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

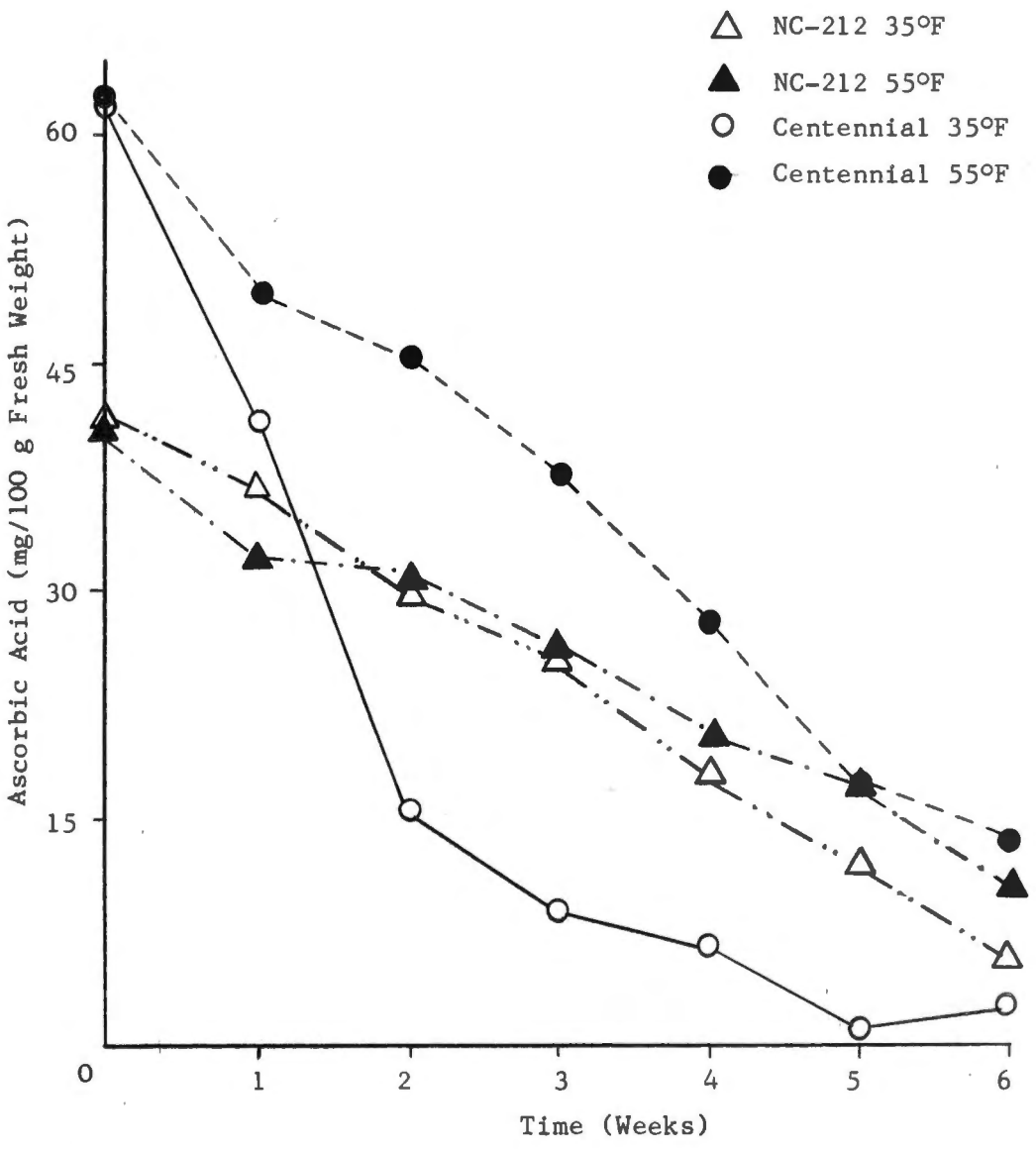

Figure 6. Influence of duration of storage temperature on the ascorbic acid content of two cultivars of non-cured sweetpotatoes.

TABLE 15. Influence of three temperature treatments on ascorbic acid content of four cultivars of cured sweetpotatoes.*

	(Mgs Ascorbic Acid per 100 g Fresh Weight			
	TEMPERATURE			
Cultivar	35°F	45°F	55°F	Cultivar Means
NC-212	20.56ab**	24.21ab	25.65ab	23.47a
NC-240	23.05ab	28.81a	28.70a	26.86a
L-4-73	21.18ab	26.60ab	26.08ab	24.62a
Centennial	11.91c	19.27bc	25.71a	18.96b
Temperature Means	19.17b	24.72a	26.53a	

*Mean of seven weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

As in the non-cured roots, cultivars were affected by temperatures in a different manner. NC-212 showed little influence of temperature treatment on the ascorbic acid content of roots. Centennial roots were lower in ascorbic acid at the lower temperature treatments.

Little change was noted in ascorbic acid content over the six-weeks treatment period with NC-212 and Centennial roots stored at 55°F as presented in Figure 7. Centennial roots at 35°F decreased in ascorbic acid from the beginning of the experiment, as they did in the non-cured roots. Ascorbic acid content of NC-212, after the third week of temperature treatment, began to decrease steadily.

VII. CHLOROGENIC ACID

Non-Cured Roots

The chlorogenic acid content of non-cured sweetpotato roots is presented in Table 16. Cultivar differences in chlorogenic acid content were observed. Chlorogenic acid was greater in the 45°F storage treatment. Cultivars responded differently to the temperature treatments. NC-212 roots were relatively unaffected by temperature treatment with a slight reduction in chlorogenic acid at the 35°F temperature treatment. Both NC-240 and Centennial roots had increased chlorogenic acid contents at the 45°F temperature treatments.

Because of the increased chlorogenic acid content at the 45°F storage temperature treatment in Centennial, this temperature effect on chlorogenic acid is shown, along with that of the other two storage temperatures, for Centennial and NC-212 cultivars in Figure 8. The three temperature treatments of NC-212 roots resulted in a relatively constant

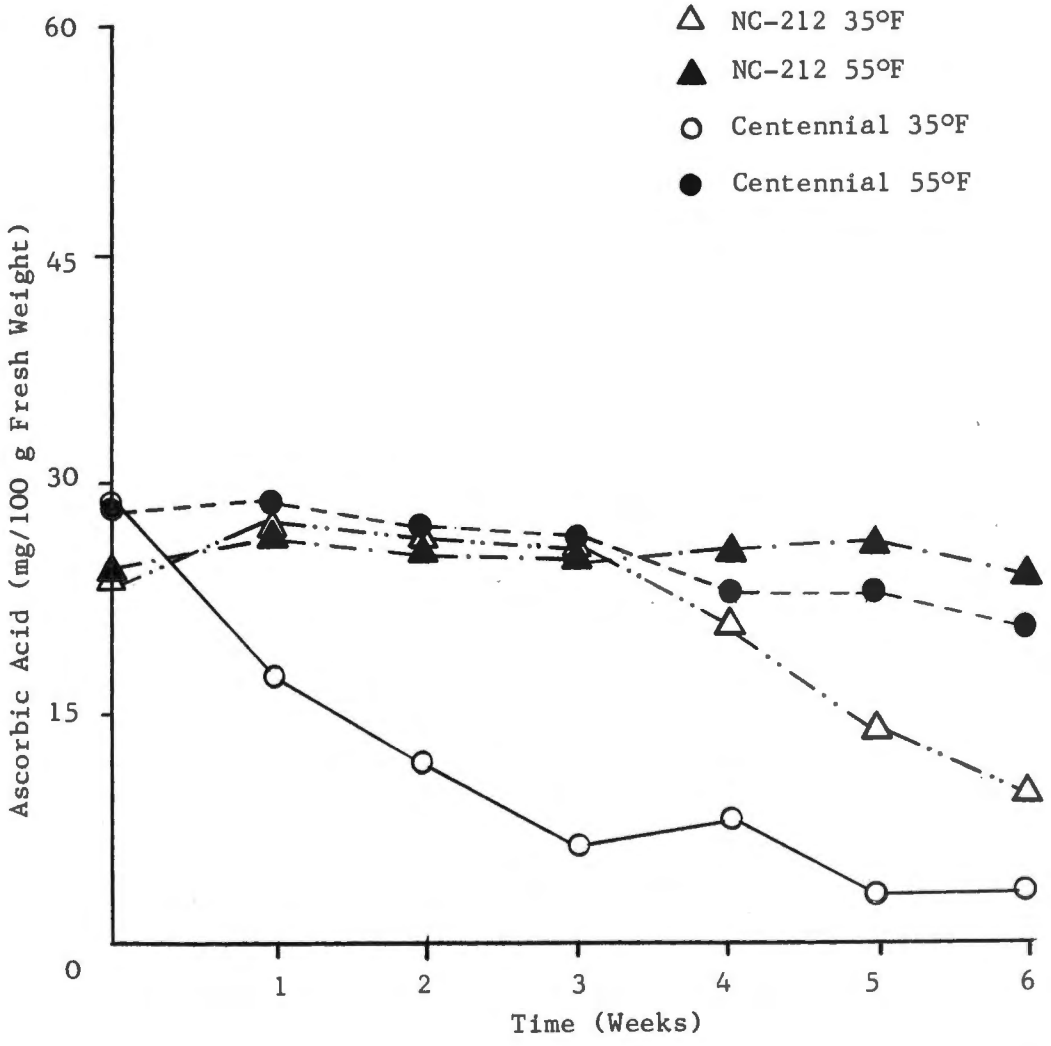

Figure 7. Influence of duration of storage temperature on the ascorbic acid content of two cultivars of cured sweetpotatoes.

TABLE 16. Effect of three temperature treatments on the chlorogenic acid content of four cultivars of non-cured sweetpotatoes.*

	(Mgs Chlorogenic Acid per 100 g Fresh Weight)			
	TEMPERATURE			
Cultivar	35°F	45°F	55°F	Cultivar Means
NC-212	30.82f**	46.42e	44.54e	40.59c
NC-240	33.94f	77.96cd	35.03f	48.97bc
L-4-73	62.34d	81.37cd	57.21d	67.09b
Centennial	126.45b	209.86a	97.22bc	144.51a
Temperature Means	63.39b	103.99a	58.50b	

*Mean of seven weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

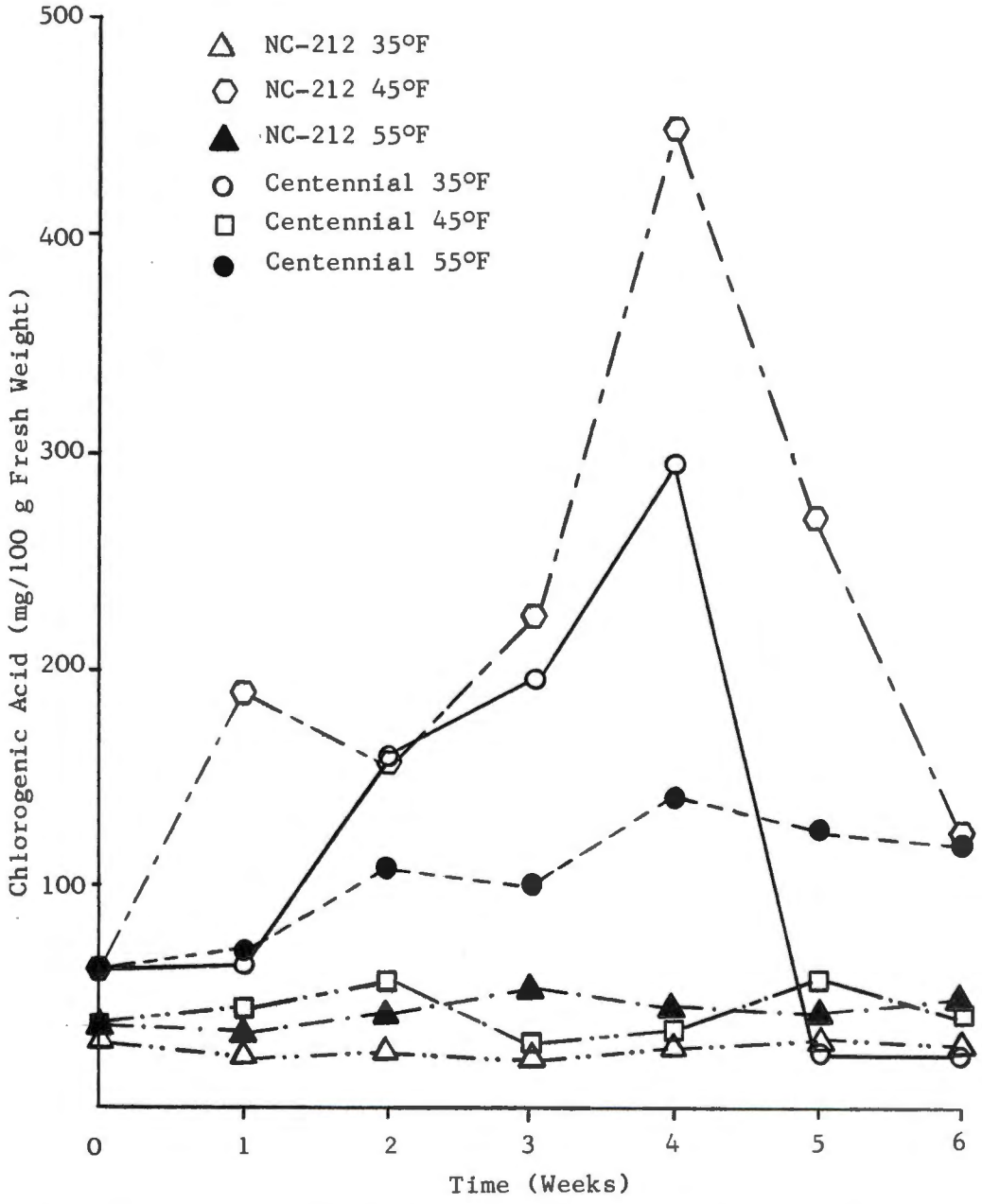

Figure 8. Influence of duration of storage temperature on the chlorogenic acid content of two cultivars of non-cured sweetpotatoes.

chlorogenic acid content throughout the duration of the experiment. In Centennial roots at the 55°F storage treatment there was a slight increase in chlorogenic acid content up to the fifth week. In both the 35°F and 45°F treatments there was a marked increase in chlorogenic acid reaching a peak after four weeks of treatment. In the 45°F treatment the peak reached was much higher than in the 35°F treatment. There was a decrease in chlorogenic acid content during the fifth and sixth week of treatment in both these temperatures. In the 35°F treatment this decrease eventually reached a point lower than the initial chlorogenic acid content.

Cured Roots

Chlorogenic acid content of cured roots is presented in Table 17. Cultivar differences in chlorogenic acid content were measured. Chlorogenic acid was greater in the 35°F storage treatment for all cultivars. Cultivars did not respond to the temperature treatments in a similar manner. NC-212 and NC-240 were relatively unaffected by temperature treatment. Chlorogenic acid was increased in the 35°F treatment of L-4-73. The levels in Centennial generally were much higher in the three temperature treatments.

When each temperature treatment period was studied changes were found in chlorogenic acid in the 35°F storage treatment for Centennial roots (Figure 9). Increases in chlorogenic acid were noted toward the end of the storage period for this treatment. In the 55°F storage treatment for the Centennial cultivar only slight increases were observed throughout the test. In NC-212 roots at both the 35°F and 55°F storage treatments there were little change in chlorogenic acid.

TABLE 17. Effect of three temperature treatments on the chlorogenic acid content of four cultivars of cured sweetpotatoes.*

	(Mgs Chlorogenic Acid per 100 g Fresh Weight)			
	TEMPERATURE			
Cultivar	35°F	45°F	55°F	Cultivar Means
NC-212	25.30c**	28.38bc	32.46bc	28.71b
NC-240	21.44c	23.85c	23.86c	23.05b
L-4-73	54.91a	34.70bc	33.87bc	41.16a
Centennial	59.22a	48.64ab	41.79abc	49.88a
Temperature Means	40.22a	33.89b	32.99b	

*Mean of seven weekly time periods.

**Means followed by a common letter are not significantly different at $p > .05$.

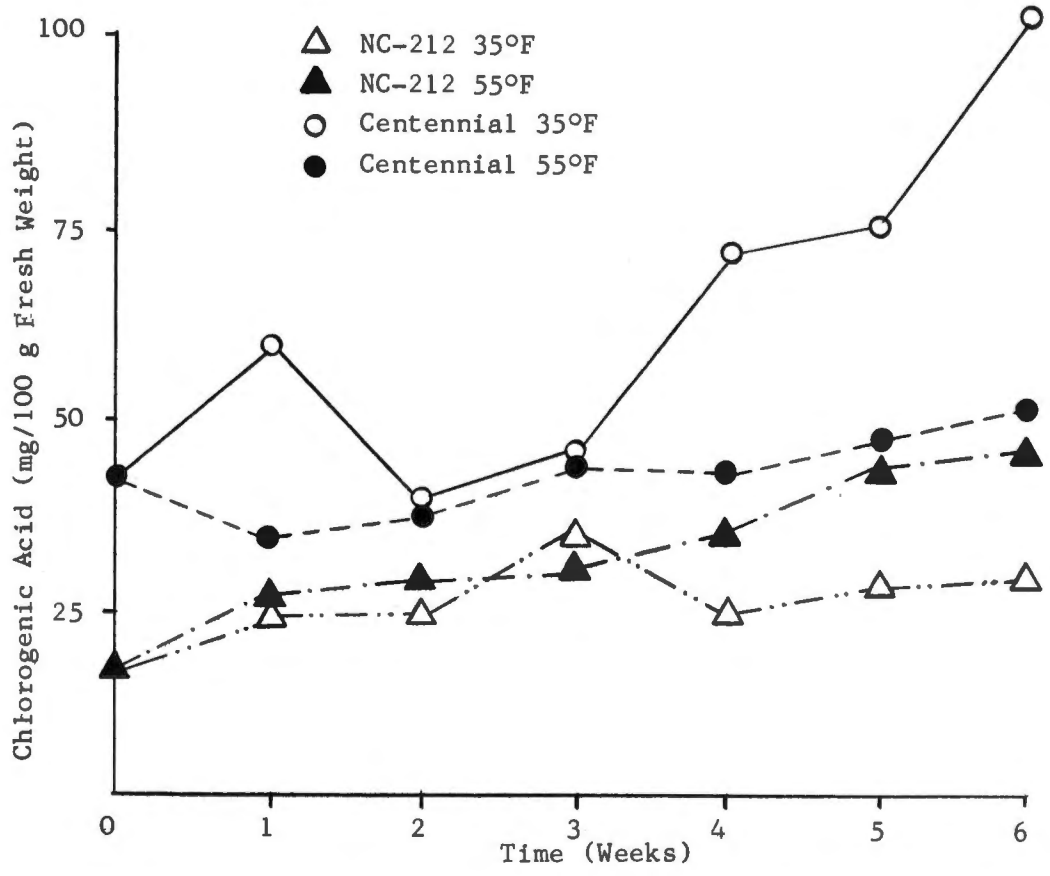

Figure 9. Influence of duration of storage temperature on the chlorogenic acid content of two cultivars of cured sweetpotatoes.

When cured roots treated with one- and two-week storage temperatures followed by a nine-week post-treatment period were examined there were only slight increases in chlorogenic acid in NC-212 roots that had been chilled. In Centennial roots, there were increases in chlorogenic acid in roots that had been chilled one week. In roots that had been chilled two weeks, however, the chlorogenic acid content was at almost the same level as in unchilled roots stored for a comparable period.

VIII. INTERRELATIONSHIPS

It would be desirable to have some means of applying an analytical measure to describe the observed organoleptic changes in chilled sweetpotatoes. It is realized that the limited range of values for organoleptic determinations has limitations for correlations of organoleptic values to analytical values.

The linear correlation coefficients for appearance ratings of raw cured and non-cured roots and the several physical and chemical measurements determined in this investigation are presented in Table 18. None of these values is of a sufficient magnitude to indicate a cause and effect relationship, although several are significant for the number of observations that were used. In the correlation of ascorbic acid and appearance ratings there is a fairly consistent relationship that existed for the four cultivars studied. In any of the other variables there is little consistency values. The differences from cultivar to cultivar may only serve to indicate that different physical and chemical measurements

TABLE 18. Linear correlation coefficients by cultivar for visual chilling injury observed during storage tests of cured and non-cured sweetpotatoes.

Visual Injury vs.	NC-212	NC-240	L-4-73	Centennial
Specific gravity	+0.210	+0.057	-0.181	-0.170
Intercellular space	-0.466*	-0.353*	-0.137	-0.352*
Dry matter	+0.105	+0.171	-0.374*	-0.048
Tissue pH	-0.433*	-0.502*	-0.518*	-0.384*
Ascorbic	-0.516*	-0.591*	-0.596*	-0.714*
Chlorogenic acid	+0.003	+0.304	+0.179	+0.393*

*Significant at the 5 per cent level.

may be associated with visual chilling symptoms in different cultivars. It may be observed also that accurate prediction of visual symptoms from chemical and physical measurements could not be made from the observation of this investigation.

CHAPTER V

DISCUSSION

Temperatures for treatment of roots were selected to be in the chilling but not the freezing range. Some authors (34, 53, and 54) have claimed chilling injury did not occur between 50°F and 55°F, but others (38) have indicated that between 50°F and 60°F, a critical temperature is reached.

I. ORGANOLEPTIC DETERMINATIONS

It is evident that cultivar differences in chilling injury symptoms were observed both in non-cured and cured roots (Tables 1 and 2, pages 24 and 27, respectively). NC-212 roots were less susceptible to chilling injury than other cultivars. This was as true when the roots had been held for a nine-week period as when they had been held for a seven-day period in other phases of this investigation (Table 7, page 37). In terms of storage parameters, NC-212 appeared to be able to endure low temperature storage periods of two to three weeks non-cured or five to six weeks cured before visible symptoms of chilling appeared. Centennial roots were most susceptible to injury at the chilling temperatures and deteriorated in appearance with increasing length of chilling time both in cured and non-cured roots. At 55°F, which several authors have indicated to be above chilling temperatures (34, 53), the appearance of Centennial roots deteriorated with longer exposures to this temperature (Tables 1 and 2) and with short exposures to this temperature followed by a prolonged holding period at 70°F (Table 7, page 37).

Several factors may have led to the differences observed on the response of the cultivars to the chilling temperatures in this study. The failure of NC-212 and to a lesser extent of NC-240 to develop the discoloration that generally seems to appear as a component of chilling injury (34, 53) indicates that this darkening is not necessarily a component associated with chilling injury in all cultivars. The ability of NC-212 to withstand colder and longer periods of chilling temperature may be due partially to the same factor that inhibits discoloration in this cultivar. Pithiness that eventually developed in this cultivar would indicate that some chilling injury did occur. This was especially evident when the roots held for a prolonged period following chilling temperature treatment. The roots were, however, still more firm than the completely deteriorated roots of Centennial. Another complicating factor in the determination of chilling injury symptoms is the difference in the nature of the internal root tissue of the several cultivars. The flesh of the NC-212 and NC-240 cultivars is smooth, uniform, and homogeneous, while that of Centennial is coarser, fibrous, and often mottled. When pithiness develops in the NC cultivars it is not easily detected until it has proceeded to an advanced stage because no small "pockets" of air space develop. Instead, the tissue takes on the appearance of a fine sponge uniformly throughout the root. In advanced stages of deterioration these cultivars did not shrink to the extent that Centennial did but rather the internal tissue became "honeycombed" in appearance.

In the NC-240 variety there was a tendency for the curing process to limit the chilling injury symptoms, while in the L-4-73 cultivar there was very little influence of the curing process other than to lessen the

overall symptoms produced (Figures 1 and 2, pages 26 and 29, respectively). Investigation of the curing process using these cultivars would be desirable to further the theory that curing may result in less susceptibility to chilling injury (54). Additional investigation into the nature of physiological changes (25) that occur in the curing process may also be desirable using these two cultivars.

This investigation suggests that damage due to chilling occurs at different temperatures for different cultivars. It may be desirable to test the cultivars to discover the level at which chilling injury may appear.

From a practical standpoint, an apparent ability of certain cultivars to withstand more and longer periods of cold exposure without visible indications of damage must be weighed with the other quality factors desired in the sweetpotato or sweetpotato product to evaluate the practicality of utilization of the observations made in this investigation. The conclusions of this investigation would support the observation of Kushman and Deonier (39) that although cultivar differences were noted, all current cultivars are susceptible to chilling injury in some form. However, parameters of storage conditions of certain varieties may be established and used in tolerating a certain amount of chilling in actual storage conditions and these parameters may be different for different cultivars.

The flavor and color determinations for non-cured and cured baked roots as presented in Tables 3, 4, 5, and 6, pages 30 through 34, respectively, generally tend to follow the same trend to the visual chilling injury symptoms observed in the raw roots. In non-cured roots (Tables 3 and 4), flavor and color remained fairly uniform in NC-212

roots regardless of the temperature treatment. Color of non-cured Centennial roots (Table 4, page 31) was uniformly unsatisfactory at all temperatures. In uncooked roots the appearance of Centennial was better at higher temperature than in lower temperature treatments. Perhaps the color of baked roots is indicative of chilling injury before symptoms appear in the uncooked raw roots of this cultivar. This cultivar showed chilling symptoms after long storage at the 55°F temperature treatment. This is in agreement with Lutz (54) who has indicated that the appearance of chilling symptoms can be detected earlier in baked roots than in raw roots for roots held sixteen weeks after temperature treatments. A similar observation was made in the baked roots of cured sweetpotatoes (Tables 5 and 6, pages 33 and 34, respectively). The color of cured Centennial also was uniformly poor at all temperature treatments while flavor was less desirable in the roots from the colder temperature treatments only. As with the uncured roots, the cured roots of NC-212 was uniform in color and flavor regardless of the temperature treatment.

Lauritzen (46) observed a discoloration that was not necessarily associated with chilling injury which appeared in some roots in a storage experiment. It may also be possible that Centennial roots were discolored for some reason other than chilling injury; however, it is felt that the discoloration Lauritizen observed was chilling injury occurring above a temperature that he considered to be a non-chilling temperature.

Cultivar differences in flavor may reflect textural differences among the cultivars studied. This may account for some of the pronounced differences in flavor, particularly in the non-cured roots. NC-240 did not show chilling symptoms in the cured state to the same degree than

did the non-cured roots. In the baked samples, flavor and color of non-cured NC-240 roots were unaffected by temperature treatment. This difference may have been due to the short period of temperature treatment (ten days) used for the baking test and the longer duration in the raw root test. In the baked samples of cured roots, color differences were observed in roots from the colder temperature storage treatments even with little other evidence of chilling injury in the raw roots. This seems to be further evidence that color differences in baked roots are early indications of chilling injury.

The reduction of pH at low temperature treatments may be involved with the hard areas found in certain roots of the L-4-73 and Centennial varieties. A lowered pH in localized areas of the roots may cause enzyme inactivation which results in the observed unsoftened areas although localized pH changes were determined. Lutz (53) noted that roots stored at 30°F produced a firmer baked product than those stored at higher temperatures. The soft areas of the roots in this investigation appeared to be as soft as the roots of higher temperature storage treatments while only localized areas were hard.

Carbon dioxide in these localized areas may have been retained to a greater degree and caused decreased pH in these locations. Further studies are needed to investigate these abnormalities.

II. SPECIFIC GRAVITY

Specific gravity values of various cultivars observed by Kushman (37) indicate that specific gravity may differ at harvest for different locations. In this study, the actual specific gravity values may not

correspond to values observed in his experiment because of the different location involved. Kishman et al. (44) observed decreases in root specific gravity with lengthening of storage. The decreases were greater with greater non-chilling storage temperatures. He judged the decreases in specific gravity to reflect increases in intercellular space since he observed dry matter to change very little in storage. Although the changes observed in specific gravity were not of the magnitude that they observed since the storage time in this study was short, there was only a tendency observed for the specific gravity to be greater in NC-212 and less in Centennial for roots at 35°F compared to the 55°F treatment in each case (Table 8, page 38). Intercellular space was found to decrease in the Centennial roots at 35°F (Table 9, page 40). Thus, it would appear that the Centennial roots did not decrease in specific gravity with increases in intercellular space and little change in dry matter as Kushman et al. (44) observed for most cultivars in non-chilling storage. The specific gravity decreases in Centennial in this case may have been due to losses of dry matter over and above other losses since intercellular space did not increase. If dry matter percentage increased after prolonged storage there were evidently water losses, but the low intercellular space values did not reflect increases in air space in the tissue or little volume change corresponded to this. Loss of weight and loss of water in sweetpotatoes are separate factors and not necessarily related to one another in all circumstances (37).

III. INTERCELLULAR SPACE

Loss of weight in sweetpotatoes stored after curing has been associated with intercellular space, as well as with changes in root volume (44). The initial intercellular space of non-cured sweetpotatoes was not different among cultivars in this experiment which is in contrast to cultivar observations made by Kushman (37). However, the cultivars and seasonal variation may have influenced this result.

Kushman et al. (44) have observed that intercellular space increases with duration of storage and with an increase in storage temperature. Thus a similarity in respiratory activity is noted. When roots were stored at various temperatures for up to six weeks and then held at 70°F for one week, a different set of conditions was imposed than if the roots had been held at a constant temperature for a period of time. Increased intercellular space in roots held at 45°F over those at 35°F in all cultivars may reflect the higher respiration rate of the roots at the 45°F, and 55°F treated roots may be a reflection of chilled versus unchilled conditions. After the cured roots were allowed to remain at 70°F for nine weeks following temperature treatments, increases in intercellular space were observed for nearly all cultivars and treatments except specific gravity in Centennial.

The fairly constant intercellular space in NC-212 (Figure 3, page 42) is shown in greater contrast to that found in Centennial. Roots stored at 55°F showed a slightly greater intercellular space value, indicating that a slight amount of chilling may have been occurring although some increase in intercellular space over time would be expected.

In roots at the 35°F temperature treatment there was a marked increase in intercellular space indicating that chilling injury may have increased respiration and thereby affected intercellular space very quickly. The sudden decrease in intercellular space at this time may have been caused by excessive volume losses at this point, perhaps caused by water losses due to chilling injury although no evidence in this experiment indicated this. Other cultivars and temperature treatments did not show this abrupt increase in intercellular space followed by the sudden decrease.

A similar relationship between temperature treatments and cultivars existed in the cured and non-cured roots (Tables 9 and 10, pages 40 and 43, respectively). The greater intercellular space values for the cured roots is a reflection of the time that the roots had been held in storage before this test was begun.

Little association between the intercellular space and the specific gravity in the non-cured roots was observed.

IV. DRY MATTER CONTENT

Dry matter differences were observed among cultivars in this experiment. Kushman (37) also observed extreme differences in dry matter of roots at harvest.

Dry matter content was similar for both the non-cured and cured roots. This corresponds to an observation by Kishman et al. (44). However, Scott and Matthews (65) reported percentage dry matter decreased in storage from that observed at harvest. In their experiment water losses over dry matter losses could have influenced these observations.

V. TISSUE pH

The decrease in the pH of sweetpotato tissue at lower storage temperatures observed in these experiments (Tables 13 and 14, pages 49 and 52, respectively) are in accord with similar observations by several authors (31, 41, 72). All cultivars were rather similar in pH at the initiation of the experiment and at the 55°F storage treatment. The mean pH values for roots from the lower temperature storage are not indicative of the changes that occurred during the experiments for either the cured and non-cured roots. Figure 4, page 31, shows that the pH of both NC-212 and Centennial at the 55°F storage treatment to be fairly constant throughout the experiment. The decrease in pH followed by increases in pH in the 35°F treatment in Centennial roots corresponded to a similar observation by Kushman and Hoover (41). They also indicated little change in pH with time in roots stored at 60°F. The time that passed before a decrease in the pH of NC-212 roots at 35°F may reflect the longer time period required to injure this cultivar by chilling. In the cured roots (Table 13 and Figure, pages 49 and 51, respectively) reductions of pH at lower storage temperatures were also observed. The decrease in pH in the 35°F Centennial roots was observed to occur after a longer period of treatment than in the non-cured roots. At the conclusion of the experiment the pH of NC-212 roots at 35°F storage temperature had not decreased.

A close similarity can be noted between the appearance of visual symptoms of chilling injury and pH decline in certain instances, while in others, visual symptoms were observed before a decline in pH was

observed. In NC-212 a decline in pH was observed before any sign of visual symptoms was noted. Kushman and Hoover (41) observed pH decreases corresponding to observed chilling symptoms in their experiment; however, in this experiment different cultivars behaved differently. In some varieties pH changes were observed to occur after the presence of visual changes in sweetpotato roots.

Kushman and Hoover (41) also suggested the probability that increased solubility and retention of carbon dioxide may account for the increase in acidity observed in sweetpotato. In these experiments, non-cured Centennial roots of the 35°F treatment were observed to increase in pH about the time that a degree of tissue deterioration occurred that would allow carbon dioxide to be more easily lost. Perhaps the lower pH level reached in NC-212 roots of this same treatment may have been due to the more intact tissue of these roots preventing carbon dioxide losses. Again the possibility of organisms or secondary reactions of the decay process can not be ruled out as being able to cause changes in pH of the root tissue. These experiments give little insight into the cause of the pH changes. Further experimentation is necessary to explain this observation.

VI. ASCORBIC ACID

The values observed for ascorbic acid content of certain cultivars of this experiment at harvest time (Figure 6, page 54) were much higher than observed by Barry (4). His investigation was conducted with the Goldrush cultivar which we observed to be similar in apparent chilling injury susceptibility to Centennial. It is possible that the season and

location differences could have permitted a high ascorbic acid content at harvest for Centennial and L-4-73 at Knoxville. Observations of season and location influences on ascorbic acid have been made by other investigators (67).

In the non-cured roots (Table 14, page 52) ascorbic acid was found to be reduced at the lower temperature treatments. This is in accord with the observations of Lieberman et al. (51) who observed similar reductions of ascorbic acid content in cured roots. The cured roots also contained less ascorbic acid at the lowest temperature treatment in this experiment. The curing process slowed the losses of ascorbic acid in all treatments (Figures 6 and 7, page 34 and 37, respectively). At the 55°F storage treatment in non-cured roots both Centennial and NC-212 decreased in ascorbic acid content over time. In the cured roots these same treatments remained at a constant level during the six weeks of the experiment. Centennial roots at 35°F decreased rapidly in ascorbic acid in the non-cured experiment as time increased. In the cured roots a decrease was noted but the decrease was not delayed. Barry (4) observed an increase in ascorbic acid content of roots stored at colder temperatures similar to this initial increase and he also noted the decline with duration of storage. In the cured roots (Figure 7), NC-212 at 35°F maintained a fairly constant ascorbic acid content until after the third week when the decrease began.

The decrease in ascorbic acid with temperature treatments and duration of temperature treatments was much more immediate and pronounced than any other of the factors previously reported. As was the case for most of the other factors, NC-212 roots were not affected to the degree

that Centennial roots were, either in the cured or non-cured experiment. Of the factors studied, the ascorbic acid changes were most indicative of the observed changes in appearance of the raw roots.

VIII. CHLOROGENIC ACID

Chlorogenic acid content was observed to increase in certain cultivars at low temperature storage treatments. Lieberman et al. (51) have suggested a direct relationship between chlorogenic acid content and ascorbic acid in sweetpotatoes. They observed ascorbic acid decreases and chlorogenic acid increases in chilled sweetpotato roots. They suggest that ascorbic acid functions in the hydroxylation reactions of the phenolase system to prevent chlorogenic acid from being utilized. Decreases in ascorbic acid content were observed in this investigation without increases in chlorogenic acid in the NC-212 variety. In the Centennial cultivar, increases in chlorogenic acid were initially accompanied by decreases in chlorogenic acid. The physiological implications are discussed further in this chapter.

Increases in chlorogenic acid observed (Table 16 and Figure 8, pages 58 and 59, respectively), in the non-cured roots at 45°F storage temperatures for Centennial and L-4-73 varieties again may indicate, not that less chilling injury had occurred at the 35°F treatment over the 45°F treatment but that the warmer 45°F could have allowed more tissue metabolic activity during the storage period for increased development of chlorogenic acid. In this situation there was not an association between chlorogenic acid and ascorbic acid since no accompanying decrease in ascorbic acid was observed to occur at this 45°F storage temperature.

The production of chlorogenic acid by the roots was less as a result of the curing process. Some slight increases were observed in cured Centennial roots at the 45°F treatment over those of the 55°F treatment (Table 17 and Figure 9, pages 61 and 62, respectively). As in several of the other components measured, the curing process decreased the high levels and tended to moderate the buildup of chlorogenic acid in the roots of all cultivars. There was no change in chlorogenic acid of NC-212 roots either in the cured or non-cured roots during the experiment.

IX. INTERRELATIONSHIPS

The interrelationships that were attempted only serve to further indicate that there was no observational, chemical, or physical factor measured in these experiments that could be used as a measure of the observed visual evaluations in the cultivars of sweetpotatoes studied. The decrease in ascorbic acid, although not correlated to visual ratings, was the most suitable for indicating injury to the raw cured and non-cured roots for all cultivars. In NC-212, NC-240, and L-4-73, tissue pH was found to be slightly related to observed chilling injury symptoms for certain temperature treatments, but in Centennial little relationship existed. Slight relationship existed between the appearance of raw roots and the chlorogenic acid content.

X. GENERAL AND PHYSIOLOGICAL IMPLICATIONS

It was generally observed that the curing process lessens the appearance of injury symptoms under chilling conditions. Lutz (54) made

a similar observation for the Puerto Rico variety. The curing process delayed a decrease in pH of tissue for about three weeks (Figures 4 and 5, pages 48 and 51, respectively). Curing also had a delaying effect on ascorbic acid decreases in NC-212 roots. Not necessarily a delaying effect but a moderating effect on ascorbic acid losses in Centennial was observed. Curing also tempered the production of chlorogenic acid by Centennial roots.

There were more immediate, direct changes in ascorbic acid content than in any of the other factors measured and its changes preceded observed chilling injury symptoms. Miller and Heilman (58) suggested a direct relationship between losses of ascorbic acid and chilling in pineapple tissue. Data available at present do not permit any such conclusion for sweetpotatoes, but the suggestion is interesting. Ascorbic acid content was reduced over time by chilling treatments both in cured and non-cured roots. Observed changes in pH and chlorogenic acid would appear to be of a more secondary nature. In NC-212, there were several factors measured which did not change with chilling storage, while ascorbic acid content was reduced in this cultivar in both the cured and non-cured roots. NC-212 roots did become pithy after prolonged holding following temperature treatments, indicating that a degree of chilling injury occurred. This may be an indication that ascorbic acid serves a direct role as predecessor of visual chilling injury. It was observed to change in NC-212 roots long before changes in specific gravity, intercellular space, and dry matter when prolonged holding followed chilling treatment. Few changes in these factors were observed in NC-212 during the six weeks of chilling treatments in either cured or non-cured roots.

The failure of chlorogenic acid to accumulate in all cultivars when ascorbic acid decreased would indicate that the ability of ascorbic acid to reduce the quinones formed from polyphenol oxidation, thus preventing the darkening discoloration from polymerized quinones is not present in all sweetpotato cultivars. A different system may be present for different cultivars. Some such as Centennial were observed to correspond to the observation of Lieberman and Biale (49) but not to the extent, however, that a definite cause and effect relationship existed as they theorized. Chlorogenic acid may serve as an uncoupling agent and increased carbon dioxide evolution may accompany its buildup in tissues (1,4), but this may occur over and above an already uncoupled or injured system. Thus, chlorogenic acid may cause an additional injury to an already injured tissue. It was observed in these experiments that the greatest chilling injury occurred in cultivars that produced chlorogenic acid in the greatest concentrations. However, in cultivars that exhibited no increases in chlorogenic acid increases with chilling storage treatment, there was still evidence of chilling injury that occurred after a period of time had passed. This chilling injury was of a more limited nature, however. Accumulation of chlorogenic acid at 45°F over that at 35°F in certain cultivars, with no reduction in ascorbic acid content observed in these treatments, may serve as further evidence that ascorbic acid may be involved with chilling injury independently of chlorogenic acid. Chlorogenic acid may be produced as a result of such injury. Minamikawa *et al.* (56) observed that low temperatures inhibited the increase of polyphenols in sweetpotato root tissue. Exposure to warmer temperatures may be necessary for chlorogenic acid to increase. Fontenot (18)

also observed no chlorogenic acid accumulation in short exposures to chilling temperatures or after the roots had been recured and stored for a prolonged period of time following cold treatment. This may also indicate that chlorogenic acid may not be readily produced immediately at colder temperatures and can be inactivated by the recuring process. Barry (4), in a study using the Goldrush variety, also noted chlorogenic acid to be lower at 5°C than at 15°C or at 25°C until the second week of storage when a reversal occurred. This again may indicate that, at least in initial stages of chilling, higher temperatures may tend to favor chlorogenic acid accumulation. It is also noteworthy that Barry (4) observed a short peak of chlorogenic acid about one to two weeks after the initiation of storage in roots at 15°C similar to the short peak in this experiment observed at about the same period for cured Centennial roots at the 35°F treatment (Figure 9, page 62).

Changes in pH observed in these experiments are difficult to relate to physiological changes occurring in the tissue. Changes in the pH of the tissue occurred later in time than ascorbic acid changes or chlorogenic acid changes (Figures 4, 5, 6, 7, 8, and 9, pages 48, 51, 54, 57, 59, and 62, respectively). Kushman and Hoover (41) posed the possibility that retention of carbon dioxide may be responsible for the pH reduction that was observed in their experiment in chilled sweetpotato roots. In an unbuffered system, pH reduction of the magnitude observed in these experiments may have been possible with carbon dioxide retention. Microorganism infection may have been the cause of the pH reduction that was observed. Weimer and Harter (70) have indicated that pH reductions by certain Rhizopus species and, to a lesser extent, by Botrytis cinerea,

occur in sweetpotato roots. In one case, a species of Rhizopus seemed to have been responsible for a reversal of the pH reduction over time such as that measured (Figure 6, page 54) in the Centennial roots stored at 35°F in this experiment. It is also possible that these disease organism infections, carbon dioxide from them, carbon dioxide from respiration of the potato tissue, and organic acid accumulation may have combined to produce the results observed in these experiments. Further investigation is necessary to explain the pH changes associated with chilling injury.

Kushman et al. (44) have observed that during storage at non-chilling temperatures for prolonged periods, there were various changes in the physical measurements on sweetpotato roots made in their experiments. In general weight loss exceeded volume loss, and intercellular space increased in proportion to excess weight lost. Except in a few cultivars in their experiment, volume changed very little during storage. The measurements in this investigation were not made on constant temperature storage conditions, however, but rather on roots stored at a lower temperature for weekly periods up to six weeks and followed by a post-treatment holding period of usually one week. Thus, the observations of linear changes in certain of the variables measured may not be applicable to the conditions of these experiments. It was generally observed that NC-212 non-cured roots were not significantly influenced visually by temperature treatment, but there was a trend for specific gravity to be greater at the lowest temperature storage (Table 7, page 37), and intercellular space to be less (Table 9, page 40), and dry matter to be slightly higher (Table 11, page 45). These observations would correspond

to those of Kushman et al. (44) for lower non-chilling temperature storage in most cultivars studied. At least over the short term of this experiment, these changes were similar to the lower temperature (non-chilling) effect observed in their experiment. Centennial roots under the same lowest temperature conditions showed a tendency for reduced specific gravity (Table 7, page 37) and fluctuation in intercellular space (Figure 3, page 42), and a greater dry matter content (Table 11, page 45). These changes would indicate that Centennial may have had a physical change similar to the roots stored at high temperature conditions in the experiment by Kushman et al. (44). This may have been due to excessive water losses and shrinkage during the period. Barry and Patterson (5) have indicated that chilling temperatures reduce water uptake by root tissue discs. Barry (4) has indicated a possible connection between auxin destruction and loss of ability to take up water. He cited several examples of auxin involvement in adenosine triphosphate influencing water uptake and uncoupling agents being able to reduce water uptake. He suggested that accumulation of chlorogenic acid may be involved as an uncoupling agent in affecting membrane permeability. From this, it would seem possible that a loss of water in severely damaged root tissue may have occurred, producing the observed physical measurement changes in Centennial roots stored at 35°F.

Slight changes observed in this experiment for physical measurements would indicate that these changes were not consistently or abruptly altered in cured roots and only slightly modified in non-cured roots by the temperature treatments used. None of the physical determinations were

consistently related to observed chilling injury symptoms of the roots. Further investigation is necessary to establish the relationships between weight and volume losses, as well as other physical changes that occur in chilled sweetpotato roots.

CHAPTER VI

SUMMARY

The purpose of this investigation was to evaluate the effect of chilling temperatures in non-cured and cured, raw and baked roots of some sweetpotato cultivars. Appearance ratings, color and flavor changes were determined by organoleptic tests. Cultivars selected to give a range of chilling injury were NC-212, NC-240, L-4-73, and Centennial. Specific gravity, intercellular space, dry matter content, tissue pH, ascorbic acid content, and chlorogenic acid content determinations were made on these roots. The relationship between subjectively determined chilling injury and these chemical and physical attributes was investigated. Storage temperatures used were 35°F, 45°F, and 55°F for one-week periods up to six weeks. The roots were then allowed to remain at 70°F for one week before evaluation took place. In some cases, a nine-week holding period at 70°F was used before evaluations were made.

Roots of the NC-212 variety were less susceptible to chilling injury measured organoleptically. NC-240, L-4-73, and Centennial followed, in increasing order of their "resistance" to chilling injury. Roots of the NC-212 variety and, to a lesser extent roots of the NC 240 cultivar, failed to develop the characteristic darkening discoloration generally associated with chilling injury. Flavor and color of baked roots were reduced in Centennial after low temperature storage but not in NC-212. After prolonged storage following treatment, pithiness in NC-212 indicated that this variety was not immune to chilling injury but that it was less

susceptible than the other cultivars studied. In general, curing reduced visual symptoms of chilling in the raw roots and improved baked root flavor and color.

Specific gravity and intercellular space changed only slightly with temperature treatments. Cultivar differences were noted in all these factors, except in the intercellular space of non-cured roots. NC-212 maintained fairly constant specific gravity and intercellular space while there was some indication that non-cured roots of Centennial at the chilling temperature treatments may have suffered water losses and shrinkage. Dry matter remained constant in both the cured and non-cured roots over all cultivars and treatments, while intercellular space increased in the cured, stored roots.

Tissue pH was found to decrease and then increase with increasing duration of storage in chilled, non-cured Centennial roots. A longer duration of chilling temperature was required before decreases in the pH of NC-212 were observed. There was some indication that reductions in pH may be related to micro-organism infection in the roots.

Ascorbic acid content was observed to decrease rapidly with duration of storage in non-cured roots. Greater decreases were observed in Centennial than in NC-212, although the initial level in Centennial was greater. Decreases in ascorbic acid content were greater in the colder temperature treatments and changed more rapidly than any of the other factors measured.

Chlorogenic acid increased in Centennial at chilling temperatures in non-cured roots, but no increase was observed in NC-212 at any temperature or duration of temperature treatments. Curing delayed and

reduced the accumulation of chlorogenic acid in chilled Centennial roots and accumulation was marked as compared with other cultivars.

Of all variables measured, ascorbic acid was most closely related to observed chilling injury symptoms in all cultivars. Little consistent relationship was noted between root appearance and any of the other variables measured.

LITERATURE CITED

LITERATURE CITED

1. Akazawa, T., and I. Uritani. 1954. Respiratory oxidation and oxidative phosphorylation by cytoplasmic particles of sweet potato. Journal of Biochem. (Japan) 41:631-638.

2. Almanac of the canning, freezing, and processing industries. 1969. Ed. Judge and Sons Publishers, Westminster, Md.

3. Appleman, C. O., and C. L. Smith. 1963. Effects of previous cold storage on the respiration of vegetables at higher temperatures. Journal of Agr. Research 53:557-580.

4. Barry, J. R. 1961. A study of the post-harvest physiology and chemical composition of the sweet potato. Unpublished Doctoral Dissertation, Texas A&M University, College Station.

5. _____, and D. R. Patterson. 1961. Some effects of a chilling temperature, variety, maleic hydrazide on water absorption by sweet potato tissue. Proc. Amer. Soc. Hort. Sci. 77:479-482.

6. Biale, J. B. 1950. Post-harvest physiology and biochemistry of fruits. Ann. Rev. of Plant Physiology 1:183-206.

7. Cooley, J. S. 1951. Origin of the sweetpotato and primitive storage practices. Sci. Monthly 72:323-331.

8. _____, and L. J. Kishman. 1947. Effects of storage temperature on the sprouting of four varieties of sweet potatoes. Proc. Amer. Soc. Hort. Sci. 50:311-313.

9. _____, _____, and N. F. Smart. 1954. Effect of temperature and duration of storage on quality of stored sweet potatoes. Economic Botany 8:21-28.

10. Deonier, M. T., C. E. Steinbauer, W. D. Kimbrough, and R. E. Wright. 1950. Cooperative studies of the delayed harvesting of sweet potatoes. U. S. Dept. Agr. Circular 841.

11. Doby, G. 1965. Plant Biochemistry. Interscience Publishers, New York, p. 636.

12. Eaks, I. L. 1960. Physiological studies of chilling injury in citrus fruits. Plant Physiology 35:632-636.

13. _____, and L. L. Morris. 1956. Respiration of cucumber fruits associated with physiological injury at chilling temperatures. Plant Physiology 31:308-314.

14. _____, and _____. 1957. Deterioration of cucumbers at chilling and non-chilling temperatures. Proc. Amer. Soc. Hort. Sci. 69:388-399.

15. Ezell, D. D., and M. S. Wilcox. 1952. Influence of storage temperature on carotene, total carotenoid, and ascorbic acid content of sweet potatoes. Plant Physiology 27:81-94.

16. _____, M. S. Wilcox, and J. N. Crowder. 1952. Pre- and post-harvest changes in carotene, total carotenoids, and ascorbic acid content of sweet potatoes. Plant Physiology 27:355-369.

17. _____, _____, and K. D. Demaree. 1956. Physiological and biological effects of storage humidity on sweetpotatoes. J. Agr. Food Chem. 4:640-644.

18. Fontenot, J. F. 1965. Some factors associated with post-harvest physiology of Ipomea batatas. Unpublished Doctoral Dissertation, University of Missouri, Columbia.

19. Freebarin, H. T. 1960. Changes in amounts of organic acids in cirtrus leaves during periods of cold storage. Nature 188:243-244.

20. Harborne, J. B. 1954. Biochemistry of phenolic compounds. Academic Press, New York.

21. Hasselbring, H., and L. A. Hawkins. 1915. Respiration experiments with sweet potatoes. Journal of Agr. Research 5:543-560.

22. _____, and _____. 1914-1915. Physiological changes in sweetpotatoes during storage. Journal of Agr. Research 3:331-341.

23. Heber, Ulrich. 1967. Freezing injury and uncoupling of phosphorylation from electron transport in chloroplasts. Plant Physiology 42:1343-1350.

24. _____, and K. A. Santarius. 1964. Loss of adenosine triphosphate synthesis caused by freezing and its relationship to frost hardiness problems. Plant Physiology 39:712-719.

25. Heinze, P. H., and C. D. Appleman. 1943. A biochemical study of the curing process in sweet potatoes. Plant Physiology 18:548-555.

26. Holm, E. T., and A. P. Adams. 1960. An investigation of the relationship of the chlorogenic acid and phenol oxidase content of a potato variety and its resistance to common scab. Enzymoliga 22:245.

27. Hoover, M. W., and L. J. Kushman. 1966. Influence of raw product storage treatment on the quality of sweet potato flakes. Proc. Amer. Soc. Hort. Sci. 88:501-506.

28. Hughes, J. C., and T. Swain. 1962. After cooking blackening in potatoes I. Introduction and analytical methods. Journal Sci. Food and Agr. 13:244-236.

29. _____, and _____. 1962. After cooking blacking in potatoes III. Examination of the interaction of factors by in vitro experiments. Journal Sci. Food and Agr. 13:358.

30. Hulme, A. C. 1953. The isolation of chlorogenic acid from the apple fruit. Biochem. Journal 53:337-340.

31. Hyde, R. B., and J. W. Morrison. 1964. The effect of storage temperature on reducing sugars, pH, and phosphorylase enzyme in potato tubers. Amer. Potato Journal 41:163-168.

32. James, W. O., and J. M. Cragg. 1943. The ascorbic acid system as an agent in barley respiration. New Physiologist 42:28-44.

33. Johnstone, G. R. 1925. Physiological study of two varieties of Ipomea batatas. Bot. Gazette 80:145-167.

34. Kimbrough, W. D., and M. F. Bell. 1942. Internal breakdown of sweetpotatoes due to exposure to cold. Louisiana Agr. Exp. Sta. Bull. 354.

35. Kreuger, R. C. 1958. The role of reducing agents in the action of tyrosinase. Archives of Biochem. and Biophys. 76:87-96.

36. Kushman, L. J. 1969. A common regression method for estimating dry matter content of carbohydrate containing commodities from specific gravity. Amer. Potato Journal 46:234-238.

37. _____. 1970. Regional variety storage tests. North Carolina State University (unpublished).

38. _____, and M. T. Deonier. 1957. Effects of storage temperatures on Porto Rico, Allgood and Goldrush sweetpotatoes. Proc. Amer. Soc. Hort. Sci. 70:425-431.

39. _____, and _____. 1958. Effects of weather, date of harvest, and curing treatments on keeping qualities of Porto Rico sweetpotatoes. Proc. Amer. Soc. Hort. Sci. 71:369-375.

40. _____, and _____. 1959. Relation of internal gas content and respiration to keeping quality of Porto Rico sweetpotatoes. Proc. Amer. Soc. Hort. Sci. 74:622-641.

41. _____, and M. W. Hopver. 1965. Effects of temperature on acidity of sweetpotato roots and flakes made from them. Proc. Amer. Soc. Sci. 87:391-397.

42. _____, and D. T. Pope. 1968. Procedure for determining intercellular space of roots and specific gravity of sweetpotato root tissue. Hort. Science 3:44-45.

43. _____, _____, and J. A. Warren. 1968. A rapid method of estimating dry matter content of sweetpotatoes. Proc. Amer. Soc. Hort. Sci. 92:814-821.

44. _____, _____, and R. J. Monroe. 1966. Estimation of intercellular space and specific gravity in five varieties of sweet potatoes. North Carolina Agr. Exp. Sta. Tech. Bull. 175.

45. Lambou, M. G. 1956. Sweetpotato dehydration: time and temperature of storage related to organoleptic evaluations. Food Tech. 10:258-264.

46. Lauritzen, J. I. 1931. Some effects of chilling temperature on sweetpotatoes. Journal of Agr. Research 42:617-627.

47. Lewis, D. A. 1956. Protoplasmic streaming in plants sensitive and insensitive to chilling temperatures. Science 124:75-76.

48. _____, and L. L. Morris. 1956. Effects of chilling storage on respiration and deterioration of several varieties of sweetpotatoes. Proc. Amer. Soc. Hort. Sci. 68:421-428.

49. Lieberman, M., and J. B. Biale. 1956. Oxidative phosphorylation by sweetpotato mitochondria and its inhibition by polyphenols. Plant Physiology 31:420-424.

50. _____, C. C. Craft, W. V. Audia, and M. S. Wilcox. 1958. Biochemical studies of chilling injury in sweetpotatoes. Plant Physiology 33:307-311.

51. _____, _____, and M. S. Wilcox. 1959. Effect of chilling on chlorogenic acid and ascorbic acid content of Porto Rico sweetpotatoes. Proc. Amer. Soc. Hort. Sci. 74:642-648.

52. Loeffler, H. J., and J. D. Pointing. 1942. Ascorbic acid rapid determination in fresh, frozen or dehydrated fruits and vegetables. Ind. Eng. Chem. Anal. Ed. 14:846-849.

53. Lutz, J. M. 1944. Curing and storage methods in relation to quality of Puerto Rico sweetpotatoes. U. S. Dept. Agr. Circ. 699.

54. _____. 1945. Chilling injury of cured and non-cured Puerto Rico sweetpotatoes. U. S. Dept. Agr. Circ. 729.

55. Lyons, J. M., T. A. Wheaton, and H. K. Pratt. 1964. Relationship between physical nature of mitochondrial membranes and chilling sensitivity in plants. Plant Physiology 39:262-268.

56. Minamikawa, T., T. Akazawa, and I. Uritani. 1961. Mechanism of cold injury in sweetpotatoes. II. Biochemical mechanism of cold injury with special reference to mitochondrial activities. Plant and Cell Physiology 2:301-309.

57. McClure, T. T. 1959. Rhizopus decay of sweet potatoes as affected by chilling, recuring, and hydrowarming after storage. Phytopath. 49:359-361.

58. Miller, E. V., and A. S. Heilman. 1952. Ascorbic acid and physiological breakdown in fruits of the pineapple (Ananas comosus). Science 116:505-506.

59. Pentzer, W. T., and P. H. Heinze. 1954. Post-harvest physiology of fruits and vegetables. Ann. Rev. Plant Physiology 5:205-224.

60. Plank, R. 1941. The theory of cold storage troubles in fruit. Planta 32:364.

61. Rudkin, G. O., and J. M. Nelson. 1947. Chlorogenic acid and respiration in sweet potatoes. Journal of Amer. Chem. Soc. 69:1470-1475.

62. Salisbury, F. B., and Cleon Ross. 1969. Plant Physiology. Wadsworth Publ Co., Beaumont, California.

63. Schichi, H., and I. Uritani. 1956. Alteration of metabolism in plants at various temperatures. Part I. Mechanism of cold damage of sweet potatoes. Bul. Agr. Chem. Soc. Japan 20:284-288.

64. Scott, L. E. 1962. Specific gravity studies with sweetpotatoes. Southern Agr. Workers' Abstracts 59:182.

65. _____, and W. A. Matthews. 1957. Carbohydrate changes in sweet potatoes during storage. Proc. Amer. Soc. Hort. Sci. 70:407-418.

66. Simmonds, A. O., G. Johnson, and L. A. Schaal. 1954. Comparative effects of catechol, some related compounds and other chemicals on suberization of cut potato tubers. Bot. Gazette 115:190.

67. Speirs, M. 1953. The effect of variety, curing, storage, and time of planting on carotene, ascorbic acid, and moisture content of sweetpotatoes grown in six southern states. Southern Coop. Series Bull. 30.

68. United Fresh Fruit and Vegetable Association. 1967. Fruit and vegetable facts and pointers: Sweetpotatoes. United Fresh Fruit and Vegetable Association, Washington, D. C.

69. Uritani, I., and M. Mizano. 1955. Derivatives of caffeic acid in sweetpotato attacked by black rot. Nature 175:812.

70. Weimer, J. L., and L. L. Harter. 1923. Hydrogen ion changes induced by Rhizopus and by Botrytis cinerea. Journal of Agr. Research 25:155-164.

71. White, Abraham, Phillip Handler, and Emil Smith. 1968. Principles of biochemistry. McGraw-Hill Book Co., New York.

72. Whiteman, T. M. 1957. Freezing points of fruits, vegetables, and florist stock. U. S. Dept. Agr. Mkt. Res. Rept. 196.

73. _____, and R. C. Wright. 1946. The effects of temperature on losses in sweetpotatoes. Proc. Amer. Soc. Hort. Sci. 48:437-442.

74. Wright, R. C., D. H. Rose, and T. M. Whiteman. 1954. The commercial storage of fruit, vegetables, and florist and nursery stocks. U. S. Dept. Agr. Handbook 66.

VITA

The author, Charles William Marr, was born in Springfield, Illinois, on August 18, 1941. He attended elementary school in Sangamon County, Illinois, and was graduated from Springfield High School in 1959. He entered Southern Illinois University in 1959 and received the Bachelor of Science degree in 1963 with a major in Plant Industries. He was employed for two years by the Illinois Department of Agriculture as a Weed and Herbicide Control Adviser. He entered the graduate school of Southern Illinois University in 1965 and received the Master of Science degree in 1968 with a major in Plant Industries. He was employed as a research assistant at Southern Illinois University while completing the degree requirements. In 1967, he entered the graduate school of The University of Tennessee and was granted the Doctor of Philosophy degree with a major in Plant and Soil Science in 1970. He was employed as a research assistant in horticulture by The University of Tennessee Agricultural Experiment Station while completing the degree requirements.

He is married to the former Joyce Ann Tanner of Pickneyville, Illinois.