A PHYSIOLOGICAL AND BIOCHEMICAL STUDY OF THE CURING PROCESSES IN SWEET POTATOES

by

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TABLE OF CONTENTS

INTRODUCTION

The storage of sweet potatoes has long been one of the most serious problems confronting commercial sweet potato growers. Losses ranging from 20 to 30 percent and sometimes as high as 50 percent of the stored crop are frequently reported. The greatest portion of the loss is directly attributed to decay and physiological shrinkage.

If sweet potatoes are to be kept for any length of time in storage they must be subjected to a preliminary curing period of 10 days to 2 weeks. Elmer (13) states that the optimum condition for curing sweet potatoes is a temperature of approximately 85°F. and a relative humidity of 90 percent. Thompson et al. (43) compared sweet potatoes cured at 75 and 85°F. and after a period of storage found those cured at 75° F. contained a markedly lower proportion of attractive, high grade roots.

This investigation has been concerned chiefly with the effect of various curing conditions on the biochemical changes that occur during the curing process and the subsequent storage period and the possible relationships that may exist between these changes and the keeping quality of the sweet potatoes. A study was made of some of the carbohydrate transformations that occur, the changes in the pectic materials, and the nitrogen metabolism involving a detailed analysis of the soluble non-protein nitrogen.

REVIEW OF LITERATURE

The anatomical investigations of McCormick (26) and Artschwager (7) show that the fleshy storage organs of Ipomoea batatas are roots. In this respect the sweet potato differs from the Irish potato which is a tuber.

The sweet potato is extremely sensitive to the treatment it receives and great precaution must be observed during harvesting and the later handling if large losses are to be avoided. Thompson and Beattie (42) have compared the keeping quality of injured and uninjured sweet potatoes of three common varieties. Every potato in the damaged lots was either cut or bruised. After 164 days of storage the average loss due to shrinkage was 28.13 percent of the original weight for the injured and 13.83 percent for the uninjured. The losses due to decay were 13.79 percent for the injured and .75 percent for the uninjured. In all cases the injured roots of the Jersey varieties showed much higher losses than other varieties. Various storage temperatures ranging from 50 to 65° F. were also compared. When both shrinkage and decay were considered a storage temperature of 50 to 55° F. proved to be the most satisfactory.

Manns (25) emphasized the importance of supplying stored sweet potatoes with plenty of ventilation. He also showed that allowing moisture to collect on the potatoes results in a rapid decay of all of the roots.

Weimer and Harter (47) and Artschwager and Starrett (8) have shown that one of the processes occurring during curing is the formation of a wound periderm over those injured areas that must necessarily occur

at the ends of the potato. The periderm was found to develop most readily at relative humidities of 90 percent or above and at temperatures from 28.7 to 34.8°C. The formation of a wound cork periderm helps to exclude various microorganisms that are very destructive to the roots.

Harter and Weimer (17) have shown that various species of Rhizopus produce a powerful intracellular and extracellular pectinase which dissolves the middle lamella so that the cells of the sweet potato readily separate and provide an excellent source of nourishment for the mycelium.

Lauritzen (24) states that sweet potatoes are susceptible, at temperatures below 9°C., to infection by various fungi which do not normally appear at temperatures above 9°C. and suggests that this may indicate a change in the physiology of the host. A chilling injury evidenced by internal browning also appeared in the roots held at temperatures below 9.5°C. He concludes, "Taking into consideration the danger of both chilling injury and infection, there is nothing to commend even the temporary exposure of sweet potatoes to temperatures below 10°C."

It is generally known that sweet potatoes become sweeter to the taste as the length of the storage period increases. Harrington (16), in 1895, found that sweet potatoes in storage from harvest time until March increased in total sugar content as the storage period advanced. Shiver (38), in 1901, found that starch gradually decreased and cane sugar increased during the storage period but that the reducing sugars showed only slight changes. Neither of these investigators describe the curing and storage conditions to which the potatoes were subjected. In a much more thorough and extensive investigation Hasselbring and Hawkins (19) showed that the moisture content remains fairly constant in sweet potatoes stored at a temperature of 11.7° to 16.7°C. and that a gradual disappearance of starch

occurs during the season from October to March. However, they noted a disappearance of cane sugar accompanied by a probable reformation of starch during the latter part of the storage period (March to June), when appreciably higher temperatures existed. These same writers reported that sweet potatoes stored at low temperatures (4° C.) show a rapid disappearance of starch and an accompanying increase in cane sugar. An equilibrium is not reached because the potatoes invariably rot within a short time under these conditions. Hasselbring and Hawkins (20) concluded that in the carbohydrate transformations in stored sweet potatoes starch is first converted to reducing sugars then cane sugar is synthesized from the reducing sugars. The rates of starch hydrolysis and sugar formation were found to conform in a general way to the Van't Hoff temperature rule for chemical reactions. At higher temperatures the reactions are rapid at first, but soon become slower and approach an endpoint. At low temperatures the rates are slower and the endpoint is so shifted as to permit a greater concentration of sugar. Hopkins and Phillips (22) found the change in sugar content of sweet potatoes with time in storage to be very uniform and constant. This was demonstrated by plotting the log of the percent of sucrose against the log of the time in days. Straight lines were obtained from which they have derived equations for the reaction.

The effect of temperature on the starch-sugar change in stored Irish potatoes is well known. Müller-Thurgau (28) and Appleman (3) have shown that the equilibrium is very sensitive to temperature changes. Sugar accumulates at low temperatures (0° to 6°C.) but rapidly disappears and starch increases when the potatoes are placed in a higher storage temperature (8° to 10°C.).

Anderson (1) and Keitt (23) report that the percent of starch in the sweet potato gradually increases and the percent of moisture and total sugars gradually decrease as the growing season advances. Thus the highest starch content exists at about harvest time or shortly before. The rapid hydrolysis of starch to sugar after harvest has become of great concern to those interested in the commercial production of starch from sweet potatoes. This is evidenced by the report of Paine et al. (31) in which a method of rapid drying is proposed to prevent the loss of starch.

Dastur and Agnihotri (12) have studied the pectic changes in the Irish potato tubers at different stages of growth and during the storage period. They determined the free soluble pectin, protopectin, middle lamella pectin, and total pectin. The free soluble fraction was found to increase with the advance of the storage period and decay of the tubers. A corresponding decrease was noted in the other fractions. Softening of the tubers was attributed largely to the loss of middle lamella pectin and protopectin.

White-Stevens (48) investigated the different pectic constituents in celery during cold storage. He found no definite correlation between pectic hydrolysis and storage maturity except when storage pathogenes induced cytolytic effects.

Rosa (36) in his work on the changes in composition during ripening and storage of melons noted that the total pectic material remained constant during ripening on the vine but a slight loss was found when the melons were ripened in storage. In both cases a transformation of protopectin to pectin took place during the ripening and softening of the flesh.

Elwell and Dehn (14) have given data on the concentration of three pectic fractions in various vegetables and other plants. The lack of

description of the material and the limited information concerning their methods makes the data of little value for comparison. They report the pectic content of sweet potatoes at 3.45 percent of the fresh weight.

Parker and Stuart (32) determined the total pectin, soluble pectin, and protopectin in harvested green snap beans during storage. Large beans were found to contain more soluble pectin than small beans but the soluble pectin increased in both during cold storage. A synthesis of protopectin caused an increase in the total pectic substances during storage.

Appleman and Conrad (5), in a study of the pectic constituents of tomatoes, found protopectin to predominate in the green mature tomato but a rapid transformation of protopectin to pectin occurred as the tomatoes reached a full ripe stage.

Nightingale et al. (30) found that sweet potatoes at harvest time contained as high as 65 percent of their total nitrogen in the soluble non-protein form. Gruntuch (15) and Rahn (34) earlier reported that such underground storage organs as roots, tubers, and bulbs have a characteristically high amount of their nitrogen in the form of soluble compounds.

Stuart and Appleman (39) have shown that the distribution of the various nitrogen fractions remained very constant in the Irish potato tuber for storage periods up to five months. They found that the nitrogen fractions varied considerably in different parts of the tuber. The medulla contained as high as 61 percent of its total nitrogen in the soluble non-protein form as compared to 49 percent in the cortical tissue. They also reported that the reversion of parenchymatous cells to embryonic cells of the new cork cambium in cut tubers was accompanied

by an increase in protein and basic nitrogen at the expense of the amino nitrogen. The amide fraction remained fairly constant. Thus they concluded that amino acids rather than amides are concerned in the regeneration of proteins.

Appleman and Miller (6) observed that hydrolysis of protein is one of the important ripening and maturing processes in Irish potatoes. Appleman (4) noted that the seed and stem end of the potato differed in their nitrogen content and in the form of nitrogen. He also detected increases in the soluble nitrogen fractions after sprouting occurred. Andre (2) analyzed the expressed juice of two varieties of potatoes during the storage period from October until May. He determined the total nitrogen, the nitrogen that passed through a collodion membrane, and the nitrogen coagulated by heat. Each fraction was found to increase with the age of the potato.

Stuart and Appleman (39) found that differences up to 4.5 percent in the moisture content of Irish potatoes caused by different storage conditions had no appreciable effect on the nitrogen metabolism during storage.

It is impossible to review here all the work dealing with the metabolism of the various nitrogen fractions in plants. The recent extensive reviews by Robinson (35), Nightingale (29), and McKee (27) practically bring up to date the present knowledge of the physiological role of nitrogen in plants.

The origin and function of amides has remained in question since their discovery in plant tissues. Chibnall (11) in his treatise of protein metabolism in plants, discusses in considerable detail amide metabolism. According to his conception carbohydrates undergo trans-

formations to 3-carbon products from which oxalacetic and α ketoglutaric acids are formed. These acids react with ammonia to give the two most commonly occurring amides. Chibnall (10) found nitric nitrogen and monoamino nitrogen to vary directly with the protein content in the leaves of runner bean plants. This, he says, indicates they may be connected with protein synthesis. In starvation experiments he found that asparagine nitrogen remained unchanged. From this he concludes that asparagine is not derived from the decomposition of the leaf proteins.

Thompson (41) noted that amino nitrogen accumulates in celery when it is exposed to low temperature treatment. Harvey (18) reported that cold treatment of cabbage plants caused an increase in amino nitrogen content.

Vickery and Pucher (44) have shown that by varying the nutrient solution the ammonia content of tobacco leaves may range from 2.25 percent to as much as 10.3 percent of the soluble nitrogen while the amide nitrogen remains essentially unchanged. Prianischnikow and Schulow (33) in 1910 advanced the hypothesis that an important function of amides was to provide a means of maintaining a low level in the ammonia content which might otherwise become toxic. Vickery and Pucher (44) state that this hypothesis does not explain the conditions existing in rhubarb and tobacco leaves.

ANALYTICAL PROCEDURE

A lot of six representative sweet potatoes constituted a sample for analysis. The roots were washed and allowed to dry for about 30 minutes in the laboratory. Then they were passed through a Nixtamal mill and the pulp thoroughly mixed.

Moisture. Duplicate samples of the pulp approximating 5 g. each were placed between tared watch glasses, clamped together, weighed immediately, and dried to a constant weight in a vacuum equivalent to 30 inches of mercury, at a temperature of 80°C.

Sugars. Duplicate samples of 25 g. each of the pulp were weighed into counterpoised 200 ml. Kohlrauch sugar flasks and immediately covered with 75 ml. of boiling 95 percent alcohol. The samples were placed on a steam bath and 50 ml. of boiling water added. The solutions were kept boiling very gently and the extraction continued for 30 minutes. Glass bulbs blown from thick walled tubing served as small condensers for the flasks. The flasks were removed and made to volume with 95 percent alcohol. An aliquot of the filtered extract was evaporated on the steam bath. A few ml. of water were added from time to time and the evaporation continued until no odor of alcohol could be detected. The solutions were clarified with lead acetate, deleaded, and made to volume. The reducing sugars were determined by a modification of the Shaffer-Somogyi semi-micro method (21). For total sugars a 50 ml. aliquot of the cleared extract was hydrolyzed with 5 ml. of concentrated hydrochloric acid (sp. gr. 1.178) for 10 hours at a temperature of 35°C. The solution was made to volume, a portion of the sample neutralized with anhydrous sodium carbonate, and the sugar determined as described for reducing sugars.

Starch and Dextrin. For the starch and dextrin determinations 25 g. of pulp were weighed into a 250 ml. Erlenmeyer flask and covered with 125 ml. of cold 95 percent alcohol. At the time of analysis the storage alcohol was removed in a Buchner funnel. The pulp was washed with 80 percent alcohol until free of sugars as indicated by the

Molisch test. After washing with ether the pulp was dried and ground to pass a 60 mesh sieve in a micro- Wiley mill. The ground material was dried to a constant weight in a vacuum oven at 80°C. One gram of the dried material was used for starch and dextrin determination. About 100 ml. of boiling water were added to the starch and dextrin sample and the mixture boiled gently for 15 minutes to gelatinize the starch. It was then cooled to 45°C., 10 ml. of freshly collected, diluted saliva (1:4 and filtered) were added, and the temperature maintained at 45°C. for one hour. The solution was boiled, cooled, and again digested with saliva until no further indication of the presence of starch could be detected with the iodine test. The solution was filtered into a 250 ml. volumetric flask, made to volume, and a 200 ml. aliquot removed and hydrolyzed with 12.5 ml. of concentrated hydrochloric acid for 2.5 hours. Following hydrolysis the solution was cooled and transferred to a 500 ml. volumetric flask and made to volume. The solutions were neutralized and the reducing values determined as for the sugars.

The dextrins were determined by extracting 3 g. of the dried material with 300 ml. of water for 1 hour on a mechanical shaker. After extraction the samples were filtered, a 200 ml. aliquot was hydrolyzed with 12.5 ml. of concentrated hydrochloric acid for 2.5 hours, and the reducing power determined as for the starch and dextrin sample.

The percentage of starch was estimated by subtracting the percentage of dextrin from the percentage of starch and dextrin.

Hemicellulose. The insoluble residue remaining after starch digestion was placed in a digestion flask with 200 ml. of water, 12.5 ml. of concentrated hydrochloric acid were added, and the pulp hydrolyzed for 2.5 hours under reflux condensers. The solution was filtered and

made to volume. A portion was neutralized and the reducing values determined as for the previous materials. The reducing substances secured by this treatment were termed hemicellulose.

Total Pectin. Duplicate samples of 50 grams of the freshly ground pulp were weighed into counterpoised Erlenmeyer flasks and covered with 260 ml. of hot 95 percent alcohol. After the storage alcohol had been removed by filtration the samples were washed with alcohol and ether, dried at 60°C. in a vacuum oven, and ground to pass a 60 mesh sieve. The total pectic materials were determined by the Carre-Haynes method (9) with some modifications as described below. A 2 g. sample of the dried material was placed in a 500 ml. Erlenmeyer flask, covered with 100 ml. of 0.5 percent ammonium citrate solution, and boiled very gently for 30 minutes. The solutions were filtered into a 500 ml. volumetric flask. The pulp was washed with warm water, returned to the Erlenmeyer flask with 100 ml. of N/30 hydrochloric acid, and refluxed gently for one hour. The material was again filtered and washed with warm water. The filtrates were combined, made to volume, and the pectic materials precipitated from an aliquot as calcium pectate as described by Carre-Haynes (9). The calcium pectate gels were found to contain impurities which according to various protein tests and nitrogen content were largely proteinaceous. Attempts were made to estimate the impurities, as described by Appleman and Conrad (5), by redissolving the precipitate in ammonium citrate solution and determining the undissolved residue. The limited quantity of the calcium pectate precipitate present and the extreme difficulty encountered in washing the undissolved impurities from the filter paper with a small volume of water made this method unusable. The impurities were estimated by

determining the nitrogen content of a portion of the dried precipitate by the micro-Kjeldahl method and by calculating the protein content by use of the usual conversion factor, 6.25. This value was subtracted from the weight of the original precipitate to give the amount of calcium pectate.

Soluble Pectin. Four grams of the washed and dried plant sample were transferred to a one liter bottle with 500 ml. of 0.2 percent ammonium citrate solution. After shaking for one hour on a mechanical shaker the solution was filtered and a 200 ml. aliquot taken for the determination of the soluble pectic materials, which were determined as described for total pectin.

Protopectin. The percentage of protopectin was calculated by subtracting the percentage of soluble pectin from the percentage of total pectin.

Total Nitrogen. Two portions of the pulp of approximately 5 grams each were placed on tared watch glasses, clamped together, weighed, then transferred to 800 ml. Kjeldahl flasks. The nitrogen was determined by the usual Kjeldahl method. Since no nitrates could be detected the modification to include nitrates was omitted.

Extraction of Non-Protein Nitrogen. A sample of 100 g. of the freshly ground pulp was placed in a mortar and a small quantity of acid washed quartz sand added. The pulp was thoroughly triturated and after the gradual addition of 200 ml. of water the mixture was transferred onto a square of Huck toweling suspended over a 2 liter beaker and the extract expressed by hand. The residue was returned to the mortar and the extraction repeated two additional times. The extract was centrifuged to remove as much starch as possible. It was heated to boiling,

a few ml. of 5 percent Fe_2O_3 solution were added, and the boiling continued for approximately 2 minutes. The solution was filtered in a Buchner funnel containing an asbestos mat. The beaker and the mat were thoroughly washed with hot water. The filtrate was made to a volume of 1000 ml. and preserved with toluene when not analyzed immediately.

Total Non-Protein Nitrogen. Duplicate 100 ml. aliquots of the non-protein filtrate were analyzed as described for total nitrogen.

Total Alpha-Amino Nitrogen. A special preliminary procedure as perfected by Stuart and Appleman (39) was adopted to eliminate errors that occur in the usual Van Slyke procedure. A 200 ml. aliquot of the soluble non-protein extract was placed in a Claisen flask, immersed in a water bath, a slight excess of calcium oxide and 50 ml. of alcohol were added and the solution distilled for one hour under a reduced pressure at a temperature of 40 to 50°C. The calcium oxide residue was filtered off and the filtrate was slightly acidified with acetic acid and made to a volume of 100 ml. Aliquots of 10 ml. each were used for the determination of total alpha-amino nitrogen in the Van Slyke apparatus. The burette of the Van Slyke micro apparatus was used for measuring the gas evolved. The volume of the gaseous nitrogen was reduced to standard conditions and the proper corrections made for the blank determinations.

Basic Nitrogen. Duplicate 100 ml. aliquots of the non-protein extract were acidified with 2.5 ml. of concentrated sulfuric acid. When cooled to room temperature, 30 ml. of phosphotungstic acid solution (20 g. phosphotungstic acid and 5 g. of sulfuric acid made to 100 ml. of solution) were added. After standing for 24 hours in a refrigerator, the solutions were filtered and the precipitates washed thoroughly with a dilute solution of phosphotungstic acid, containing 2.5 g. of phospho-

tungstic acid and 5 g. of sulfuric acid per 100 ml. of solution. The filter paper and the precipitates were transferred to a Kjeldahl flask and digested as for total nitrogen. The ammonia was distilled into .01 N acid and the excess acid titrated with .01 N base.

Mono-Amino Nitrogen. The filtrates from the duplicate basic nitrogen samples were combined and neutralized with concentrated sodium hydroxide. The solution was then subjected to the distillation treatment as for total alpha-amino nitrogen. The volume of the approximately 400 ml. was reduced to about 100 ml. Aliquots of 10 ml. each of the solution were used for the determination of the amino nitrogen.

Ammonia Nitrogen. The determination of ammonia was made by the aeration method of Sessions and Shive (37). To each of the 50 ml. duplicate aliquots of the non-protein solution 50 ml. of the carbonate reagent were added and the samples aerated for 12 hours. Preliminary experiments showed approximately 99 percent recovery of the nitrogen from an ammonium sulfate solution containing .2 mg. of nitrogen per ml. when treated in a similar manner. The ammonia was collected in .01 N acid and the excess acid titrated with .01 N base. Blanks were run with each determination.

Amide Nitrogen. Duplicate 50 ml. aliquots of the non-protein extract were hydrolyzed under reflux condensers with 3 ml. of concentrated sulfuric acid in a boiling water bath for 2.5 hours. The solutions were filtered, the residue washed with a few milliliters of dilute sulfuric acid, and the filtrate neutralized with sodium hydroxide. The ammonia was determined by the Sessions and Shive method. An attempt was made to determine the glutamine nitrogen present according to the hydrolyzing conditions described by Vickery et al. (45). A buffer con-

sisting of a mixture of .1 M potassium dihydrogen phosphate and .05 M borax was added to 50 ml. of the non-protein extract in order to have the solution at a pH between 6 and 7. The solutions were hydrolyzed for 2.5 hours in a boiling water bath then aerated as for the ammonia determination. The maximum change during hydrolysis was .3 pH unit.

Humin Nitrogen. The residues filtered off following the amide hydrolysis were placed in a Kjeldahl flask and digested as for total nitrogen and the ammonia distillation was carried out as for the basic nitrogen.

Residual Nitrogen. The residual nitrogen was determined by finding the difference between the total non-protein nitrogen and the sum of the determined soluble nitrogen fractions. In the data for 1938 the residual nitrogen represents the difference between the total non-protein nitrogen and the sum of the total alpha-amino, amide, and ammonia nitrogen. For 1939 it represents the difference between the total non-protein nitrogen and the sum of the mono-amino, amide, basic, ammonia, and humin nitrogen.

MATERIALS AND EXPERIMENTAL PROCEDURE

The sweet potatoes used were of the Maryland Golden variety, developed from the Yellow Jersey group, grown near College Park, Maryland. In 1938 the potatoes were dug on October 11, allowed to dry for an hour or more in the sunshine, and brought to the laboratory. The following day they were sorted into lots containing six potatoes of as nearly the same size and shape as possible. The loose sand and soil particles were removed by brushing lightly with a soft brush. The lots weighing 1310 ± 25 g. were divided into two sets. One set was placed in a curing oven at a temperature of 30°C. The

other lots were cured at a temperature of 35°C. The temperature, with a maximum variation of ± 1°, was regulated by use of a mercury relay thermoregulator. The air was kept in constant circulation by a sirocco fan located at one end of the oven. Small vents allowed an exchange of air and prevented an accumulation of carbon dioxide in the chamber. The potatoes were kept in the curing chambers for ten days, then removed and stored in refrigerators at a temperature of 9 to 10°C. By placing the lots in individual wire baskets, 4 x 6 x 12 inches, immediately after sorting, the necessary handling and transfer from ovens to the storage chambers could be made with a minimum disturbance to the roots.

In 1939 the same variety was secured on October 5 from the Eastern Shore of Maryland. In both years, 1938 and 1939, the writer gathered the potatoes in the field and thus prevented bruises etc. that might have been inflicted by careless commercial handling. The sweet potatoes were sorted into lots of six roots each with an average weight per lot of 1700 ± 25 g. In 1939 the lots were divided into four sets. Each set was subjected to a different curing condition of temperature and humidity as indicated in the tables. After a curing period of 11 days all lots were stored in a refrigerator at a temperature of 10 to 12°C. Analyses were made at intervals during the curing and storage period.

EXPERIMENTAL RESULTS

Immediately after the sweet potatoes had been brought from the field and sorted, one lot was prepared for analysis. This lot was termed the harvest sample. The weights of all lots were recorded after the potatoes had been sorted and again as they were brought out of storage for analysis. Table 1 and 2 show the loss in weight and the corresponding moisture contents during the storage period of

the differently cured lots.

Table 1. Loss in weight and change in percentage of moisture in sweet potatoes cured at different temperatures and stored at 9--10°C. Curing period October 12 to October 22. (1938 crop)

Curing Temperature	Date of Analysis	Loss in Weight	Moisture
		Percent	Percent
30° C.	Oct. 12	---	75.07
	Oct. 22	6.54	74.99
	Nov. 23	11.11	74.27
	Dec. 31	18.02	73.75
	Feb. 10	38.25	73.45
35°C.	Oct. 12	---	75.07
	Oct. 22	8.58	74.51
	Dec. 31	20.54	73.41
	Feb. 10	25.29	73.10

As was pointed out by Hasselbring and Hawkins (19) there is a considerable loss in total weight of the sweet potatoes during storage, without any significant change in the moisture content.

Table 2. Loss in weight and change in percentage of moisture in sweet potatoes cured under different conditions of temperature and humidity and stored at 10-12°C. Curing period October 7 to October 18.

(1939 crop)

Curing conditions		Date of Analysis	Loss in weight	Moisture
Temperature	Humidity		Percent	Percent
		Oct. 7	---	75.57
		Oct. 13	4.67	74.80
	80—85 percent	Oct. 18	5.58	74.61
		Nov. 24	6.96	76.17
30° C.		Jan. 1	11.49	74.62
		Feb. 22	11.83	75.51
		Oct. 18	.76	76.81
	95—100 percent	Nov. 24	4.86	75.41
		Feb. 22	6.35	76.10
		Oct. 7	---	75.57
		Oct. 13	7.51	73.84
	70—75 percent	Oct. 18	10.39	75.07
		Nov. 24	16.10	74.72
40° C.		Jan. 1	16.92	74.24
		Feb. 22	22.68	73.47
		Oct. 18	8.73	75.35
	90—95 percent	Nov. 24	13.30	74.42
		Feb. 22	26.15	75.00

Carbohydrate Transformations in Sweet Potatoes During Curing and Storage

The data showing some of the carbohydrate changes that take place during curing and storage of sweet potatoes are given in Table 3.

Table 3. Carbohydrates calculated as dextrose and expressed as percentages of the fresh weight at the time of the analysis. Potatoes cured from October 12 to October 22 and stored at 9-10°C.
(1938 crop)

Date of Analysis	Starch & Dextrin	Dextrin	Starch	Hemicellulose	Total Sugars	Reducing Sugars	Sucrose	Total Carbohydrates
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Curing Temperature 30°C.								
Oct. 12	17.24	.24	17.00	.81	3.55	.64	2.91	21.60
Oct. 22	13.16	.16	13.00	.81	5.01	.49	4.52	18.98
Nov. 23	11.80	.18	11.62	.57	5.43	.45	4.98	17.80
Dec. 31	10.20	.84	9.36	.63	9.46	1.38	8.08	20.29
Feb. 10	8.02	.95	7.07	.66	12.22	1.09	11.13	20.90
Curing Temperature 35°C.								
Oct. 22	15.04	.19	14.85	.72	4.84	.91	3.93	20.60
Dec. 31	10.05	.89	9.16	.76	9.67	.92	8.75	20.48
Feb. 10	8.63	1.03	7.60	.67	10.21	.65	9.56	19.51

A rapid hydrolysis of starch with a corresponding increase in total sugars occurred during the curing process. Dextrin and hemicellulose fractions decreased slightly. The reducing sugars remained fairly constant showing only a slight increase in the lots cured at 30°C. and a slight increase in the lots cured at 35°C.

Following curing the hydrolysis of starch continued at a lower rate throughout the remainder of the storage period. With the changes in starch

content there was a closely corresponding inverse change in the percentage of sucrose. The reducing sugar content changed comparatively very little. There was a tendency for it to increase in the lots cured at 30°C. and to decrease in the lots cured at 35°C. An increase in dextrin content occurred late in the season but the hemicelluloses decreased throughout the storage period. Both of these last two fractions were present in relatively small amounts.

Table 4. Carbohydrates calculated as dextrose and expressed as percentages of the fresh weight at harvest time. Potatoes cured from October 12 to October 22 and stored at 9 to 10°C.
(1938 crop)

Date of Analysis	Starch & Dextrin	Dextrin	Starch	Hemicellulose	Total Sugars	Reducing Sugars	Sucrose	Total Carbohydrates
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Curing Temperature 30°C.								
Oct. 12	17.24	.24	17.00	.81	3.55	.64	2.91	21.60
Oct. 22	12.29	.15	12.14	.76	4.68	.46	4.22	17.73
Nov. 23	10.48	.16	10.32	.51	4.82	.40	4.42	15.81
Dec. 31	8.39	.69	7.70	.52	7.78	1.13	6.65	16.69
Feb. 10	4.94	.59	4.35	.41	7.53	.67	6.86	12.88
Curing Temperature 35°C.								
Oct. 22	13.76	.17	13.58	.66	4.43	.83	3.60	18.85
Dec. 31	8.00	.71	7.29	.61	7.70	.73	6.97	16.31
Feb. 10	6.10	.73	5.38	.47	7.22	.46	6.76	13.79

All of the above facts are brought out more vividly when the data in Table 3 are recalculated on the basis of the fresh weight at harvest time. The results are given in Table 4.

On the basis of the fresh weight at the time of analysis the total determined carbohydrates show very little change during the entire storage period but when expressed as percentages of the fresh weight at harvest time a considerable decrease occurs. Thus the data as presented in Table 4 represents a truer picture of the carbohydrate changes during curing and storage. Hasselbring and Hawkins (19) showed that the total determined carbohydrates remained practically constant throughout the storage period when expressed as percentages of the weight at the time of analysis. They calculated the percentages on the basis of the moisture content in the harvest sample but neglected the loss in weight that occurred during storage.

The same relationships between the various fractions are apparent when the data are calculated on the basis of the dry weights, as shown in Tables 5 and 6. Since the maximum variation in the moisture content is less than 2 percent it is to be expected that the dry weight basis would reveal the same trends.

The differences in the carbohydrate changes of the lots cured at the two different temperatures are very small. The only noticeable variation is in the reducing sugars as pointed out above.

Table 5. Carbohydrates calculated as dextrose and expressed as percentages of the dry weight at the time of analysis. Potatoes cured from October 12 to October 22 and stored at 9 to 10°C. (1938 crop)

Date of Analysis	Starch & Dextrin	Dextrin	Starch	Hemicellulose	Total Sugars	Reducing Sugars	Sucrose	Total Carbohydrates
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Curing Temperature 30°C.								
Oct. 12	69.16	.94	68.22	3.25	14.25	2.57	11.68	86.66
Oct. 22	52.60	.64	51.96	3.25	20.05	1.95	18.10	75.90
Nov. 23	45.87	.69	45.18	2.20	21.12	1.76	19.36	69.19
Dec. 31	38.84	3.20	35.64	2.39	35.96	5.26	30.70	77.19
Feb. 10	30.20	3.57	26.63	2.50	46.02	4.10	41.92	78.72
Curing Temperature 35°C.								
Oct. 22	59.01	.74	58.37	2.84	18.98	3.56	15.42	80.83
Dec. 31	37.79	3.34	34.45	2.85	36.35	3.50	32.85	76.99
Feb. 10	32.09	3.82	28.27	2.49	37.95	2.42	35.53	72.53

Table 6. Carbohydrates calculated as dextrose and expressed as percentages of the dry weight at harvest time. Potatoes cured from October 12 to October 22 and stored at 9 to 10°C. (1938 crop)

Date of Analysis	Starch & Dextrin	Dextrin	Starch	Hemicellulose	Total Sugars	Reducing Sugars	Sucrose	Total Carbohydrates
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Curing Temperature 30°C.								
Oct. 12	69.16	.94	68.22	3.25	14.25	2.57	11.68	86.66
Oct. 22	49.14	.60	48.54	3.04	18.73	1.82	16.91	70.91
Nov. 23	40.67	.61	40.05	1.95	18.72	1.54	17.16	61.34
Dec. 31	31.84	2.63	29.22	1.96	29.48	4.31	25.17	63.28
Feb. 10	18.64	2.20	16.44	1.54	28.41	2.53	25.88	48.59
Curing Temperature 35°C.								
Oct. 22	53.92	.68	53.34	2.59	17.35	3.25	14.10	73.86
Dec. 31	30.03	2.66	27.37	2.27	28.88	2.78	26.10	61.18
Feb. 10	25.50	3.04	22.46	1.97	30.15	1.92	28.23	57.62

Pectic Changes in Sweet Potatoes During Curing and Storage

Since firmness and keeping quality of many fruits and vegetables seem to be closely correlated with the changes that occur in the pectic material in the tissues, it was considered desirable to determine some of the pectic constituents in the sweet potatoes during curing and storage. Tables 7 and 8 give the results for the 1938 crop.

The data in Table 7 indicate that the total pectic material was higher in all of the stored lots than in the original harvest samples. When the data are recalculated as percentages of the fresh weight at harvest time an increase in the total pectic material occurred only during the curing period. A slight decrease occurred during the early part of the storage period. The samples analyzed on February 10 showed considerable decrease in the total pectic material. These lots were beginning to break down and decay. This may have accounted for the loss. No decayed tissues were used for analysis but all of the potatoes of those lots containing decayed material were much softer than the potatoes in the other lots. Table 7 shows that the soluble pectin and protopectin were present in larger quantities in nearly all of the stored lots than in the original harvest sample.

Table 7. Pectic constituents calculated as calcium pectate and expressed as percentages of the fresh weight at the time of analysis. Potatoes cured at different temperatures and stored at 9—10°C. Curing period October 12 to October 22.
(1938 crop)

Curing Temperature	Date of Analysis	Total Pectin	Soluble Pectin	Protopectin
		Percent	Percent	Percent
	Oct. 12	.808	.399	.409
	Oct. 22	.919	.349	.570
30°C.	Nov. 23	.879	.425	.454
	Dec. 31	.971	.588	.383
	Feb. 10	.968	.535	.433
	Oct. 22	1.068	.465	.603
35°C.	Dec. 31	1.052	.651	.401
	Feb. 10	1.006	.555	.451

Table 8. Pectic constituents calculated as calcium pectate and expressed as percentages of the fresh weight at harvest time. Potatoes cured at different temperatures and stored at 9—10°C. Curing period October 12 to October 22.
(1938 crop)

Curing Temperature	Date of Analysis	Total Pectin	Soluble Pectin	Protopectin
		Percent	Percent	Percent
	Oct. 12	.808	.399	.409
	Oct. 22	.858	.326	.532
30°C.	Nov. 23	.781	.377	.404
	Dec. 31	.798	.483	.315
	Feb. 10	.596	.329	.267
	Oct. 22	.976	.425	.551
35°C.	Dec. 31	.838	.518	.320
	Feb. 10	.711	.392	.319

Expressed as percent of the fresh weight at harvest time the soluble pectin remained more nearly constant while protopectin increased during the curing period then decreased throughout the remainder of the storage period.

The data for the pectic constituents in the 1939 crop are presented in tables 9 and 10. Here, as in the previous year, the total pectic material increased during storage but calculated on the basis of the harvest weight the only consistent increase in all cases was during curing. A rather consistent increase in protopectin occurred throughout storage in the lots cured at 30°C. The lots cured at 40°C. were less consistent but in most cases contained more protopectin than the harvest sample. The lots cured at 40°C. and high humidity showed a decrease in all the pectic fractions on the last sampling date. This lot was in a relatively poor condition. Some of the roots were beginning to show decay.

The storage synthesis of protopectin apparently continues in the roots until the first indication of decay is noticeable. This discontinuance of protopectin synthesis is followed by a decrease in the total pectic constituents and to some extent a decrease in the soluble pectin.

Table 9. Pectic constituents calculated as calcium pectate and expressed as percentages of the fresh weight at time of analysis. Potatoes cured under different conditions of temperature and humidity and stored at 10 to 12°C. Curing period October 7 to October 18 (1939 crop)

Curing Conditions		Date of Analysis	Total Pectin	Soluble Pectin	Protopectin
Temperature	Humidity		Percent	Percent	Percent
30°C.	80—85 percent	Oct. 7	.776	.426	.350
		Oct. 13	.837	.444	.393
		Oct. 18	.927	.608	.319
		Nov. 24	1.017	.575	.442
		Jan. 1	1.059	.336	.723
		Feb. 22	1.127	.385	.742
	95—100 percent	Oct. 18	.854	.542	.312
		Nov. 24	1.065	.489	.576
		Feb. 22	1.240	.424	.816
40°C.	70—75 percent	Oct. 13	.984	.481	.503
		Oct. 18	.977	.649	.328
		Nov. 24	.995	.545	.450
		Jan. 1	1.025	.303	.722
		Feb. 22	1.373	.391	.982
	90—95 percent	Oct. 13	.913	.471	.442
		Oct. 18	.913	.655	.258
		Nov. 24	1.196	.557	.639
		Feb. 22	1.021	.418	.603

Table 10. Pectic constituents calculated as calcium pectate and expressed as percentages of the fresh weight at harvest time. Potatoes cured under different conditions of temperature and humidity and stored at 10—12°C. Curing period October 7 to October 18. (1939 crop)

Curing Conditions		Date of Analysis	Total Pectin	Soluble Pectin	Protopectin
Temperature	Humidity		Percent	Percent	Percent
30°C.	80—85 percent	Oct. 7	.776	.426	.350
		Oct. 13	.798	.423	.375
		Oct. 18	.876	.574	.302
		Nov. 24	.946	.535	.411
		Jan. 1	.937	.298	.639
		Feb. 22	.994	.339	.654
	95—100 percent	Oct. 18	.847	.538	.309
		Nov. 24	1.013	.465	.548
		Feb. 22	1.089	.372	.717
40°C.	70—75 percent	Oct. 13	.910	.445	.465
		Oct. 18	.876	.582	.294
		Nov. 24	.855	.458	.377
		Jan. 1	.922	.252	.670
		Feb. 22	1.062	.302	.759
	90—95 percent	Oct. 13	.856	.442	.414
		Oct. 18	.833	.598	.235
		Nov. 24	1.037	.483	.554
		Feb. 22	.754	.309	.445

Effects of Storage in an Aqueous Solution On the Non-Protein Nitrogen Fractions

Webster (46) has shown that alcoholic solutions of plant materials show a continually decreasing percentage of amino nitrogen during storage regardless of the concentration of alcohol used. He found an increase in ammonia nitrogen which did not account for all of the decrease in amino nitrogen. The following experiment was undertaken to determine whether a similar shift of the non-protein nitrogen fractions occurs during storage in an aqueous solution preserved with toluene.

The soluble nitrogen was extracted from duplicate 100 g. samples of the pulp from the 1939 harvest lot of sweet potatoes. The proteins were removed and the solutions made to volume. One solution was analyzed immediately. The other solution was covered with toluene and stored in a dark chamber at room temperature. After 4 months of storage the solution was analyzed by the usual procedure. The results are given in Table 11.

Table 11. Distribution of nitrogen in stored and unstored aqueous non-protein nitrogen extracts of sweet potatoes. The results are expressed as percentages of the fresh weight.

	Total N	Non-Protein N	Protein N	Ammonia N	Alpha Amino N	Mono-Amino N	Amide N	Basic N	Residual N
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Harvest Sample	.1899	.0408	.1491	.0003	.0286	.0193	.0015	.0075	.0122
After 4 months storage	.1899	.0407	.1492	.0005	.0201	.0143	.0021	.0061	.0177

Although no marked changes were noted, there was a decrease in amino nitrogen and a slight increase in ammonia and amide nitrogen. The increase in the last two fractions does not account for all of the decrease in the amino nitrogen, thus the greatest increase occurred in the residual fraction.

Unless stated otherwise, the data in the following tables represent the results of fractionation immediately after extraction.

Nitrogen Metabolism in Sweet Potatoes During Curing and Storage

In Tables 1 and 2 it was shown that there is a considerable loss in total weight of sweet potatoes during curing and storage. In order to take into account this loss of water and dry matter, the results for all nitrogen determinations, after having first been presented as percentages of the fresh weight at the time of analysis, are given in subsequent tables from recalculated data as percentages of the fresh weight at harvest time. The results for the 1938 experiments are given in tables 12 and 13. The 1939 results are given in tables 14, 15, 16 and 17.

During the curing process a considerable hydrolysis of protein occurred. The rate of hydrolysis was greater in all cases at the higher temperatures and also for the higher humidities at the same temperature. Concomitant with the increase in the total soluble non-protein nitrogen there was an increase in nearly all of the soluble fractions. Amino and basic nitrogen increased more rapidly at the higher curing temperatures. High humidity tended to favor the formation of basic nitrogen. Amide nitrogen was somewhat variable and showed decreases during curing in the 1938 experiments and increases in 1939.

The humidities were not determined in the 1938 experiments but probably corresponded closely to those of the lower humidity sets in the 1939 experiments.

Table 12. Distribution of nitrogen expressed as percentages of the fresh weight at the time of analysis. Cured from October 12 to October 22 and stored at 9 to 10°C.
(1938 crop)

Date of Analysis	Total N	Protein N	Non-Protein N	Ammonia N	Alpha Amino N	Amide N	Basic N	Residual N
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Curing Temperature 30°C.								
Oct. 12	.217	.145	.972	.0010	.047	.008	.010	.016
Oct. 22	.239	.149	.090	.0016	.047	.006	.015	.035
Nov. 23	.264	.166	.098	.0013	.032	.010	.022	.055
Dec. 31	.256	.160	.096	.0020	.029	.018	.021	.047
Feb. 10	.243	.135	.108	.0015	.012	.019	.018	.075
Curing Temperature 35°C.								
Oct. 22	.273	.163	.110	.0014	.067	.002	.024	.040
Dec. 31	.260	.142	.118	.0025	.032	.020	.022	.063
Feb. 10	.319	.158	.161	.0022	.017	.033	.030	.109

Table 13. Distribution of nitrogen expressed as percentages of the fresh weight at harvest time. Potatoes cured from October 12 to October 22 and stored at 9 to 10°C.
(1938 crop)

Date of Analysis	Total N	Protein N	Non-Protein N	Ammonia N	Alpha Amino N	Amide N	Basic N	Residual N
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Curing Temperature 30°C.								
Oct. 12	.217	.145	.072	.0010	.047	.008	.010	.016
Oct. 22	.223	.139	.084	.0015	.044	.006	.014	.032
Nov. 23	.235	.148	.087	.0012	.028	.009	.020	.049
Dec. 31	.210	.131	.079	.0016	.024	.015	.017	.038
Feb. 10	.150	.083	.066	.0009	.007	.012	.011	.046
Curing Temperature 35°C.								
Oct. 22	.250	.150	.100	.0013	.061	.002	.022	.036
Dec. 31	.207	.113	.094	.0020	.025	.016	.017	.051
Feb. 10	.238	.118	.120	.0016	.013	.025	.022	.080

Table 14. Distribution of nitrogen expressed as percentages of the fresh weight at the time of analysis. Potatoes cured at different temperatures and humidities and stored at 10 to 12°C. Curing period October 7 to October 18. (1939 crop)

Curing temperature 30°C., relative humidity 80 to 85 percent

Date of Analysis	Moisture	Total N	Protein N	Non-Protein N	Ammonia N	Alpha Amino N	Mono Amino N	Amide N	Basic N	Humin N	Residual N
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Oct. 7	75.57	.190	.149	.041	.0003	.029	.019	.0015	.008	.0000	.012
Oct. 13	74.80	.196	.150	.046	.0006	.043	.022	.0022	.009	.0005	.012
Oct. 18	74.61	.172	.123	.049	.0004	.026	.018	.0035	.008	.0003	.019
Nov. 24	76.17	.169	.110	.059	.0007	.032	.023	.0031	.015	.0017	.016
Jan. 1	74.62	.164	.111	.053	.0006	.029	.022	.0026	.018	.0009	.009
Feb. 22	75.51	.201	.113	.088	.0002	.049	.033	.0071	.018	.0004	.029

Curing temperature 30°C., relative humidity 95 to 100 percent

Oct. 18	76.81	.190	.133	.057	.0003	.030	.020	.0036	.013	.0006	.020
Nov. 24	75.41	.193	.133	.060	.0006	.036	.031	.0042	.012	.0014	.011
Feb. 22	76.10	.185	.129	.056	.0002	.030	.023	.0030	.027	.0000	.003

Table 15. Distribution of nitrogen expressed as percentages of the fresh weight at the time of analysis. Potatoes cured at different temperatures and humidities and stored at 10 to 12°C. Curing period October 7 to October 18. (1939 crop)

Curing temperature 40°C., relative humidity 70 to 75 percent

Date of Analysis	Moisture	Total N	Protein N	Non-Protein N	Ammonia N	Alpha Amino N	Mono Amino N	Amide N	Basic N	Humin N	Residual N
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Oct. 7	75.57	.190	.149	.041	.0003	.029	.019	.0015	.008	.0000	.012
Oct. 13	73.84	.172	.103	.069	.0006	.053	.039	.0053	.009	.0015	.014
Oct. 18	75.07	.195	.098	.097	.0006	.065	.050	.0096	.014	.0016	.021
Nov. 24	74.72	.220	.130	.090	.0024	.048	.034	.0140	.018	.0016	.020
Jan. 1	74.24	.212	.107	.105	.0013	.058	.050	.0086	.027	.0026	.016
Feb. 22	73.47	.230	.107	.125	.0015	.063	.046	.0178	.026	.0027	.029

Curing temperature 40°C., relative humidity 90 to 95 percent

Oct. 18	75.35	.154	.061	.093	.0004	.060	.047	.0092	.014	.0020	.020
Nov. 24	74.42	.189	.105	.084	.0014	.047	.037	.0103	.015	.0005	.020
Feb. 22	75.00	.230	.091	.139	.0015	.069	.056	.0227	.027	.0027	.029

Table 16. Distribution of nitrogen expressed as percentages of the fresh weight at harvest time. Potatoes cured at different temperatures and humidities and stored at 10 to 12°C. Curing period October 7 to October 18. (1939 crop)

Curing temperature 30°C., relative humidity 80 to 85 percent

Date of Analysis	Total N	Protein N	Non-Protein N	Ammonia N	Alpha Amino N	Mono-Amino N	Amide N	Basic N	Humin N	Residual N
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Oct. 7	.190	.149	.041	.0003	.029	.019	.0015	.008	.0000	.012
Oct. 13	.187	.145	.044	.0006	.041	.021	.0021	.009	.0005	.011
Oct. 18	.162	.116	.046	.0004	.025	.017	.0033	.008	.0003	.017
Nov. 24	.157	.102	.055	.0007	.030	.021	.0029	.014	.0016	.015
Jan. 1	.145	.098	.047	.0005	.026	.019	.0023	.016	.0008	.008
Feb. 22	.177	.099	.078	.0002	.043	.029	.0063	.016	.0004	.026

Curing temperature 30°C., relative humidity 95 to 100 percent

Oct. 18	.189	.132	.057	.0003	.030	.020	.0036	.013	.0006	.020
Nov. 24	.184	.127	.057	.0006	.034	.029	.0040	.011	.0013	.011
Feb. 22	.162	.113	.049	.0002	.026	.020	.0026	.024	.0000	.002

Table 17. Distribution of nitrogen expressed as percentages of the fresh weight at harvest time. Potatoes cured at different temperatures and humidities and stored at 10 to 12°C. Curing period October 7 to October 18. (1939 crop)

Curing temperature 40°C., relative humidity 70 to 75 percent

Date of Analysis	Total N	Protein N	Non-Protein N	Ammonia N	Alpha Amino N	Mono Amino N	Amide N	Basic N	Humin N	Residual N
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Oct. 7	.190	.149	.041	.0003	.029	.019	.0015	.008	.0000	.012
Oct. 13	.159	.095	.064	.0006	.049	.036	.0049	.008	.0014	.013
Oct. 18	.175	.088	.087	.0005	.058	.045	.0086	.013	.0014	.019
Nov. 24	.185	.109	.076	.0020	.040	.029	.0117	.015	.0013	.017
Jan. 1	.176	.089	.087	.0011	.048	.042	.0071	.022	.0022	.013
Feb. 22	.178	.083	.095	.0012	.049	.036	.0138	.020	.0021	.022

Curing temperature 40°C., relative humidity 90 to 95 percent

Oct. 18	.141	.056	.085	.0004	.055	.043	.0084	.013	.0018	.018
Nov. 24	.164	.091	.073	.0012	.041	.032	.0089	.013	.0004	.018
Feb. 22	.170	.067	.103	.0011	.051	.041	.0167	.020	.0020	.022

Ammonia and humin nitrogen increased during curing. These forms of nitrogen were present in very small amounts and in most cases represent less than one percent of the total nitrogen. Residual nitrogen increased in every case during the curing period. It should be remembered that the residual nitrogen in the 1938 experiments represents the difference between the total soluble non-protein nitrogen and the sum of the ammonia, alpha amino, and the amide nitrogen. The residual nitrogen of the 1939 data represents the difference between the total soluble non-protein nitrogen and the sum of the ammonia, mono-amino, amide, basic, and humin nitrogen. Although the trend in the residual nitrogen fraction was the same during the curing period for the two years considerable variation occurs during storage. This may be due in part to the method of calculation.

The hydrolysis of protein continues to some extent after the sweet potatoes are placed in storage. An increase in the non-protein fraction is noted particularly in the February sampling of both years. The lots cured at 30°C. and high humidity showed the least protein hydrolysis or change in the relative amounts of protein and soluble non-protein nitrogen during the storage period.

Amide nitrogen increased during the latter part of the storage period and to a much greater extent in the lots cured at the higher temperature.

The glutamine nitrogen content of the harvest sample was approximately .0005 percent of the fresh weight or one third of the amide nitrogen. No glutamine nitrogen could be detected in the lots cured at 30°C. in the February sampling.

The changes in the amino nitrogen were not consistent. A decrease

occurred during storage in the 1938 experiments while in 1939 the amino nitrogen tended to remain more nearly constant. A slight trend toward an increase may be present in the lots cured at the lower temperatures.

No very definite trends occur in the ammonia and humin nitrogen during storage except that they appear in larger quantities in the lots cured at the higher temperatures.

Basic nitrogen increased during the storage period. In 1938 the fluctuations in this fraction were comparatively small but in 1939 an increase was noted in all sets.

The residual nitrogen increased during storage in both sets of experiments in 1938. In 1939 there was only a slight tendency toward an increase. An exception was noted in the lots cured at 30°C. and high humidity where a decided decrease in the residual nitrogen occurred. Whether any significance can be attached to the mid-storage season decrease and the later increase in the residual nitrogen in the lots of the other three sets in the 1939 experiments is not known.

The relative distribution of the various nitrogen fractions is more clearly shown by expressing them as percentages of the total nitrogen. These results are given in Tables 18 and 19. The changes in the various fractions that were previously pointed out become more evident after a study of these tables.

Table 18. Distribution of nitrogen expressed as percentages of the total nitrogen in sweet potatoes cured at different temperatures and stored at 9 to 10°C. Curing period October 12 to October 22. (1938 crop)

Curing temperature 30°C.

Date of Analysis	Protein N	Non-Protein N	Ammonia N	Alpha Amino N	Amide N	Basic N	Residual N
	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Oct. 12	66.82	33.18	.46	21.66	3.69	4.61	7.37
Oct. 22	62.34	37.66	.67	19.67	2.51	6.28	14.81
Nov. 23	62.88	37.12	.49	12.12	3.79	8.33	20.72
Dec. 31	62.50	37.50	.78	11.33	7.03	8.20	18.36
Feb. 10	55.56	44.44	.62	4.94	7.82	7.41	31.06

Curing temperature 35°C.

Oct. 22	59.71	40.29	.51	24.54	.73	8.79	14.51
Dec. 31	54.62	45.38	.96	12.31	7.69	8.46	24.42
Feb. 10	49.53	50.47	.69	5.33	10.34	9.40	34.11

Table 19. Distribution of nitrogen expressed as percentages of the total nitrogen in sweet potatoes cured at different temperatures and humidities and stored at 10 to 12°C. Curing period October 7 to October 18. (1939 crop)

Date Analysis	Protein N	Non-Protein N	Ammonia N	Alpha Amino N	Mono-Amino N	Amide N	Basic N	Humin N	Residua N
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Curing temperature 30°C., relative humidity 80 to 85 percent									
Oct. 7	78.42	21.58	.16	15.26	10.00	.79	4.21	.00	6.42
Oct. 13	76.47	23.53	.32	21.93	11.23	1.12	4.81	.27	5.78
Oct. 18	71.60	28.40	.25	15.43	10.49	2.04	4.94	.19	10.49
Nov. 24	64.97	35.03	.45	19.11	13.38	1.85	8.92	1.02	9.41
Jan. 1	67.59	32.41	.34	17.93	13.10	1.59	11.03	.55	5.80
Feb. 22	55.93	44.07	.11	24.29	16.38	3.56	9.04	.23	14.75
Curing temperature 30°C., relative humidity 95 to 100 percent									
Oct. 18	69.84	30.16	.16	15.87	10.58	1.90	6.88	.32	10.32
Nov. 24	69.02	30.98	.33	18.48	15.76	2.17	5.98	.71	6.03
Feb. 22	69.75	30.25	.12	16.05	12.35	1.61	14.81	.00	1.36
Curing temperature 40°C., relative humidity 70 to 75 percent									
Oct. 13	59.75	40.25	.38	30.82	22.64	3.08	5.03	.88	8.24
Oct. 18	50.29	49.71	.29	33.14	25.71	4.91	7.43	.80	10.57
Nov. 24	58.92	41.08	1.08	21.62	15.68	6.32	8.11	.70	9.19
Jan. 1	50.57	49.43	.62	27.27	23.86	4.03	12.50	1.25	7.17
Feb. 22	46.63	53.37	.67	27.52	20.22	7.75	11.24	1.18	12.36
Curing temperature 40°C., relative humidity 90 to 95 percent									
Oct. 18	39.72	60.28	.28	39.01	30.50	5.96	9.22	1.28	13.04
Nov. 24	55.49	44.51	.73	25.00	19.51	5.43	7.93	.24	10.67
Feb. 22	39.41	60.59	.65	30.00	24.12	9.82	11.76	1.18	13.06

Distribution of Nitrogenous Compounds in the Proximal and Distal Ends of the Sweet Potato

It has been shown that the seed and stem ends of the Irish potato tuber differ in content and form of nitrogen (4). This suggested the possibility of a difference in the nitrogen distribution of the proximal and distal ends of the sweet potato.

Analyses were made of the proximal and distal halves of the harvest sample and of potatoes that had been in storage for six weeks. The samples were extracted on the dates indicated in the table. The non-protein nitrogen solution was preserved with toluene, stored at room temperature, and analyzed on February 9. The results are given in Table 20.

Table 20. Distribution of nitrogen in the proximal and distal halves of sweet potatoes. Results are expressed as percentages of the fresh weight at the time of analysis.

	Moisture	Total N	Non-Protein N	Ammonia N	Alpha Amino N	Mono Amino N	Amide N	Basic N	Residual N
Harvest sample, October 7.									
Proximal half	75.68	.187	.044	.0011	.020	.013	.003	.010	.017
Distal half	75.60	.181	.044	.0008	.019	.012	.003	.010	.018
Potatoes cured and stored until November 27.									
Proximal half	75.84	.178	.062	.0012	.036	.018	.008	.010	.025
Distal half	75.81	.172	.054	.0016	.032	.019	.007	.013	.013

The proximal half showed a slightly higher total nitrogen content. The variations were so small that it may be concluded from this experiment there is no apparent difference in the nitrogen distribution in the proximal and

distal halves of the sweet potato.

Distribution of Nitrogenous Compounds in the Inner and Outer Areas of the Sweet Potato

In the mature sweet potato root a somewhat irregular but distinct cambium ring separates a narrow cortex and periderm from the inner areas of storage parenchyma and vascular tissue.

Sweet potatoes in a harvest lot and in a lot that had been in storage for 6 weeks were divided into inner and outer portions. A fair mechanical separation of the two areas was made by using a sharp knife. The inner portion contained the greater part of the meristematic tissue of the cambium ring. The samples were extracted. The soluble non-protein fraction was preserved with toluene, stored, and analyzed on February 10. The results are given in table 21.

Table 21. Distribution of nitrogen in the inner and outer portions of the sweet potato expressed as percentages of the fresh weight at the time of analysis.

	Moisture	Total N	Non-Protein N	Ammonia N	Alpha Amino N	Mono Amino N	Amide N	Basic N	Residual N
Harvest sample, October 7.									
Outer portion	74.46	.178	.037	.0031	.012	.003	.004	.014	.013
Inner portion	76.61	.160	.041	.0004	.024	.018	.003	.009	.010
Potatoes cured and stored until November 27.									
Outer portion	74.64	.195	.051	.0016	.029	.020	.005	.007	.017
Inner portion	77.12	.159	.061	.0002	.037	.016	.005	.012	.028

There is an appreciable difference in some of the nitrogen fractions of the inner and outer portions of the sweet potato. The moisture content was found to be higher in the inner portion. The data in Table 21 was recalculated to the dry weight basis and presented in Table 22.

Table 22. Distribution of nitrogen in the inner and outer portions of the sweet potato expressed as percentages of the dry weight at the time of analysis.

Harvest sample, October 7.

	Total	Non-Protein N	Ammonia N	Alpha Amino N	Mono Amino N	Amide N	Basic N	Residual N
Outer portion	.697	.145	.012	.047	.012	.016	.055	.050
Inner portion	.684	.175	.002	.103	.077	.013	.038	.045

Potatoes cured and stored until November 27.

Outer portion	.769	.201	.006	.114	.079	.020	.028	.069
Inner portion	.695	.267	.001	.162	.070	.022	.052	.122

The data in Tables 21 and 22 show that the outer portions were higher in total nitrogen. The inner areas contained a higher percentage of soluble non-protein nitrogen which is accounted for largely in the amino nitrogen fraction.

Keeping Quality of Sweet Potatoes Cured Under Different Conditions

A lot of potatoes was cured for 11 days at 30°C and a relative humidity of 80 to 85 percent, and stored for four months in a refrigerator at a temperature of 10 to 12°C and at a relative humidity of 80 to 85 percent. These potatoes kept comparatively well in storage during the 1939-1940 season. The ends of some of the roots were shriveled, indicating an excessive loss of moisture which probably occurred during the curing period although the ends merely appeared spongy at that time and became shriveled later.

Figure 1 shows a lot cured at 30°C. and a relative humidity of 95 to 100 percent. These potatoes kept very well and compared with all other treatments lost the least weight during the storage period. The entire loss expressed as percentage of the harvest weight amounted to 6.35 percent. There was very slight evidence of shriveling and the potatoes remained firm throughout the storage period.

Figure 2 shows a lot cured at 40°C and a relative humidity of 70 to 75 percent and stored in a basement at approximately 10 to 12°C. The effects of low humidities during curing and storage are very evident in this picture.

Sweet potatoes cured at 40°C. and a relative humidity of 90 to 95 percent and stored for four months at 10° to 12°C and a relative humidity of 80 to 85 percent appeared sound but when they were examined internally about one half of the lot appeared as shown in figure 3. The internal breakdown was noted when the roots were removed from the curing ovens on October 18,

and was found in some of the potatoes from every lot in the set cured at high temperature and high humidity. It was not found in any of the lots subjected to the other three curing conditions.

The region of breakdown was more or less centralized in the tissue just inside the cambium ring. The remnants of the cells were pure white in appearance but the tissue surrounding the cavities and destroyed cells turned dark very rapidly when exposed to the air.

Artschwager (7) has described an internal breakdown that he found in sweet potatoes which had been in storage for a number of weeks. The description and illustrations given by him correspond very closely with the conditions observed in the group of potatoes just described. Artschwager referred to the cavities as "polyhedral chambers lined with cottony debris of the disintegrated tissue". He considered the mechanism of their formation might be the same as that in the lysigenous air spaces found in the stems, leaves, and roots of grasses, sedges and other plants. The same writer suggests that noting the changes which take place under various conditions of storage might help to provide a satisfactory explanation of the breakdown.

Only those potatoes cured at high temperatures combined with high humidity showed the internal breakdown. Therefore it is evident that the breakdown is correlated with the curing conditions and not with any growth processes.

Fig. 1. Sweet potatoes cured for 11 days at 30°C. and a relative humidity of 95 to 100 percent. The picture was taken after the potatoes had been stored in a refrigerator for four months at 10 to 12°C. and a relative humidity of 80 to 85 percent.

Fig. 2. Sweet potatoes cured for 11 days at 40°C. and a relative humidity of 70 to 75 percent. The picture was taken after the potatoes had been stored in a basement for four months at a temperature of approximately 10 to 15°C.

Fig. 3. Internal breakdown as seen in the sweet potatoes cured at 40°C. and a relative humidity of 90 to 95 percent.

SUMMARY AND CONCLUSIONS

Maryland Golden sweet potatoes were cured under different conditions of temperature and humidity and placed in storage. Chemical analyses were made and the keeping qualities noted periodically throughout the curing and storage periods.

A rapid hydrolysis of starch to sugar occurred during curing and continued less rapidly throughout storage. The increase in sucrose content almost entirely accounted for the increase in total sugars. Reducing sugars showed comparatively little change. A marked decrease in the total determined carbohydrates occurred during storage when calculated as percentages of the weight at harvest time.

An increase in total pectic material was found in all lots during the curing period. With the first evidence of decay a marked decrease in all pectic constituents was noted.

A distinct hydrolysis of protein occurred in all treatments during the curing period. A more rapid hydrolysis was noted at the higher temperatures and at the higher humidities which resulted in an increase in nearly all of the soluble fractions over those cured at the lower temperatures and humidities. Residual nitrogen increased in all lots during curing. Increases were noted in humin and ammonia nitrogen but both fractions were present in very small quantities. Lots cured at the higher humidities showed the least hydrolysis of protein during the subsequent storage period. Amide and basic nitrogen tended to increase in all lots during storage.

The proximal and distal halves of the sweet potato were found to be almost identical in nitrogen distribution and content. Comparison

of the nitrogen content of the inner and outer portions of the sweet potato showed the inner portion to be higher in amino nitrogen and soluble non-protein nitrogen but lower in total nitrogen.

The effect of humidity during the curing period has been shown to be a very important factor in the curing process. Sweet potatoes cured at 30°C. and high humidity showed the least shrinkage and were in the best condition after 4 months of storage. A combination of high temperature and high humidity during curing was conducive to an internal breakdown not found under other curing conditions.

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