THE EFFECT OF CONTROLLED ATMOSPHERES ON THE KEEPING QUALITY OF SWEETPOTATOES

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INTRODUCTION

The sweetpotato of commerce consists of the thickened roots of the sweetpotato plant Ipomea batatas (L) Lam.

Sweetpotatoes are recognized as an important dietary component for humans and livestock in the United States and various parts of the world chiefly because of their high carbohydrate and carotene (provitamin A) content.

Storage of sweetpotatoes is required for a continuous supply in all seasons, and propagation of the crop depends upon the storage of the seed roots from one growing season to the next.

Successful storage of sweetpotatoes is one of the most serious problems confronting the sweetpotato industry. Losses in storage frequently amount to 25% and occasionally as high as 50% of the crop.

Curing of stored sweetpotatoes is a commercial practice recommended to decrease decay from wounds occurring in harvesting and handling. In curing, layers of protective cells (periderm) are formed in the wound area which inhibit the entrance of decay organisms and decrease water loss. A temperature of up to 85 to $90^{o}F$ is used for several or more days, with a relative humidity of 85 to 90%. Sweetpotato holding temperature after curing is 55 to $60^{o}F$ with 85 to 90% relative humidity.

Roots often fail to keep well even when recommended curing procedures and proper storage conditions have been provided.

Although modern methods of sweetpotato storage have decreased losses from disease and shrinkage, appreciable weight loss still occurs during the storage period.

Much experimental work has been done on the storage of different fruits and vegetables in controlled atmosphere (CA) storage. Some of the findings have been commercially used as with apples and pears.

Interest in controlled atmosphere storage and its development made it possible to store 14 million bushels of apples in controlled atmosphere in 1964 in the United States. This growth in capacity was probably due to the realization that with certain varieties better quality can be achieved in controlled atmosphere storage than in cold storage.

Controlled atmosphere storage involves storage of the produce in refrigerated chambers under lower than normal oxygen and higher than normal carbon dioxide levels.

Fresh fruits and vegetables carry on respiration. During respiration fruit sugars are oxidized and oxygen is used. As a result of the process, carbon dioxide, water vapor, and heat are produced. The more rapid the rate of respiration the faster the produce deteriorates. The rate of respiration, ripening, and deterioration may be retarded in several ways. One of these is to lower the temperature. However, sweetpotatoes are sensitive to a low temperature which causes chilling injury. Most sweetpotatoes storage studies recommended a storage temperature of 55 to 60^{o}F.

It is possible that other methods used to reduce respiration might be beneficial in the storage of sweetpotatoes. One such method is lowering the oxygen level below the normal 21 percent and/or increasing the carbon dioxide level above the normal level of 0.03 percent. This is the basic principles involved in controlled atmosphere storage.

The use of high concentrations of carbon dioxide in transit of some produce and the use of gas tight polyethylene film liners provide a modified atmosphere.

Storage of sweetpotatoes under modified atmospheres was studied by Senn (74) in 1958. Results were not encouraging. However, only a few possible combinations of oxygen and carbon dioxide atmospheres in the natural controlled atmosphere range were tested. A limited number of roots of one variety, Nemagold, were used in the study and they were stored for only a short period.

The use of a larger number of sweetpotato varieties, more atmosphere levels, and longer storage periods were needed to help ascertain whether or not CA storage might be applicable for sweetpotatoes. This study was begun in the fall of 1963 to determine the effect of several combinations of carbon dioxide and oxygen in the natural CA range on several varieties of sweetpotatoes. The effect of the different CA levels was studied on decay, weight loss, taste of raw and baked roots, dry matter, soluble solids, shelf life, sprouting, flesh color, and carotene content.

LITERATURE REVIEW

In prehistoric times the sweetpotato was used for food in the tropics. No storage problems existed when the sweetpotato was growing in its native habitat. However, after this plant was taken to countries having a temperate climate, it was necessary to devise a method of storage to keep the edible fleshy roots alive and sound throughout the winter to have them available as winter food and for use in the reproduction of the plant.

The requirements for the successful storage of the sweetpotato differ from those recommended for most vegetable crops in its need for a relatively high storage temperature.

Cooley (18) in his review of the origin of the sweetpotato and its storage practices reported that many generations ago an Indian tribe carried the sweetpotato from a tropical region to a more temperate climate. After trial and error, they probably learned the importance of a warm storage for the keeping of the sweetpotato. Among the records of sweetpotato storage are the details of the construction of the sweetpotato cellar in which heat was used. It was once recommended that sweetpotatoes be piled on poles and a smoky fire be made every day for three or four weeks. Special emphasis was given to smoke but heat rather than smoke was probably the important factor. This was one of the earliest records of the use of heat in curing of sweetpotatoes.

Sweetpotato roots are highly perishable when stored under unfavorable conditions. Therefore, storage treatments demand exacting procedures to guarantee successful storage.

The fundamental principles to keep sweetpotato roots in a viable condition and to prevent decay until the next season are proper curing and a relatively warm storage with high relative humidity.

Curing

Formation of periderm.

During harvesting of the sweetpotato roots injury is unavoidable to the delicate skin either by harvesting implements or through abrasion of roots against sand. Even under the greatest possible care in harvesting and handling, there are two small wounds on almost every root, one at each end. A cut or broken place in sweetpotatoes will heal under proper conditions forming a new periderm layer.

Several investigators (53, 58, 68, 79) indicated by their experimental work that the purpose of curing is to encourage the development of new cells commonly called wound cork because of their corky nature.

The development of the wound periderm layer was reported (79) to differ in thickness from one variety to another. The cork layer was reported to be beneficial in reducing the possibilities of infection by decay causing organisms and excessive moisture loss (8, 13, 58, 68, 69, 70).

Length of curing period.

Numerous investigations (8, 57, 84) have been carried out to determine the exact conditions most favorable for the healing process.

Lutz (58) reported that the length of time required for proper curing can not be stated as definitely as can the temperature or humidity requirement. The condition of the crop at harvest, the season of the year, the weather during the curing period, and the efficiency of the house and its operation all determine how rapidly the curing process will proceed.

In practice the length of the curing period generally ranges from 5-10 days. However, longer curing requires more heat and may result in excessive sprouting (57). Many workers (13, 37, 70) recommended a period of 6-8 days at 85°F and 90% relative humidity.

McCombs (64) concluded from his study that four days at 85°F and relative humidity of 92% wound cork begins to form in two days and is well developed in five to six days.

Poole (70) pointed out that ventilation should be provided continuously to supply necessary fresh air for roots during curing. However, Thompson (81) has shown that ventilation during commercial curing is neither essential nor desirable except to control temperature or condensation of water vapor.

Pope (71) and McCombs (64) in their studies on the effect of length of curing period on the quality of sweetpotatoes found that there was little difference in dry matter or total and reducing sugars at the end of curing periods of four and 10 days. Roots cured for 10 days had lost approximately 11 percent more weight than roots cured for four days.

Curing temperature.

Sweetpotato curing temperatures employed vary considerably. Daines (22) found that roots held at 60°F, regardless of humidity, had not developed a callus layer even after one month of storage. If the curing temperature was 80°F and the humidity about 85 percent, the callus layer was well developed in four days.

Lauritzen (53) reported that the rate of wound healing tended to increase as the temperature, combined with the relative humidity above 90 percent, is raised from 53.6°F to 89.6°F. Above 89.6°F wound healing starts to decline.

Appleman (6) reported that the best combination of temperature and relative humidity was 86°F and 95-100 percent relative humidity for the Maryland Gold variety. Sweetpotatoes cured at a temperature higher than 86°F showed breakdown.

Curing relative humidity.

Weimer and Harter (84) found that suberization and formation of wound periderm in sweetpotatoes occurred much more rapidly at higher humidity than at lower. The benefit of curing was then ascribed to healing of the wounds and consequent prevention of entrance of decay organisms. A high relative humidity is now recognized as a primary requisite for rapid curing as indicated by Lauritzen (53).

Lutz (58) pointed out that even though the temperature is high enough, healing will not take place promptly if the air surrounding the sweet-potatoes is as dry as 66 percent relative humidity.

Daines (23) found that there was an increase in spoilage when sweetpotatoes were cured at lower humidity than if they were cured at a higher humidity. The increase in spoilage was 2-1/2 times as much as those cured at higher humidity.

Curing is generally practiced in areas where sweetpotatoes are produced. It can be done on the farm without an elaborate curing chamber or temperature and relative humidity control devices as long as the structure is reasonably air tight and care is exercised to insure the availability of heat and moisture (5, 16). The convenience of electric heating has made the construction of larger storage houses an increasingly popular method of curing sweetpotatoes.

Advantage of curing.

As reported earlier curing results in the formation of wound cork which reduces the infection by decay causing organsims, and excessive moisture loss (8, 13, 58, 76).

Anderson (2) has shown that there was a small increase in the percentage of dry matter during the curing period. There was also a small gain in absolute carotene content of the Porto Rico variety during the curing period.

Cooley (19) indicated that when black rot is present it is probably best to cure the sweetpotatoes at 85°F and a high relative humidity for 5-10 days. This will allow time for development of much of the rot that would otherwise develop after storage.

Kushman (43, 44) reported that some success has been achieved in controlling decay by recuring the roots after storage and before shipping.

Storing

After curing sweetpotatoes, special care in handling is recommended since the roots are easily wounded.

The temperature of the storage house should be brought down below 60°F but not lower than 50°F as rapidly as possible, preferably during the week or two after curing (58).

Commercially cured sweetpotatoes are stored to extend their marketing period. The length of time a crop can be successfully stored depends on several environmental factors. Temperature and humidity are generally considered the major factors upon which the storage behavior of sweetpotatoes depends.

Storage temperature.

Being of tropical origin, sweetpotatoes are very susceptible to low temperature injury. A great deal of work has been done on the effect of storage temperature. In much of the literature on the storage of cured sweetpotatoes, recommendations for the proper storage temperature are fairly constant. Most workers (9, 20, 21, 26, 58, 64, 65, 67, 70, 84) favor temperatures of 50-60°F. Others (37, 58, 68, 86) reported a temperature of 55°F.

Lutz (58) states that the culinary quality of cured roots held at 50^{o}F is not equal to that of roots held at fluctuating temperature with a minimum of 50^{o}F and an average of 58^{o}F.

Cooley (21) studied the effect of temperature on quality of stored sweetpotatoes. At the end of three months storage at 50^{o}F, 55^{o}F and 60^{o}F, there was no significant difference in percentage of sound sweetpotatoes. After seven months storage, there was a large difference. A temperature of 55^{o}F to 60^{o}F was necessary for successful storage.

Temperature of 55^{o}F to 60^{o}F were reported (9, 49, 62) to stop the development of corky spots during an eight or nine months storage period. However, corky spots increased at a higher temperature of 70^{o}F to 80^{o}F.

The effect of holding sweetpotatoes at low temperature has been studied. Some workers (1, 52) found that exposure of sweetpotatoes for 10 days at temperatures above the freezing point and below 48.2^{o}F would not be injurious. A prolonged exposure, however, would subject the roots not only to chilling injury, but also to their susceptibility to infection by certain rotting organisms (58, 63, 86). Wright (85) indicated that varieties differ in their sensitivity to low temperature.

Kimbough and Laüritzen (42, 52) described the effect of cold on the internal condition of the sweetpotato. They indicated that the chilling injury may or may not be evident at the end of the chilling period and that such signs of injury may become evident after a period of storage even under temperatures favorable to sweetpotatoes.

Hildebrand and Lutz (37, 56) showed that subjecting sweetpotatoes to a short period of chilling developed more decay in uncured roots than in those which had been cured.

Kushman (47, 48, 55) reported that roots stored at 50^{o}F did not have good keeping, culinary and sprouting qualities. Such roots developed high respiration rates and produced more carbon dioxide than roots stored at a higher temperature.

Lewis and Whiteman (55, 85) showed that a temperature of 50^{o}F had a deleterious effect on the color of the raw roots and also on the color and flavor of the cooked product.

Storage relative humidity.

Much less study has been given to the effect of storage humidity than to the temperature.

Early workers were of the opinion that high humidity was conducive to decay and therefore undesirable both during curing and after storage.

Manns and Thompson (61, 81) studied the effects of humidity and temperature after curing on the storage of sweetpotatoes. They concluded that a humidity of 80 percent or above was dangerous, that it would produce soft rot. They recommended a relative humidity of 60 percent and warned against humidities higher than 65 percent with a temperature of 55^{o}F.

Lauritzen (54) reported that sweetpotatoes held at 73.4^{o}F developed rhizopus rots most readily at a relative humidity of 75 percent to 84 percent. Departure from this range, either above or below, decreased the amount of infection by rhizopus.

Jones and Rosa (38) reported that the humidity factor in sweet-potatoes storage had not received the attention desired.

Most of the specifications of humidity recommended are based on general observation rather than controlled studies.

Ezell (27) found after two years study that a humidity of 85 percent to 90 percent would appear to be optimum for sweetpotato storage. Humidity was of major importance in determining loss of weight in sweetpotatoes. Minges (68) and Ezell (27) reported that low humidity caused an excessive loss in weight and tended to hasten internal breakdown. High humidity resulted in a high moisture content of the roots during storage but there was no additional decay. Humidity above 90 percent caused surface discoloration and a poor appearance.

Physiological and chemical changes during storage.

The physiological and chemical changes which taken place in sweet-potatoes during storage have received considerable attention.

Blackwell (12) and Pope (71) found that weight loss was greater as storage temperature was increased from 55°F to 83°F. Weight loss for the Porto Rico variety was reported by several workers (25, 28, 57, 65, 67, 73) to be approximately 10 to 15 percent when stored for a period of four months.

Pope (71) reported that there were varietal differences in weight loss under different temperatures. Although weight loss was three to five percent greater at 65°F than at 55°F for the Porto Rico variety, it was about the same at 55°F and 62°F for the Maryland Gold variety. Scott (73) found that Nemagold and Jersey varieties lost approximately twice as much weight as Porto Rico and Goldrush. Loss of weight was more rapid during the curing period and during the later part of storage than during a two or four months storage period.

Ezell (25) found that the dry matter content appears to remain fairly constant throughout the storage period. Pope (71) reported a higher dry matter content of roots held at a higher temperature due to greater moisture loss.

Scott (73) reported that there was a slight increase in dry matter at the end of two months storage followed by a decrease after further storage. The amount of dry matter loss in a six months storage period varied from less than one percent of the harvest value for the Sunnyside variety to more than 25 percent for Nemagold. This loss was largely accounted for in the change in reserve carbohydrate or the starch plus the sugar portion.

McCombs (64) reported that storage temperature may affect the dry matter content. Dry matter was generally higher at 65°F than 55°F. This could be due to increased moisture loss from the roots at the higher storage temperature.

There was agreement among several investigators (10, 32, 34, 35, 71, 74, 81) that the total sugar increases during curing and storage, particularly during the first portion of the storage period. In several studies it has been observed that a marked increase in the total sugar content of roots occurred by the seventh day of curing.

In a study made by Scott (73) an increase during curing was reported for only those varieties having a relatively low content of total sugar at the time of harvest. During the first two months of storage all varieties increased markedly in sugar content. In later storage certain varieties showed a pronounced decrease in percentage of sugar while others maintained a high level throughout the period. The final amount of sugar in most varieties was greater than the amount present at the time of harvest.

Haselbring (36) showed some relation between respiration rate and reducing sugars, but not between respiration and sucrose. Appleman and Smith (7), however, concluded that from their data there was no relation between respiration rate and either reducing or total sugars.

McCombs (64) reported that the length and temperature of storage affected the total sugar content of sweetpotatoes. The difference in accumulation of sugar was suggested to be due to an increase in starch hydrolysis rather than a decrease in utilization of sugar at the lower temperature.

Ezell and MacNair (26, 60) reported an increase in carotene content during curing and storage. Anderson (2) found that during storage the carotene in Porto Rico increased 10 to 15 percent while that in Goldrush decreased 13 percent.

Baumgardner (11) found that storage temperature has an effect on the firmness of the processed sweetpotatoes. Softer potatoes resulted from temperature of 59°F to 86°F while firmer roots resulted from a holding temperature of 32°F.

Controlled atmosphere studies.

Controlled atmosphere storage was originally developed in England by Kidd and West (40). They devised a new system that controlled the carbon dioxide and oxygen content within the storage space, and were able to prolong the life of the fruits in storage. They found that an atmosphere of 5-15 percent O_2 combined with 10-15 percent CO_2 about doubled the storage life of apples as long as the temperature was above that associated with low-temperature injury.

Favorable results on the use of carbon dioxide treatments on a number of fruits were reported by several investigators (14, 15, 66, 76, 80). They found that exposure of sweet cherries, plums, peaches, Bartlett pears, raspberries, dewberries, blackberries, figs, grapefruits, and oranges to carbon dioxide treatments results in less decay, produced firmer fruits, and retarded the rate of ripening.

Kidd and West in 1930 (41) published their recommendations for gas storage of English apples and pears, but commercial development in the U.S. did not occur until after 1940.

Smock (77) reported that in 1958 three million boxes of apples were stored under regular controlled atmosphere storage in the U.S.

With the introduction of the Tectrol gas generator in 1962 (4, 51) it became easier to obtain and maintain the gas concentrations needed for the storage of fresh fruits and vegetables. In 1962 (4) it was reported that 8.6 million bushels of apples, about 7 percent of the crop in the U.S., were stored under CA and Smock (78) reported 14 million bushels in 1965.

From the size of expansion in the use of controlled atmosphere storage to extend the shelf life of the fruits, Kendenburg (39) believed that the controlled atmosphere system of storage will be the major method of future fruit storage.

Tomkins (82) reported that there is a great demand for information concerning the most suitable conditions for the storage of different types of fruits and vegetables under modified atmosphere storage.

Controlled atmosphere research in the storage of several fruits and vegetable was conducted by many investigators.

Anderson (3) reported that several controlled atmosphere tests using cranberries were significantly better than in storage at $46.4^{o}F$ in normal atmospheres. Lyons (59) studied the effect of controlled atmosphere on storage of brussel sprouts and concluded that the quality rating of brussel sprouts held at all CO_2 concentrations was higher than that of those held in air.

Rygg (72) studied the effect of controlled atmosphere storage on California lemons and reported that a concentration of five percent carbon dioxide is suitable for lemons. This concentration was beneficial in delaying degreening and lengthening the period of marketability.

An early investigation concerning the use of controlled atmosphere storage of sweetpotatoes was by Hasselbring (33). He studied the effects of different oxygen pressures on the carbohydrate metabolism of the sweetpotatoes. He concluded that the quantity of carbohydrate consumed in a given period of time in anaerobic respiration was greater than that consumed in normal respiration at the same temperature. Carbon dioxide output was greater under anaerobic conditions. Kushman (45) investigated the relation of internal gas content and respiration to keeping quality of Porto Rico sweetpotatoes. He reported that sweetpotatoes held a week, in atmosphere containing a high level of carbon dioxide and about 20 percent oxygen, developed high respiration rates. When returned to normal atmospheres, the sweetpotatoes failed to develop wound periderm properly and did not keep well.

Senn (74) reported the results of his study on the effect of controlled atmosphere on the composition and respiratory activity of sweetpotatoes. He found that the storage behavior of the roots as measured by compositional changes or organoleptic qualities was not beneficially affected by the changes in normal oxygen and of carbon dioxide content of the storage atmosphere.

In 1964 Kushman (51), using polyethylene film bags for packing sweetpotatoes, found that non-perforated polyethylene bags which had 5.2 percent CO_2 and 12.5 percent oxygen lost 0.1 percent of their weight. Perforated polyethylene bags having atmospheres of 0.2 -

8 percent CO_2 and 20.8 - 19.5 percent oxygen with 96-99 percent relative humidity lost 0.4 - 4.5 percent of their weight. He concluded that reducing weight loss with non-perforated polyethylene bags was off-set by improvement of quality with those held in perforated polyethylene bags. The reduction in quality was due to the fact that relative humidity in the non perforated polyethylene bags was 98 percent or higher and condensation occurred which encouraged sprouting and decay.

METHODS AND MATERIALS

Controlled atmosphere studies were conducted on Nemagold, Oklamar, Porto Rico, and Jersey varieties of sweetpotatoes in the 1963-64 storage season.

In 1964-65 the Centennial and Goldrush varieties were used in addition to the other 4 varieties used in the previous year.

The sweetpotatoes used were commercially grown on the Eastern Shore of Virginia. In 1963 the roots were harvested and handled commercially and were removed from the Eastern Shore within a month after harvest and taken to Blacksburg. In 1964 the roots were carefully picked, field sized, and packed and transported to the V.P.I. storage rooms at Blacksburg.

In both years the roots used were wiped with tissue paper to remove excess soil, weighed, and marked individually using a marking pen. They were then randomized according to their weight. The roots were placed in wooden boxes which had been treated with a copper sulfate disinfecting spray. As soon as the roots were placed in the boxes they were transferred to the curing room where a temperature of 85° and a relative humidity of 85-90% was used for one week. After curing, the boxes were placed in 55 gallon steel drums, which were used as gas-tight chambers. Each drum held 4 boxes of sweetpotatoes. The drum opening was covered with polyethylene film. Vaseline was applied around the edge of the drum, and a rubber gasket around the polyethylene film provided a gas-tight chamber.

In the 1963-64 season a single drum of each atmosphere was used. In 1964-65 there were three drums of each atmosphere, connected together with large plastic tubing.

When 7% or lower carbon dioxide was to be maintained a three to five pound bag of hydrated lime was placed within a drum to help absorb excess carbon dioxide.

Desired atmospheres were obtained in a few days after the drums were sealed. To reduce oxygen concentration to the desired gas level, nitrogen gas was blown into the drums containing the sweetpotatoes. The desired carbon dioxide level was obtained from CO_2 produced as a result of respiration of the sweetpotato roots. Daily checks were made on the concentration of the gases in the drums using an Orsat gas analyzer. When the carbon dioxide concentration in the drums was higher than desired, nitrogen gas was supplied to flush the excess gas. Oxygen was supplied as needed.

In 1963-64 the 12 atmospheres used were:

		Percent Gas Concentration		
Drum	Air Movement	CO_2	O_2	Atmosphere*
1	Continuous flow	2.1	4.1	2 - 4
2	Stagnant	5.1	16.0	5 - 16
3	Stagnant	9.8	10.9	10- 11
4	Stagnant	15.4	5.5	15 - 6
5	Continuous flow then stagnant	1.9	3.8	2 - 4
6	Stagnant	0.3	2.6	0 - 3

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* Designated atmosphere, percent CO_2 and O_2.

Percent Gas Concentration

Drum	Air Movement	CO_2	O_2	Atmosphere*
7	Stagnant	0.8	4.1	1 - 4
8	Stagnant	3.2	4.6	3 - 5
9	Check covered	0.4	18.1	0 - 18
10	Stagnant	6.9	5.0	7 - 5
11	Stagnant	3.0	7.1	3 - 7
12	Check open	0.3	18.7	0 - 19

In 1964-65 fewer combinations of atmospheres were used and more roots and varieties were used. The gas concentrations were:

Percent Gas Concentration

Drum	Air Movement	CO_2	O_2	Atmosphere*
1	Stagnant	6.8	8.2	7 - 8
2	Stagnant	2.9	8.2	3 - 8
3	Stagnant	3.0	10.8	3 - 11
4	Covered check	0.5	18.1	1 - 18
5	Open Check	0.3	18.1	0 - 18
6	Tectrol room	1.9	7.1	2 - 7

Counts of decayed roots were made 3 times in the first year and 2 times in the second year during the storage period. In the first year decay counts were made on the lot, while in the second year one box of about 30 to 34 roots of each variety and atmosphere was removed after 4 months leaving a second box to be checked after 8 months.

To determine weight loss, three to four roots were removed on each of 3 examination dates in the 1963-64 storage period. Roots were weighed individually to determine their weight. In the second year 30-34 roots were weighed individually for weight loss. The losses measured were expressed as percentage of the original weight. Only

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* Designated atmosphere, percent CO_2 and O_2.

roots free from decay were used for weight loss determinations. The weight loss included water loss as well as dry matter loss.

Organoleptic evaluations of raw and baked roots from each variety under each atmosphere were carried out, to evaluate taste. Roots were checked for "off flavor", alcoholic flavor, and bitter taste by tasting roots raw and baked. Baking was carried out at a temperature of 400°F for 1-1½ hours, depending on the size of the roots and the variety used.

Remaining non-decayed roots were held at room temperature and then examined for decay.

To determine the effect of controlled atmospheres on seed-stock sprouting, roots were checked for sprouting after holding at room temperature.

Six roots from each variety and atmosphere were used for dry weight determinations. A sample of 100 grams was taken from 6 roots by cutting 3 cross sections from each roots, one from the middle and one from each end of the roots. The sample was chopped into small pieces, placed in a Waring Blendor vessel with 100 ml. of distilled water and blended for 5 minutes. Aliquots of 50 grams of the resulting blend were used for dry matter determinations. Total dry matter was determined by placing the 50 grams in a 75°F oven for 24 hours then weighing the sample reheating and reweighing until a constant weight was obtained.

Soluble solids were determined with a Ziess table model refractometer. These readings were made on juice expressed from the sweetpotato roots using a special tissue-juice squeezer or by using juice from blended roots.

The pH of the root hemogenate was checked with a pH meter.

Color was determined by the Hunter color and Color-Difference meter. White standard $L = 92.2$ $a_1 = -1\text{-}1$ and $b = 3.1$ on hemogenate of baked roots after peeling was used. Samples were placed on a glass plate for color determinations. The thickness of the puree layer was sufficient to obviate differences in meter reading due to transmitted light.

Carotene content was calculated from the transmittance results obtained by the Hunter Color and Color Difference meter as indicated by Esam and Scott (24).

RESULTS AND DISCUSSION

In discussing controlled atmosphere results the percentage of CO_2 in a given atmosphere will be stated first followed by the percentage of O_2, thus an atmosphere of 2% CO_2 and 4% O_2 will be indicated as 2-4.

Percent of Decay

1963-64. The effect of controlled atmosphere (CA) storage on the percent of decay for the year 1963-64 is shown in Table 1. The different atmospheres had a pronounced effect on the percent of decay as indicated by the Duncan multiple range test at the 5% level.

Sweetpotatoes in an atmosphere of 3-7 were found to be significantly lower in percent of decay after 6 months storage than the covered check, 0-19, and the open check, 0-18. Atmospheres 2-4 (drum 1), 5-16 and 10-11 were significantly lower in percent of decay than the open check but not significantly different from the covered check.

Atmosphere 0-3 had the highest decay and was significantly different from all other atmospheres with the exception of atmosphere 15-6 which had the second highest decay.

The high decay in atmosphere 15-6 could be due to physiological breakdown of the tissue which developed from the high level of CO_2. This may have prevented the periderm from functioning properly and destroyed the ability of the cells to act as a protective barrier against decay organisms. Kushman (45) experimentally showed that a

Table 1. Percent of decay of sweetpotatoes stored for 6 months under controlled atmospheres in 1963-64.

Drum	Air Movement	Atmosphere Percent		Varieties				
		CO_2	O_2	Jersey	Nemagold	Oklamar	Porto Rico	Mean[1]
1	Continuous	2	4	8.3	28.6	9.1	34.4	20.1^{de}
2	Stagnant	5	16	15.4	38.6	37.5	3.3	23.7^{de}
3	Stagnant	10	11	7.5	53.6	25.6	3.0	24.4^{de}
4	Stagnant	15	6	20.0	80.5	78.9	43.3	56.8^{ab}
5	Continuous then Stagnant	2	4	14.3	37.5	2.1	55.6	27.4^{cde}
6	Stagnant	0	3	35.7	100.0	72.2	100.0	77.0^{a}
7	Stagnant	1	4	0.0	82.7	10.8	79.4	43.2^{bcd}
8	Stagnant	3	5	10.5	56.8	17.9	63.6	37.2^{bcde}
9	Open check	0	18	22.6	27.8	20.6	11.5	40.6^{bcd}
10	Stagnant	7	5	16.7	44.4	21.0	41.4	30.9^{cde}
11	Stagnant	3	7	7.1	40.0	16.1	0.0	15.8^{e}
12	Covered check	0	19	48.5	66.6	50.0	28.6	48.4^{bc}
Mean[1]				17.2^{c}	54.8^{a}	30.2^{b}	39.1^{b}	

[1] The superscripts (a,b,c,d, and e) indicate statistical differences among the means at the 5% level by the Duncan Multiple Range Test.

high level of CO_2 prevented proper development of the periderm. The roots in atmosphere 0-3 were found to have a distinct alcoholic smell and taste. This probably resulted from anaerobic respiration caused by the low external oxygen level and deficient oxygen within the roots.

From data in Table 1, it appears that 10% CO_2 was the highest level that could be used with no significant increase in decay. On the other hand, the critical O_2 level seemed to be 5%.

The data also shows that there were significant differences among the varieties at the 5% level. The Nemagold variety exhibited the highest losses from decay under CA during the 6 months storage period. It was significantly different from all other varieties. The Jersey variety showed the lowest percent of decay under all controlled atmospheres than in either the open or covered check. The Oklamar and Porto Rico varieties did not exhibit the high losses of Nemagold but were significantly higher than Jersey.

1964-65. In the second year CA tests the atmospheres used were those found to be within the safe limits from the previous year's results. The percent decay in 1964-65 is presented in Table 2.

After 4 months storage there were no significant differences in decay between treatments. After 8 months storage, the 2-7 atmosphere sweetpotatoes had significantly less decay than those in atmospheres 7-8 and 3-11 but not significantly different than either the covered check, 1-18, or the open check, 0-18. However, the percent of decay was two to three times higher in the covered and open check compared with the 2-7 atmosphere.

Table 2. Percent of decay of sweetpotatoes stored 4 and 8 months under controlled atmospheres in 1964-65.

Atmosphere	Air Movement	Percent CO_2	O_2	Varieties Centennial	Goldrush	Jersey	Nemagold	Oklamar	Porto Rico	Mean
				After 4 months storage						
1	Stagnant	7	8	0.0	0.0	2.4	10.0	3.3	0.0	2.6[a]
2	Stagnant	3	8	0.0	40.0	0.0	16.6	0.0	3.4	10.0[a]
3	Stagnant	3	11	0.0	0.0	0.0	12.9	0.0	0.0	2.2[a]
4	Open Check	1	18	0.0	0.0	0.0	22.6	0.0	6.9	4.9[a]
5	Covered Check	0	18	0.0	0.0	6.8	25.8	0.0	10.3	7.2[a]
6	Continuous flow	2	7	0.0	0.0	0.0	6.9	3.3	0.0	1.7[a]
Mean				0.0[b]	6.7[ab]	1.5[b]	15.8[a]	1.2[b]	3.4[b]	
				After 8 months storage						
1	Stagnant	7	8	0.0	41.2	11.6	60.0	30.0	6.9	24.9[a]
2	Stagnant	3	8	0.0	0.0	4.5	90.0	3.3	6.9	17.4[ab]
3	Stagnant	3	11	0.0	20.6	4.7	56.7	40.0	10.3	22.0[a]
4	Open Check	1	18	0.0	0.0	7.0	26.7	10.0	27.6	11.9[ab]
5	Covered Check	0	18	3.3	2.9	20.9	23.3	26.7	27.6	17.5[ab]
6	Continuous flow	2	7	0.0	0.0	2.3	23.3	0.0	3.5	4.9[b]
Mean				0.6[c]	14.2[bc]	8.5[bc]	46.7[a]	18.3[b]	13.8[bc]	

There were varietal differences similar to those obtained in the previous year. The Nemagold variety had significantly more decay than all other varieties after 4 and 8 months storage except for Goldrush after 4 months. The loss due to decay of Nemagold was high in controlled atmosphere as well as in the checks.

After 4 months storage there were no significant differences in percent decay between Porto Rico, Oklamar, Jersey, and Goldrush. The Centennial variety decay was very low, 0.6%. For all varieties there was a 4.8% average decay after 4 months storage and 16.4% after 8 months.

Since the Nemagold variety exhibited very high losses from decay compared with the other varieties, the percent decay calculated without Nemagold showed that after 8 months decay was low in atmosphere 3-8, 2.9%, and atmosphere 2-7, 1.2%, while the open and covered check had 20.3% and 22.9%, or over 7 times more decay. However, atmospheres 7-8 and 3-11 exhibited high losses, 17.9% and 15.1%.

The higher losses from decay in atmospheres 7-8 and 3-11 were probably due to stagnant conditions, water condensation, and the higher relative humidity than the 2-7 atmosphere in the continuously flushed CA (Tectrol) storage room.

For both years, sprouting which occurred to a greater extent in the Nemagold variety and to a lesser extent in the other varieties could have provided an entry to decay organisms causing more decay.

The development of wound periderm even under favorable conditions may differ in thickness depending on the variety. Therefore, the degree of susceptibility of the sweetpotato roots to entry of decay organisms would be different from one variety to another.

In flushing atmospheres 7-8, 3-11 and to a lesser degree atmosphere 3-8, nitrogen gas was blown in for a period of 5 to 15 minutes to reduce CO_2 in the drums. This might have decreased air and root surface temperature due to the cooling effect of compressed nitrogen gas evaporation causing root surface chilling injury and increased the root susceptibility of decay.

Weight Loss

1963-64. The effect of different atmospheres on the percent weight loss in 1963-64 is shown in Table 3. The data show a greater weight loss in the open check as compared to the loss in CA atmospheres and the covered check.

Weight loss includes loss of water as well as dry matter loss. The greater weight loss in the open check is partly due to the lower relative humidity in the room, about 70-75%, as compared with the relative humidity in the drums, about 95%.

Weight loss was the highest in the Nemagold variety but was not significantly different at the 5% level from Oklamar or Porto Rico. The Jersey variety had the smallest weight loss and was significantly different from the Nemagold.

1964-65. Results similar to those of 1964 were obtained in 1964-65, as shown in Table 4. The open check exhibited the highest weight loss and was significantly different from the CA atmospheres and the

Table 3. Percent weight loss of sweetpotatoes stored for 6 months under controlled atmospheres in 1963-64.

Drum	Percent CO_2	O_2	Jersey	Namagold	Oklamar	Porto Rico	Means
1	2	4	7.4	10.8	8.0	8.2	8.60[b]
2	5	16	6.8	10.7	13.0	7.1	9.40[b]
3	10	11	6.7	12.1	10.4	7.9	9.28[b]
4	15	6	7.4	-	8.5	6.5	7.47[b]
5	2	4	7.6	10.3	11.7	6.2	8.95[b]
6	0	3	8.9	-	9.8	-	9.35[b]
7	1	4	9.1	16.7	10.6	-	12.20[b]
8	3	5	5.5	12.5	13.3	18.5	12.45[b]
9	0	18	9.1	14.8	11.8	8.8	11.13[b]
10	7	5	6.5	8.8	10.7	12.2	9.55[b]
11	3	7	7.2	14.0	10.5	10.8	10.63[b]
12	0	19	23.1	21.9	18.3	15.8	19.78[a]
Mean			8.88[b]	12.88[a]	11.97[ab]	10.61[ab]	

Table 4. Percent weight loss of sweetpotatoes stored 4 and 8 months under controlled atmospheres in 1964-65.

Atmosphere	CO_2	O_2	Varieties: Centennial	Goldrush	Jersey	Nemagold	Oklamar	Proto Rico	Mean
			After 4 months storage						
1	7	8	6.04	5.90	5.16	10.05	7.60	8.16	7.15^{b}
2	3	8	5.59	8.19	5.29	9.04	6.74	8.09	7.15^{b}
3	3	11	5.89	6.41	5.73	9.43	7.18	7.83	7.07^{b}
4	1	18	6.82	7.33	7.62	7.89	7.57	8.87	7.68^{b}
5	0	18	11.24	10.32	11.14	11.23	11.09	13.16	11.36^{a}
6	2	7	6.87	6.53	6.54	9.54	7.88	7.82	7.51^{b}
Mean			7.08^{c}	7.45^{c}	6.90^{c}	9.53^{a}	8.01^{bc}	8.99^{ab}	
			After 8 months storage						
1	7	8	8.48	8.78	8.10	11.16	9.99	9.90	9.40^{c}
2	3	8	8.40	8.96	7.04	15.50	9.90	10.39	10.03^{c}
3	3	11	8.08	9.06	7.94	16.08	10.56	9.59	10.22^{c}
4	1	18	9.00	11.25	12.08	11.74	9.88	11.81	10.96^{c}
5	0	18	15.12	13.94	15.86	18.67	17.36	18.10	16.51^{a}
6	2	7	12.36	11.56	11.56	19.87	12.49	12.69	13.42^{b}
Mean			10.24^{c}	10.59^{bc}	10.43^{c}	15.50^{a}	11.70^{bc}	12.08^{b}	

covered check after 4 and 8 months storage. After 8 months storage the open check had the highest weight loss and the 2-7 atmosphere the next highest loss. The losses in atmospheres 7-8, 3-8, 3-11 and the covered check were significantly lower than the open check or the 2-7 atmosphere weight loss.

Weight loss in the Nemagold variety was not significantly higher than that of the Porto Rico variety after 4 months storage but was significantly higher after 8 months. Weight loss in the varieties Centennial, Jersey, Goldrush and Oklamar were significantly lower than that of the Nemagold. The differences in weight loss among varieties may be explained as due to one or more of the following factors:

Varieties differ in the periderm thickness formed during curing which influences water loss. Excessive sprouting was observed in the Nemagold variety and little in the Jersey variety. Sprouting would contribute to the higher rate of water loss. The gas diffusion permeability of the different varieties may vary. Low oxygen and carbon dioxide gas exchange would result in low internal oxygen levels and anaerobic respiration. Roots carrying on anaerobic respiration would consume more material in a given period than those carrying on aerobic respiration according to Hasselbring, 1918 (33) which would result in a higher weight loss.

Total Losses

1963-64. The effect of controlled atmosphere storage on percent total losses in 1963-64 are presented in Table 5.

Table 5. Percent total loss of sweetpotatoes stored for 6 months under controlled atmospheres in 1963-64.

Drum	Atmosphere CO_2	O_2	Jersey	Nemagold	Oklamar	Porto Rico	Mean
1	2	4	15.7	39.4	17.1	42.6	28.7[de]
2	5	16	22.2	49.3	50.5	10.4	33.1[de]
3	10	11	14.2	65.7	36.0	10.9	31.7[de]
4	15	6	27.4	80.5	87.4	54.8	62.5[ab]
5	2	4	21.9	47.8	13.8	61.8	36.3[cde]
6	0	3	44.6	100.0	82.0	100.0	81.7[a]
7	1	4	9.1	99.4	21.4	100.0	57.5[bc]
8	3	5	16.0	69.4	31.2	82.1	49.7[bcd]
9	0	18	31.7	42.6	32.4	20.4	31.8[de]
10	7	5	23.2	53.2	31.7	53.6	40.4[cde]
11	3	7	14.3	54.0	26.6	10.8	26.4[e]
12	0	19	71.6	88.5	68.3	44.4	68.2[ab]
Mean			26.0[c]	65.8[a]	41.5[b]	49.3[b]	

Total losses were based on percent loss in weight, due to water and dry matter loss and decay.

The data show that sweetpotatoes in atmosphere 3-7 were significantly lower in total losses as compared with atmospheres 15-6, 0-3, 1-4, 3-5 and the open check 0-19. There was more total loss in the covered check, 0-18, but not significantly different than in atmospheres 3-7, 2-4 (drum 1) and 10-11.

The variety Nemagold had the highest total loss and was significantly different from all other varieties. Oklamar and Porto Rico were second highest and were significantly higher than Jersey.

The high total loss in atmospheres 0-3, 15-6, and 1-4 could be due to either low oxygen level in 0-3 and 1-4 or the high CO_2 level in 15-6 which was discussed previously. Under these conditions decay organisms could penetrate the periderm tissue more readily and increase decay.

In the open check, 0-19, high total losses were due to the high decay that developed and the high weight loss caused by the low relative humidity of 70-75%.

<u>1964-65</u>. The effect of controlled atmosphere storage for 4 and 8 months on total losses of sweetpotatoes in 1964-65 are shown in Table 6.

The data show that total losses after 4 months storage were higher in the open check as well as in atmosphere 3-8 compared with losses in atmospheres 7-8, 3-11, and 2-7.

After 8 months storage the open check was still the highest in total losses. The increase in total losses up to 8 months storage was

Table 6. Percent total loss of sweetpotatoes stored 4 and 8 months under controlled atmospheres in 1964-65.

Atmosphere	CO_2	O_2	Centennial	Goldrush	Jersey	Nemagold	Oklamar	Porto Rico	Mean
					Varieties				
1	7	8	6.0	5.9	7.1	24.9	10.0	8.2	10.4^{b}
2	3	8	5.6	43.1	5.3	27.5	6.7	15.7	17.3^{a}
3	3	11	5.9	6.4	5.7	29.9	7.2	7.8	10.5^{b}
4	1	18	6.8	7.3	7.6	24.9	7.6	17.2	11.9^{ab}
5	0	18	11.2	10.3	16.1	32.3	11.1	22.4	17.2^{a}
6	2	7	6.9	6.5	6.5	16.0	14.5	7.8	9.7^{b}
Mean			7.1^{b}	13.3^{b}	8.1^{b}	25.9^{a}	9.5^{b}	13.2^{b}	
					After 8 months storage				
1	7	8	8.5	38.6	20.1	61.7	48.6	13.7	31.9^{bc}
2	3	8	8.4	8.7	9.7	100.0	16.5	15.2	26.4^{bc}
3	3	11	8.1	34.1	12.5	72.0	54.5	23.3	34.1^{b}
4	1	18	9.0	11.3	16.5	38.9	24.8	39.8	23.4^{bc}
5	0	18	16.7	15.7	33.7	44.9	44.2	48.7	57.4^{a}
6	2	7	12.4	11.6	12.8	46.7	12.5	15.8	18.6^{c}
Mean			10.5^{d}	20.0^{bcd}	17.6^{cd}	60.5^{a}	33.5^{b}	26.1^{bc}	

drastic in the open check which amounted to 40% more loss than in the 4 month period. This was followed by atmospheres 7-8 which lost 21% more and the covered check with 11%. Atmospheres 3-8 and 2-7 had the smallest increase in total losses, about 9%.

Varietal differences were pronounced. The Nemagold variety lost approximately 3 times more than the Centennial or Jersey after 4 months and 6 times more than Centennial after 8 months and 3 times more than Goldrush, Jersey or Porto Rico.

Dry Matter

1963-64. The effect of controlled atmosphere storage on the change of dry matter content of sweetpotatoes is shown in Table 7 and 8.

In Table 7 the dry matter values were based on the weight at time of sampling. There were no significant differences between the check and the CA atmospheres with exception of the open check which was significantly higher in dry matter compared with 10-11. The higher dry matter content of the open check was due to a relatively high loss in moisture because of a lower relative humidity. Therefore, dry matter percent appears to be higher.

In Table 8 the dry matter values were determined on the basis of after harvest weight, the weight of roots at the time they were placed in storage at VPI. The amount of dry matter in grams per 100 grams of initial fresh weight was calculated by substracting the weight loss from 100 and multiplying the difference by the final dry matter percent. On this basis the amount of dry matter was significantly lower in the

Table 7. Percent dry matter* of sweetpotatoes stored 6 months under controlled atmospheres in 1963-64

Drum	Atmosphere CO_2	O_2	Jersey	Oklamar	Porto Rico	Mean
1	2	4	21.2	23.0	29.8	24.67[ab]
2	5	16	22.5	21.0	29.4	24.30[ab]
3	10	11	24.5	19.0	28.1	23.87[b]
4	15	6	25.6	-	-	-
5	2	4	24.1	24.3	27.9	25.43[ab]
6	0	3	25.6	-	-	-
7	1	4	23.4	-	-	-
8	3	5	22.5	-	-	-
9	0	18	23.5	21.4	28.3	24.40[ab]
10	7	5	21.9	-	-	-
11	3	7	23.6	24.7	28.3	25.53[ab]
12	0	19	27.5	24.3	28.0	26.6[a]
Mean			23.84[b]	22.53[b]	28.54[a]	

* Based on the fresh weight at time of sampling.

Table 8. Percent dry matter* of sweetpotatoes stored 6 months under controlled atmospheres in 1963-64.

Drum	CO_2	O_2	Jersey	Oklamar	Porto Rico	Mean
1	2	4	19.6	21.2	27.4	22.73[abc]
2	5	16	21.0	18.3	27.3	22.30[abc]
3	10	11	22.9	17.0	25.9	21.93[bc]
4	15	6	23.7	-	-	
5	2	4	22.3	21.5	26.2	23.30[a]
6	0	3	23.3	-	-	
7	1	4	21.3	-	-	
8	3	5	21.3	-	-	
9	0	18	21.4	18.9	25.8	22.01[bc]
10	7	5	20.5	-	-	
11	3	7	21.9	22.1	25.2	23.10[ab]
12	0	19	21.2	19.9	23.9	21.63[c]
Mean			21.47[b]	19.84[b]	25.96[a]	

* Based on fresh weight after harvest at the time the roots were placed in the V.P.I. Storage.

open check, 0-18, than in atmosphere 2-4, drum 5. In atmosphere 3-7 the dry matter content was significantly higher than the open check but was not significantly different though higher than the covered check, 1-18.

Determination of dry matter in 1963-64 was made at the end of the 6 months storage period. In some atmospheres and especially in the variety Nemagold there were no sound roots left to make the determination.

There were varietal differences in the dry matter content. Porto Rico had a higher percent dry matter compared to Jersey and Oklamar.

The significantly lower dry matter content in the open and covered check than in atmosphere 2-4, drum 5, was probably due to a higher loss in reserve carbohydrate which was found to be parallel to the loss in dry matter through a higher rate of respiration as reported by Scott (73).

The lower dry matter content of sweetpotatoes 10-11 indicates that there was a greater loss in reserve carbohydrate. The high level of carbon dioxide in the 10-11 atmosphere probably injured the roots and stimulated a higher rate of respiration which resulted in a lower dry matter content.

1964-65. The percent dry matter content of sweetpotatoes in 1964-65 after 4 and 8 months storage is presented in Tables 9 and 10. The data are based on fresh weight at time of sampling after storage as well as at the time of harvest before roots were placed in the storage.

The results obtained were similar to those in the previous year. In both after 4 and 8 months, Tables 9 and 10, there was a higher dry

Table 9. Percent dry matter of sweetpotatoes stored for 4 months under controlled atmospheres in 1964-65.

Atmosphere	CO_2	O_2	Centennial	Goldrush	Jersey	Nemagold	Oklamar	Porto Rico	Mean
			Dry matter % based on fresh weight at sampling						
1	7	8	22.6	25.7	30.4	26.3	23.7	29.4	26.33
2	3	8	24.2	23.6	29.7	26.8	24.4	30.2	26.46
3	3	11	23.4	24.9	30.6	26.8	24.1	31.6	26.88
4	1	18	24.0	24.9	30.7	27.8	23.2	29.8	27.40
5	0	18	24.3	25.6	31.5	26.3	23.4	30.8	27.15
6	2	7	24.3	24.9	30.6	27.5	23.5	31.1	26.98
Mean			23.96	24.93	30.58	26.91	23.71	30.47	
After Harvest			25.52	26.64	31.92	28.72	26.24	30.68	
			Dry matter % based on fresh weight at harvest						
1	7	8	21.30	24.2	29.1	24.0	21.9	26.3	24.5
2	3	8	22.7	21.8	28.3	24.5	22.8	27.6	24.6
3	3	11	21.9	24.3	28.7	23.7	22.6	28.9	24.8
4	1	18	22.3	22.2	28.8	24.9	21.2	26.4	24.5
5	0	18	22.2	22.5	28.6	23.1	20.8	26.7	24.0
6	2	7	22.6	23.5	28.5	24.9	21.7	28.6	25.0
Mean			22.2	23.1	28.7	24.2	21.8	27.4	
After Harvest			25.52	26.64	31.92	28.72	26.24	30.68	

Table 10. Percent dry matter of sweetpotatoes stored for 8 months under controlled atmospheres in 1964-65.

Atmosphere	CO_2	O_2	Centennial	Goldrush	Jersey	Nemagold	Oklamar	Porto Rico	Mean
			Dry matter % based on fresh weight at time of sampling						
1	7	8	23.0	23.3	29.8	24.2	19.9	28.2	24.8
2	3	8	23.1	23.7	29.5	24.4	20.3	29.5	25.1
3	3	11	22.0	33.0	28.5	24.9	21.3	29.9	24.9
4	1	18	17.4	23.0	28.6	25.2	20.0	30.9	24.2
5	0	18	22.5	24.5	29.9	24.4	21.4	30.8	25.6
6	2	7	22.5	23.3	29.9	26.8	22.0	29.0	25.6
Mean			21.7	23.5	29.4	25.0	20.9	29.7	
After Harvest			25.52	26.64	31.92	28.72	26.24	30.68	
			Dry matter % based on fresh weight at time of harvest						
1	7	8	20.6	21.3	26.4	21.2	17.5	24.6	21.9
2	3	8	20.7	20.9	26.5	20.6	18.0	25.8	22.1
3	3	11	19.9	20.4	26.3	21.1	18.5	26.4	21.9
4	1	18	15.5	20.6	25.3	21.8	17.7	26.4	21.2
5	0	18	19.8	21.9	26.4	20.6	18.3	26.1	22.2
6	2	7	19.7	20.7	26.5	22.7	18.9	24.6	22.2
Mean			19.4	21.0	26.1	21.4	18.1	25.6	
After Harvest			25.52	26.64	31.92	28.72	26.24	30.68	28.29

matter content under CA atmospheres than in the check if the dry matter values are based on fresh weight after time of harvest, before roots were placed in storage. On the other hand, there is a higher dry matter content in the check compared with CA atmospheres if the dry matter values are based on fresh weight at the time of sampling after storage. This is due to the relatively higher weight loss in the check while in storage.

In Table 11, losses in dry matter of sweet potatoes after 4 months were significantly higher in the open check 0-18 than atmosphere 2-7 or 3-11.

After 8 months, sweetpotatoes in the covered check 1-18, lost significantly more dry matter than those in atmospheres 2-7, 3-8, and the open check 0-18.

Again there were distinct differences among the varieties in dry matter losses. The variety Oklamar lost a significantly greater amount of dry matter compared to all other varieties, with exception of the Nemagold after 4 months storage. The variety Porto Rico had the smallest loss in dry matter, but was not significantly different from Jersey. There were no significant differences in dry matter loss of the varieties Centennial and Goldrush.

The higher loss in dry matter in the covered check 1-18 as compared with the open check 0-18 could be due to the sprouting of some roots of the Centennial and Jersey varieties in the covered check because of holding at a higher relative humidity, 90-95%, compared to the open check, 70-75%. Also, sprouting would increase the respiration rate and the consumption of the reserve carbohydrate.

Table 11. Percent loss in dry matter* of sweetpotatoes stored for 4 and 8 months under controlled atmospheres in 1964-65.

Atmosphere	CO_2	O_2	Varieties: Centennial	Goldrush	Jersey	Nemagold	Oklamar	Porto Rico	Mean
1	7	8	16.5	9.2	8.9	16.6	16.4	14.2	13.6^{ab}
2	3	8	11.1	18.4	11.5	14.8	13.3	10.1	13.2^{ab}
3	3	11	14.3	12.1	10.1	17.7	14.0	5.9	12.4^{b}
4	1	18	12.7	12.8	9.6	13.2	19.1	13.9	13.6^{ab}
5	0	18	12.9	15.4	10.5	19.7	20.9	12.9	15.4^{a}
6	2	7	11.6	11.9	10.8	13.2	17.5	6.7	11.9^{b}
Mean			13.2^{b}	13.3^{b}	10.2^{c}	15.9^{a}	16.9^{a}	10.6^{c}	
				After 8 months storage					
1	7	8	19.4	20.2	17.4	26.2	33.2	19.9	22.7^{ab}
2	3	8	19.0	21.7	16.9	28.1	31.6	15.9	22.2^{b}
3	3	11	22.2	23.5	20.8	26.4	29.6	14.0	22.8^{ab}
4	1	18	39.1	22.5	20.7	24.0	32.5	13.9	25.5^{a}
5	0	18	22.5	17.7	17.2	28.1	30.2	14.9	21.8^{b}
6	2	7	22.7	22.4	17.1	21.1	28.0	19.9	21.9^{b}
Mean			24.2^{bc}	21.3^{cd}	18.4^{de}	25.7^{b}	30.9^{a}	16.4^{e}	

* Based on the original dry matter content after harvest and before roots were placed in storage.

The higher loss of the dry matter in the covered check, 1-18, compared with atmospheres 2-7 and 3-8 was probably due to the higher respiratory activity in the check lot.

There were slightly higher losses in dry matter in atmospheres 7-8 and 3-11 compared with 2-7 and 3-8. There was also a higher production of carbon dioxide and consumption of oxygen in the 7-8 and 3-11 atmospheres which required more flushing of excess carbon dioxide and more adding of oxygen to readjust the atmospheres each day. This would indicate that the respiratioon rate was higher in these atmospheres. For flushing out the excess carbon dioxide, nitrogen gas was used for longer periods of 5-15 minutes. This might have caused chilling injury due to lowered root temperature and therefore higher respiratory activity in the 7-8 and 3-11 atmospheres.

Total Soluble Solids

1964-65. The effect of controlled atmospheres on total soluble solids of sweetpotatoes stored for 4 and 8 months in 1964-65 are presented in Table 12.

After 4 months storage there were significantly higher total soluble solids in atmosphere 3-8 compared to all other atmospheres. After 8 months storage sweetpotatoes under atmospheres 7-8, 3-8, 3-11, and 2-7 were not significantly different in total soluble solids. Sweetpotatoes in these atmospheres were significantly higher in total soluble solids compared to the open check. Atmosphere 7-8 was also significantly higher than the covered check.

Table 12. Total soluble solids of sweetpotatoes stored 4 and 8 months under controlled atmospheres in 1964-65.

Atmospheres	CO_2	O_2	Varieties Centennial	 Goldrush	 Jersey	 Namagold	 Oklamar	 Porto Rico	 Mean
					After 4 months storage				
1	7	8	11.7	12.0	12.1	11.2	13.0	12.6	12.1^{b}
2	3	8	14.8	15.6	10.8	14.9	14.4	12.6	13.9^{a}
3	3	11	12.9	13.0	12.5	11.9	13.0	12.5	12.6^{b}
4	1	18	12.0	12.2	11.8	11.8	11.4	12.1	11.9^{b}
5	0	18	12.9	12.4	11.3	12.0	12.0	11.8	12.1^{b}
6	2	7	12.9	12.8	12.0	12.0	12.8	12.4	12.5^{b}
Mean			12.9^{a}	13.0^{a}	11.8^{b}	12.3^{ab}	12.8^{ab}	12.3^{ab}	12.5^{b}
					After 8 months storage				
1	7	8	12.6	14.0	13.8	12.6	13.6	13.2	13.3^{a}
2	3	8	12.9	14.5	13.0	13.3	12.1	12.5	13.1^{ab}
3	3	11	13.0	14.2	13.6	12.1	12.9	12.2	13.0^{ab}
4	1	18	11.9	13.5	12.9	11.3	11.1	12.0	12.1^{c}
5	0	18	11.6	13.1	13.2	12.3	11.1	12.8	12.4^{bc}
6	2	7	11.6	13.8	13.8	12.6	12.1	13.4	12.8^{ab}
Mean			12.2^{a}	13.9^{a}	13.4^{a}	12.4^{b}	12.2^{b}	12.7^{b}	

The varieties Centennial and Goldrush had significantly higher total soluble solids compared with Jersey after 4 months storage. The varieties Goldrush and Jersey had a significantly higher total soluble solids compared to all other varieties after 8 months.

Total soluble solids or refractive index as determined with a Ziess table refractometer were used in this experiment to give a fair estimation of the total sugar content in sweetpotatoes. According to the results obtained by Webb _et al_. (83), soluble solids as determined by the Ziess refractometer can be used as a fairly reliable guide to sugar content in sweetpotatoes. Also, Morris and Mann (69) found that the regression of refractive index obtained with a Ziess refractometer on total sugars was statistically significant at the 1% level.

The higher total soluble solids or the higher sugar content of sweetpotatoes under atmospheres 7-8, 3-8, 3-11 and 2-7 compared with the covered check, 1-18, is probably due to a higher utilization of sugar in the covered check due to a higher rate of respiration. This was substantiated by the higher loss in dry matter and the consequent lower sugar content of the covered check. Although the open check was not significantly different in total sugar from the 3-8, 3-11 and 2-7 atmospheres, it was lower in value.

The differences in sugar levels may be due to starch hydrolysis rather than a decrease in utilization of sugars at high respiration rates.

Carotene Content

1964-65. Carotenoids are responsible for most of the flesh color of sweetpotato roots. The major component of this group is beta carotene. A high correlation coefficient was obtained between the Hunter color meter value a and the logarithm of carotenoid content estimated chemically. Hunter color meter value a was reported by Esam (24) to be best suited as a rapid method for the evaluation of sweetpotato carotene content.

The amount of carotene content in mgm/100 gm of sweetpotato stored for 8 months in 1964-65 is presented in Table 13.

The amount of carotene was estimated using the Hunter a value and the equation $\log c = 0.6120 + 0.0467\ Ha$.

The data show that sweetpotatoes in atmosphere 3-11 had significantly higher carotene content compared with those in atmosphere 2-7, but was not significantly different from all other atmospheres.

There were significant differences among the varieties in their carotene content. Centennial was significantly higher than all other varieties.

Homogenate pH

1964-65. The effect of controlled atmosphere storage for 8 months on the pH of sweetpotato homogenate is presented in Table 14.

The data shows that the homogenate of sweetpotatoes under the covered check 1-18 and atmosphere 2-7 had significantly higher pH values compared to those under atmosphere 7-8, but were not significantly

Table 13. Actual carotene content* mgm/100 gm of sweetpotatoes stored for 8 months under controlled atmospheres in 1964-65.

Atmospheres	CO_2	O_2	Centennial	Goldrush	Jersey	Nemagold	Oklamar	Porto Rico	Mean
1	7	8	7.8	3.4	0.4	4.0	4.1	1.6	3.6[ab]
2	3	8	6.7	3.2	0.4	4.2	4.6	1.6	3.4[ab]
3	3	11	8.9	3.4	0.5	4.9	4.9	1.5	4.0[a]
4	1	18	7.9	3.0	0.4	3.7	3.8	1.7	3.4[ab]
5	0	18	7.8	2.6	0.6	4.3	4.2	1.5	3.5[ab]
6	2	7	5.3	2.9	0.3	4.5	4.9	1.5	3.2[b]
Mean			7.4[a]	3.1[c]	0.4[e]	4.3[b]	4.4[b]	1.6[d]	

* Evaluated by Hunter a Value

Table 14. Homogenate pH of sweetpotatoes stored for 8 months under controlled atmospheres in 1964-65.

Atmospheres	CO_2	O_2	Centennial	Goldrush	Nemagold	Oklamar	Porto Rico	Mean
1	7	8	4.70	5.30	5.35	5.35	4.65	5.07[b]
2	3	8	4.85	5.40	5.45	5.60	4.50	5.16[ab]
3	3	11	4.90	5.45	5.60	5.60	4.60	5.23[ab]
4	1	18	5.00	5.40	5.60	5.60	5.50	5.42[a]
5	0	18	5.40	5.40	5.65	5.60	4.85	5.38[ab]
6	2	7	5.20	5.35	5.65	5.60	5.25	5.41[a]
Mean			5.08[b]	5.38[a]	5.55[a]	5.56[a]	4.89[b]	

different from those under atmospheres 1-7 and 3-11 and the open check 0-18.

Jersey, Nemagold and Oklamar varieties had a significantly higher pH value compared with Centennial and Porto Rico.

According to Kushman (45) sweetpotato roots absorb carbon dioxide in atmospheres high in carbon dioxide. The higher the carbon dioxide levels around the roots, the more it would be absorbed in the roots. Therefore, sweetpotatoes from atmosphere 7-8 would have a higher carbon dioxide content. Carbon dioxide might dissolve in the tissue and therefore lower the pH value of the homogenate.

Condition After Storage

1963-64. Sweetpotatoes were removed from controlled atmospheres and placed in normal air at room temperature. The percent decay after one month is presented in Table 15.

The covered check 0-18 had significantly lower decay compared with any other treatment with exception of the 0-3 atmosphere roots.

The varieties Oklamar and Nemagold showed significantly high losses from decay compared with Jersey and Porto Rico.

The higher decay when roots were removed from controlled atmospheres and held at room temperature could be due to one or more reasons.

Chilling injury could have occurred during flushing with nitrogen gas and therefore increased susceptibility of roots to decay, surface pitting, shriveling and internal breakdown as reported by Sistrunk 1954 (75). Senn 1958 (74) reported that when sweetpotato discs were

Table 15. Percent decay of sweetpotatoes stored for 6 months under controlled atmosphere followed by holding at room temperature, 1963-64.

Atmosphere	CO_2	O_2	Jersey	Nemagold	Oklamar	Porto Rico	Mean
1	2	4	18.2	100.0	57.9	66.6	60.7^{a}
2	5	16	13.0	100.0	42.9	16.6	43.1^{a}
3*	10	11	3.7	-	8.0	15.0	-
4*	15	6	58.8	-	100.0	100.0	-
5	2	4	10.5	100.0	59.4	0.0	42.5^{a}
6	0	3	25.0	0.0	100.0	0.0	31.3^{ab}
7*	1	4	0.0	100.0	100.0	-	-
8*	3	5	9.1	-	100.0	-	-
9	0	18	0.0	13.3	7.7	0.0	5.3^{b}
10*	7	5	7.1	-	94.4	100.0	-
11	3	7	25.0	100.0	87.5	34.8	61.8^{a}
12	0	19	50.0	60.0	62.5	36.5	52.5^{a}
Mean			20.2^{b}	67.6^{a}	59.7^{a}	22.2^{b}	

* Not included in means

removed from partially aerobic to anaerobic conditions, respiratory activity increased but did not become greater than the check. Therefore, it appears that injury when roots were removed from CA atmosphere was not due to a higher respiratory activity than the check, but may have been due to a modified metabolism which reduced root resistance to invasion by decay organisms.

1964-65. The percent of decay of sweetpotatoes stored for four and eight months under controlled atmospheres followed by holding at room temperature is presented in Table 16.

The data showed that sweetpotatoes in the covered check 1-18, open check 0-18 and atmosphere 3-11 were significantly lower in percent decay compared with those from atmosphere 3-8 after four months.

After eight months storage there were no significant differences between CA treatment and the covered and open check. Although no significant differences were found between CA treatments and the check after eight months storage, the percent of decay was usually higher after CA holding compared with the checks. This could be due to the injury caused by high carbon dioxide which at times rose above the desired levels.

High carbon dioxide was reported to cause injury to sweetpotato roots and therefore inhibit the ability of roots to resist decay organisms, Kushman 1957 (47). This is indicated by the higher decay obtained after holding in atmosphere 3-8 which frequently fluctuated to a maximum of 5.0% carbon dioxide compared with atmosphere 2-7 in

Table 16. Percent decay of sweetpotatoes stored for 4 and 8 months under controlled atmospheres followed by holding at room temperature, 1964-65.

Atmospheres	CO_2	O_2	Centennial	Goldrush	Jersey	Nemagold	Oklamar	Porto Rico	Means
					After four months storage				
1	7	8	5.9	0.0	0.0	56.3	0.0	0.0	10.4^{ab}
2	3	8	21.0	18.2	3.2	87.5	11.1	0.0	23.5^{a}
3	3	11	0.0	0.0	0.0	53.3	0.0	0.0	8.9^{b}
4	1	18	0.0	0.0	0.0	6.5	0.0	0.0	1.1^{b}
5	0	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0^{b}
6	2	7	0.0	4.5	0.0	75.0	0.0	0.0	13.3^{ab}
Mean			4.5^{b}	3.8^{b}	1.6^{b}	45.4^{a}	1.9^{b}	0.0^{b}	
					After eight months storage				
1	7	8	0.0	12.5	16.7	100.0	100.0	6.3	39.3^{a}
2	3	8	0.0	0.0	9.1	100.0	11.1	11.8	22.0^{a}
3	3	11	0.0	6.7	3.2	100.0	100.0	0.0	35.0^{a}
4	1	18	5.6	0.0	3.6	35.3	0.0	18.8	10.6^{a}
5	0	18	11.1	5.0	19.2	31.3	0.0	12.5	13.2^{a}
6	2	7	11.1	9.5	3.3	75.0	0.0	0.0	16.5^{a}
Mean			4.6^{c}	5.6^{c}	9.2^{bc}	73.6^{a}	35.2^{b}	8.2^{bc}	

which the CO_2 level was fairly constant. Also atmosphere 7-8 which had a maximum of 8.5% CO_2 had the highest percent of decay.

Chilling injury might have occurred during flushing of excess carbon dioxide using nitrogen gas. Chilling injury increased susceptibility of sweetpotato roots to decay organisms. Lutz 1945 (56). This could be an explanation of the higher decay in atmospheres 7-8 and 3-11 which required nitrogen gas to reduce the CO_2 level for longer periods of time than roots in atmosphere 3-8.

In both years the Nemagold variety showed exceptionally high decay compared with the other varieties.

Sprout Formation After Storage

1963-64. The effect of controlled atmosphere on the ability of sweetpotato roots to form sprouts was determined upon removal from storage and placing at room temperature of 75-85°F for one month.

For most of the controlled atmospheres used there were no roots left in the Nemagold, Oklamar and the Porto Rico to determine sprouting ability except for atmosphere 5-16 and 10-11. Percent sprouting of roots after atmosphere 5-16 was 100% for the Nemagold and 89% for the Porto Rico variety which was similar to the sprouting of the covered checks. The Jersey variety did not sprout after any treatment including the covered and open check. Nemagold and Porto Rico sprouted after holding in a 5-16 atmosphere as much as those from the covered check.

1964-65. The data in Table 17 shows that sweetpotatoes stored for 4 months under controlled atmospheres were not significantly different

Table 17. Percent sprouting of sweetpotatoes stored for 4 and 8 months under controlled atmosphere followed by holding at room temperature, 1964-65.

Atmospheres	CO_2	O_2	Centennial	Goldrush	Jersey	Nemagold	Oklamar	Porto Rico	Mean
				After four months storage					
1	7	8	46.2	90.9	0.0	0.0	82.4	82.4	53.3
2	3	8	18.2	-	3.4	40.0	100.0	37.5	39.8
3	3	11	16.7	59.1	0.0	50.0	94.1	52.9	45.5
4	1	18	16.7	57.1	0.0	100.0	94.1	82.4	58.4
5	0	18	44.4	54.5	3.8	100.0	94.4	73.3	61.7
6	2	7	11.1	38.1	0.0	100.0	70.6	64.7	47.4
Mean			25.6^{c}	59.9^{b}	1.2^{d}	65.0^{ab}	89.3^{a}	65.5^{ab}	
				After eight months storage					
1	7	8	77.7	42.9	0.0	-	-	40.0	40.1^{bc}
2	3	8	83.3	22.7	3.0	-	24.0	26.7	32.2^{bc}
3	3	11	27.8	21.5	0.0	-	-	20.0	17.3^{c}
4	1	18	82.4	59.0	7.4	100.0	100.0	85.7	72.4^{a}
5	0	18	62.5	80.0	38.4	72.7	83.3	71.4	68.1^{a}
6	2	7	37.5	78.9	48.2	0.0	94.2	64.7	53.9^{ab}
Mean			61.9^{a}	50.8^{ab}	16.2^{c}	28.8^{bc}	50.4^{ab}	51.4^{ab}	

from those stored under covered or open check in their ability to form sprouts upon removal from storage.

However, 8 months storage under 7-8, 3-8 and 3-11 atmospheres significantly decreased the ability of roots to sprout at room temperature compared with the covered and open check. Atmosphere 2-7 was not significantly different from the open or covered check in percent sprouting.

Sprouting ability differed among varieties. The Oklamar, Porto Rico and Nemagold varieties had more sprouts compared with Jersey and Centennial after storage for 4 months. After 8 months Centennial, Oklamar and Goldrush varieties formed a high percent of sprouts compared with Jersey.

The ability of roots to form sprouts was increased after 8 months compared with 4 months storage under atmosphere 2-7, the covered check 1-18, and the open check 0-18. However, there was a reduction in sprouting after 8 months on roots from atmospheres 7-8, 3-8, and 3-11. This was probably due to the higher holding room temperature after 8 months compared with the room temperature after holding for 4 months. The longer storage period might have broken the proximal dominance and therefore increased sprouting.

The lower percent sprouting of roots stored under atmospheres 7-9, 3-8, and 3-11 compared to the open check and covered check could be due to the effect of controlled atmospheres in inhibiting the development of sprouts. Also, at these atmospheres, nitrogen gas used to flush the excess carbon dioxide might have caused chilling injury and therefore inhibited the meristematic tissue of stored roots. According to Cooley 1954 (21) chilled roots sprouted meagerly or not at all when bedded down under good growing conditions.

The ability of roots to sprout upon removal from storage when placed under favorable conditions is of importance for propagation purposes, but sprouting is not desired for roots intended for human consumption.

Organoleptic Evaluation

1963-64. The effect of controlled atmosphere storage on the eating quality of raw and baked roots of Jersey, Oklamar, Nemagold, and Porto Rico sweetpotatoes is presented in Table 18.

The results show that sweetpotatoes under atmospheres 5-16, 10-11, 3-7, 3-5 covered check 0-18 and open check 0-19 had a high percent of acceptable tasting roots compared with other atmospheres.

Some 51% of the roots held at 0-3 had an alcoholic taste which was a result of the anaerobic respiration under this low oxygen atmosphere. A few roots tasted alcoholic from atmospheres 0-4, 2-4 drums 1 and 5, 15-6, and 3-5.

Roots from atmospheres 5-16, 10-11 and 3-7 were as good or better than the open or covered checks in percent of acceptable roots.

1964-65. The effect of controlled atmosphere storage on the eating quality of sweetpotato roots in 1964-65 is presented in Table 19.

Table 18. Organoleptic evaluation of raw and baked sweetpotatoes stored under controlled atmospheres for 6 months in 1964-65.

Drum	Atmosphere CO_2	O_2	% Normal	% Alcoholic	% Off-Taste
1	2	4	80.8	8.9	10.3
2	5	16	86.4	0.0	13.6
3	10	11	90.9	0.0	9.1
4	15	6	67.2	8.6	24.1
5	2	4	69.8	14.3	15.9
6	0	3	45.1	51.0	3.9
7	0	4	40.6	14.5	44.9
8	3	5	82.0	6.6	11.4
9	0	18	84.4	3.1	12.5
10	7	5	79.4	1.6	19.0
11	3	7	87.3	0.0	12.7
12	0	19	82.4	0.0	17.6

Table 19. Organoleptic evaluation of raw and baked sweetpotatoes stored under controlled atmospheres for eight months, 1964-65.

			% of Normal Tasting Roots						
Atmosphere	CO_2	O_2	Centennial	Goldrush	Jersey	Nemagold	Oklamar	Porto Rico	Mean
1	7	8	95.8	95.8	100.0	62.5	62.5	95.8	85.4[a]
2	3	8	95.8	62.5	100.0	70.8	91.7	91.7	85.4[a]
3	3	11	95.8	95.8	100.0	83.3	75.0	95.8	91.0[a]
4	1	18	91.7	95.8	100.0	83.3	66.7	100.0	89.6[a]
5	0	18	91.7	95.8	79.2	66.7	70.8	91.7	82.6[a]
6	2	7	100.0	95.8	91.7	66.7	95.8	95.8	91.0[a]
Mean			95.1[a]	90.3[a]	95.1[a]	72.2[b]	77.1[b]	95.1[a]	

The results show that there were no significant differences between treatments in the percent of acceptable tasting roots. Sweetpotatoes in CA storage were more consistent in texture and more moist compared with the check. This was probably due to the higher weight loss in the check.

Nemagold and Oklamar varieties showed significantly higher percent of roots with an off-flavor and a smaller percent with acceptable flavor.

CONCLUSIONS

The objective of this study was to determine the effects of using controlled atmospheres in the storage of sweetpotatoes and the range of CO_2 and O_2 that would help maintain good keeping quality of sweetpotatoes.

In controlled atmosphere tests in 1963-64 ranges of CO_2 from 0 percent to 15 percent were used in combination with O_2 from 2 percent to 15 percent.

Sweetpotatoes under atmospheres 0-3 and 1-4 had a high total loss and a high percent of roots had an alcoholic taste. Apparently under these atmospheres oxygen was deficient within the roots for aerobic respiration. Consequently, anaerobic respiration proceeded and as a result alcohol was formed and was present in the raw and baked roots. Sweetpotato roots showed browning upon cutting in addition to breakdown.

Sweetpotatoes under the atmosphere 2-4, in drums 1 and 5, did not exhibit the high total losses as in 0-3 and 1-4. Roots from atmosphere 2-4 also showed a high percent of acceptable tasting sweetpotatoes.

The 2-4 atmosphere was only 1% higher in carbon dioxide compared with atmosphere 1-4. It is possible that 2-4 was a better atmosphere than 1-4 or this could be due to root variability, atmosphere extremes, or gas level differences at a critical time.

A high percent of sweetpotatoes under 15-6 were lost due to decay and weight loss. Also a high percent of roots were "off" or bitter in taste. The high level of carbon dioxide in the atmosphere, 15%, and an expected higher CO_2 inside the roots resulted in injury. Fox in 1933 (30) reported that accumulation of carbon dioxide in roots may act as a cell poison and bring about injury or death of some cells.

Apparently the high carbon dioxide level of this atmosphere caused injury to the periderm tissue and destroyed the ability of the periderm cells to act as a protective barrier. High carbon dioxide levels were found (45) to prevent formation of wound periderm in uncured roots.

Sweetpotatoes under atmosphere 3-7 had a lower percent total loss, higher dry matter content, and a higher percent of acceptable tasting roots as compared with the check. However, sweetpotatoes under this atmosphere exhibited high losses from decay after removal from storage and holding at room temperature for one month. The large loss in atmosphere 3-7 was not significantly different from the open check 0-19 but was significantly higher compared to the covered check.

Senn (74) in 1958 reported that sweetpotato discs held under partially anaerobic conditions for 2 hours then transferred to aerobic conditions resumed a normal rate of respiration. But probably under a long term CA storage, of 6 months used in this experiment, this pattern was not followed.

Storage for six months under CA atmosphere probably upset the normal metabolism and decreased the ability of roots to resist decay organisms.

Chilling injury which might have occurred during the use of nitrogen gas to flush the excess carbon dioxide from some CA atmospheres increased susceptibility for roots to decay. As reported by Kushman in 1957, chilled roots were more susceptible to decay organisms especially after removal to a higher temperature.

The results obtained in the first year indicated that sweetpotatoes held at concentration of 7 percent or lower oxygen as well as those held at 10 percent or higher carbon dioxide developed an alcoholic flavor and off taste.

In 1964-65 controlled atmosphere levels of 2 to 7% carbon dioxide in combination with 7 to 11% oxygen were used.

Sweetpotatoes stored for 4 months in atmosphere 3-8 showed a high percent of total loss and dry matter disappearance but were not significantly different from the check. However, after 8 months storage total losses and dry matter disappearance were significantly lower in 3-8 compared with the check.

After removal from 4 months storage and holding at room temperature for one month, there was a significantly higher percent decay in 3-8 than in checks. The difference was not significant after 8 month storage and holding at room temperature.

Sweetpotatoes held in atmosphere 2-7 had the smallest total loss and dry matter disappearance. Soluble solids or total sugars were significantly higher than the covered check. Because there was a higher weight loss in the open check compared to atmosphere 2-7, sugar content appears to be higher than it would be if water loss were less, or similar to the covered check and CA held roots.

After removal from CA storage at 2-7 losses from decay were not significantly different from the checks. Under this atmosphere there was a higher percent of acceptable tasting roots compared to the check. In general, there were better quality sweetpotatoes obtained under 2-7 compared with 3-8 even though there was only a difference of one percent in the levels of oxygen and carbon dioxide. However, relative humidity was different. A relatively higher humidity existed and free water condensation was found in atmosphere 3-8 which increased sprouting during storage and provided an entry for decay organisms. Also in atmosphere 3-8 the gas levels fluctuated more and to a greater extent than in 2-7.

Total losses in sweetpotatoes in atmospheres 7-8 and 3-11 were significantly lower than the open check. However, after removal to room temperature more loss occurred, but it was not significantly different from the checks. Sweetpotatoes under both atmospheres are believed to have had a higher rate of respiration compared with the 3-8 atmosphere because they required frequent flushing for longer periods of time to remove excess carbon dioxide. Using nitrogen gas for longer periods could have caused chilling injury which would increase susceptibility of roots to decay especially after holding at room temperature.

The fact that sweetpotatoes under atmosphere 7-8 had the highest percent decay upon removal to normal air at room temperature indicated that a high carbon dioxide level appeared to cause injury to the periderm tissues and increased susceptibility of roots to decay organisms.

In general sweetpotatoes stored in an atmosphere of 2-7 were as good as or better than from the open or the covered check.

Controlled atmospheres used in this study had a pronounced effected on the different varieties used. Centennial, Jersey, Porto Rico, and to a lesser extent Goldrush, seemed to maintain their quality better under controlled atmosphere, while CA had a determintal effect on the qualities of Nemagold and Oklamar varieties. This could be explained by one or more of the following factors. Varieties differ in the thickness of periderm formed under favorable curing conditions. Therefore, the ability of periderm tissues to act as a barrier against decay organisms is expected to be different. Different sweetpotato varieties may require different low oxygen levels for minimum respiratory activity. This was found to be true for different apple varieties.

The rate of diffusion of gases between the tissues and the surrounding air may differ among varieties. Therefore, greater accumulation of carbon dioxide inside roots of some varieties could cause injury or a modified metabolism.

Controlled atmosphere storage significantly decreased the ability of roots to sprout at room temperature. This effect is desirable for the bulk of the sweetpotato crop which is used for human consumption. On the other hand, for those used for seed purposes, it is not beneficial to hold them under CA because of reduction of sprouting.

Many factors appeared to influence the storage behavior and the possibility of using controlled atmosphere for sweetpotatoes. The condition of the crop at harvest, the season of the year and the weather at the harvest time all of which determine the success of storage under regular or controlled atmosphere.

Better results were obtained in the 2-7 atmosphere of 1964-65 than in the 3-7 atmosphere of 1963-64 although both were better than the checks. Atmosphere 3-7 in 1963-64 had a high percent decay upon removal from CA and holding at room temperature for one month. This was probably due to the greater care exercised by research personnel in harvesting and handling roots in the fall of 1964. Roots used from the 1963 crop were obtained from commercial storages and normal commercial handling practices result in fairly high injury.

Therefore, successful commercial storage of sweetpotatoes under controlled atmosphere could be influenced by factors mentioned as well as the variety used.

In both years beneficial results were obtained in CA storage of the Jersey variety. The variety Centennial tested only in the second year was much better under CA compared to the check.

SUMMARY

The effect of controlled atmospheres (CA) on the keeping quality of Centennial, Jersey, Goldrush, Nemagold, Oklamar, and Porto Rico sweetpotatoes was studied in the 1963-65 period.

Evaluations were made of decay loss, weight and dry matter loss, soluble solids percent, carotene content, taste, keeping after storage, and the ability of roots to sprout.

In 1963-64, it was found that sweetpotato roots stored under atmospheres having an oxygen level below seven percent developed an alcoholic flavor. Increasing carbon dioxide level about 10 percent caused roots to develop an off-flavor and bitter taste.

Sweetpotatoes benefited from an atmosphere of three percent carbon dioxide and seven percent oxygen (3-7) as evaluated by low total losses due to decay and weight loss, higher dry matter content and a high percent of acceptable tasting roots compared with the checks. The only disadvantage of this CA treatment was a higher loss due to decay upon holding at room temperature for one month after storage. However, this high loss was not significantly different from the open air check.

Results similar to those of 1963-64 were obtained in 1964-65. Sweetpotatoes under an atmosphere of 2-7, in a gas generated CA, had better storage quality as measured by low total losses, low dry matter disappearance, higher total soluble solids, and a high percent of acceptable tasting roots compared to the checks.

Roots removed from CA and held at room temperature for one month did not exhibit the high decay found in 1963-64. Decay was slightly higher than the check but not significantly different. The 2-7 atmosphere did not impair sprouting when roots were held at room temperature after storage.

Sweetpotato roots under a 3-8 atmosphere in a sealed 55 gallon drum were relatively similar to roots held in a 2-7 room atmosphere but were generally poorer in keeping quality.

Sweetpotatoes under atmospheres 7-8 and 3-11 had lower total losses compared to the room air or open check but not the covered drum check. Roots under these atmospheres lost more dry matter compared with the open check but were not different from the covered check. They were also higher in soluble solids, carotene content, and percent of acceptable tasting roots than the open check. Roots from the 7-8 and 3-11 atmospheres had higher decay losses than the checks after holding at room temperature for one month.

There were pronounced varietal responses to controlled atmosphere storage. CA storage had a beneficial effect on the Centennial and Jersey varieties and to a lesser degree on the Porto Rico and Goldrush varieties, as evaluated by reduction of totallosses, dry matter loss, higher soluble solids levels, and a higher percent of acceptable tasting roots. More off-flavor developed in the roots of the Nemagold and Oklamar varieties. The Nemagold, and to a lesser degree Oklamar, had a higher total loss, dry matter loss, and lower soluble solids than other varieties.

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ABSTRACT

Controlled atmosphere (CA) storage of horticulture crops involves the holding of such produce in refrigerated storage with a reduction of oxygen and an increase in carbon dioxide.

The effect of controlled atmospheres on the keeping quality of Centennial, Jersey, Goldrush, Nemagold, Oklamar, and Porto Rico sweetpotato varieties was studied in the 1963-65 period.

Evaluations were made of decay loss, weight and dry matter loss, soluble solids percent, carotene content, taste of raw and baked roots, keeping after storage, and the ability of roots to sprout.

In 1963-64, ranges of carbon dioxide from 0 to 15 percent were used in combination with 2 to 16 percent oxygen. Sweetpotato roots stored under atmospheres having an oxygen level below 7 percent or a carbon dioxide level above 10 percent developed a high percent of roots with either an alcoholic flavor or an off-flavor.

Sweetpotatoes under an atmosphere of 3 percent carbon dioxide and 7 percent oxygen (3-7) had better quality than check lots as evaluated by low total losses due to decay and weight loss, higher dry matter content and a low dry matter loss, high total soluble solids and a high percent of acceptable tasting roots. The only disadvantage of this CA treatment was a higher loss due to decay upon holding at room temperature for one month after storage. However, this high loss was not significantly different from the open air check.

In 1964-65 controlled atmosphere levels of 2 to 7 percent carbon dioxide in combination with 7 to 11 percent oxygen were used.

Results similar to those of 1963-64 were obtained in 1964-65. Sweetpotatoes under an atmosphere of 2-7 in a gas generated CA room, had better storage quality as measured by low total losses, low dry matter disappearance, higher total soluble solids and a high percent of acceptable tasting roots compared to the checks. Roots removed from CA in 1964-65 and held at room temperature for one month did not exhibit the high decay found in the 1963-64 season. Decay was slightly higher than the check but not significantly different. The 2-7 atmosphere did not impair sprouting when roots were held at a warm temperature after storage.

Sweetpotato roots under a 3-8 atmosphere in a sealed 55 gallon drum were relatively similar to roots held in the 2-7 room atmosphere, but were generally poorer in keeping quality.

Sweetpotatoes under atmospheres 7-8 and 3-11 had lower total losses compared to the room air or open check, but not the covered drum check. Roots under these controlled atmospheres were not different from the covered check in dry matter loss and were higher in soluble solids, carotene content and percent acceptable tasting roots than the open check. Roots removed from the 7-8 and 3-11 atmospheres had higher decay losses than the checks after holding at room temperature for one month. The 7-8 and 3-11 atmospheres significantly decreased the ability of roots to sprout at room temperature.

There were pronounced varietal responses to controlled atmosphere storage. CA holding had a beneficial effect on the Centennial and Jersey varieties and to a lesser degree on the Porto Rico and Goldrush varieties as evaluated by reduction of total losses, dry matter loss, higher soluble solids levels and a higher percent of acceptable tasting roots. More off-flavor developed in roots of the Nemagold and Oklamar varieties. The Nemagold and to a lesser degree the Oklamar had a higher total loss, dry matter loss, and lower soluble solids than the other varieties and after removal from CA and holding at room temperature the Nemagold variety developed more decay.