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Factors Influencing the Nutritive Value of Potatoes

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Bulletins may be obtained by writing to any of the experiment stations listed on the front cover.

Factors Influencing the Nutritive Value of Potatoes

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INTRODUCTION

THE NUTRITIONAL welfare of the American people long has been a subject of engrossing interest, and research designed to improve and conserve the nutritive content of foods generally consumed has been under way for some time under the direction of the United States Department of Agriculture. It has been known that foods may suffer serious losses in nutritive value because of various processes through which they must pass from the time of production to final consumption. The extent of such losses, however, and how they affect the health of the consuming public has been a largely unexplored field.

The menace of war in 1940 focused attention upon the need for protecting and improving the health and well-being of the civilian population and the armed forces of the United States. It was recognized that the nutritional status of man is dependent not only upon the quantity of food available but also upon its nutritive quality. It was apparent that there was an urgent need to ascertain both the nutritive content of individual foods and the best methods of conserving these nutrients.

The beginning of the National Cooperative Project may be traced directly to the National Nutrition Conference for Defense, called by President Roosevelt and held in Washington, D.C., May 26-28, 1941. This conference made plans to intensify research in nutrition. Organizations already in existence in the State Agricultural Experiment Stations were utilized and a committee called "Section I—Research and National Nutrition Problems" was organized. This committee concentrated on clarifying the problems that most urgently needed investigation.

Meanwhile the sub-committee on home economics of the Committee on Experiment Station Organization and Policy suggested the following project: "The conservation of the nutritive values of foods in the process of marketing, storage, and cookery or home preparation." It was adopted in principle and organized on a national and regional basis, thus providing the framework for launching and developing the project.

In February, 1942, a national conference was held in Chicago. From this meeting evolved the reports of two committees, the first of which listed, in order of their importance, the foods requiring investigation, the second of which dealt with methods of analysis, cooking, and statistical treatment of accumulated data.

Research workers at the experiment stations were encouraged to participate in the undertaking. Some continued working with commodities already under investigation, intensifying their efforts; others initiated new projects, selecting commodities important in their own areas which would fit in with the national plan.

Subsequently it was proposed that the experiment stations collaborate in the study of cooking losses at army and navy training camps located on the campuses of various land-grant colleges. Stations which had facilities for participating in this additional phase of the national project entered upon the new cooperative endeavor.

The foregoing constitutes a brief résumé of the organization and development of the National Cooperative Project, Conservation of the Nutritive Values of Foods. The need for protecting and promoting the good health of

the American people continues. The information accumulated through the national cooperative project is of inestimable value. In order that it may be made more readily available to all persons who are concerned with the maintenance and improvement of public health, the findings accumulated on each of the commodities studied are being presented in a series of publications.

The experiment stations that cooperated in this bulletin studied the Irish potato, the United States' most used vegetable.

Numerous studies on factors affecting the dietary value of this commodity have been conducted in this country as well as in foreign lands. Work has centered particularly around the ascorbic acid content of the potato because (1) depending upon the amount consumed, it may make a significant contribution to the intake of this nutrient; and (2) since ascorbic acid is both water soluble and heat labile, any procedure which conserves this vitamin will at the same time conserve other food nutrients. Hence ascorbic acid measurement may serve as an index to the harmful effects of various handling processes on the nutritive value of the potato.

This bulletin is a compilation of the research findings reported by the collaborating stations and the Bureau of Human Nutrition and Home Economics on factors influencing the nutritive value of Irish potatoes, particularly their ascorbic acid content.

PROCEDURE

THE ASSAY, sampling, and cooking procedures followed were essentially those recommended by the several committees for the National Cooperative Project, Conservation of the Nutritive Values of Foods. It was inevitable that previous experiences of the cooperators with various assay methods, together with the limitations imposed by available equipment, storage facilities, personnel, and other factors, should result in some differences in the experiments conducted at the several institutions. Inasmuch as an interpretation of the findings requires a thorough understanding of the conditions of each experiment, mention will be made here of the practices followed generally, and differences in procedure will be pointed out briefly, with more detailed descriptions to precede the presentation of the individual collaborator's findings.

Tubers usually were sampled by cutting radial sectors from the bud to the stem end, and 25-gram samples were used for analysis. The values given here represent in most instances the means of duplicate measurements on two or more replicates.

Reduced ascorbic acid determinations were made by employing one of the following accepted methods: (1) the 2, 6-dichlorophenolindophenol titration method of Tillmans, Hirsch, and Hirsch (1932), as modified by Bessey and King (1933), Bessey (1938), and Harris and Olliver (1942); or (2) the adaptations of this method for use in a photoelectric colorimeter as reported by Morell (1941) and by Loeffler and Ponting (1942). Total and dehydroascorbic acid determinations were made using the procedures of Roe and Kuether (1943) and Roe and Oesterling (1944).

It has been recognized for some time that the indophenol method is not specific for reduced ascorbic acid. Substances which react with indophenol have been shown to result when hydrogen sulfide is used for the reduction of dehydroascorbic acid. Similar substances have been found in foods subjected to relatively high temperatures as in canning or dehydration. Several such compounds have been studied by King (1941), and various methods proposed for estimating reduced ascorbic acid in their presence have been re-

viewed by Stewart and Sharp (1945). More recently it has been shown by Penney and Zilva (1945) and Pijoan and Gerjovich (1946) that the dinitrophenylhydrazine method also is lacking in specificity.

Thiamine was measured by the method of Conner and Straub (1941); riboflavin by the fluorometric procedure of Peterson, Brady, and Shaw (1943); and nicotinic acid by the microbiological assay method of Snell and Wright (1941), using the modification suggested by Isbell (1942). Total ash was determined by ashing dried samples in a muffle furnace at 575° C. for one and one-half hours to constant weight. For calcium the method of Morris, Nelson, and Palmer (1931), for phosphorus, that of Koenig and Johnson (1942), and for iron the dipyridyl method as modified by Andrews and Felt (1941) were employed.

Some variation was evident between harvesting and analysis, in the methods of sampling the potato tubers, in the number and the size of the tubers sampled, in the size of the samples used, in the number of replications, and in the analytical methods employed. Mature and immature potatoes were investigated. The number of potatoes used for each analysis ranged from individual tubers to composites prepared from lots consisting of two to ten tubers. In a few experiments potatoes of the same size were selected; in others, care was taken in making up the composites to include potatoes of different sizes. In some studies pared, and in others, unpared tubers were analyzed. Although moisture content was not always determined, the procedure usually followed was that of air-drying a representative sample at 100° C. or below.

The home cooking methods studied were boiling, steaming, baking, and mashing. The effect of holding both before and after cooking also was investigated. Again the procedures used show certain differences. These include cooking with or without salt, boiling in distilled or tap water, and boiling in different amounts of water. Variations also were noted in the types and composition of cooking utensils, in the criteria used for "doneness," and in the time and conditions of sampling after cooking.

Methods used for quantity cooking of potatoes showed similar variations in sampling procedures, quantities cooked, cooking temperatures, length of holding period both before and after cooking, and in the use of seasoning.

Where feasible, appropriate statistical tests were applied to the data. The techniques used most extensively were the analysis of variance (Snedecor, 1940), Fisher's (1941) method for testing the significance of the mean of a unique sample employing Student's "t" table to evaluate P, and the A. S. T. M. method (1943) for defining the limits of uncertainty. In the interest of brevity, only those statistical constants which demonstrate significant differences are included in the data.

EFFECT OF SAMPLING AND OTHER TECHNIQUES

BEFORE starting these investigations, the Nebraska Agricultural Experiment Station investigated the effect of sampling procedure and other techniques on the reduced ascorbic acid content of potato tubers. These workers made a study of the relative importance of such factors as the method of handling, the size of the tubers, and the effect of cooking. The results indicate that in interpreting the findings from the several stations, differences in sampling procedures must be considered.

Red Warba potatoes, grown at Lincoln with irrigation, were used. On the first sampling date potatoes were dug from individual plants located opposite each other in adjacent rows at six intervals in the row. On each succeeding sampling date the tubers were harvested from plants in adjacent locations. They were washed to remove dirt,

Table 1. Summary of Values for Reduced Ascorbic Acid and Moisture Contents of 174 Individual Immature Red Warba Potato Tubers Grown at Lincoln, Nebraska, and Harvested from Green Vines in July, 1943*

Potato size		Number of tubers	Mean weight of tubers	Moisture		Reduced ascorbic acid (moist weight basis)	
				Range	Mean	Range	Mean
Size No.	Diameter (inches)		Grams	Per cent		Milligrams per 100 grams	
1	under 1¼	14	13.5	79.0–87.6	84.9	7.5–52.1	29.8
2	1¼–1½	18	24.7	79.7–87.2	83.6	9.1–64.8	40.6
3	1½–2	21	52.5	79.0–84.3	81.3	29.2–62.1	44.6
4	2 –2½	101	96.4	79.2–86.7	82.5	24.2–62.2	46.4
5	2½–3¼	20	158.3	78.6–86.2	82.9	27.0–64.0	46.8

* Data from Nebraska Agricultural Experiment Station.

sorted for size, and taken to the laboratory within an hour after harvesting. At the laboratory the potatoes were washed again more carefully, scraped, rinsed with a minimum amount of water, and dried by wadding in a piece of cleansing tissue to remove all visible moisture especially from the eyes. A 25-gram wedge-shaped piece, cut lengthwise from the tuber, was used for ascorbic acid analysis. The method of Loeffler and Ponting (1942) with the modification of Heinz and Kanapaux, as reported by Werner and Leverton (1946), was followed throughout for the determination of reduced ascorbic acid. The 25-gram sample was blended with one per cent metaphosphoric acid in a Waring blendor for two minutes. The remainder was chopped in a mechanical salad cutter, and 50 grams of the chopped product were used for the moisture determination.

The Horticulture Department at the Nebraska Station classified the tubers into sizes, based on the least diameter, as follows: size 1, less than 1¼ inches; size 2, 1¼ to 1½ inches; size 3, 1½ to 2 inches; size 4, 2 to 2½ inches; and size 5, 2½ to 3¼ inches.

Determinations of reduced ascorbic acid and moisture contents were made on 174 immature tubers ranging in size from 1 through 5. The results, summarized in table 1, show that the mean ascorbic acid value increased with tuber size. The greatest difference is found between tubers of sizes 1 and 2. It is possible that tubers of size 1 were appreciably more immature than potatoes of sizes 2 through 5 and that this accounts for the marked difference in reduced ascorbic acid content. The percentage distribution of individual ascorbic acid values for each of the five sizes studied is given in table 2. It is

Table 2. Percentage Distribution of Reduced Ascorbic Acid Values for 174 Individual Immature Red Warba Potato Tubers Grown at Lincoln, Nebraska, and Harvested from Green Vines in July, 1943*

Potato size		Distribution of tubers	Range of reduced ascorbic acid values in milligrams per 100 grams (moist weight basis)							
			0–20	20–30	30–40	40–45	45–50	50–55	55–60	60–65
Size No.	Diameter (inches)	Per cent	Per cent							
1	under 1¼	8.05	1.72	2.30	2.87	0.57	0.00	0.57	0.00	0.00
2	1¼–1½	10.34	0.57	1.72	2.30	0.57	2.30	1.15	1.15	0.57
3	1½–2	12.07	0.00	1.15	3.45	1.15	1.72	1.15	2.87	0.57
4	2 –2½	58.05	0.00	2.87	10.34	11.49	13.22	12.07	5.75	2.30
5	2½–3¼	11.49	0.00	1.15	0.57	2.87	2.87	1.72	1.15	1.15
Total		100.00	2.29	9.19	19.53	16.65	20.11	16.66	10.92	4.59

* Data from Nebraska Agricultural Experiment Station.

evident that despite wide variation in the values secured for tubers of the same size, there is a definite tendency for a greater percentage of large-sized tubers to fall within the higher ranges of ascorbic acid values. These findings are at variance with those of Smith and Paterson (1937), who found that tuber size did not influence the ascorbic acid values obtained.

Variation in the ascorbic acid content of tubers of the same size was investigated in 101 Red Warba tubers of size 4. The statistical constants were:

Mean ascorbic acid, milligrams per 100 grams moist weight	46.36
Standard deviation of single observation	8.163
Standard deviation of mean	10.050
Probable error	0.548
Coefficient of variation	17.61

This study confirms the marked intravarietal differences observed by Lyons and Fellers (1939) and by Tedin (1941).

It is customary in analyzing potatoes for ascorbic acid to prepare a composite sample from a number of tubers. Since this procedure involves taking several small wedges to make a 25-gram sample, it was desirable to ascertain how closely such a sampling procedure could be duplicated. To determine the error inherent in this method of sampling, three or four tubers, constituting the lot to be sampled, were halved lengthwise through the narrowest width. For each assay one composite was taken from one group of halves and a similar composite from the other group. The remaining pulp was chopped fine and

Table 3. Comparison of Reduced Ascorbic Acid Content of Two Series of Composites Prepared from Corresponding Halves of Three to Four Red Warba Potato Tubers Grown at Lincoln, Nebraska, and Harvested from Green Vines in July, 1943 (Moist Weight Basis)*

Reduced ascorbic acid		Difference between high and low values
Low value	High value	
Milligrams per 100 grams		Per cent
47.4	47.6	0.42
43.3	43.3	0.00
49.4	51.4	4.05
46.4	48.2	3.88
45.5	47.6	4.62
49.8	51.0	2.41
53.8	55.4	2.97
52.2	53.8	3.07
41.2	45.9	11.41
51.8	52.2	0.77
49.0	51.8	5.71
50.3	53.8	6.96
45.0	49.4	9.78
51.8	53.4	3.09
49.0	49.8	1.63
50.6	50.6	0.00
53.0	53.0	0.00
49.0	51.0	4.08
47.5	49.0	3.16
45.9	47.6	3.70
53.0	53.8	1.51
Mean 48.8	50.4	3.28
Random mean 49.4†	49.8	0.81

* Data from Nebraska Agricultural Experiment Station.
† Mean of results taken as they occurred without sorting into lower and higher values.

Table 4. Retention of Reduced Ascorbic Acid in Five Varieties of Nebraska-Grown Cooked Potato Tubers*

Variety	Number of lots cooked	Raw value	Retention
		Milligrams per 100 grams	Per cent
Irish Cobbler	24	33.4	89.9
Kasota	21	40.5	90.1
SCIA 27†	20	26.5	91.4
Triumph	24	37.7	86.8
Red Warba	30	36.2	91.1

* Data from Nebraska Agricultural Experiment Station.
† A seedling selected from a cross between Peachblow and Katahdin.

sampled for moisture content. The results of analyzing both halves of 21 lots of potatoes for reduced ascorbic acid are given in table 3. The data for the two groups of halves were sorted into low and high values and the difference between them was computed. When means are taken from the values for the two groups of halves, *as they occurred on analysis,* without sorting into low and high values, no difference is apparent.

These findings were supplemented by the development of a cooking procedure in which the loss of ascorbic acid was comparatively small. Five pounds of size 4 tubers, washed, scraped, rinsed, and dried, as previously described, were selected at random. Three batches of 700 to 800 grams each were analyzed. Each tuber in each batch was halved. One lot of halves was used for ascorbic acid and moisture determinations on the raw tissue; the other lot was cooked. The potato halves to be cooked were placed in a light aluminum pan, containing 50 milliliters of tap water and 3 grams of salt, over a gas flame turned high, and with a cover set slightly ajar. As soon as steam began to escape, usually within two minutes, the pan was covered tightly and the flame turned low. Twenty to 30 minutes were required to cook the potatoes, and at least once during the interval the cover was lifted slightly and the content inspected to be sure that it was not boiling dry. The fork test was used for determining "doneness." The potatoes were drained and the cooking liquid measured in a graduated cylinder and found to seldom exceed 8 or 9 milliliters. The potatoes then were broken up and mixed with three quick, well-placed strokes of a masher, care being taken to avoid beating air into them. About 2 tablespoonfuls of this product were placed in a beaker set in a pan of chopped ice and cooled for 5 to 8 minutes to 30° C. A 25-gram sample was used for analysis. One milliliter of cooking water was placed in a 25-milliliter flask, made up to volume with one per cent metaphosphoric acid, and analyzed for reduced ascorbic acid.

The results obtained on five varieties of potatoes (table 4) indicate that retentions of reduced ascorbic acid were high with the cooking procedure described.

EFFECT OF VARIETY ON ASCORBIC ACID CONTENT

MANY WORKERS have investigated varietal differences in potato tubers (Ijdo, 1937; Wacholder and Nehring, 1938; Lyons and Fellers, 1939; Mathiesen, 1939; Westas, 1941; Tedin, 1931; Esselen, Lyons, and Fellers, 1942; Karikka, Dudgeon, and Hauck, 1944; Julén, 1944-45; and Lampitt, Baker, and Parkinson, 1945). Numerous factors, such as soil, culture, maturity, and storage conditions, have been shown to influence the ascorbic acid content of potatoes. In any study of varietal differences, these factors must be adequately controlled. Evidence to this effect will be presented later in this bulletin.

Maine

In 1942 an extensive investigation was made at the Maine Agricultural Experiment Station to determine the ascorbic acid content of 54 varieties of potatoes of diverse parentage (Murphy, Dove, and Akeley, 1945). Included in their study were 22 leading commercial varieties, 14 promising seedlings (three of which have since been named), two wild varieties from South America, and 16 German varieties. Six of the commercial varieties were grown at Orono, Penobscot County, and the remainder at Presque Isle, Aroostook County,

Table 5. Reduced Ascorbic Acid Content of Commercial, German, and Seedling Varieties of Potato Tubers Grown in Maine, 1942, Harvested on September 15, and Analyzed between October 8 and 23 (Moist Weight Basis)*

Variety	Number of samples	Reduced ascorbic acid	
		Range	Mean and S.D.
		Milligrams per 100 grams	
COMMERCIAL VARIETIES			
Grown at Presque Isle, Aroostook County			
Chippewa†	12	22–25	23 ± .20
Irish Cobbler†	12	21–30	25 ± .48
Earlaine No. 2	6	26–29	27 ± .33
Red Warba†	8	23–31	27 ± .66
Warba†	6	27–30	29 ± .39
Triumph†	6	28–31	30 ± .23
Earlaine†	6	28–32	30 ± .41
Green Mountain	12	26–32	30 ± .45
Pontiac	8	27–35	30 ± .56
Mesaba†	6	29–35	32 ± .52
Houma	8	31–38	34 ± .73
Katahdin	12	32–38	35 ± .37
Sebago	16	29–42	35 ± .61
Mohawk	6	34–37	36 ± .32
White Rose	6	36–38	37 ± .23
Sequoia	6	35–42	38 ± .64
Grown at Orono, Penobscot County			
Golden	4	21–24	22 ± .41
Garnet Chili	4	22–24	23 ± .28
Russet Burbank	4	23–27	24 ± .55
Rural Russet	4	22–27	25 ± .77
Early Ohio	4	27–29	28 ± .24
Rural New York No. 2	8	28–41	33 ± .96

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Variety	Number of samples	Reduced ascorbic acid	
		Range	Mean and S.D.
		Milligrams per 100 grams	
SEEDLING VARIETIES			
Grown at Presque Isle, Aroostook County			
46847	4	19–24	20 ± .70
Wild S. A. "A"	2	21–22	22 ± .24
47452	6	20–24	22 ± .35
Wild S. A. "B"	2	22–24	23 ± .48
46952†	6	23–27	25 ± .42
CS 1608 (Pawnee)	6	26–29	27 ± .28
47456	6	24–29	27 ± .55
47102	10	23–33	27 ± .73
47002†	10	24–33	28 ± .60
47101 (Erie)	6	27–31	29 ± .39
46926†	6	28–31	30 ± .36
47458	10	26–39	32 ± .99
Storr's Seedling	6	32–36	34 ± .38
528–194	6	34–35	35 ± .17
Kittery Seedling	8	33–40	35 ± .52
B 247 (Potomac)	6	38–42	40 ± .35
GERMAN VARIETIES			
Grown at Presque Isle, Aroostook County			
Record	6	21–24	22 ± .35
Matador	6	22–25	24 ± .33
Frühegold	10	21–28	24 ± .45
Prisca	8	21–30	26 ± .61
Rigenheimer	10	24–32	27 ± .59
To be identified	6	26–30	28 ± .41
Popular	6	25–32	28 ± .60
Triumf	6	26–30	29 ± .42
Ultimus	6	25–32	29 ± .69
Erdgold	8	25–32	30 ± .57
Iduna	8	25–35	30 ± .84
Ackersegen	8	24–42	31 ± 1.49
Stackeragis	6	27–36	32 ± .87
Mittelfrühe	8	30–41	36 ± .72
Ostbote	8	34–45	38 ± .93
Voran	6	38–42	40 ± .40

* Data from Maine Agricultural Experiment Station.
† Mature at time of harvest; other varieties harvested green.

Maine. All potatoes were harvested September 15. The following ten varieties were early maturing tubers, and the vines were completely dead at the time of harvest: Triumph, Warba, Red Warba, Mesaba, Irish Cobbler, Earlaine, Chippewa, 47,002, 46,952, and 46,926. The remainder were late maturing varieties, and the vines were green at time of harvest. This difference in the degree of maturity of the vines is a factor to be considered in interpreting the results of analyses for the effect of variety. Analyses were made between October 8 and 23. In the interim they were held in normal storage which usually averaged 50° to 55° F.

Unpeeled radial sectors (bud to stem end) from two tubers constituted a sample. Duplicates were prepared using the opposite sectors. Two additional tubers were treated similarly, the mean of the four determinations being the value assigned to the sample. Dry matter was not determined. The analytical method used was that of Bessey and King (1933), with adaptations suggested by Musulin and King (1936), Bessey

(1938), and Morell (1941), using 5 per cent metaphosphoric acid as the extractant and titrating an aliquot of the filtered extract. The analyses extended over a two-week period, resulting in variable intervals between harvest and analysis. Since the rate of loss in ascorbic acid is relatively rapid at this season of the year, the values obtained of necessity reflect the effect of this variable storage interval. The results of the analyses are given in table 5. Similar ranges of values were secured for the seedling and German varieties as for the commercial varieties. Although highly significant varietal differences are evident, based on the data presented in this table, these differences cannot be dissociated from the effects of maturity and date of analysis and attributed solely to variety.

Minnesota

Some common commercial varieties, as well as a number of seedlings, were investigated at the Minnesota Station. Thirteen varieties, produced at Halstad, Minnesota, in the summer of 1942, were harvested early in October and analyzed on the first three days in December and from January 26 to February 2. In the interim they were stored in a root cellar at a mean temperature of 41° F.

Two lots of six tubers from each of the 13 varieties were used. The tubers were pared and sampled by removing radial sectors from the bud to the stem end. Duplicate samples were taken from each lot and two readings were made on each sample. A 25-gram composite was blended with 100 milliliters of 3 per cent metaphosphoric acid in a Waring blendor for 2 minutes. The material was filtered through No. 12 Whatman corrugated filter paper and the filtrate used for reduced ascorbic acid assay following the procedure of Morell (1941). Readings were made in a Coleman spectrophotometer. Moisture content was determined on all samples.

The results of these analyses show significant varietal differences in reduced ascorbic acid content (table 6). The highest value was obtained for Mesaba, the lowest for Early Ohio potatoes. Although loss of this vitamin undoubtedly had occurred in these po-

Table 6. Effect of Variety on Reduced Ascorbic Acid, Thiamine, and Mineral Contents of Potato Tubers Grown at Halstad, Minnesota, 1942, and Harvested Early in October (Moist Weight Basis)*

Variety	Date of analysis	Moisture	Reduced ascorbic acid	Thiamine	Calcium	Phosphorus	Iron
		Per cent	Milligrams per 100 grams				
Chippewa	12/1/42	79.4	10.7	0.094	4.86	40.9	0.39
Red Warba	12/1/42	78.8	13.4	0.068	5.74	38.2	0.27
Triumph	12/1/42	80.4	11.9	0.082	5.50	38.4	0.30
Irish Cobbler	12/3/42	76.0	12.1	0.080	7.50	43.6	0.28
Katahdin	1/26/43	77.9	15.6	0.129	4.74	50.0	0.35
Mesaba	1/26/43	77.0	17.4	0.123	4.20	48.4	0.27
42—1	1/26/43	78.4	17.3	0.106	4.57	48.3	0.35
Early Ohio	1/28/43	76.3	8.2	0.160	5.49	49.6	0.37
Pawnee	1/28/43	76.5	10.8	0.133	5.06	40.2	0.32
20—20	1/30/43	78.8	14.8	0.116	4.55	53.0	0.35
Houma	1/30/43	76.2	14.4	0.094	5.24	53.0	0.33
Pontiac	2/ 2/43	79.6	12.2	0.111	6.94	37.5	0.28
1.33—1—34	2/ 2/43	78.5	13.8	0.140	6.00	49.3	0.24
D. F.		12	12	12	12	12	12
F as calculated		4.28	11.65	7.25	4.76	2.72	2.28
F for sign.—5 per cent level		2.60	2.60	2.60	2.60	2.60	2.60
1 per cent level		3.96	3.96	3.96	3.96	3.96	3.96
					Milligrams		
L. S. D.†—5 per cent level		2.16	2.97	0.03	1.34	10.73	0.10
1 per cent level		3.01	3.32	0.04	1.87	14.96	0.13

* Data from Minnesota Agricultural Experiment Station.
† L. S. D. denotes least significant difference.

tatoes in proportion to the length of time they were in storage, nevertheless, from the differences observed in potatoes analyzed on comparable dates, there is some evidence that potatoes grown in the same locality and harvested on the same date vary in reduced ascorbic acid content.

Nebraska

In 1943 the Nebraska Station (Werner and Leverton, 1946) studied five varieties of potatoes produced at Alliance and Scottsbluff in western Nebraska. The tubers were planted June 15 in five sandy loam soils. Those at Scottsbluff were irrigated four times during the growing season, resulting in a vigorous vine growth. Harvesting for testing was begun August 30. Analyses were made the third day after harvest. At both locations, the vines of Red Warba and Triumph potatoes were almost mature October 1, while those of the other varieties were less than 15 per cent mature. Potatoes for winter storage were harvested September 27 and kept at 50° F. until January 6 when they were transferred to a room in which the temperature was held at 40° F. These were analyzed first at two-week and later at four-week intervals. The values in table 7 in each instance represent means of duplicate analyses on three samples of four tubers each from each locality. The varietal differences observed at harvest persisted but were less marked at the end of the storage period. Since the least difference required to show significance at the one per cent level was 1.11 milligrams, it is evident that there were highly significant differences in the reduced ascorbic acid content of the varieties investigated. Because of the variation in the degree of maturity of the vines at the time of harvest, the varietal differences noted were undoubtedly affected by the maturity factor.

North Dakota

The North Dakota Station studied varietal differences in the reduced ascorbic acid content of potato tubers for three successive years. Potatoes grown at Park River, North Dakota, were analyzed at the College Station at Fargo. Some varieties were assayed on the fourth day after harvest; others were stored for a period before analyses were made. The method of Bessey and King (1933), as adapted for the Evelyn pho-

Table 7. Effect of Variety and Date of Analysis on Reduced Ascorbic Acid Content of Potato Tubers Grown at Alliance, Nebraska, on Dry Land, and at Scottsbluff, Nebraska, on Irrigated Land, 1943 (Moist Weight Basis)*

Variety	Reduced ascorbic acid										
	Date of analysis										Variety mean
	1943							1944			
	8/30	9/13	9/27	10/14	10/26	11/9	12/3	1/6	1/31	2/29	
	Milligrams per 100 grams										
Kasota	40.4	34.5	30.3	31.6	30.3	27.6	25.2	20.8	18.9	13.5	27.3
Red Warba	39.6	38.0	32.6	30.8	29.3	28.5	22.4	17.2	16.1	13.0	26.8
Triumph	38.6	30.8	34.1	30.2	27.9	22.3	22.2	16.7	12.2	10.7	24.6
SCIA 27	30.6	30.9	33.5	30.4	27.3	24.2	25.0	14.8	14.4	8.8	24.0
Irish Cobbler	30.3	30.8	28.0	28.0	23.8	17.2	19.3	14.4	13.5	10.3	21.6
Analysis date mean	35.9	33.0	31.7	30.2	27.7	24.0	22.8	16.8	15.0	11.3	24.8

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 1% level
					Milligrams
Variety	4	35.0	2.42	3.41	1.11
Analysis date	9	22.6	1.98	2.60	1.57
Variety × analysis date	36	2.9	1.14	1.21	3.50

* Date from Nebraska Agricultural Experiment Station.

toelectric colorimeter by Bessey (1938) and Morell (1941), was used. In 1942, 150 grams of wedge-shaped sections from ten pared potatoes were liquefied in the Waring blendor at high speed (one minute). From this homogenized potato two 25-gram samples were each blended with 100 milliliters of 3 per cent metaphosphoric acid for 2 minutes. The filtered extract was used for ascorbic acid determinations. In 1943 and 1944, determinations were made on unpeeled potatoes which had been washed with a soft brush and dried on a towel. Equal weights of sample and 3 per cent metaphosphoric acid were blended. Fifty grams of this product were then blended with 75 milliliters of 3 per cent metaphosphoric acid. The size of the aliquot utilized was determined by the quantity of ascorbic acid in the sample.

Irish Cobbler, N.D. 1, Triumph, and Red Warba varieties were analyzed for reduced ascorbic acid in 1942, 1943, and 1944. Early Ohio, Katahdin, Pontiac, and Russet Rural varieties were tested for one or two of the same seasons. The results of these determinations, with dates of harvest and assay, are given in table 8. There was considerable variation between the varieties in ascorbic acid and moisture contents during the three years. Based on the four varieties which were grown during all three seasons, a difference of 17.94 milligrams or greater is significant at the one per cent level (dry weight basis). Using this as a criterion, the three-year averages show that the Triumph variety was significantly higher in reduced ascorbic acid content than the other three varieties listed on the next page.

Table 8. Effect of Variety and Crop Year on Reduced Ascorbic Acid Content of Potato Tubers Grown at Park River, North Dakota, 1942-44*

Variety	Date of harvest	Interval between date of harvest and date of assay	Moisture	Reduced ascorbic acid	
				Moist weight	Dry weight
	1942	Days	Per cent	Milligrams per 100 grams	
Irish Cobbler	9/11	4	80.0	21.6	100.5
N.D. 1	9/11	4	77.8	15.1	67.9
Triumph	9/11	4	82.4	23.1	131.5
Red Warba	9/11	4	78.5	23.5	109.7
Early Ohio	9/11	4	81.0	17.6	92.2
	1943				
Irish Cobbler	9/27	31	73.4	27.1	101.9
N.D. 1	9/27	31	73.4	24.4	91.6
Triumph	9/27	32	77.1	26.9	117.5
Red Warba	9/27	32	73.5	24.6	92.9
Katahdin	9/27	28	74.4	25.3	98.7
	1944				
Irish Cobbler	9/30	33	76.7	25.3	108.2
N.D. 1	9/30	33	74.8	25.7	102.1
Triumph	9/30	33	80.3	29.4	149.3
Red Warba	9/30	33	77.8	24.0	107.8
Early Ohio	10/14	20	77.9	19.5	88.2
Katahdin	10/14	19	83.5	19.0	115.2
Pontiac	10/14	20	79.2	20.4	97.9
Russet Rural	10/14	20	78.7	17.3	81.0

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Variety†	3	160.3	3.49	5.95	13.74	17.94
Crop year†	2	45.9	3.88	6.93	17.75	23.72
Variety × crop year†	6	17.8	3.00	4.82	.....	.....

* Data from North Dakota Agricultural Experiment Station.

† Based on four varieties (dry weight).

Three-year Averages Showing Effect of Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown at Park River, North Dakota, from 1942 to 1944, Inclusive

	Moist weight	Dry weight
	Milligrams per 100 grams	
Irish Cobbler	24.7	103.5
N.D. 1	21.7	87.2
Triumph	26.5	132.8
Red Warba	24.0	103.5

Idaho

The Idaho Station studied two varieties of potatoes, Russet Burbank and White Rose, grown at Aberdeen. Analyses were made on both immature and mature tubers of U. S. No. 1 grade, and all analyses were made on individual tubers. Potatoes were sampled by quartering from the bud to the stem end and opposite quarters were used for duplicate samples. In 1942 and 1943 the Loeffler and Ponting method and in 1944 a modification of the Roe and Oesterling procedure were employed. Distinctly higher values were found for the White Rose variety (table 9). This was true of both years studied (1943 and 1944), and the superiority of the White Rose potatoes persisted throughout storage during the years the comparable study was conducted.

The varietal differences in ascorbic acid content noted in the present study are in agreement with the published findings. Losses in ascorbic acid during storage tend to minimize greatly the varietal differences observed although, as will be pointed out later, the superiority of certain varieties persists throughout storage.

Table 9. Effect of Variety, Storage, and Crop Year on Reduced Ascorbic Acid Content of Potato Tubers Grown at Aberdeen, Idaho, 1942-44 (Moist Weight Basis)*

Variety	Crop year	Reduced ascorbic acid							
		Summer tubers analyzed in Aug. and Sept.		Stored tubers analyzed during					
				Fall (Oct.-Dec.)		Winter (Jan.-Mar.)		Spring (After Apr. 1st)	
		No.	Mg. per 100 g.	No.	Mg. per 100 g.	No.	Mg. per 100 g.	No.	Mg. per 100 g.
Russet Burbank	1942	.....	.....	.....	.....	40	10.6	22	12.0
Russet Burbank	1943	5	38.5	30	19.6	24	15.3	.....	.....
Russet Burbank	1944	36	27.4	9	17.4	8	13.0	7	9.3
Mean		41	28.8	39	19.1	72	12.4	29	11.3
White Rose	1943	4	50.9	.....	.....	.....	.....	.....	.....
White Rose	1944	30	40.1	5	32.3	8	20.5	5	14.0
Mean		34	41.4	.....	.....	.....	.....	.....	.....
White Rose†	1943	5	41.0	.....	.....	.....	.....	.....	.....
White Rose†	1944	16	40.7	.....	.....	.....	.....	.....	.....
Mean		21	40.8	.....	.....	.....	.....	.....	.....

* Data from Idaho Agricultural Experiment Station.

† Purchased on commercial market.

EFFECT OF LOCALITY ON ASCORBIC ACID CONTENT

SIGNIFICANT differences in reduced ascorbic acid content attributable to the locality in which the potatoes were grown have been reported by a number of workers. Karikka, Dudgeon, and Hauck (1944) noted significant differences in the ascorbic acid values. On the other hand, Esselen, Lyons, and Fellers (1942), in a study on potatoes grown in Massachusetts and several other states, found little variation attributable to geographic factors; and Branion, Roberts, and Cameron (1947) reported that the ascorbic acid content of individual varieties of potatoes grown in different sections of Canada appeared to be reasonably constant. Thiessen (1936) obtained slightly higher values for potatoes grown on dry land than for those produced on irrigated land. According to Westas (1941) the amount of rainfall is a factor of considerable importance in determining the effect of soil type upon the ascorbic acid content of potatoes. In 1938 potatoes produced on sandy soil were richer in ascorbic acid than those from loamy soil; in 1940, a very dry season, no significant difference was evident. Tedin's data (1941) suggest that potatoes from south Sweden are higher in ascorbic acid than those from more northerly areas. However, the response in a given locality varied with the variety. Some varieties had either a high or a low value at all locations, while others had comparatively high values in some places and low ones in others.

In this study, when considering the effect of locality on the reduced ascorbic acid content of potatoes, "locality" is considered to be the combination of those environmental factors which are characteristic and consistently present and which influence growing conditions in a region, such as mean temperature, amount of rainfall, sunlight, and soil type.

Nebraska

Data bearing on this aspect of the problem have been secured by several cooperators in the present project. The Nebraska Station studied the reduced ascorbic acid content of five varieties of potatoes (Red Warba, Irish Cobbler, SCIA 27, Triumph, and Kasota) pro-

Table 10. Effect of Variety and Locality on Reduced Ascorbic Acid Content of Potato Tubers Grown at Alliance, Nebraska, on Dry Land, and at Scottsbluff, Nebraska, on Irrigated Land, and Sampled on Ten Different Dates, 1943 (Moist Weight Basis)*

Locality	Reduced-ascorbic acid					
	Red Warba	Irish Cobbler	SCIA 27	Triumph	Kasota	Mean
	Milligrams per 100 grams					
Alliance	26.8	22.3	26.3	26.5	30.3	26.4
Scottsbluff	26.7	20.8	21.7	22.6	24.4	23.2
Mean	26.8	21.6	24.0	24.6	27.3	.....

	D. F.	F as calculated	F for Sign.		L. S. D.
			5% level	1% level	1% level
					Milligrams
Variety	4	35.0	2.42	3.41	1.11
Locality	1	83.6	3.89	6.76	0.70
Variety × locality	4	9.3	2.42	3.41	1.57

* Data from Nebraska Agricultural Experiment Station.

Table 11. Effect of Locality and Analysis Date on Reduced Ascorbic Acid Content of Five Varieties of Potato Tubers Grown at Alliance, Nebraska, on Dry Land, and at Scottsbluff, Nebraska, on Irrigated Land, 1943 (Moist Weight Basis)*

Date of analysis	Reduced ascorbic acid		
	Alliance	Scottsbluff	Mean
	Milligrams per 100 grams		
At harvest			
8/30/43	41.6	30.2	35.9
9/13/43	38.1	28.0	33.0
9/27/43	32.7	30.7	31.7
After storage			
10/14/43	29.6	30.8	30.2
10/26/43	28.6	26.8	27.7
11/ 9/43	25.2	22.8	24.0
12/31/43	23.6	22.0	22.8
1/. 6/44	18.2	15.4	16.8
1/31/44	15.8	14.3	15.0
2/29/44	11.1	11.5	11.3
Mean	26.4	23.2	

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 1% level
					Milligrams
Locality	1	83.6	3.89	6.76	0.70
Analysis date	9	22.6	1.98	2.60	1.57
Locality × analysis date	9	14.3	1.98	2.60	2.21

* Data from Nebraska Agricultural Experiment Station.

duced at each of two locations, Alliance and Scottsbluff, in western Nebraska. The soil at both locations was a fine sandy loam. These tubers were harvested on the same day, held under identical conditions, and analyzed on the same dates.

Table 10 gives the means of the ascorbic acid values secured for the five varieties on the 10 different dates shown in table 11. The first three dates give results of analyses made within two to three days after harvest. The remaining dates show the results obtained after intervals of storage. It may be noted that potatoes produced at Alliance contained more ascorbic acid than did those from Scottsbluff although for Red Warba the difference was not significant. This superiority of the Alliance potatoes was apparent throughout the study but was especially noticeable in the early harvested tubers (table 11).

At later dates the difference is relatively small although on only two storage dates is the mean value for Scottsbluff potatoes greater than that for Alliance potatoes. It should be borne in mind, however, that since the Alliance potatoes were grown on dry land and those at Scottsbluff on irrigated land the apparent difference in the ascorbic acid content may be due to the difference in the amount of moisture available. Highly significant differences attributable to the influence of locality on the reduced ascorbic acid content are shown, the difference required for significance at the one per cent level being 0.70 milligram. In only a few instances, however, were the differences significant for comparisons on the same date.

The effect of locality on the reduced ascorbic acid content is evident also from a brief comparison of data on potatoes produced at Lincoln in eastern Nebraska with those for potatoes grown at Scottsbluff in the western part of the state. Potatoes were grown in irrigated fields at both localities. The soil at Lincoln was heavy clay, and the crop was grown as a spring and early summer crop. The vines at each place had attained the same degree of ma-

Table 12. Effect of Locality and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown on Irrigated Land at Lincoln in Eastern and at Scottsbluff in Western Nebraska, and Harvested at Comparable Stages of Physiological Maturity, 1943*

Locality	Number of harvests	Reduced ascorbic acid					
		Red Warba	Irish Cobbler	SCIA 27	Triumph	Kasota	Mean
		Milligrams per 100 grams Moist weight basis					
Lincoln	6†	35.6	36.4	27.6	37.2	41.9	35.7
Scottsbluff	3‡	35.9	27.6	25.4	29.4	29.8	29.6
		Dry weight basis					
Lincoln	6†	216.6	211.2	229.5	258.9	287.0	243.6
Scottsbluff	3‡	178.3	137.4	148.9	168.4	171.9	161.0

* Data from Nebraska Agricultural Experiment Station.
† Harvested weekly.
‡ Harvested bi-weekly.

turity when the first lots were harvested. The means are given in table 12.

On the moist weight basis, the tubers produced at Lincoln, with the exception of Red Warba, contained more ascorbic acid than those from Scottsbluff. For the Kasota variety this difference was marked, whereas for SCIA 27 potatoes it was relatively small. On the dry weight basis the superiority of the Lincoln potatoes was greatly emphasized due to high moisture content. When comparing the data from these two localities, one must recognize that soil, temperature, and duration and intensity of light differed greatly.

Minnesota

The Minnesota Station investigated the reduced ascorbic acid content of four varieties of potatoes (Red Warba, Triumph, Irish Cobbler, and Chippewa) produced in three Minnesota localities. At Halstad the soil is Fargo silty clay loam; at Grand Rapids, Swan silt loam; and at Hollandale, peat soil. The tubers, harvested in September, were received in the laboratory about the middle of October and stored in a root cellar for six weeks, after which reduced ascorbic acid content was determined on six tubers from each of two lots of each variety. Thereafter, analyses were made at six-week intervals for a period of 18 weeks.

The means of the values for the four varieties, given in table 13, are based on values included in table 30. These show that throughout storage, on the moist weight basis, the tubers produced at Halstad were highest in ascorbic acid content while those from Hollandale were lowest. Since the potatoes grown at Halstad were the first to be harvested and those produced at Hollandale the last, it might have been anticipated that the reverse would be true; i.e., the longer interval between time of harvest and date of analysis might have been expected to cause a greater loss in ascorbic acid in the potatoes grown at Halstad. The effect of locality on ascorbic acid content was found to be highly significant. Differences of 0.61 milligrams are significant at the one per cent level.

On the dry weight basis, the potatoes from Halstad are again the highest in ascorbic acid content (appendix table I), while those from Grand Rapids now have a slightly lower mean value than those from Hollandale. Distinct differences in moisture content (table 30) account for the change in the rank order of the localities on the dry weight basis.

Maine

Murphy, Dove, and Akeley found no significant difference attributable to locality in 13 varieties of potato tubers produced at Orono, Penobscot County, Maine, situated at 44°54′2″, and at Presque Isle, Aroostook County, situated at 46°40′30″, during the 1942 season, and harvested and analyzed at

Table 13. Effect of Locality and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown in Three Minnesota Localities and Analyzed at Six-week Intervals for a Period of 18 Weeks, 1942 (Moist Weight Basis)*

Locality	Date of harvest†	Reduced ascorbic acid				
		Red Warba	Triumph	Irish Cobbler	Chippewa	Mean
		Milligrams per 100 grams				
Grand Rapids	9/10	11.2	10.5	11.5	9.2	10.6
Hollandale	9/20	10.2	9.1	9.4	7.9	9.1
Halstad	9/ 5	13.4	11.8	13.4	10.9	12.4
Mean		11.6	10.5	11.4	9.3	

	D. F.	F as calculated	F for Sign.		L. S. D.	
			5% level	1% level	5% level	1% level
					Milligrams	
Locality	2	92.5	3.20	5.10	0.45	0.61
Variety	3	27.9	2.81	4.24	0.52	0.70

* Data from Minnesota Agricultural Experiment Station.

† In all cases vines were prematurely killed by frost. The season of maturity indicates the relative stage of development: Red Warba, extra early; Triumph, medium late; Irish Cobbler, early; and Chippewa, medium late.

practically the same time. They believe that differences in ascorbic acid content associated with localities are the result of variable environmental influences and that locality is significant only as these influences are characteristic and consistent in the locality.

In other words, if in a given locality those environmental influences which markedly increase the ascorbic acid content of potato tubers are regularly present, tubers produced in that locality might be expected to have a significantly higher ascorbic acid content than tubers produced in a less favored location. There is some evidence that potatoes produced in Nebraska, for instance, are superior in ascorbic acid content to the same varieties of tubers grown in Minnesota. However, because the conditions of the experiments were not always identical with respect to length of storage before analysis, maturity of the vines at time of harvest, etc., the evidence of superiority attributable to locality is not conclusive.

EFFECT OF CROP YEAR ON ASCORBIC ACID CONTENT

EVIDENCE has been accumulating to the effect that potato tubers may vary in reduced ascorbic acid content from season to season. According to Westas (1941) and Julén (1944-45), the chief determining factors are amount of rainfall, available sunshine, and the mean temperature during the growing season.

Maine

The Maine Agricultural Experiment Station investigated the effect of crop year on the reduced ascorbic acid content of seven varieties of potatoes grown in Aroostook County in 1938, 1939, and 1942 (table 14). In 1938 analyses were made between November 4 and 18; in 1939 between December 13 and 15; and in 1942 completed in October. Every variety of potato produced in 1942 was found to have a significantly higher reduced ascorbic acid content than potatoes of the same varieties grown in 1938 and 1939, differences of 3.9 milligrams or greater being significant at the one per cent level. However, in view of the differences in the length of the storage periods in the three years

Table 14. Effect of Crop Year and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown in Aroostook County, Maine, 1938, 1939, and 1942 (Moist Weight Basis)*

Variety	1938 Analyzed 11/4 to 11/18		1939 Analyzed 12/13 to 12/15		1942 Analyzed in October		Mean
	Number of samples	Reduced ascorbic acid	Number of samples	Reduced ascorbic acid	Number of samples	Reduced ascorbic acid	
		Mg. per 100 g.		Mg. per 100 g.		Mg. per 100 g.	
Chippewa†	3	11.6	1	15.9	12	23.2	16.9
Earlaine	2	19.4	1	18.7	6	29.5	22.5
Golden	3	9.9	1	12.1	4	22.0	14.7
Green Mountain	3	12.7	2	12.4	12	29.8	18.3
Houma	3	18.2	1	17.3	8	34.1	23.2
Irish Cobbler†	3	12.3	1	13.7	12	25.2	17.0
Sebago	3	14.4	2	19.6	16	35.1	23.0
Mean		14.1		15.7		28.4	

	D.F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Crop year	2	74.9	3.9	6.9	2.8	3.9
Variety	6	6.3	3.0	4.8	4.3	6.0

* Data from Maine Agricultural Experiment Station.
† Mature at time of harvest; other varieties harvested green.

of the study, it cannot be stated with certainty that the potatoes produced in 1942 actually were superior in ascorbic acid content.

Another study on six varieties of potatoes produced in Aroostook County, which were stored and analyzed at monthly intervals during 1943 and 1944, confirms the observation of a significant difference in the reduced ascorbic acid content of tubers produced in different seasons. Potatoes grown in 1944 had distinctly higher values when analyzed in October than did those produced in 1943:

	Reduced ascorbic acid content	
	October 1943	October 1944
	Milligrams per 100 grams	
Mohawk	18.5	30.3
Green Mountain	13.7	24.0
Sebago	18.7	29.8
Irish Cobbler	20.4	30.1
Chippewa	13.0	23.1
Katahdin	19.0	31.4

Based on the means of values obtained throughout the storage period (table 15), it is evident that the 1944 crop maintained the superiority which was noted in October. The slightly earlier date of harvest in 1944 (late September) as compared with the time of harvest in 1943 (early October), coupled with the sustained superiority of the 1944 crop throughout seven months of storage, would indicate that the difference between the two crop years is real and due to more favorable growing conditions during the 1944 season.

Idaho

The workers at the Idaho Station also reported marked differences in reduced ascorbic acid content attributable to crop year. They studied two varieties of potatoes, Russet Burbank and White Rose, produced at Aberdeen in 1943 and 1944. Data given in table 9 show distinctly higher values for 1943.

North Dakota

At the North Dakota Station four varieties of potatoes, Irish Cobbler, N.D. 1, Triumph, and Red Warba, were studied in 1942, 1943, and 1944. In addition the Early Ohio variety was investigated in 1942 and 1944 and the Katahdin in 1943 and 1944. The values for reduced ascorbic acid on both moist and dry weight bases are given in table 16.

Table 15. Effect of Crop Year and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown in Aroostook County, Maine, Stored for Seven Months at Different Temperatures, and Analyzed at Monthly Intervals, 1943-44 (Moist Weight Basis)*

Variety	Reduced ascorbic acid: Harvested early Oct. 1943	Harvested late Sept. 1944	Mean
	Milligrams per 100 grams		
Mohawk	11.0	15.5	13.2
Green Mountain	8.6	12.1	10.4
Sebago	8.9	12.3	10.6
Irish Cobbler†	10.3	13.2	11.7
Chippewa†	7.5	10.7	9.1
Katahdin	9.5	15.0	12.2
Mean	9.3	13.1	

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Crop year	1	1461.3	3.8	6.7	0.20	0.26
Variety	5	144.4	2.2	3.0	0.34	0.45
Crop year × variety	5	16.8	2.2	3.0	0.48	0.63

* Data from Maine Agricultural Experiment Station.

† Mature at time of harvest; other varieties harvested green.

Table 16. Effect of Crop Year and Variety on Reduced Ascorbic Acid and Moisture Contents of Potato Tubers Grown at Park River, North Dakota, 1942-44*

Variety	Moisture content† 1942	1943	1944	Reduced ascorbic acid† Moist weight 1942	1943	1944	Dry weight 1942	1943	1944
	Per cent			Milligrams per 100 grams					
Irish Cobbler	80.0	73.4	76.7	21.6	27.1	25.3	100.5	101.9	108.2
N.D. 1	77.8	73.4	74.8	15.1	24.4	25.7	67.9	91.6	102.1
Triumph	82.4	77.1	80.3	23.1	26.9	29.4	131.5	117.5	149.3
Red Warba	78.5	73.5	77.8	23.5	24.6	24.0	109.7	92.9	107.8
Early Ohio	81.0	.....	77.9	17.6	.....	19.5	92.2	.....	88.2
Katahdin	.....	74.4	83.5	.....	25.3	19.0	.....	98.7	115.2
Pontiac	.....	.....	79.2	.....	.....	20.4	.....	.....	97.9
Russet Rural	.....	.....	78.7	.....	.....	17.3	.....	.....	81.0

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Crop year‡	2	45.9	3.88	6.93	17.75	23.72
Variety‡	3	160.3	3.49	5.95	13.74	17.94
Crop year × variety‡	6	17.5	3.00	4.82		

* Data from North Dakota Agricultural Experiment Station.

† In 1942 potatoes were harvested on September 11 and analyzed four days later; in 1943 potatoes were harvested on September 27 and analyzed about one month later; in 1944 potatoes were harvested on September 30 and analyzed approximately one month later.

‡ Based on four varieties (dry weight).

Maximum variation was observed in the N.D. 1 variety. Growing conditions appeared to be unfavorable for this variety in 1942 since in the 1943 and 1944 seasons values for N.D. 1 potatoes were distinctly higher. These significantly higher ascorbic acid values for N.D. 1 potatoes in 1943 and 1944 over 1942 probably do not represent a true seasonal variation but may merely reflect lack of protection against oxidation during extraction in 1942 since metaphosphoric acid was not used in the first homogenization in any of the samples in that year. The ascorbic acid content of Triumph in 1944 was significantly higher than in 1943. A somewhat higher value was shown for Irish Cobbler potatoes in 1943 than in 1944, but the difference was not significant. Red Warba tubers responded similarly in the three years of study. Apparently conditions which are favorable to certain varieties in one crop year may be less favorable for other varieties.

As mentioned above, only the four varieties, Irish Cobbler, N.D. 1, Triumph, and Red Warba, were grown and analyzed in all three years of the study. Therefore, in order to show the effect of crop year, the discussion which follows is based on data for these four varieties only. Below are listed the means of the values for these four varieties for moisture content and the reduced ascorbic acid content on both moist and dry weight bases.

For 1943 and 1944, on the moist weight basis, the reduced ascorbic acid content of the tubers was distinctly higher than for 1942. Again it is pointed out that the comparatively low content observed in 1942 may be attributable to the fact that in that year metaphosphoric acid was not added before the first blending of the samples. Actually on the dry weight basis the reduced ascorbic acid content of the tubers grown in 1942 was slightly greater than that of the potatoes produced in 1943. In 1943 and 1944 metaphosphoric acid was used in the first homogenization of all samples. Although no difference in reduced ascorbic acid content was observed on the moist weight basis, when calculated on the dry weight basis the tubers grown in 1944 were found to have an appreciably, but not significantly, greater reduced ascorbic acid content than those produced in 1943. It is apparent, therefore, that one effect of crop year upon the reduced ascorbic acid content of the potato tuber is its effect on the moisture content. It must be remembered, however, that the growing conditions in any one crop year would be influenced by such factors as rainfall, sunlight, mean temperature, and the length of the particular growing season.

Year	Sunlight	Mean Temp.	Rainfall	Length of growing season	Moisture content	Reduced ascorbic acid content	
						Moist weight	Dry weight
		Deg. F.	Inches	Days	Per cent	Milligrams per 100 grams	
1942	63 days clear, 23 days partly cloudy, and 17 days cloudy	.....	10.16	103	79.7	20.8	102.4
1943	79 days clear, 32 days partly cloudy, and 16 days cloudy	62.5	12.27	127	74.4	25.8	101.0
1944	67 days clear, 32 days partly cloudy, and 23 days cloudy (eight days in May not included)	61.8	16.55	130	77.4	26.1	116.8

EFFECT OF MATURITY AND STORAGE ON ASCORBIC ACID CONTENT

NUMEROUS investigations have been carried out regarding the effect of maturity and storage on the ascorbic acid content of potato tubers. From a review of the reports appearing in the literature, there would appear to be some differences of opinion as to the effect of maturity. Immature potatoes were found by Woods (1935) to be a more satisfactory antiscorbutic than were mature tubers which had been in storage for eight weeks, whereas Olliver (1938) noted no difference, the mean value for growing tubers agreeing closely with that obtained for fully-grown potatoes. Lyons and Fellers (1939) reported that the ascorbic acid content remained rather constant from the first digging in August until the potatoes were fully matured in October. Zilva and Barker (1938), on the other hand, observed an increase in the ascorbic acid content of tubers between July 20 and September 7, but a considerable decrease between this latter date and October 5, when the crop was harvested. According to Julén (1944-45), Josefsson found that the results vary greatly in different years. In 1941 the highest content was observed on August 7, after which a rapid decrease was noted in all varieties; in 1942 an increase was noted up to August 31, after which a decrease set in. These differences were attributed by Josefsson to very dissimilar weather conditions during those years. Probably the stage of maturity, as influenced by these weather conditions, was responsible for the wide variation noted in ascorbic acid content. It would appear that during growth and ripening of the tubers, temperature and the amount of rainfall and sunlight are other factors which influence the ascorbic acid content at harvest time.

Potatoes are among the crops which are stored regularly over relatively long periods. Data accumulated in 1946 by the United States Department of Agriculture indicate that, on the average, approximately 30 per cent of the total potato crop is carried over into the following calendar year. Potatoes produced in areas where the crop is harvested early in the year may actually be subjected to periods of storage which would be longer than is indicated by the figure cited above. In consequence, information regarding the effects of the length and conditions of storage on the nutritive value of this food is of particular significance.

Studies by Woods (1935); Thiessen (1936); Pett (1936); Mayfield, Richardson, Davis, and Andes (1937); Zilva and Barker (1938); Rolf (1940); Julén (1941); Esselen, Lyons, and Fellers (1942); Karikka, Dudgeon, and Hauck (1944); Julén (1944-45); Lampitt, Baker, and Parkinson (1945); and Branion, Roberts, and Cameron (1947) are in general agreement that decreases in reduced ascorbic acid content are very rapid during the first weeks after harvest and are much more gradual thereafter. In the spring the values are usually one third as great as those obtained in the fall, or less.

Temperature of storage has been shown to be important from the standpoint of its effect on the ascorbic acid content and on cooking quality. Mayfield, Richardson, Davis, and Andes noted better retentions of reduced ascorbic acid in potatoes stored in a warm dry cellar than in tubers kept in a cool damp room. A varietal difference in response to the two storage temperatures also was observed. Although Pett reported a slightly greater loss as a result of storage at 15° C. than at 10° C. and 5° C., Rolf, Julén, and Karikka, Dudgeon, and Hauck obtained better retentions at higher storage temperatures. Sprouting of potatoes was found by Pett to be associated with a rapid rise in ascorbic acid content, followed by a decrease. The increase occurred even after storing potatoes for some

months at 5° C. Smith and Gillies (1940), on the other hand, reported that more ascorbic acid disappeared from the tubers during sprouting than could be accounted for in the sprouts. Dehydroascorbic acid was found by these authors to be low in newly harvested potatoes but to increase fairly rapidly during storage, amounting to one third of the total ascorbic acid after six months. Julén (1944-45) noted a statistically significant decrease in the ascorbic acid content of potatoes during the first part of the sprouting period but no further loss after the sprouts had grown to visible size. An increase in ascorbic acid was noted uniformly in all lots of stored tubers in May by Julén and also by Westas in June. Julén pointed out that since sprouting begins much earlier in the year, this increase cannot be identical with that observed by Pett, and suggested that a more plausible explanation is that the increase is due to evaporation of water. According to Edgar, Jefferson, and Wheeler (1942), storage temperatures of 50° F. or higher result in high quality of table stock. However, storage at these temperatures for more than 12 to 14 weeks results in excessive shrinkage and early sprouting. Storing potatoes for long periods at temperatures below 40° F. retards sprouting but increases the sugar content and makes the potatoes soggy. In consequence, a temperature of approximately 40° F. is the most desirable compromise for long storage periods because at this temperature shrinkage is small, cooking quality is fair, and sprouting is retarded.

Nebraska

At the Nebraska Station the effects of maturity and storage were investigated in the summer of 1943 on five varieties of potatoes, Triumph, Red Warba, Irish Cobbler, Kasota, and SCIA 27, produced in three localities, Lincoln, Alliance, and Scottsbluff. Potatoes produced at Lincoln were harvested in the early forenoon at weekly

Table 17. Effect of Maturity and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown at Lincoln, in Eastern Nebraska, on Irrigated Land, 1943 (Moist Weight Basis)*

Date of harvest	Reduced ascorbic acid						Least significant difference	F value for varieties
	Red Warba	Irish Cobbler	SCIA 27	Triumph	Kasota	Mean		
	Milligrams per 100 grams						Milligrams	
6/22	32.9	24.0	.....	32.8	.....	.....	.....	.....
6/29	38.3	36.8	26.2	38.0	41.7	36.2	4.77	13.89
7/6	33.8	29.3	26.4	32.3	37.0	31.8	2.66	18.96
7/13	38.7	42.8	30.9	42.9	44.4	40.0	2.43	39.16
7/20	41.0	39.8	30.0	38.6	42.6	38.4	3.62	14.61
7/27	31.0	37.5	29.5	37.2	46.0	36.2	3.74	24.66
8/3	31.0	32.2	22.6	34.4	39.6	31.9	5.35	10.68
8/10	30.7	23.8	22.3	29.4	34.5	28.1	4.08	12.06
8/17	23.6	24.7	20.2	29.6	32.0	26.0	3.90	11.78
8/23	22.1	23.1	14.8	22.2	25.1	21.5	2.41	21.00
9/23	16.1	15.0	13.3	17.9	20.1	16.5	2.76	7.17
10/19	11.6	10.2	9.8	13.3	13.8	11.7	2.10	5.95
Mean 6/29/43 through 10/19/43	28.9	28.6	22.4	30.5	34.3			

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 1% level
					Milligrams
Harvest date	10	269.0	1.95	2.50	1.59
Variety	4	129.0	2.45	3.50	1.07
Harvest date × variety	40	3.6	1.26	1.39	3.55

* Data from Nebraska Agricultural Experiment Station.

intervals from June 29 to August 23 and thereafter at monthly intervals. Potatoes 2 inches to 2½ inches in diameter were analyzed immediately for the effect of maturity. The vines of all varieties except Kasota attained maximum size about July 6. The Kasota vines were at their maximum on July 20. The vines of all varieties except Kasota were practically mature by August 15 to 20. Kasota tubers were mature a week later. Potatoes for the storage study were dug on August 10 and held in baskets in cellar storage at about 70° F. In November, when the tubers had started to sprout, they were held in the 50° F. room, and on December 14 they were moved to the 40° F. room. On November 3 another lot of tubers was harvested to determine the comparative merit of leaving the potatoes in the field in contrast with early harvesting and cellar storage. Some of these potatoes were analyzed at intervals during the winter. At Alliance and Scottsbluff harvesting of potatoes was begun on August 30 and those for winter storage were dug on September 27. At both locations the vines of Red Warba and Triumph potatoes were almost mature on October 1, at which time the other varieties were less than 15 per cent mature. The potatoes to be analyzed for the effects of storage were held at 50° F. until January 6 when they were transferred to storage at 40° F.

The results of the analyses on the Lincoln potatoes (table 17) show that the highest reduced ascorbic acid values were obtained when the plants had attained their maximum vigor and before the older leaves had begun to die off. Tubers harvested thereafter showed lower values, the means for successive dates being in most instances significantly different at the one per cent level. By August 3 the mean value for the five varieties had dropped to four fifths, by August 17 to two thirds, and by October 19 to less than one third of the maximum reported.

Significant differences attributable to variety, harvest date, and the interaction between variety and harvest date were demonstrated. Differences exceeding 1.07 milligrams for variety, 1.59 milligrams for harvest date, and 3.55 milligrams for the interaction can be expected to occur less than once in 100 trials through random sampling alone.

Tubers which had been harvested on August 10 and held in storage thereafter also showed significant losses in reduced ascorbic acid (table 18). A comparison of the values for tubers harvested on August 10 and on November 3 shows that the decreases were more rapid in the tubers which had been left in the field. Tubers harvested August 10 lost more than one half of their ascorbic acid content by November 16. By March 7 they had lost better than three fourths and by May 2 almost four fifths of their original reduced ascorbic acid content. Potatoes harvested on November 3 contained somewhat less ascorbic acid on November 16 than those harvested and stored in August. The mean values on subsequent corresponding dates, however, were slightly higher for the tubers harvested in November.

At the time of harvest reduced ascorbic acid values for potatoes produced at Alliance, Nebraska (table 19) were higher than those for the tubers from Lincoln (table 18). The values for Scottsbluff potatoes (table 20) also were higher than those for the Lincoln potatoes but lower than those for the Alliance potatoes. For the five varieties the mean loss in ascorbic acid during the first two months of storage on a percentage basis was essentially the same for the tubers from the three locations and constituted about three tenths of the content at time of harvest. After five months' storage further losses had occurred so that the amount retained represented about one third of the original content.

North Dakota

At the North Dakota Station Irish Cobbler potatoes were tested for reduced ascorbic acid content after varying periods of storage in the station root cellar during three successive years. Triumph was tested under identical treatment during two years. De-

Table 18. Effect of Storage and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown at Lincoln, in Eastern Nebraska, on Irrigated Land, 1943 (Moist Weight Basis)*

Date of harvest	Date of analysis	Reduced ascorbic acid						Least significant difference	F value for varieties
		Red Warba	Irish Cobbler	SCIA 27	Triumph	Kasota	Mean		
		Milligrams per 100 grams						Milligrams	
8/10/43	8/17/43	22.2	26.7	18.8	29.0	27.3	24.8	7.07	2.84
8/10	8/23	25.0	21.6	14.6	24.9	26.5	22.5	2.88	38.64
8/10	9/22	17.5	18.1	13.7	20.7	21.1	18.2	2.66	10.30
8/10	10/20	15.5	16.2	12.8	22.9	20.0	17.5	4.86	5.56
8/10	11/16	11.2	10.6	7.7	12.8	15.5	11.6	3.63	5.03
8/10	12/14	11.1	11.5	6.4	11.0	14.3	11.0	2.09	14.67
8/10	1/15/44	8.3	8.9	5.1	7.8	11.0	8.2	0.98	38.12
8/10	2/10	9.2	10.1	7.1	9.6	11.1	9.4	0.43	12.09
8/10	3/7	4.8	5.6	4.8	7.8	6.1	5.8	2.10	2.82
8/10	4/4	5.4	7.2	2.9	6.4	3.2	5.0	0.69	61.14
8/10	5/2	5.7	5.7	3.6	5.1	3.6	4.7	0.67	20.78
8/10	6/23	6.4	7.4	4.1	6.0	7.2	6.2	0.47	60.38
Mean		11.8	12.5	8.5	13.7	13.9			
11/3	11/16/43	11.0	9.1	8.7	11.2	12.9	10.6	1.94	6.39
11/3	1/13/44	8.6	9.5	6.7	8.9	10.6	8.8	1.24	10.92
11/3	3/8	6.5	7.4	6.7	6.1	7.5	6.8	1.39	1.47
11/3	5/23	6.0	6.1	.....	5.2	6.0	.....	.....	.....
Mean through	11/16/43 3/ 8/44	8.7	8.7	7.4	8.7	10.3			

	D. F.	F as calculated	F. for Sign. 5% level	F. for Sign. 1% level	L. S. D. 1% level
					Milligrams
Analysis date	14	207.0	1.80	2.29	1.26
Variety	4	56.8	2.43	3.45	0.73
Analysis date × variety	56	33.3	1.25	1.40	2.81

* Data from Nebraska Agricultural Experiment Station.

terminations were made on peeled Irish Cobbler potatoes in 1942 and on peeled and unpeeled Irish Cobblers and on the peelings of the same tubers in 1943 and 1944. Ten potatoes constituted one lot. Wedge-shaped sections for the unpeeled sample were taken from one side of the potato and for the peeled sample from the same relative position on the opposite side. The data are presented in tables 21, 22, and 23.

It may be observed that decreases in ascorbic acid content were very rapid during the first one and one half months of storage in 1942 (table 21). These low values may be attributable, in part, to the fact that metaphosphoric acid was not used in the first homogenization of the sample. (The Idaho Agricultural Experiment Station has shown that this procedure results in a rapid conversion of reduced ascorbic acid to the dehydro form.) Decreases in reduced ascorbic acid, calculated on both the moist and dry weight bases, were somewhat more rapid during the early stages of storage in 1943 and 1944 in both the unpeeled and peeled Irish Cobbler potatoes than during the latter part of the storage period (tables 22, II and figure 1).

The tubers grown in 1944 contained somewhat greater amounts of reduced ascorbic acid than those produced in 1943. Therefore, the former were a considerably better source of this nutrient throughout the greater part of storage. After 200 days in storage, the percentage of retention was quite similar for the two years of observation, constituting about one third of the amount observed after the first month of storage. In both years the peeled tubers had slightly higher values than the unpeeled since the peelings are very much lower in reduced ascorbic acid content than the potato tissue.

Table 19. Effect of Storage and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown at Alliance, in Western Nebraska, on Dry Land, 1943 (Moist Weight Basis)*

Date of harvest	Date of analysis	Reduced ascorbic acid						Least significant difference	F value for varieties
		Red Warba	Irish Cobbler	SCIA 27	Triumph	Kasota	Mean		
		Milligrams per 100 grams						Milligrams	
8/30/43	.....	42.0	34.0	37.9	44.1	49.9	41.6	2.57	40.88
9/13	.....	39.5	33.5	38.3	38.7	40.4	38.1	5.38	2.03
9/27	.....	31.3	27.7	37.5	36.1	30.9	32.7	2.55	20.03
9/27	10/14/43	30.8	23.8	28.0	30.6	34.9	29.6	5.99	6.41
9/27	10/26	30.6	24.3	26.7	28.3	33.3	28.6	4.52	4.80
9/27	11/9	27.8	18.9	26.5	23.3	29.4	25.2	4.72	6.11
9/27	12/3	21.5	19.6	26.4	23.2	27.5	23.6	2.38	15.82
9/27	1/6 /44	16.0	15.7	17.4	17.5	24.4	18.2	1.94	27.84
9/27	1/31	15.9	15.3	14.8	13.4	19.4	15.8	2.46	6.68
9/27	2/29	13.0	10.0	9.8	10.0	12.5	11.1	.....	.....
9/27	3/28	10.1	8.4	.....	8.8	12.1	.....	.....	.....
9/27	4/25	9.3	9.1	.....	7.5	11.6	.....	.....	.....
9/27	5/23	8.6	9.7	.....	7.6	10.0	.....	.....	.....
Mean 8/30/43 through 2/29/44		26.8	22.3	26.3	26.5	30.3			

	D. F.	F as calculated	F. for Sign. 5% level	F. for Sign. 1% level	L. S. D. 1% level
					Milligrams
Analysis date	9	281.1	2.03	2.69	1.63
Variety	4	48.1	2.46	3.51	1.16
Analysis date × variety	36	3.8	1.26	1.39	3.66

* Data from Nebraska Agricultural Experiment Station.

Table 20. Effect of Storage and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown at Scottsbluff, in Western Nebraska, on Irrigated Land, 1943 (Moist Weight Basis)*

Date of harvest	Date of analysis	Reduced ascorbic acid						Least significant difference	F value for varieties
		Red Warba	Irish Cobbler	SCIA 27	Triumph	Kasota	Mean		
		Milligrams per 100 grams						Milligrams	
8/30/43	.....	37.2	26.5	23.2	33.2	30.8	30.2	5.82	7.12
9/13	.....	36.6	28.1	23.5	22.8	28.6	28.0	10.60	2.15
9/27	.....	34.0	28.2	29.5	32.1	29.8	30.7	5.80	1.23
9/27	10/14/43	30.9	32.2	32.8	29.8	28.4	30.8	5.22	2.30
9/27	10/26	28.0	23.2	27.9	27.5	27.7	26.8	6.80	5.44
9/27	11/9	29.3	15.6	22.0	21.3	25.8	22.8	5.84	6.23
9/27	12/3	23.4	18.9	23.8	21.2	22.8	22.0	2.47	5.13
9/27	1/6 /44	18.4	13.1	12.2	16.0	17.2	15.4	2.59	8.40
9/27	1/31	16.3	11.7	14.1	11.0	18.4	14.3	2.47	12.89
9/27	2/29	13.1	10.7	7.7	11.5	14.4	11.5	1.62	20.33
9/27	3/28	10.0	8.4	.....	7.4	11.7	.....	.....	.....
9/27	4/25	9.6	10.6	.....	6.3	10.2	.....	.....	.....
9/27	5/23	7.9	7.9	.....	5.9	7.6	.....	.....	.....
9/27	6/24	.....	.....	.....	5.7	6.1	.....	.....	.....
Mean 8/30/43 through 2/29/44		26.7	20.8	21.7	22.6	24.4			

	D. F.	F as calculated	F. for Sign. 5% level	F. for Sign. 1% level	L. S. D. 1% level
					Milligrams
Analysis date	9	6.1	2.07	2.78	2.66
Variety	4	12.6	2.56	3.72	1.88
Analysis date × variety	36	1.8	1.65	2.00	5.94

* Data from Nebraska Agricultural Experiment Station.

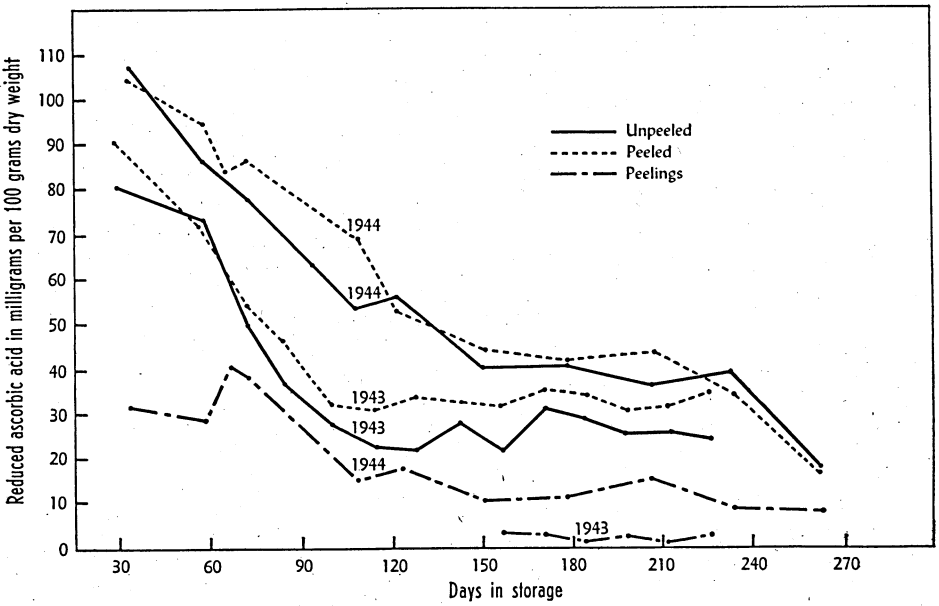

Fig. 1. Reduced ascorbic acid content during storage of peeled and unpeeled Irish Cobbler potato tubers grown at Park River, North Dakota, 1943 and 1944, and of peelings from the same tubers, as reported by the North Dakota Agricultural Experiment Station

Unpeeled Triumph potatoes apparently showed a similar rate of loss in reduced ascorbic acid during storage in the two years of study (table 23). Retention after 200 days in storage amounted to slightly less than one fourth of that reported after one month in storage. Since the Triumph potatoes produced in 1944 also contained more ascorbic acid than those grown in 1943, they were a somewhat better source of this nutrient throughout storage. Comparison of the rate of loss during storage in both 1943 and 1944 for unpeeled Triumph and unpeeled Irish Cobbler potatoes shows that the former decreased in reduced ascorbic acid content more rapidly than the latter. In consequence, although the Triumph potatoes originally contained more of this vita-

Table 21. Effect of Storage on Reduced Ascorbic Acid Content of Peeled Irish Cobbler Potato Tubers Grown at Park River, North Dakota, 1942*

Date of harvest	Days in storage	Moisture	Reduced ascorbic acid†			
			Moist weight		Dry weight	
			Amount	Apparent retention‡	Amount	Apparent retention‡
		Per cent	Mg. per 100 g.	Per cent	Mg. per 100 g.	Per cent
9/11/42	.....	79.3	20.0	.....	96.8	.....
9/11	29	78.8	13.4	.....	63.3	.....
9/11	45	79.4	11.6	86.5	56.5	89.2
9/11	104	77.4	3.1	23.2	13.8	21.8
9/11	195	78.9	1.2	8.9	5.7	9.0

* Data from North Dakota Agricultural Experiment Station.

† Metaphosphoric acid not used with the first homogenization of sample.

‡ Based on 29 days of storage.

Table 22. Effect of Storage and Crop Year on Reduced Ascorbic Acid Content of Unpeeled and Peeled Irish Cobbler Potato Tubers Grown at Park River, North Dakota, and on Peelings from the Same Tubers, 1943-44 (Moist Weight Basis)*

Date of harvest	Days in storage	Unpeeled tubers			Peeled tubers			Peelings	
		Moisture	Reduced ascorbic acid		Moisture	Reduced ascorbic acid		Moisture	Reduced ascorbic acid
			Amount	Apparent retention†		Amount	Apparent retention†		Amount
1943		Per cent	Milligrams per 100 g.	Per cent	Per cent	Milligrams per 100 g.	Per cent	Per cent	Milligrams per 100 g.
9/27	29	75.0	20.5	.....	75.1	22.8	.....	.....	.....
9/27	57	76.6	17.3	84.4	75.1	18.3	80.1	.....	.....
9/27	72	75.3	12.5	60.8	75.4	13.5	59.1	.....	.....
9/27	84	73.8	9.8	47.8	73.0	12.7	55.6	.....	.....
9/27	100	74.8	7.1	34.6	73.6	8.7	38.0	.....	.....
9/27	114	74.3	6.1	29.6	73.8	8.2	35.7	.....	.....
9/27	128	73.9	5.8	28.2	73.9	8.7	38.0	.....	.....
9/27	142	74.0	7.3	35.8	73.2	8.8	38.6	.....	.....
9/27	156	74.2	5.8	28.2	75.0	8.1	35.3	77.3	0.82
9/27	170	74.5	8.1	39.4	74.1	9.1	39.8	75.0	0.57
9/27	183	74.6	7.5	36.5	73.3	9.2	40.3	76.6	0.41
9/27	196	75.2	6.6	32.3	74.4	8.0	35.1	76.6	0.51
9/27	211	73.9	6.8	33.1	73.1	8.6	37.5	74.7	0.29
9/27	225	74.2	6.5	31.6	73.9	9.2	40.1	76.7	0.64
1944									
9/30	2	76.9	29.6	.....	.....	.....	.....	.....	.....
9/30	33	76.7	25.3	.....	76.0	25.3	.....	80.4	6.3
9/30	58	75.5	21.4	84.6	76.0	22.9	90.3	79.4	6.0
9/30	65	77.4	18.7	74.0	76.8	19.6	77.3	77.7	9.0
9/30	72	78.2	17.2	68.0	77.1	19.9	78.6	77.3	8.7
9/30	107	76.1	12.8	50.8	77.1	16.1	63.6	78.5	3.5
9/30	121	76.8	13.0	51.5	75.7	13.1	51.6	79.5	3.6
9/30	149	76.6	9.5	37.6	75.8	10.7	42.4	79.5	2.1
9/30	177	77.4	9.1	36.2	76.4	9.7	38.2	79.3	2.2
9/30	205	77.2	8.3	32.8	77.3	9.7	38.2	81.0	3.2
9/30	233	77.6	8.9	35.1	76.5	10.3	40.6	81.0	1.7
9/30	261	78.4	4.0	15.8	77.8	3.8	15.0	80.3	1.6

* Data from North Dakota Agricultural Experiment Station.

† Based on 29 days of storage in 1943 and on 33 days of storage in 1944.

min than the Irish Cobbler potatoes, during the latter part of the storage period the values were quite similar for the two varieties (figure 2).

Idaho

In studying the effect of maturity and storage on the reduced ascorbic acid content of potatoes, the Idaho Station used two varieties, Russet Burbank and White Rose. The latter variety is customarily marketed in the immature state. Accordingly immature tubers of the White Rose variety purchased on the Moscow market, together with immature White Rose and Russet Burbank potatoes grown at Aberdeen, were studied in 1943 and 1944. The data included in table 9 represent the means of values for immature tubers analyzed in August and September. Immature potatoes of both varieties contained relatively large amounts of reduced ascorbic acid, the values for the White Rose variety being distinctly higher than those for the Russet Burbank tubers.

The effect of storage was determined on the same two varieties produced at Aberdeen under similar conditions during three growing seasons (1942, 1943, and 1944). These potatoes were harvested the latter part of October or the first part of November each year and held until spring in a commercial type of storage house. Temperatures ranged from approximately 45° F. during November and December to 40° F. during January and February, with slightly higher temperatures during the late spring months.

A comparison of the values obtained in the fall for the stored tubers with those secured earlier on the immature potatoes shows a marked reduction in the reduced ascorbic acid content of both varieties during early storage, with further decreases throughout the winter and spring. The superiority of the White Rose variety persisted throughout storage.

Maine

The effect of storage temperature on the reduced ascorbic acid content of six varieties of potatoes produced in Aroostook County, Maine, was investi-

Table 23. Effect of Storage and Crop Year on Reduced Ascorbic Acid Content of Unpeeled Triumph Potato Tubers Grown at Park River, North Dakota, 1943-44*

Date of harvest	Days in storage	Moisture	Reduced ascorbic acid			
			Moist weight		Dry weight	
			Amount	Apparent retention†	Amount	Apparent retention†
1943		Per cent	Milligrams per 100 g.	Per cent	Milligrams per 100 g.	Per cent
9/27	29	79.2	24.1	.....	115.8	.....
9/27	57	78.8	18.4	76.5	87.0	75.1
9/27	72	79.4	16.7	69.4	81.3	70.2
9/27	84	77.2	16.5	68.4	72.2	62.4
9/27	100	78.4	14.9	61.8	68.9	59.5
9/27	114	78.4	11.2	46.4	51.8	44.7
9/27	128	78.4	9.6	40.0	44.6	38.5
9/27	142	79.0	6.0	24.7	28.3	24.4
9/27	156	79.3	7.0	28.8	33.5	28.9
9/27	170	78.7	7.0	29.0	32.8	28.4
9/27	183	78.5	7.1	29.4	33.1	28.6
9/27	196	78.9	5.1	21.3	24.3	21.0
9/27	211	79.2	5.8	23.9	27.6	23.9
1944						
9/30	2	79.9	37.8	.....	188.2	.....
9/30	33	80.3	29.4	.....	149.3	.....
9/30	58	80.4	22.8	77.5	115.9	77.6
9/30	65	80.5	20.4	69.4	104.7	70.1
9/30	72	79.9	19.9	67.7	98.9	66.2
9/30	107	80.4	13.7	46.6	69.7	46.7
9/30	121	79.4	13.1	44.7	63.6	42.6
9/30	149	80.9	8.6	29.3	45.1	30.2
9/30	177	79.6	6.7	22.9	33.0	22.1
9/30	205	80.5	6.6	22.3	33.6	22.5
9/30	233	81.6	6.1	20.7	33.0	22.1
9/30	251	81.1	3.0	10.2	15.9	10.6

* Data from North Dakota Agricultural Experiment Station.

† Based on 29 days of storage in 1943 and on 33 days of storage in 1944.

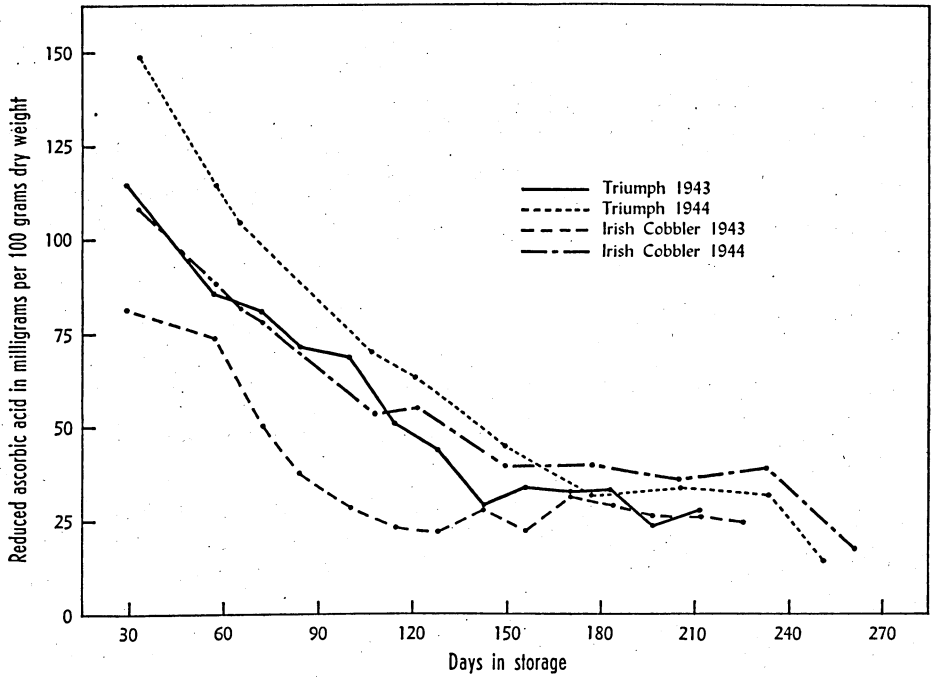

Fig. 2. Reduced ascorbic acid content during storage of two varieties of unpeeled potato tubers grown at Park River, North Dakota, 1943 and 1944, as reported by the North Dakota Agricultural Experiment Station

gated at the Maine Station over a two-year period (Murphy, 1946). All were grown in or around Presque Isle, on Caribou loam having a pH of 4.8 to 5.5. Irish Cobbler and Chippewa tubers probably were the only varieties mature at time of harvest. In 1943 tubers were harvested between October 2 and 9, and lots from each variety were held in a root cellar until October 27 when the first analyses were made. The remainder were placed in storage on October 9 at temperatures of 32°, 36°, 50°, 65°, and 70° F. Six tubers of each variety, stored at each temperature, were removed at monthly intervals and analyzed for reduced ascorbic acid. The Loeffler and Ponting (1942) method was employed, using one per cent metaphosphoric acid as the extractant and the Klett-Summerson photoelectric colorimeter for readings.

In 1944 tubers produced in the same locality as the preceding year were harvested on September 19 and 20. Equal numbers of tubers were taken at random from each of the six plots on which they were grown and placed in storage on September 22. Samples were transported to the laboratory and analyzed for reduced ascorbic acid on September 25. The storage temperatures employed were the same as in the preceding year except that 60° F. was substituted for 65° F. in order to give more uniform intervals of temperature. Sampling followed the same plan as in 1943. Moisture was determined on all samples. However, another study which compared the ascorbic acid content of two varieties of potatoes stored at two temperatures, specifically 32° and 70° F., had shown that calculations based on the actual moisture content of the tubers gave fresh-weight values which did not differ significantly from those obtained when an average moisture content of 79 per cent was used. In

Table 24. Effect of Storage and Temperature on Reduced Ascorbic Acid Content of Six Varieties of Potato Tubers Grown at Presque Isle, Maine, 1943-44 (Moist Weight Basis)*

Analysis made in	Reduced ascorbic acid during storage at						
	32° F.	36° F.	50° F.	60° F.†	65° F.‡	70° F.	Mean
	Milligrams per 100 grams						
October	22.7	22.7	22.7	28.1	17.2	22.7	22.7
November	14.8	12.5	18.4	19.8	14.6	16.9	16.2
December	9.3	8.5	14.1	16.6	12.9	13.5	12.5
January	7.0	5.8	11.3	12.5	10.3	9.9	9.5
February	6.2	5.7	10.6	12.3	8.6	11.1	9.1
March	6.5	5.7	8.5	6.4	9.3	7.7	7.4
April	7.7	6.6	8.4	6.9	7.6	8.0	7.5
May	6.3	6.3	7.9	5.8	5.0	5.5	6.1
Mean	10.1	9.2	12.7	13.6	10.7	11.9	

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Storage	7	1561.5	2.0	2.7	0.39	0.52
Temperature	5	176.0	2.2	3.0	0.31	0.41
Temperature§	.....	.....	.....	.....	0.44	0.58
Storage × temperature	35	22.8	1.4	1.6	0.88	1.15
Storage × temperature§	.....	.....	.....	.....	1.24	1.63

* Data from Maine Agricultural Experiment Station.
† 1944-1945 only. Potatoes harvested on September 19 and 20.
‡ 1943-1944 only. Potatoes harvested between October 2 and 9.
§ Minimum difference for temperatures 60° and 65° F.

consequence, all values were computed using the latter factor (Morrison, 1936).

Table 24 gives the means of the ascorbic acid values for the six varieties during the two years of study. The most rapid decrease occurred during the first month of storage. Somewhat less rapid, although still appreciable, decreases occurred during the next two months, with more gradual losses during succeeding months.

A comparison of the ascorbic acid content of the tubers stored at the various temperatures indicates that during the first half of the storage period the most rapid losses occurred at the two lowest temperatures, i.e., 32° and 36° F. (table 24). During the second half of the storage period a more rapid loss occurred at 60°, 65°, and 70° F., with the result that in May the values for the tubers held at 32° and 36° F. actually were greater than those for tubers held at the higher temperatures. Based on data from the two years of the study, the highest mean ascorbic acid value for all varieties was observed in tubers stored at 50° F. A higher value was noted for those stored at 60° F., but this latter value is based on tubers studied only during the second year (1944-45). Since the potatoes produced in this year were found to have a higher ascorbic acid content than those grown in the previous year, a part of this apparently favorable effect of storage at 60° F. is undoubtedly due to the initial higher ascorbic acid content.

Although temperatures of 50° F. or above tended to retard ascorbic acid losses during storage, the losses were extremely large even at the higher temperatures. After three or four months of storage, when the bulk of the potato crop ordinarily is removed for shipment, these losses ranged from 50 to 55 per cent.

From table 25 it is apparent that in the first season a storage temperature of 65°, and in the second, of 50° F., favored the retention of reduced ascorbic acid. However, the differences between these and the other high temperatures were slight. Although the significant interaction between variety and temperature (table 26) indicates that the varieties responded in a differential manner to the several storage

Table 25. Effect of Storage Temperature on the Retention of Reduced Ascorbic Acid of Six Varieties of Potato Tubers Grown at Presque Isle, Maine, 1943-44, Stored for Seven Months, and Analyzed at Monthly Intervals (Moist Weight Basis)*

Crop year	Retention means: Temperature of storage 32° F.	36° F.	50° F.	60° F.†	65° F.‡	70° F.	Mean at all temp.
				Per cent			
1943	41.3	36.7	54.9	.....	58.1	55.1	49.2
1944	35.1	30.7	46.7	40.7	.....	40.8	38.8

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Storage temperature (1943)	4	57.9	2.4	3.5	3.5	4.6
Storage temperature (1944)	4	47.9	2.4	3.5	2.5	3.3

* Data from Maine Agricultural Experiment Station.
† 1944 only.
‡ 1943 only.

temperatures, in general all varieties responded favorably to storage at 50° F.

From the point of view of quality, storage at 36° and 50° F. resulted in potato tubers of good physical appearance. Storage at lower and higher temperatures resulted in tubers of very poor quality as shown by internal mahogany browning in the first instance and browning of the tissue after removal from storage in the second. When ascorbic acid retention is considered, storage at 50° is better than storage at 36° F.

The reduced ascorbic acid content of Mohawk, Green Mountain, and Chip-

Table 26. Effect of Storage Temperature and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown at Presque Isle, Maine, 1943-44, Stored for Seven Months, and Analyzed at Monthly Intervals (Moist Weight Basis)*

Variety	Reduced ascorbic acid during storage at 32° F.	36° F.	50° F.	60° F.†	65° F.‡	70° F.	Mean
				Milligrams per 100 grams			
Mohawk	15.3	11.0	14.6	14.8	11.3	12.1	13.2
Green Mountain	8.7	8.7	12.2	13.4	9.8	10.6	10.6
Sebago	8.0	8.6	12.7	13.0	11.0	11.8	10.8
Irish Cobbler§	9.2	9.1	13.2	14.5	12.1	13.9	12.0
Chippewa§	8.4	7.9	9.6	10.4	8.9	10.0	9.2
Katahdin	10.9	10.0	14.0	15.2	10.9	13.2	12.4
Mean	10.1	9.2	12.7	13.6	10.7	11.9	

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Storage temperature	5	176.0	2.2	3.0	0.31	0.41
Storage temperature¶	.....	.....	.....	.....	0.44	0.58
Variety	5	144.4	2.2	3.0	0.34	0.45
Storage temperature × variety	25	14.7	1.5	1.8	0.76	1.00
Storage temperature × variety¶	.....	.....	.....	.....	1.07	1.41

* Data from Maine Agricultural Experiment Station.
† 1944-45 only. Potatoes harvested on September 19 and 20.
‡ 1943-44 only. Potatoes harvested between October 2 and 9.
§ Mature at time of harvest; other varieties harvested green.
¶ Minimum differences for temperatures 60° and 65° F.

Table 27. Effect of Storage and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown at Presque Isle, Maine, 1943-44, and Stored at Six Different Temperatures (Moist Weight Basis)*

Variety	Reduced ascorbic acid, Analyzed in: Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Mean
	Milligrams per 100 grams								
Mohawk	24.4	18.0	15.0	10.3	10.8	9.0	10.5	7.6	13.2
Green Mountain	18.9	14.9	10.5	8.4	9.4	7.6	7.1	6.0	10.4
Sebago	24.3	15.3	11.2	8.8	7.7	5.8	6.1	5.6	10.6
Irish Cobbler†	25.3	16.9	12.5	8.3	8.9	7.9	6.8	7.3	11.7
Chippewa†	18.1	13.3	9.5	8.1	7.2	5.5	6.4	4.9	9.1
Katahdin	25.2	17.3	13.6	10.5	8.8	7.7	8.6	6.3	12.2
Mean	22.7	15.9	12.0	9.1	8.8	7.3	7.6	6.3	

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Storage	7	1561.5	2.0	2.7	0.39	0.52
Variety	5	144.4	2.2	3.0	0.34	0.45
Storage × variety	35	11.1	1.4	1.6	0.96	1.26

* Data from Maine Agricultural Experiment Station.
† Mature at time of harvest; other varieties harvested green.

pewa potatoes tended to be relatively more resistant to oxidation than that of other varieties (table 27). This was shown by the fact that mean ascorbic acid retention for these three varieties was more than 50 per cent of the October value compared with percentages below 50 for the other three varieties. In general, although the differences observed were not great, the ascorbic acid content in May was higher in those varieties having the highest initial values.

In table 28 are given the means of the reduced ascorbic acid values for the six varieties of potatoes stored at six temperatures in the two years of the study. It may be noted that in 1943 the mean value in October was 17.2 milligrams as compared with a value of 28.1 milligrams in 1944. This difference in favor of the potatoes produced

Table 28. Effect of Storage and Crop Year on Reduced Ascorbic Acid Content of Six Varieties of Potato Tubers Grown at Presque Isle, Maine, 1943-44, and Stored at Six Different Temperatures (Moist Weight Basis)*

Crop year	Reduced ascorbic acid, Analyzed in: Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Mean
	Milligrams per 100 grams								
1943	17.2	11.9	9.9	8.0	7.6	7.2	7.5	5.1	9.3
1944	28.1	20.0	14.2	10.2	10.1	7.3	7.7	7.4	13.1

	D.F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Storage	7	1561.5	2.0	2.7	0.39	0.52
Crop year	1	1461.3	3.8	6.7	0.20	0.26
Storage × crop year	7	181.1	2.0	2.7	0.55	0.73

* Data from Maine Agricultural Experiment Station.

Table 29. Effect of Storage, Temperature, Variety, and Crop Year on Reduced Ascorbic Acid Content of Potato Tubers Grown at Presque Isle, Maine, 1943-44 (Moist Weight Basis)*

Variety	Initial value in October	Length of storage	Reduced ascorbic acid after storing at					
			32° F.	36° F.	50° F.	60° F.	65° F.	70° F.
1943	Milligrams per 100 g.	Months	Milligrams per 100 grams					
Mohawk	18.5	3	11.8	7.6	13.7	.....	11.2	8.8
		7	7.9	4.9	8.8	.....	6.0	5.2
Green Mountain	13.7	3	4.4	6.4	9.4	.....	10.2	11.4
		7	5.4	6.0	10.6	.....	4.6	3.7
Sebago	18.7	3	3.9	5.8	10.0	.....	11.6	10.2
		7	3.1	5.1	7.9	.....	6.0	5.0
Irish Cobbler†	20.4	3	5.0	5.1	8.5	.....	12.2	11.9
		7	8.1	6.7	8.0	.....	4.2	8.1
Chippewa†	13.0	3	6.4	5.6	7.5	.....	10.3	8.6
		7	3.3	3.0	4.7	.....	5.0	5.8
Katahdin	19.0	3	6.7	5.2	10.4	.....	11.5	9.9
		7	6.2	4.6	6.8	.....	6.6	7.2
1944								
Mohawk	30.2	3	15.0	8.3	13.4	13.2	.....	11.6
		7	15.1	9.1	11.9	6.6	.....	7.4
Green Mountain	24.0	3	6.1	6.1	13.8	12.7	.....	7.9
		7	6.9	8.7	9.4	6.7	.....	2.5
Sebago	29.8	3	4.2	5.8	11.9	14.1	.....	9.7
		7	4.8	8.2	7.0	5.7	.....	6.9
Irish Cobbler†	30.1	3	4.8	3.5	15.3	11.0	.....	11.8
		7	8.9	8.5	8.3	5.9	.....	8.0
Chippewa†	23.1	3	9.7	5.9	8.1	9.7	.....	8.3
		7	6.0	8.1	6.6	4.8	.....	5.8
Katahdin	31.4	3	10.1	8.1	18.4	14.2	.....	12.7
		7	6.6	8.1	9.8	4.7	.....	5.8

* Data from Maine Agricultural Experiment Station.

† Mature at time of harvest; other varieties harvested green.

in the second year persists throughout storage but is much less marked and relatively unimportant after the third month. It is probable that the lower values for 1943, as well as the more gradual rate of loss in that year, were due to the longer interval between harvesting and analysis, 18 to 25 days in 1943, and only four days in 1944. In 1943 the longer interval which elapsed between harvesting and testing may have permitted a large part of the early losses to have occurred before analytical work was begun. Differences exceeding 0.26 milligrams for crop year, 0.52 milligrams for storage, and 0.73 milligrams for the interaction between storage and crop year are significant at the one per cent level.

Table 29 gives a comparison between the ascorbic acid values secured in October for the six varieties of potatoes and values for the same tubers after three and after seven months' storage in the two years of study. It is apparent from this table that the several varieties reacted similarly in both years to storage at the different temperatures.

Table 30. Effect of Storage, Locality, and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown in Three Minnesota Localities, 1942 (Moist Weight Basis)*

Locality	Date of harvest†	Variety	Moisture	Reduced ascorbic acid after storing for 6 wks.	12 wks.	18 wks.	24 wks.	Mean
	1942		Per cent	Milligrams per 100 grams				
Grand Rapids	9/10	Red Warba	79.8	13.7	12.8	10.8	7.3	11.2
	9/10	Triumph	82.1	13.8	10.6	10.1	7.7	10.6
	9/10	Irish Cobbler	79.2	15.0	12.6	10.8	7.7	11.5
	9/10	Chippewa	81.0	10.6	11.0	8.6	6.4	9.2
		Mean	80.5	13.3	11.8	10.1	7.3	10.6
Hollandale	9/20	Red Warba	84.4	14.4	10.4	10.2	5.8	10.2
	9/20	Triumph	83.8	10.8	10.0	9.2	6.4	9.1
	9/20	Irish Cobbler	81.9	12.2	10.3	8.2	6.6	9.3
	9/20	Chippewa	85.2	9.5	9.0	7.4	5.8	7.9
		Mean	83.8	11.7	9.9	8.8	6.2	9.1
Halstad	9/5	Red Warba	78.9	18.4	13.4	12.6	9.0	13.4
	9/5	Triumph	80.6	15.8	11.9	11.6	8.0	11.8
	9/5	Irish Cobbler	76.0	19.0	12.1	10.8	11.6	13.4
	9/5	Chippewa	79.3	13.4	10.7	12.0	7.7	11.0
		Mean	78.7	16.6	12.0	11.8	9.1	12.4
		Mean of all	.....	13.9	11.2	10.2	7.5	.....

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Storage	3	184.0	2.81	4.24	0.52	0.70
Locality	2	92.5	3.20	5.10	0.45	0.61
Variety	3	27.9	2.81	4.24	0.52	0.70
Storage × locality	6	4.5	2.30	3.22	1.28	1.71
Storage × variety	9	4.6	2.09	2.82	1.48	1.98

* Data from Minnesota Agricultural Experiment Station.

† In all cases vines were prematurely killed by frost. The season of maturity indicates the relative stage of development: Red Warba, extra early; Triumph, medium late; Irish Cobbler, early; and Chippewa, medium late.

Minnesota

The Minnesota Station studied the effect of storage on the reduced ascorbic acid content of four varieties of potatoes (Red Warba, Triumph, Irish Cobbler, and Chippewa) produced in 1942 in three Minnesota localities. These were stored at University Farm in a root cellar, the temperature of which remains fairly uniform throughout the winter months. From November to the middle of April mean monthly temperatures were as follows: November 44.6°, December 41.6°, January 42.0°, February 42.9°, March 41.5°, and April (15 days) 43.6° F. At the end of November, after six weeks of storage, the first lot of tubers was removed and analyzed. Thereafter additional lots were removed and analyzed at six-week intervals. The reduced ascorbic acid values given in table 30 are the means of duplicate determinations on two lots of six tubers each. Storage resulted in highly significant decreases in the reduced ascorbic acid content of the potatoes. Differences exceeding 0.70 milligrams were found to be significant at the one per cent level.

For the tubers produced at Halstad, the most rapid loss occurred between 6 and 12 weeks of storage. For those from the other two localities, the decrease was more gradual in the early periods but showed some acceleration

during the last six-week period. The interaction between storage and locality was also highly significant, indicating that the tubers from the several localities responded to storage in a differential manner.

All the varieties showed highly significant decreases in reduced ascorbic acid content between 6 and 24 weeks of storage. The greatest decrease was observed in the Red Warba, which had had the highest value at the end of the first six-week storage period. The smallest loss occurred in the Chippewa potatoes, which were lowest in ascorbic acid at the end of the first storage period. After 24 weeks' storage Irish Cobbler potatoes were the best source of ascorbic acid, the Chippewa variety the poorest. The significant interaction between variety and storage shows that the rate of loss during storage varied with the different varieties. A value which exceeds 1.98 milligrams indicates significance at the one per cent level.

It has been demonstrated that losses in reduced ascorbic acid are most rapid in the early weeks following harvest, and that thereafter there is a leveling off to a more constant rate of loss. Accordingly it might have been anticipated that the potatoes produced at Halstad, which were harvested first, would have undergone a greater loss in reduced ascorbic acid content during the interval between harvest and the initial analysis, followed by a slower rate of loss during the period of observation, than the potatoes grown at Hollandale, which were harvested last. Actually the reverse was true. The potatoes grown at Halstad showed the greater loss during the period of observation. It will be recalled that all the tubers were held under identical conditions for a six-week period before the initial observation was made. It is suggested that this controlled storage period should have had a stabilizing effect in that all varieties were brought to a common temperature and held long enough to vitiate the effects of the differences in the temperatures of the localities in which they were produced.

On the dry weight basis also (Appendix table I) significant differences attributable to variety, locality, storage, and the interactions between locality and storage, and variety and storage are noted.

During the year 1944-45 the Minnesota Station studied the effect of temperature of storage on the ascorbic acid content of potato tubers. Two lots of each of three varieties (Red Warba, Mesaba, and Chippewa), grown at Grand Rapids, Minnesota, were stored at four different temperatures (35.6°, 47°, 57°, and 68° F.) from mid-December to mid-March. These tubers were harvested in September, stored immediately in a root cellar at Grand Rapids, and delivered to the laboratory on December 10. To permit stabilization the tubers were held in a root cellar at 40° F. for one additional week before the first analyses for total, reduced, and dehydroascorbic acid were made. The method of sampling and the determination of reduced ascorbic acid were the same as those followed in 1942-43, page 11. Total and dehydroascorbic acid were assayed according to the methods of Roe and Oesterling (1944) and Roe and Kuether (1943). At three-week intervals for a period of 12 weeks, tubers from each lot, held at the four storage temperatures, were analyzed for reduced ascorbic acid. Total and dehydroascorbic acid determinations were made at the end of three and 12 weeks of storage. After six weeks half the tubers stored at the three lower temperatures were removed and placed in storage at 68° F. The latter were analyzed for reduced ascorbic acid at the end of three and six weeks and for total and dehydroascorbic acid at the end of six weeks.

The means of the reduced ascorbic acid values are given in table 31. The low initial value for each of these varieties may be explained, in part, by the fact that the tubers had been in storage for nearly three months before delivery at the University Farm in mid-December when the outside temperature was just below freezing.

Storage resulted in significant decreases in the reduced ascorbic acid content of the tubers since, in most instances, differences greater than the 0.29 milligrams were observed.

Table 31. Effect of Storage, Temperature, and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown at Grand Rapids, Minnesota, 1944 (Moist Weight Basis)*

Variety	Initial value Dec., 1944	Length of storage	Reduced ascorbic acid after storing at 35.6° F.	47° F.	57° F.	68° F.	Mean
	Mg. per 100 g.	Weeks	Milligrams per 100 grams				
Red Warba	6.2	3	5.6	5.3	6.6	7.0	6.1
		6	5.8	6.0	6.8	7.3	6.5
		9	5.8	5.6	6.0	7.0	6.1
		12	4.6	4.4	5.5	6.4	5.2
	Mean		5.4	5.3	6.2	6.9	6.0
Mesaba	8.5	3	7.3	7.3	8.0	8.0	7.6
		6	8.2	7.9	7.6	9.0	8.2
		9	7.6	7.0	7.4	8.4	7.6
		12	6.5	6.4	7.5	7.9	7.1
	Mean		7.4	7.2	7.6	8.3	7.6
Chippewa	3.6	3	6.4	6.0	6.6	6.9	6.5
		6	5.8	6.0	6.6	7.4	6.4
		9	6.1	6.0	5.9	7.8	6.4
		12	5.4	5.2	5.9	7.1	5.9
	Mean		5.9	5.8	6.2	7.3	6.3
	Mean of all		6.2	6.1	6.7	7.5	

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Storage	3	28.9	2.81	4.24	0.21	0.29
Temperature	3	70.9	2.81	4.24	0.21	0.29
Variety	2	176.6	3.20	5.10	0.18	0.25
Storage × temperature	9	2.7	2.09	2.82	0.60	0.81

* Data from Minnesota Agricultural Experiment Station.

After three weeks of storage significant differences attributable to temperature are apparent in the mean values for the three varieties. Higher values were obtained for tubers stored at 57° and 68° F. than for those stored at the two lower temperatures. These differences became more pronounced with continued storage. The fact that the values obtained after six weeks' storage were somewhat higher than those noted after three weeks' time would suggest the possibility that the first three-week period was not sufficiently long to permit complete adjustment of the metabolism of the tuber to its environment. As will be shown later, an apparent increase in the reduced ascorbic acid content results when potato tubers are transferred from a cold to a warmer temperature. In this instance the increase was sufficient to more than offset the loss associated with storage. Significance was attached also to the interaction between storage and temperature, differences greater than 0.60 milligrams being significant at the 5 per cent level.

It may be observed that the three varieties responded similarly to the four storage temperatures. Comparison of the mean values shows that all varieties contained significantly smaller amounts of reduced ascorbic acid after storage at the two lower temperatures than after storage at the higher temperatures.

Statistically significant differences attributable to variety, storage, temperature, and the interaction between storage and temperature were noted also on the dry weight basis (Appendix table

III). Apparently differences in moisture loss do not account for temperature effects observed on the moist weight basis.

Evidence has been accumulating which demonstrates the biological availability of dehydroascorbic acid. In consequence it seemed desirable to ascertain the extent to which losses in reduced ascorbic acid during storage were attributable to its conversion to the dehydro form. Roe and Oesterling (1944) indicated a fair amount of agreement between values for total ascorbic acid obtained by analysis and those secured by the summation of the values for the reduced and dehydro forms. However, the instability of the color developed in the determination of dehydroascorbic acid suggested the advisability of determining both total and dehydroascorbic acid directly on the potato tubers. In the data presented in this bulletin, the sums of the values obtained for reduced and dehydroascorbic acid very rarely equaled the total ascorbic acid values obtained by analysis. No explanation is offered for this discrepancy.

At the time this study was undertaken it was recognized that the indophenol method had its limitations in that it was not specific for reduced ascorbic acid. Therefore, it was hoped that the independent determination of reduced ascorbic acid by the indophenol method and of total and dehydroascorbic acid by the dinitrophenylhydrazine method would make it possible to show whether there were present reducing substances which react with indophenol.

The results of analyses for total ascorbic acid are given in table 32. After three weeks' storage no consistent effect of temperature on the total ascorbic acid content is evident. As has been pointed out in discussing the reduced ascorbic acid values, it is possible that the time allowed was not sufficient for complete metabolic adjustment. However, after 12 weeks' storage, total ascorbic acid values generally varied directly with the storage temperature. At the two lower temperatures decreases in total ascorbic acid content occurred, whereas at the two higher temperatures increases are recorded in all but one

Table 32. Effect of Storage, Temperature, and Variety on Total Ascorbic Acid Content of Potato Tubers Grown at Grand Rapids, Minnesota, 1944 (Moist Weight Basis)*

Variety	Initial value Dec., 1944	Length of storage	Total ascorbic acid after storing at 35.6° F.	47° F.	57° F.	68° F.	Mean
	Mg. per 100 g.	Weeks	Milligrams per 100 grams				
Red Warba	9.5	3	9.6	9.4	10.0	9.4	9.6
Mesaba	10.5	3	11.2	12.6	12.2	10.2	11.6
Chippewa	8.0	3	8.8	8.8	8.3	7.3	8.3
	Mean		9.9	10.3	10.2	9.0	9.8
Red Warba	9.5	12	7.4	8.6	10.2	10.8	9.2
Mesaba	10.5	12	9.8	11.0	11.3	12.2	11.1
Chippewa	8.0	12	8.6	7.2	9.4	11.5	9.2
	Mean		8.6	8.9	10.3	11.5	9.8
	Mean of all		9.2	9.6	10.2	10.2	

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Temperature	3	4.2	3.03	4.76	0.68	0.93
Variety	2	43.3	3.42	5.66	0.59	0.80
Storage × temperature	3	15.0	3.03	4.76	1.37	1.85
Storage × variety	2	3.5	3.42	5.66	1.18	1.60

* Data from Minnesota Agricultural Experiment Station.

Table 33. Effect of Storage, Temperature, and Variety on Dehydroascorbic Acid Content of Potato Tubers Grown at Grand Rapids, Minnesota, 1944 (Moist Weight Basis)*

Variety	Initial value Dec., 1944	Length of storage	Dehydroascorbic acid after storing at 35.6° F.	47° F.	57° F.	68° F.	Mean
	Mg. per 100 g.	Weeks	Milligrams per 100 grams				
Red Warba	1.6	3	2.5	2.4	2.5	1.8	2.3
Mesaba	1.9	3	2.8	2.8	2.8	2.6	2.8
Chippewa	1.2	3	2.0	1.8	1.8	1.3	1.7
	Mean		2.4	2.3	2.4	1.9	2.2
Red Warba	1.6	12	2.8	3.0	2.4	2.6	2.7
Mesaba	1.9	12	3.6	3.6	3.1	2.9	3.3
Chippewa	1.2	12	1.4	1.6	1.7	2.0	1.7
	Mean		2.6	2.7	2.4	2.5	2.6
	Mean of all		2.5	2.5	2.4	2.2	

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Storage	1	56.5	4.28	7.88	0.09	0.12
Temperature	3	14.1	3.03	4.76	0.12	0.17
Variety	2	317.7	3.42	5.66	0.11	0.15
Storage × temperature	3	8.0	3.03	4.76	0.25	0.34
Storage × variety	2	16.6	3.42	5.66	0.22	0.29
Temperature × variety	6	2.9	2.53	3.71	0.31	0.42

* Data from Minnesota Agricultural Experiment Station.

instance. The reaction of the tubers to storage at the lowest temperature was significantly different from their reaction to storage at the two higher temperatures. It is evident that for the Red Warba and Mesaba varieties the mean change during storage is a net loss since the decreases noted at the two lower temperatures more than offset the increases observed at the higher temperatures. For Chippewa potatoes, on the other hand, the reverse is true, a net gain being recorded for this variety.

These findings for total ascorbic acid differ from those obtained for reduced ascorbic acid in that for the latter all varieties showed net decreases resulting from storage at the several temperatures whereas in the case of total ascorbic acid only Red Warba and Mesaba varieties showed net decreases.

Statistically significant differences were associated with variety, temperature, and the interactions between variety and storage and between storage and temperature.

On the dry weight basis, regardless of moisture loss, differences associated with variety, temperature, and the interactions between variety and storage and between storage and temperature were found to be significant (appendix table IV).

Values showing the dehydroascorbic acid content of the potatoes are given in table 33. The initial dehydroascorbic acid content constituted essentially 17, 18, and 15 per cent for the three varieties, respectively, of the initial total ascorbic acid content of the tubers. After three weeks' storage increases in the dehydroascorbic acid content of all varieties are evident at the different temperatures. From that point on the tubers responded differently to storage at the various temperatures. After 12 weeks, in all but one instance, further increases were evident for the Red Warba and Mesaba varieties at all temperatures. The Chippewa potatoes, on the other hand, showed decreases after 12 weeks of storage at the three lowest temperatures and an increase after 12 weeks' storage at 68° F. Despite differences in total ascorbic acid content, after three weeks' storage at the various

Table 34. Proportion of Dehydroascorbic Acid in Total Ascorbic Acid Content of Potato Tubers Grown at Grand Rapids, Minnesota, 1944, and Stored at Different Temperatures*

Varieties	After 3 weeks' storage at				After 12 weeks' storage at			
	35.6° F.	47° F.	57° F.	68° F.	35.6° F.	47° F.	57° F.	68° F.
	Per cent				Per cent			
Red Warba	26	26	25	19	38	35	24	24
Mesaba	25	22	23	25	37	33	27	24
Chippewa	23	20	22	18	16	22	18	17

* Data from Minnesota Agricultural Experiment Station.

temperatures dehydroascorbic acid constituted a fairly uniform proportion of the total ascorbic acid in each of the three varieties (table 34). Twelve weeks of storage at the two lowest temperatures resulted in an appreciably higher proportion of dehydroascorbic acid in the Red Warba and Mesaba potatoes while at the two higher temperatures storage appeared to have little effect. For the Chippewa variety, on the other hand, although 12 weeks of storage tended to reduce the proportion of dehydroascorbic acid, temperature of storage had little effect since the relative amounts of dehydroascorbic acid remained fairly uniform at all temperatures.

Variety, storage, temperature, and the interactions between variety and storage, variety and temperature, and storage and temperature, all influenced significantly the dehydroascorbic acid content of the potato tubers (table 33). As in the case of total ascorbic acid, computation of the dehydroascorbic acid content on the dry weight basis did not alter the statistical significance of the six factors listed above despite differences in moisture loss at the various storage temperatures (appendix table V).

Lots of potato tubers which had been placed in storage at 68° F. after the preliminary six weeks' storage at the three lower temperatures were analyzed for reduced ascorbic acid after three and six weeks and for total and dehydroascorbic acid after six weeks' storage. The reduced ascorbic acid values are given in table 35. In general, six weeks of storage at 68° F., following the preliminary six weeks' storage at the lower temperatures, resulted in an apparent increase in the reduced ascorbic acid content of all varieties, especially in the Chippewa potatoes. In all varieties the tubers which had been transferred from preliminary storage at 35.6° F. had the highest reduced ascorbic acid content after six weeks' storage at 68° F. Conversely, tubers transferred from preliminary storage at 57° F. had the lowest reduced ascorbic acid content at this point. Variety, storage, and the interactions between variety and storage and between storage and temperature, each had a statistically significant effect upon the reduced ascorbic acid content of all varieties. These data suggest that the reduced ascorbic acid content of the potato tissue is related to the metabolism of the cells which, in turn, is influenced by the temperature of storage. Differences in moisture loss at the several storage temperatures alter the picture somewhat. On the dry weight basis statistically significant differences are associated with variety, temperature, and the interaction between variety and storage (appendix table VI).

In table 36 are assembled the total, reduced, and dehydroascorbic acid values obtained for those lots of tubers stored continuously for 12 weeks at various temperatures and for additional lots of tubers placed in preliminary storage for six weeks at the same temperatures, followed by six weeks' storage at 68° F.

A comparison of the values for total ascorbic acid shows that for each variety the lower the preliminary temperature the greater is the amount of total ascorbic acid retained after an additional six weeks' storage at 68° F. For tubers held continuously at the preliminary temperatures, the highest total ascorbic acid value for each va-

Table 35. Effect of Storage, Temperature, and Variety on Reduced Ascorbic Acid Content of Potato Tubers Grown at Grand Rapids, Minnesota, 1944, and Stored at 68° F. Following Six Weeks' Preliminary Storage at Three Lower Temperatures (Moist Weight Basis)*

Variety	Preliminary storage temperature	Reduced ascorbic acid after storing at: Preliminary temperatures 6 weeks	68° F. 3 weeks	68° F. 6 weeks	Mean
			Milligrams per 100 grams		
Red Warba	35.6° F.	5.8	6.5	6.6	6.3
Mesaba	35.6° F.	8.2	8.0	8.8	8.3
Chippewa	35.6° F.	5.8	6.8	8.4	7.0
	Mean	6.6	7.1	7.9	7.2
Red Warba	47.0° F.	6.0	5.6	6.6	6.1
Mesaba	47.0° F.	7.9	7.3	8.6	7.9
Chippewa	47.0° F.	6.0	6.8	8.0	6.9
	Mean	6.6	6.6	7.7	7.0
Red Warba	57.0° F.	6.8	5.6	6.5	6.3
Mesaba	57.0° F.	7.6	8.6	8.0	8.1
Chippewa	57.0° F.	6.6	6.8	7.6	7.0
	Mean	7.0	7.0	7.4	7.1
	Mean of all	6.7	6.9	7.7	

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
Storage	2	35.6	3.37	5.53	0.25	0.33
Variety	2	122.9	3.37	5.53	0.25	0.33
Storage × temperature	4	3.8	2.74	4.14	0.60	0.82
Storage × variety	4	8.1	2.74	4.14	0.60	0.82
Storage × temperature × variety	8	3.5	2.32	3.29	1.48	

* Data from Minnesota Agricultural Experiment Station.

riety was noted for those stored at 57° F. For Red Warba and Mesaba potatoes the lowest value was obtained at 35.6° F. and for Chippewa at 47° F. Statistically significant differences were associated with variety, storage, and the interactions between variety and storage and between storage and temperature. Comparable data on the dry weight basis are given in appendix table VII which shows that differences in moisture loss did not alter the situation as far as statistical significance of the various factors was concerned.

Values for reduced ascorbic acid (table 36) followed closely the trend of values for total ascorbic acid. Significant differences attributable to variety, storage, temperature, and the interactions between variety and storage and between storage and temperature were noted. On the dry weight basis differences associated with variety, storage, and the interactions between variety and storage and between storage and temperature were found to be significant (appendix table VII).

The data for Red Warba and Mesaba varieties suggest that the recovery in reduced ascorbic acid when the tubers were placed in storage at 68° F. following a period at lower temperatures might be attributed in part to a conversion from the dehydro form. However, the increase in total ascorbic acid content observed, particularly in tubers held at the lowest storage temperature, points to more extensive metabolic

Table 36. Comparison of Moisture, and Total, Reduced, and Dehydroascorbic Acid Values for Lots of Potato Tubers Grown at Grand Rapids, Minnesota, 1944, and Stored for Six Weeks at 68° F. Following Six Weeks' Preliminary Storage at Three Lower Temperatures, with Similar Values for Lots of Tubers Stored Continuously for 12 Weeks at the Lower Temperatures (Moist Weight Basis)*

Variety	Preliminary and continuous storage temperatures (Fahrenheit)	After six weeks' storage at 68° F. following six weeks' preliminary storage				After 12 weeks' continuous storage at various temperatures			
		Moisture	Ascorbic acid			Moisture	Ascorbic acid		
			Total	Reduced	Dehydro		Total	Reduced	Dehydro
		Per cent	Milligrams per 100 grams			Per cent	Milligrams per 100 grams		
Red Warba	35.6°	77.2	10.4	6.6	2.2	79.2	7.4	4.6	2.8
Mesaba	35.6°	78.8	12.2	8.8	2.0	79.4	9.8	6.5	3.6
Chippewa	35.6°	81.9	12.2	8.4	2.2	81.4	8.6	5.4	1.4
	Mean		11.6	7.9	2.1		8.6	5.5	2.6
Red Warba	47.0°	76.0	9.8	6.6	2.2	78.4	8.6	4.6	3.0
Mesaba	47.0°	77.6	11.4	8.6	2.6	80.0	11.0	6.4	3.6
Chippewa	47.0°	83.0	10.9	8.0	2.1	83.2	7.2	5.2	1.6
	Mean		10.7	7.7	2.3		8.9	5.4	2.7
Red Warba	57.0°	75.6	8.8	6.5	2.1	79.4	10.2	5.5	2.4
Mesaba	57.0°	77.9	11.7	8.0	2.4	79.0	11.3	7.5	3.1
Chippewa	57.0°	80.4	9.7	7.6	2.0	83.3	9.4	5.9	1.7
	Mean		10.1	7.4	2.2		10.3	6.3	2.4
	Mean of all		10.8	7.7	2.2		9.3	5.7	2.6

Table 36. Comparison of Moisture, and Total, Reduced, and Dehydroascorbic Acid Values for Lots of Potato Tubers Grown at Grand Rapids, Minnesota, 1944, and Stored for Six Weeks at 68° F. Following Six Weeks' Preliminary Storage at Three Lower Temperatures, with Similar Values for Lots of Tubers Stored Continuously for 12 Weeks at the Lower Temperatures (Moist Weight Basis)*—Continued

	D. F.	F as calculated	F for Sign. 5% level	F for Sign. 1% level	L. S. D. 5% level	L. S. D. 1% level
					Milligrams	
TOTAL ASCORBIC ACID						
Storage	1	59.8	4.45 *	8.40	0.42	0.57
Variety	2	38.3	3.59	6.11	0.51	0.70
Storage × variety	2	7.2	3.59	6.11	1.02	1.40
Storage × temperature	2	22.6	3.59	6.11	1.02	1.40
REDUCED ASCORBIC ACID						
Storage	1	379.0	4.45	8.40	0.21	0.29
Temperature	2	2.7	3.59	6.11	0.29	0.40
Variety	2	120.0	3.59	6.11	0.26	0.36
Storage × temperature	2	19.0	3.59	6.11	0.52	0.72
Storage × variety	2	6.4	3.59	6.11	0.52	0.72
DEHYDROASCORBIC ACID						
Storage	1	40.6	4.45	8.40	0.12	0.17
Temperature	2	5.3	3.59	6.11	0.15	0.21
Variety	2	107.6	3.59	6.11	0.15	0.21
Storage × variety	2	63.1	3.59	6.11	0.30	0.41
Storage × temperature × variety	4	3.5	2.96	4.67	0.74	1.02

* Data from Minnesota Agricultural Experiment Station.