FACTORS IN DEHYDRATION AND SUBSEQUENT STORAGE OF APPLES AND LIMA BEANS ASSOCIATED WITH RETENTION OF ASCORBIC ACID

By

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INTRODUCTION

In the present war, as in the last one, dehydration has of necessity been employed to preserve tremendous stocks of foodstuffs for both the armed forces and civilians abroad. During the last war, 8,905,158 pounds (48) of dehydrated food of indifferent quality were shipped to France; making this total were potatoes, soup mixtures, carrots, onions, and turnips. In the present conflict the problem involved not only the feeding of a far greater fighting force spread over the entire world, but civilians as well. The vastness of this problem is reflected in the combined military and lend-lease requirements for the past two years (3). In 1942, the total pack of eleven major vegetables in this country was 75,000,000 dried pounds; in 1943, this pack was increased to 210,636,000 dried pounds, largely for overseas consumption. For the same period, the pack of dehydrated apples, the major fruit crop dehydrated for war purposes, was 54,000,000 pounds in 1942, and 50,000,000 pounds in 1943. The 1944 pack of dehydrated apples was estimated by Dodds (20) to reach 50,000,000 pounds.

Although the dried-fruit industry has long been firmly established in the United States, mechanical, forced-draft dehydration of fruits and vegetables had never been developed for commercial use in production of high quality products, except for the dehydration of a few crops such as onions, garlic, and peppers for condiments, and of prunes. The demands by the government for dehydrated food during the war have included both prodigious quantity and clearly-specified quality. Wodicka (68) stated that the Quartermaster Corps wanted "more foods which are concentrated, stable sources of vitamin C," and explained that for various reasons

the army shuns vitamin pills for regular administration. An alternative, vitamin fortification of foods, has been and is being employed for military rations. With the advent of many new dehydrating plants to be used for the first time on many vegetables and some fruits, the determination of vitamins existing in the foods and the investigation of factors in forced-draft dehydration and in storage, associated with vitamin and nutrient retention, became important in order to meet the quality demands of the armed forces.

This work was undertaken to study ascorbic acid, as a measure of vitamin C, and other quality considerations in the dehydration and subsequent storage of apples and lima beans. Apples have long been Maryland's leading fruit crop and, since the war began, this fruit in dehydrated or canned form has constituted the major dessert food used by the armed forces as well as the major fruit shipped on lend-lease agreements. Lima beans constitute a major canning crop in Maryland. When the lima bean studies were begun, this product in dried form was not used by the armed forces or in lend-lease shipments. However, previous work, which will be reviewed, showed that fresh lima beans are high in vitamin C, and since the army called for information (68) on all foods high in this vitamin, an investigation of the vitamin C, measured by ascorbic acid, in lima beans as affected particularly by dehydration was important.

The apple studies were planned to provide information on: (1) the effect of age of stored fruit on quality, yield, and reconstitution of the dehydrated material, (2) the influence of varying dehydration temperatures, especially higher temperatures, and consequent shorter drying periods, on ascorbic acid, moisture content, reconstitution, and sulfur retention, (3) the storage life of dehydrated apples as affected by variety, temperature, sulfur content, and nature of pack, and (4) factors

involved in the pre-treatment of apples before dehydration, especially the influence of a blanch used with and without sulfuring.

Of primary interest in the lima bean studies were the ascorbic acid and moisture contents as affected by: (1) maturity of fresh beans and variability therein, (2) pre-drying treatments including blanching and pre-blanching, and (3) varying primary dehydration temperatures.

PART I

DEHYDRATION OF APPLES

REVIEW OF LITERATURE

According to Cruess (16), apples have been dehydrated* (or evaporated*) in America for at least a century. Prescott and Sweet (56) uncovered reports that dried apples were issued to Union forces during the Civil War, but they assumed that the antiscorbutic property of this food probably was lost in improper handling and storage. However, it was not until the first World War and more recent years that the principles of dehydration were worked out in commercial detail. For information on the theory and principles of dehydration the reader is referred to Cruess (16), Chace, et al. (15), Wiegand and associates (67), and to Eidt (21).

Vitamin C and Ascorbic Acid. The nutritive value of apples, especially the antiscorbutic properties, received little attention until the identification of ascorbic acid and the perfection of chemical methods for its determination a little more than a decade ago. Some work is recorded in the literature concerning factors affecting the antiscorbutic properties of fresh apples. Variety seems to have considerable influence on the antiscorbutic value of apples (23, 25, 38, 40, 62, 63). Smith and Fellers (60) summed up the biological assays on varieties with the following arbitrary classification: very good sources (4-6.5 grams minimum daily feeding), Baldwin, Northern Spy, Winesap and Ben Davis; good sources

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*Dehydration is used in this paper to mean forced-draft drying under controlled temperature and humidity conditions. Evaporation is here interpreted to mean natural-draft drying and implies little control over temperature or humidity.

(7-10 grams minimum daily feeding), Rome Beauty, Rhode Island Greening, and Stayman Winesap; fair sources (10.5-15 grams minimum daily feeding), Arkansas Black Twig, Wealthy, Cortland, King David, and Golden Delicious; and poor sources (16-25 grams minimum daily feeding), Jonathan, Delicious, and McIntosh.

Cultural practices once were thought to have an effect on the vitamin C content of the fresh apple. The influence of fertilizers was investigated first by Potter and Overholser (55), who found significantly higher antiscorbutic value in apples from trees receiving a complete fertilizer than from trees which were unfertilized. This difference was significant when apples were fed at the 5 gram level, but when fed at the 10 gram level (54) no apparent difference was observed. Todhunter (63), using chemical methods for determination of vitamin C, could find no such variation between fruit from fertilized trees and that from non-fertilized trees. Comparing irrigation to dry-land culture, Todhunter failed to find any differences in vitamin C content of the fruit grown under the two conditions. Likewise, with sprayed and unsprayed fruit, Fellers, et al (22) demonstrated that antiscorbutic value was not affected by spraying.

According to Todhunter (63), highly colored fruit is apparently no higher in vitamin C than poorly colored fruit. Leaf-fruit ratio had a varying effect depending on the variety. Batchelder and Overholser (7) found no differences between fruits of high and low leaf-fruit ratios in the Delicious variety, but with Winesap, they reported that the high ratio resulted in lower vitamin C content in the fruit. This influence, however, was indirect, for analysis of large and small fruits of both varieties disclosed a rather high vitamin C content in the small Winesap apples compared to large fruits of that variety, while Delicious fruits were uniform in vitamin content regardless of size. Thus the high leaf-fruit

ratio on the Winesap variety resulted in larger fruits of lower vitamin content.

Association of vitamin content with chromosome number was suggested at one time by Fellers and associates (23). Baldwin, a triploid, was found to be high in antiscorbutic value, while McIntosh, a diploid, was shown to be very low. Brambley's Seedling, also a triploid, had previously been reported as a good source of vitamin C (9). However, later work by Smith and Fellers (60) involving 21 varieties of apples did not support this association. Manville, et al.(38) suggested that vitamin C in apples is associated with gene activity rather than with chromosome number.

Distribution of vitamin C within the apple has been recorded by several workers. Fellers, et al.(23) reported that the epidermis is four times as rich as the flesh immediately beneath it and six to ten times as rich as the flesh near the core. This is in agreement with the work of Manville, et al.(38), and of Todhunter (63). According to Todhunter's (63) analysis, the peel of an apple contains by far the greatest concentration of vitamin C, while the rest of the apple is segregated in order of decreasing vitamin content as follows: calyx flesh, whole apple, stem and flesh, flesh only.

Campbell (12) and Hessler and Anderson (32), working with Jonathan apples stored until May, were the first to investigate vitamin C in stored apples. Whereas 20 grams of fresh apple per day were sufficient until November, 30 to 40 grams were necessary to prevent scurvy in guinea pigs during the remainder of the storage season. Using a storage temperature of 36° F., Fellers, et al.(22) recorded a loss of vitamin C in the Baldwin variety of approximately 33 per cent after 9 months of storage. Batchelder (6) and Todhunter (62) estimated losses in excess of 50 per cent in Delicious apples stored for 12 months at 45° F.

A preliminary report by Marsh (40) and subsequent work by Fish, et al.(25) indicated that of several varieties grown in West Virginia ascorbic acid is lost in fresh apples quite rapidly during storage even though the crop is stored at low temperatures soon after picking. Fish, et al.(25) suggested that apples may continue to increase in vitamin C content if left on the tree after normal picking time. Their data, extending 42 days after harvest, show this to be the case in Wealthy and McIntosh apples in West Virginia.

Sulfuring. Since the principles of sulfuring are similar for the various fruits, sulfuring investigations on all fruits will be reviewed. Practiced since ancient times, the sulfuring of fruits according to Chace, Noel, and Pease (15) plasmolyzes the cells and renders permeable the semi-permeable membrane, thus facilitating the diffusion of water from the interior to the surface. The purposes of sulfuring fruits prior to dehydration have been given by Long, Mrak, and Fisher (35) as follows: (1) to preserve natural color, (2) to preserve natural flavor, (3) to prevent enzyme and microbiological deterioration, (4) to repel insects to some extent during drying (sun drying), and (5) to facilitate drying by plasmolyzing the cells. This included all fruits that are sulfured and was applied particularly to the sun-drying industry in California.

Nichols and Christie (46) were the only ones to report on investigations of sulfuring of apples for dehydration. They stated that apples are difficult to sulfur, and that this fruit never contained sulfur in excess of the legal maximums after processing. In their work, dried apples stored satisfactorily at common temperatures for eight months only if the sulfur dioxide content was 200 p.p.m. or more. A 3 per cent brine dip before sulfuring did not result in increased sulfur content after drying, and produced inferior flavor compared with non-dipped, sulfured

fruit. The authors stated, further, that it was impossible to sulfur apples in excess of 450 p.p.m. and they suggested that the sulfur dioxide over this figure was converted by oxidation to something else, presumably to sulfur trioxide.

The principles and some of the factors involved in sulfuring have been studied to a greater extent for other fruits, chiefly the soft fruits, which are sun-dried in California. Fisher, et al.(26) found that peaches, pears, and apricots as a rule absorbed less sulfur dioxide when sulfured at the relatively high temperature of 120° F., but retained more during storage than fruit sulfured at a lower temperature. Chase and associates (13), however, could attribute to temperature no influence on sulfur absorption and retention in apricots. Fisher reported also that prolonged high-temperature sulfuring treatments caused cut fruits to "bleed," become mushy, and stick to the drying trays. Whole fruits (grapes and figs), sulfured at 120° F., absorbed and retained more sulfur dioxide than when sulfured at 70° F., according to Fisher.

Sulfur retention is considered generally to be proportional to the length of the sulfuring period and the concentration of sulfur fumes or gas in the sulfuring chamber. Jewell (33), Chace, et al.(13), and Long and coworkers (35) all showed this to be correct. In tests with sulfuring periods extending up to 5 hours, Chace, et al. (13) demonstrated, however, that most of the sulfur absorbed by the fruit was taken up in the first half hour.

The effect of storage conditions on sulfur dioxide retention of dehydrated fruits was mentioned first by Morgan, Field, and Nichols (42) who stated that sulfur disappears slowly from dehydrated fruits in storage. Nichols, Mrak, and Bethel (47), working on color and sulfur dioxide retention in dried apricots, demonstrated clearly that temperature was the most

important factor in sulfur retention during storage. Length of the storage period, of course, was directly related to sulfur retention, while air in the sealed containers also was important. The authors suggested that sufficient air remained occluded in the fruit to cause oxidative changes in spite of a gas or vacuum pack. Nitrogen, carbon dioxide, and vacuum packs, therefore, did not show the retention that was expected when compared to the air pack. Moisture content seemed to have an influence on sulfur retention; in general, the lower the moisture the less was the loss of sulfur.

Morgan and Field (41), working with dried peaches, demonstrated that sulfured fruit retained the full antiscorbutic value of the fresh fruit, whereas non-sulfured fruit lost all of its vitamin C. In a later report, Morgan, Field, and Nichols (42) found that sun-dried prunes and apricots were lower in vitamin C than dehydrated fruit even when the amount of sulfur present was greater in the sun-dried samples. They stated that the vitamin protection afforded by the gas is exerted only during the actual drying, and that sulfur content is of little consequence in storage unless temperatures are unusually high. As a result of this work, the authors proposed that the lower sulfur limit for vitamin C protection in dried fruits is 450-500 p.p.m. of sulfur, beyond which level little benefit is afforded. The mechanism of vitamin C protection by sulfur is not known.

Blanching. Cruess (17) attributed the failure of commercial dehydration of many fruits and vegetables after the last war to the aversion to blanching. Blanching of fruits prior to drying has been practiced intermittently in the west for many years, but this practice has never gained widespread application in the industry. Nichols and Christie (46) increased significantly the sulfur dioxide absorption by apricots by the

use of a one-minute steam blanch. Chace, Church, and Sorber (14), however, insisted that blanching apricots resulted in a lower grade of material. They reported that blanching after sulfuring resulted in a 50 per cent higher sulfur retention than blanching before sulfuring or not blanching at all. Regardless of the blanching method, the cups filled with juice in the drying process, and this is considered wholly undesirable in the sun-drying industry. Blanching of fruits and vegetables without sulfuring has recently been proposed by Brown, et al. (10), but their data are preliminary and inconclusive.

Enzyme Activity. Though much has been written on the theory of biological oxidation causing deterioration, this review will consider only studies directly relating to apples. Onslow (50) studied the oxidase system in fruit tissue which browns on injury, and distinguished between peroxidase and an aromatic substance giving the reaction characteristic of the catechol grouping. On injury, according to Onslow, peroxidase activates the oxidation of the aromatic compound with the formation of a peroxide. The latter will react with peroxidase and guaiacum to produce a blue color. In a later paper, Onslow (51) concluded that the apple contains an oxidase system consisting of an oxygenase, a peroxidase, and an aromatic substance with the catechol grouping. The oxygenase, according to Onslow, will activate the oxidation of the catechol aromatic compounds in the cell with the production of a brown color and of a system which will produce a blue color with guaiacum; the oxygenase also will activate the oxidation of catechol, supplied artificially, with the production in the presence of peroxidase of a similar system. Overholser and Cruess (52) tested various chemicals to retard darkening in apple tissue. They indicated that sulfur dioxide prevented darkening by reacting with the organic peroxide rather than with the enzyme. Up to this time, the most

commonly accepted theory was that sulfur dioxide acted on the coloring matter formed in the darkening, and reduced this dark decomposition product as rapidly as it was formed, thereby retaining the original color of the fruit. Balls and Hale (5) emphasized the importance of inhibiting peroxidase to prevent the darkening of apples. According to these workers, inhibitors fall into two classes: (1) substances that affect the enzyme directly, and (2) substances that accelerate its inactivation by hydrogen peroxide. The former class was considered the more important. They indicated that treatment of apples with a dilute solution of glutathione or cysteine salts permitted drying or long-keeping without discoloration. The work of Denny (18, 19) resulted in the use of thiourea in this work and in apple dehydration plants throughout the nation for keeping the cut surfaces of apples from discoloring during preparation of material for dehydration.

MATERIALS AND METHODS

Dehydration Equipment and Procedure

Two machines* were used for dehydration of the fruit. A small cabinet machine (figure 1) with a capacity of 24 pounds of fresh apples was used in the fall of 1942 to determine the effect of various primary drying temperatures, and in the 1943-44 season to study the effect of maturity on the quality of dehydrated apples. This dehydrator was heated by screw-base heating elements; a small fan maintained air movement at the rate of approximately 600 linear feet per minute. Temperature was

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*Designed and built by Professor G. J. Burkhardt, Department of Agricultural Engineering, Maryland Agricultural Experiment Station.

Figure 1. The cabinet dehydrator.

regulated electrically by a thermostat, while the amount of recirculation of air was controlled by means of two small vents at the loading end of the box.

A steam-heated tunnel dehydrator of pilot-plant size (figure 2) was used for the dehydration of large amounts of fruit. This machine consisted of two compartments: a high-temperature or primary tunnel with a parallel-current air flow maintained at a rate of approximately 1,200 linear feet per minute, and a low-temperature or secondary tunnel with a counter-current air flow which was kept at about 600 linear feet per minute. The apples were exposed to temperatures in the primary tunnel at controlled higher levels than the "finishing" temperature in the secondary tunnel. The usual ratio of trucks used in the dehydrator for apples was three trucks in the primary tunnel to four trucks in the secondary tunnel. Six 18 x 24 inch trays made up a single truck. Two "buffer" trucks were used before and after any particular group of test trucks, and also when primary temperatures were raised or lowered so that the test trucks were subjected to the full time at the temperature specified. The secondary or finishing temperature was kept constant, unless otherwise specified, at a temperature of approximately 165° F. To measure temperature and humidity conditions within the machines, wet and dry bulb thermometer readings were recorded every five minutes when using either the cabinet or tunnel dehydrator. Because the primary temperatures and the drying times used in this work varied considerably, this information will be given in those sections where it applies.

Apples to be dehydrated were selected for uniformity of size before being peeled and cored with a mechanical peeler. Only medium-sized fruits were used in this work. The peeled and cored apples were dipped in a 0.05 per cent sodium thiocarbamide (thiourea) solution, hand trimmed to remove

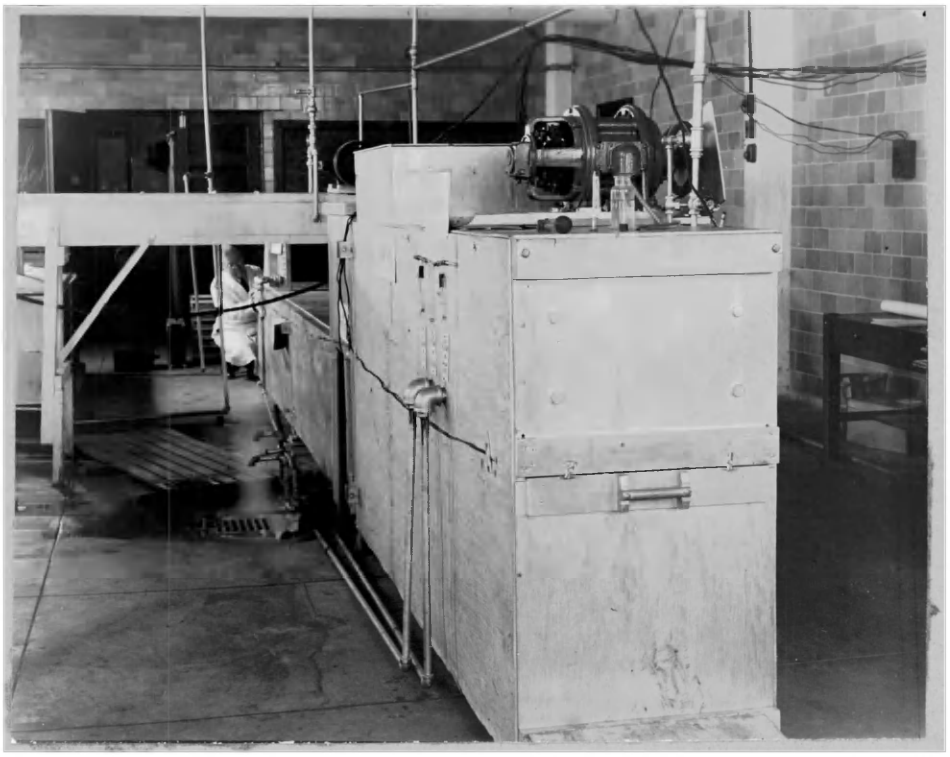

Figure 2. The tunnel dehydrator.

bruises, and each apple was then cut longitudinally by machine into 16 equal sections. The sections were dipped immediately into the thiocarbamide solution again for a minimum of 30 seconds and transferred to dry stock pans.

Trays were loaded at the rate of 0.75 pounds per square foot and placed, six (one truck load) at a time, in an air-tight, plywood sulfur box. Sulfur dioxide gas was introduced from a cylinder through 5/8 inch glass and rubber tubing and the gas was forced through a trap filled with mineral oil through which gas passage was controlled at a uniform rate. The standard sulfuring treatment consisted of a 30-minute exposure to the gas which was introduced in the first 5 minutes of the treatment at a total amount equivalent to 10 pounds per ton of fruit. The sulfuring treatment was so timed that no longer than 5 minutes elapsed from the time the trucks were removed from the sulfur box until they were rolled into the dehydrator. When the cabinet dehydrator was used, the trays were transferred immediately from the sulfur box to the dehydrator which had previously been brought up to desired temperature.

Dehydrated apples were "conditioned" for a period of at least 24 hours. The process of conditioning consisted of placing all of the dried apples from a single lot in a non-airtight container; when the time of conditioning was extended to one week, daily mixing of the material was practiced to insure thorough contact and uniform conditioning. The purpose of the conditioning was to allow the drier sections to take up moisture from the wetter sections; in this manner more uniformity in the moisture content within a single lot of apples was obtained. In the fall of 1942 enameled buckets covered with cheesecloth were used as containers for conditioning. In the spring of 1943, shallow plywood trays were built as conditioning containers and used throughout the remainder of this work.

After conditioning, all samples of dehydrated apples were thoroughly mixed and sealed in No. 1 and No. 2 tin cans at the rate of 0.25 to 0.4 pounds per can. In the first storage study begun in March, 1943, three rooms were used to obtain cold, common, and warm temperature conditions. The cold room was held at a constant temperature of 33° F.; the warm room, at 110° F.; the common storage room fluctuated in temperature between 60° and 98° F.

For the second storage study which was started in January, 1944, two cork-insulated boxes were built, each with one 750-watt strip heater as a source of heat. These one-cubic-meter boxes were so constructed that space allowed on all sides of the stored cans in the box insured a fairly uniform distribution of heat throughout the box. One of these boxes was built in the 33° storage room and heated to a constant temperature of 65° F. The other box was built in a general storage room and heated to a constant temperature of 100° F.

Analytical Procedure

Sampling. Sampling of fresh and dehydrated apples for chemical analyses was standard throughout this investigation. Fresh apples were selected from the same baskets from which corresponding dehydrated material would come. From each of the 20 apples which comprised every fresh sample, a wedge-shaped section of flesh only was cut. The 20 sections were then macerated in a wooden bowl, thoroughly mixed, and duplicate samples were quickly weighed. When sampling was done directly from the dehydrator, a minimum of 20 sections was taken to make up one sample. For a sample of dehydrated apples, the contents of one can of No. 2 size, or the contents of two cans of No. 1 size were taken. Each sample of dehydrated apples consisted of a minimum of 130 sections. Since dehydrated apples were too

dry to chop and too wet to grind, it was necessary to resort to hand-cutting with a pair of small scissors to break up the sample and obtain an aliquot for analysis. Pieces cut with the scissors did not exceed two millimeters in thickness. For all analyses, duplicate determinations were made on each sample.

Ascorbic Acid. Ascorbic acid was determined by the titration method of Bessey and King (8) using a weak solution of 2,6 dichlorophenol-indolphenol dye. For the first work started in the fall of 1942, the sample was placed in a 6 per cent acetic acid, 2 per cent metaphosphoric acid solution and ground in a mortar. Both fresh and dehydrated samples were placed in the acid solution immediately after weighing; the dehydrated samples were allowed to reconstitute one hour in the cold acid solution before macerating the tissue. Filtration through four thicknesses of cheesecloth preceded titration of aliquots of the filtrate. After Cruess (17), King (34), and Morrell (43), the remainder of the ascorbic acid determinations were made by macerating the tissue in a Waring blendor in a 2 per cent metaphosphoric acid solution for 80 seconds, centrifuging for 10 minutes at 3,500 r.p.m., and titrating the supernatant liquid with the dye. Since sulfur reduces the dye used in this titration, it was necessary to neutralize the sulfur, prior to titrating samples of sulfured, dehydrated apples. This was done according to the method of Mapson (39).

Acidity and pH. Titratable acidity and pH determinations were made on expressed juice of a 25-gram sample of dehydrated material which was reconstituted in distilled water at room temperature for 2 hours. pH determinations were made on undiluted juice in a Coleman potentiometer. Acidity was determined by titrating a 10 ml. aliquot of the juice diluted to 50 ml. with distilled water. Carefully standardized 0.1 N sodium hydroxide was used for the titration with phenolphthalein as an indicator.

Sugar and Starch. Total and reducing sugars in dried material stored in the common and cold storage rooms from March, 1943, to March, 1944, were determined using the Shaffer-Hartmann method (58). All later sugar determinations and all starch determinations were made using the Heinze and Murneek modification (31) of the Shaffer-Somogyi method, because this modification was found to be satisfactory for use with dehydrated apples, and it was considerably more rapid than the Shaffer-Hartmann method.

Peroxidase. Peroxidase was determined qualitatively by adding 3-4 drops of a 3 per cent hydrogen peroxide solution and an equal amount of a 1.0 per cent guaiacol solution to a small portion of a sample (2 or 3 grams) in 20 ml. of distilled water. The sample and reagents were thoroughly mixed and allowed to stand for 15 minutes before the results of the test were recorded. Blank determinations and boiled controls were used at least once a day. The guaiacol solution was substituted for a tincture of guaiacum used in the initial tests because guaiacol produced a reddish color in the presence of peroxidase, a color which was somewhat easier to read, and which has been reported as more reliable (53). Variations in the color intensity of the guaiacol reaction were observed in this work, and therefore, in later work an attempt was made to make the method semi-quantitative by giving a numerical value to all positive reactions, using number 5 to indicate the reaction given by fresh apple tissue. Less intense reactions were given corresponding lower numbers. The weakest positive reaction was called plus and was given no numerical value; this reaction produced color only in parts of the carpel and in some vascular bundles.

Sulfur. Sulfur determinations were made according to the method of Nichols and Reed (49) as modified by Mrak (44). The procedure was modified

in this work to the extent that more solution (about 250 ml.) was distilled over in each sample to make absolutely certain that all sulfur in the sample was transferred to the distillate. The method of preparing the sample also was changed. Instead of grinding the sample in two food grinders as specified by Mrak, the sample was partially reconstituted, macerated in a Waring blendor for 30 seconds to a semi-liquid consistency, and rinsed into the distillation flask with distilled water. This method of breaking up the sample was far more rapid as well as exceedingly thorough.

Moisture. Although official methods (1) regarding moisture determinations of dehydrated fruit called for a drying period of 6 hours in vacuo at 70° C., the curve shown in figure 3, made by drying 12 samples of Stayman Winesap apples in the vacuum oven at 70° C., indicates that 6 hours is insufficient time for complete removal of moisture from dehydrated apples. As a result of this preliminary trial, a drying time of 18 hours was adopted as standard for all moisture determinations on apples reported in this paper.

Reconstitution. Cold water reconstitution of dehydrated apples was determined by obtaining the drained weight of samples every 20 minutes for a two-hour period. Although more water would be picked up by additional soaking in cold water, it was found that differences which appeared between samples in two hours were not altered by extending the period beyond this time. Moreover, this two-hour period was double the period recommended by the army (2). Twenty-gram samples were immersed in 300 ml. of water at approximately 25° C. and the schedule was so arranged that each sample was allowed to drain for exactly one minute prior to weighing. A No. 1 tin can with a copper screen bottom was used to hold the sample, and a No. 2 can was used to hold the water. Care was

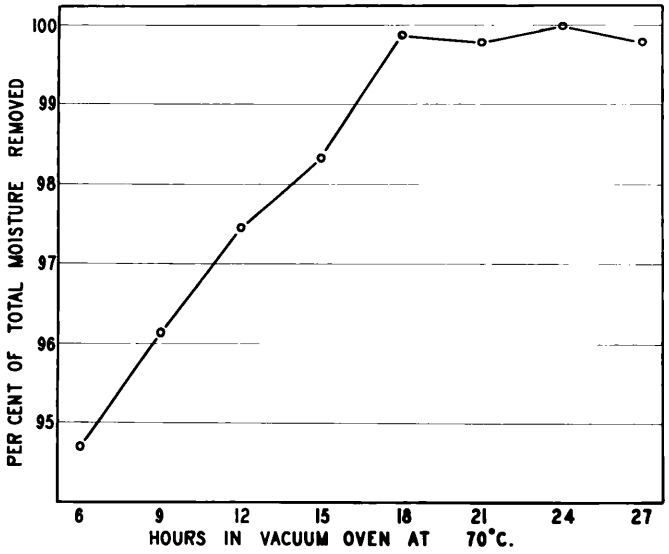

Figure 3. Mean per cent of total moisture removed from 12 samples of dehydrated Stayman Winesap apples as affected by drying time in a vacuum oven. (Calculated on a basis of moisture removed in 24 hours of drying = 100 per cent)

exercised in selecting each sample to obtain uniformity in size of sections making up the sample. Uniformity of dehydrated apple sections was found to be imperative in getting duplicate samples to agree. The results of reconstitution work are reported in terms of moisture recovered, calculated as per cent of initial moisture in the fresh fruit.

RESULTS

Effect of Temperature and Humidity in Dehydration on Ascorbic Acid and Moisture Content

Cabinet Dehydrator. York Imperial and Stayman Winesap apples were used for this study, and from harvest to processing in November and December, 1942, the fresh apples were held in the 33° F. storage room. Three primary drying temperatures, 145°, 175°, 190° F., were used with a standard secondary temperature of 165° F. For the 175° and the 190° treatments the primary temperature was held for 2½ hours, after which time the temperature was lowered and maintained at 165° F. for 2 hours. For the 145° treatment the primary time was the same, but the secondary drying period was extended to 2½ hours, since more drying time was necessary. In order to hold a temperature of 190° F. in this machine, it was necessary to keep the vent openings smaller through the primary period than when working with lower temperatures. This practice resulted in a higher temperature, but also a higher humidity since more of the moisture-laden air was thus recirculated through the machine.

Humidity differences among temperature treatments were maintained in the primary drying period only, while the humidity in the secondary period was nearly standard for all lots, and during this latter period the relative humidity was 10 per cent or less. The relative humidities produced by controlling the amount of recirculation in the cabinet are shown in

table 1. The 145° treatment resulted in a somewhat higher relative humidity than was found at higher temperatures. The 175° treatment gave a much lower humidity throughout the primary drying period, while the 190° treatment produced a high relative humidity due to the necessity of keeping the vents more nearly closed to maintain the high temperature. At the end of the primary drying period in the 190° treatment, however, the humidity was lower than that produced in any other treatment.

TABLE 1. Relative humidity prevailing in the cabinet dehydrator during dehydration at differential temperatures and two humidity levels in the primary drying period.

Hours in dehydrator	Relative humidity (per cent)		
	190° F. Treatment	175° F. Treatment	145° F. Treatment
	Low humidity conditions		
0.25	61	49	64
1	26	22	36
2.5	7	10	15
	High humidity conditions		
2.5	37	40	47

Constant low humidities could not be obtained in the cabinet dehydrator during the primary drying period, but after the first hour the humidities rapidly reached a low level, as vents were fully open. On the other hand, the high humidity conditions for all three temperature treatments, produced by keeping the recirculation vents nearly closed throughout the primary drying period, were nearly constant throughout the first 2½ hours of drying. For the 190° treatment, the relative humidity was approximately 37 per cent; for the 175° treatment, 40 per cent; and for the 145° treatment, 47 per cent.

The results of these temperature-humidity trials are presented in figures 4 through 11; the effects of primary temperatures and humidities are discussed in relation to the results from the total drying period. The loss of ascorbic acid in the 190° treatment was considerably greater than that in either of the two lower temperature treatments. Whereas the 145° treatment resulted in losses of 49 to 57 per cent of the original ascorbic acid, the 190° treatment resulted in losses of 62 to 81 per cent. The intermediate primary temperature, 175° F., was the best treatment from the standpoint of ascorbic acid retention. An exception to this is noted in figure 6 where the loss of ascorbic acid in the 175° treatment exceeded that in the 190° treatment, although the loss at the end of the primary period was much less than that in the 190° treatment. When the lower primary temperatures, 145° and 175° F., were used, a considerable lag in ascorbic acid loss took place during the first 2½ hours of drying. This was especially pronounced in York Imperial apples as compared to Stayman Winesap. The high primary drying temperature resulted in a rapid oxidation of ascorbic acid though some delay occurred in the low humidity treatments. With the 175° treatment the ascorbic acid loss was intermediate or low, depending on the humidity conditions used with the primary temperature.

High and low humidity during the primary drying period had a marked effect on ascorbic acid loss during dehydration. When either variety was dried, high humidity resulted in significantly greater losses of the ascorbic acid than low humidity. The loss was not immediate in York Imperial under high humidity conditions, while in Stayman Winesap the loss took place rapidly, especially at 190° F. Least loss of ascorbic acid was observed in the 175° treatment when used with low humidity. In both varieties this treatment resulted in losses of only 24 to 27 per cent compared to losses of 49 to 81 per cent for other treatments. A possible

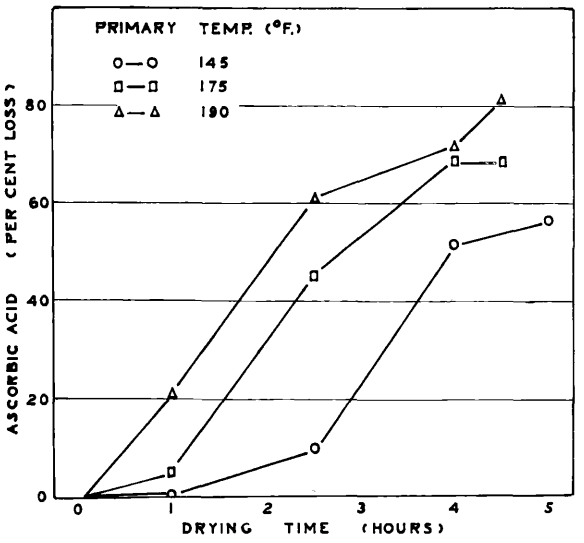

Figure 4. Loss of ascorbic acid during dehydration of Stayman Winesap apples as affected by temperature under high humidity conditions during the primary drying period in a cabinet dehydrator.

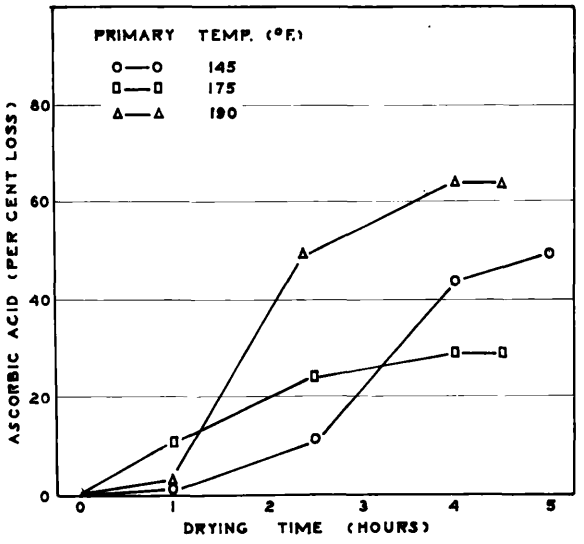

Figure 5. Loss of ascorbic acid during dehydration of Stayman Winesap apples as affected by temperature under low humidity conditions during the primary drying period in a cabinet dehydrator.

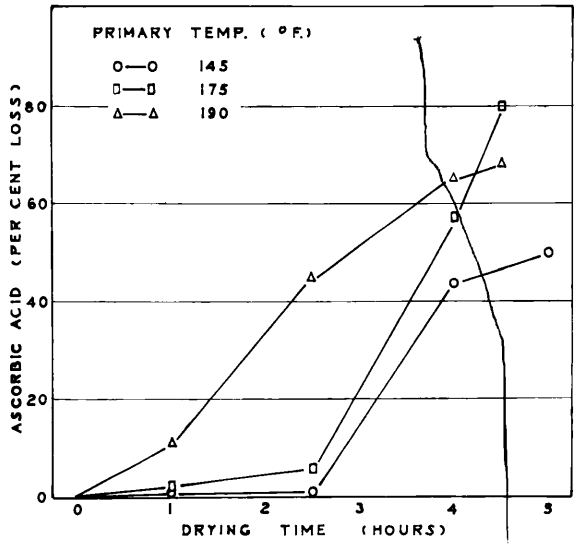

Figure 6. Loss of ascorbic acid during dehydration of York Imperial apples as affected by temperature under high humidity conditions during the primary drying period in a cabinet dehydrator.

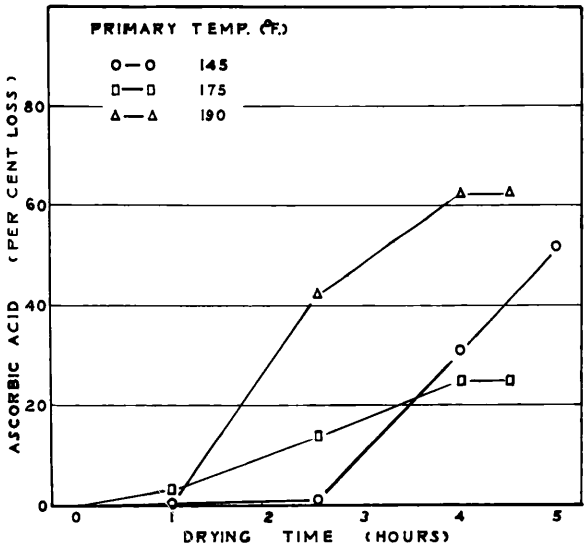

Figure 7. Loss of ascorbic acid during dehydration of York Imperial apples as affected by temperature under low humidity conditions during the primary drying period in a cabinet dehydrator.

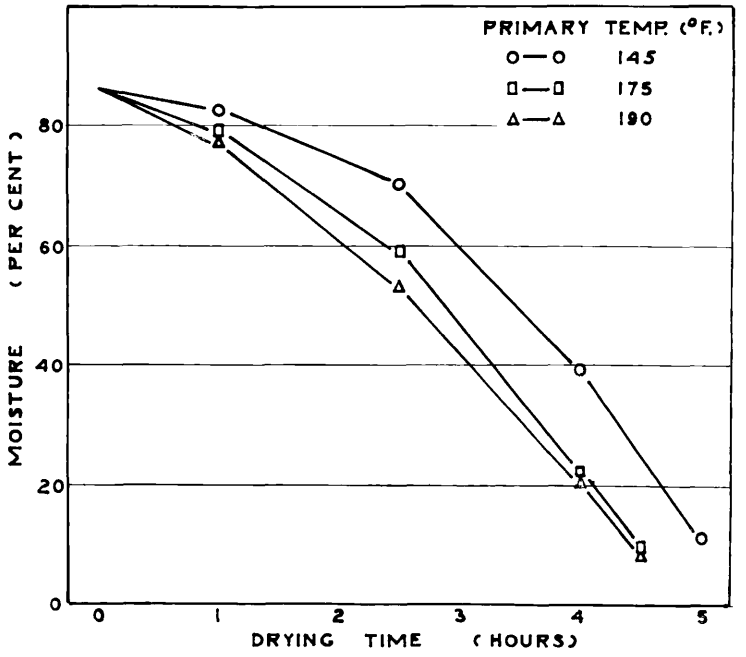

Figure 8. Moisture content of Stayman Winesap apples as affected by temperature under high humidity conditions during the primary drying period in a cabinet dehydrator.

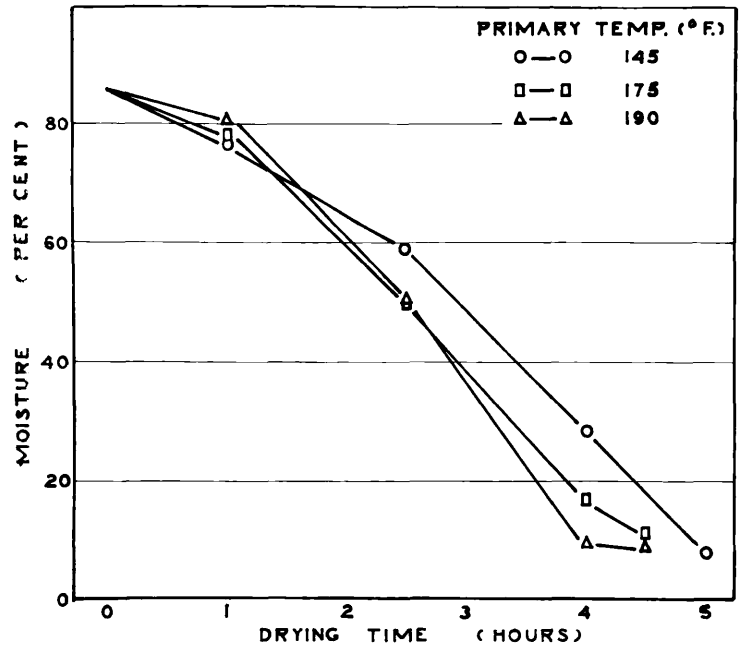

Figure 9. Moisture content of Stayman Winesap apples as affected by temperature under low humidity conditions during the primary drying period in a cabinet dehydrator.

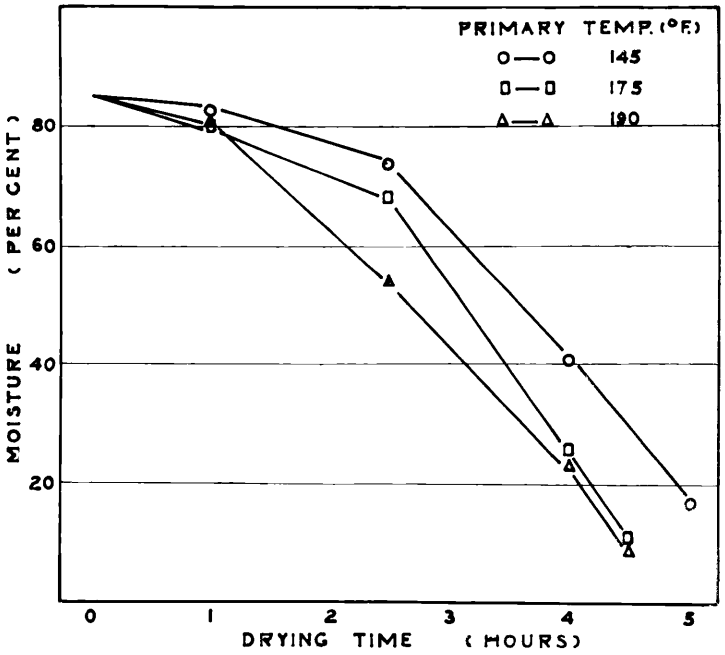

Figure 10. Moisture content of York Imperial apples as affected by temperature under high humidity conditions during the primary drying period in a cabinet dehydrator.

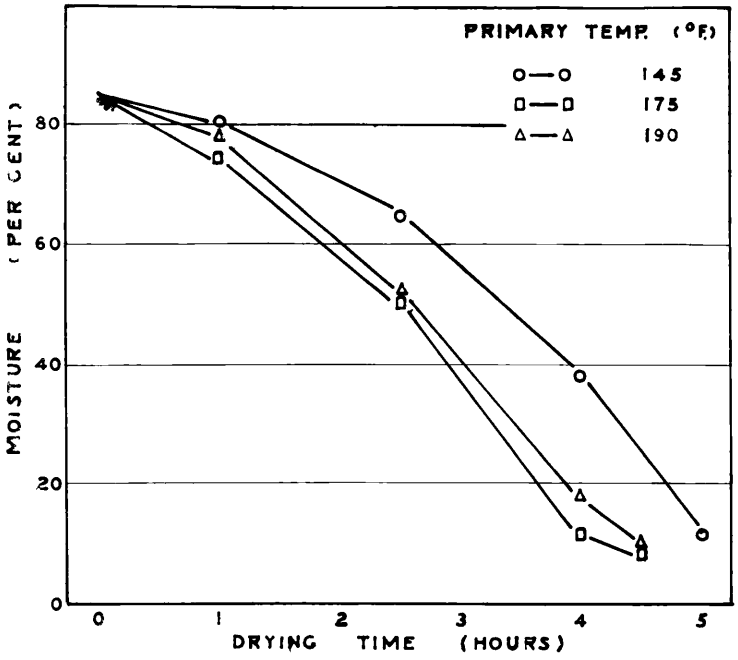

Figure 11. Moisture content of York Imperial apples as affected by temperature under low humidity conditions during the primary drying period in a cabinet dehydrator.

explanation of this may be that the drying rate, as shown in figures 9 and 11, resulting from this temperature treatment was very similar to the rapid drying at 190° but at a lower temperature; compared to the 145° treatment, the drying was much more rapid. Further, the relative humidity of the 175° treatment, shown in table 1, was considerably lower than that in either the 145° or 190° treatment. Eidt (21) has shown that the temperature of the fruit is very nearly that of the wet bulb through the primary drying period in dehydration of apples, and that high temperature with a relative humidity of 20 to 32 per cent is optimum for rapid drying of apples. The humidity in the case of the 175° treatment reached this optimum range more rapidly than did the humidity in either the 145° or the 190° treatment, and thus oxidation of ascorbic acid was reduced. The greater loss of ascorbic acid under all high humidity conditions compared to corresponding low humidity treatments may be explained by the fact that nowhere in the primary drying period did the relative humidity go below 37 per cent in any of the temperature treatments under high humidity; thus the actual temperature of the fruit was higher in this period and the rate of oxidation of ascorbic acid was consequently greater.

In figures 8 through 11 are shown the moisture contents of the apple material taken at intervals from the dehydrator. In general, higher primary temperatures resulted in a more rapid rate of drying as well as a lower final moisture content. This is clearly shown in appendix tables 28 and 29 in which the moisture removed from the fruit is calculated as per cent of initial moisture in the fresh fruit. Dehydration under conditions of low humidity resulted in considerably more rapid drying than corresponding temperature treatments at high humidity. This is readily explained by the more rapid removal of water from the surface of the fruit when low humidity prevailed. In the 175° and 190° treatments similar

rates of drying occurred under not quite the same conditions of low humidity, while in the 145° treatment the drying rate was less in all treatments regardless of humidity.

Tunnel Dehydrator. In order to determine what primary temperatures were possible in the tunnel dehydrator for rapid drying and maximum ascorbic acid retention, primary temperatures ranging from 175° to 210° F. were used with a constant secondary temperature of 165° F. As the temperature in the primary tunnel was increased, the time in this phase of the process was decreased by orderly steps from 120 minutes to 60 minutes. The velocity of 1,200 linear feet per minute which was maintained in the primary tunnel resulted in humidity conditions quite different from those obtainable in the cabinet machine. The relative humidity of the primary tunnel was 10 per cent or less for all trucks; in the secondary tunnel the relative humidity was approximately 6 per cent. Carefully selected Stayman Winesap apples were used for this study, and from the October harvest in a local orchard to dehydration in December, 1943, the fresh apples were held at 33° F.

The results of this investigation are presented in table 2. From this table it can be seen that very low relative humidity prevailed in the primary period at every temperature used, and there was a tendency for reduced humidity as the temperature was increased. By shortening the drying time as primary drying temperatures were increased, the same general moisture content was produced in all trucks. The moisture content of those apples dried in the primary tunnel at 200° F. is higher throughout the drying process, but the other treatments in general are alike in final moisture content with a slightly lower figure resulting from the 210° treatment.

[redacted]

TABLE 2. Moisture and ascorbic acid content of dehydrated Stayman Winesap apples dried under varying conditions of temperature and drying time in the tunnel dehydrator.

Minutes in primary tunnel	Minutes in secondary tunnel	Relative humidity in primary tunnel (per cent)	Temperature of primary tunnel (degrees F.)	Moisture after primary drying (per cent)	Moisture after conditioning (per cent)	Ascorbic acid after conditioning (mg./100 g. dry wt.)
120	120	8.6	175	54.1	15.2	10.2
100	120	9.0	175	58.3	17.3	10.5
100	120	8.3	190	53.8	17.9	8.4
90	140	8.3	190	53.3	17.5	7.6
80	140	8.3	190	66.3	18.4	9.6
90	120	6.9	200	57.8	22.9	10.2
80	120	6.9	200	54.5	25.2	7.8
70	120	6.9	200	65.8	21.4	7.8
80	120	6.7	210	56.0	15.0	10.2
70	120	6.5	210	61.4	16.0	8.9
60	120	5.8	210	59.1	14.9	10.3

[redacted]

The ascorbic acid content of the dehydrated fruit, obtained after a conditioning period of 48 hours, was somewhat variable. However, these figures present evidence to show that the higher primary temperatures are not detrimental to ascorbic acid retention when drying time is reduced. No attempt is made here to attach significance to any one treatment compared to another. The value of these figures lies in the fact that no consistent loss is shown for the higher temperature treatments.

This work with the tunnel dehydrator demonstrated that apples can be dried to a moisture content below commercial requirements in a period as short as 3 hours by using high primary temperatures together with high air velocity. In all of these treatments, the apples came out of the machine with good color and general appearance. Apples dried at 220° F. in the primary tunnel showed some scorching around the edges of the apple sections and a rather hard crust on all of the sections; this seemed to indicate that about 210° F. was the critical limit of primary temperature for dehydrating apples under conditions prevailing in this machine, and this temperature was adopted for the apples dried in December, 1943, for storage described later in this paper. In contrast, the cabinet dehydrator, under the limited conditions of humidity control, had an upper primary temperature limit of about 190° F., since drying at 200° F. in this machine caused scorching.

Effect of Storage Temperature on Dehydrated Apples

1943 Studies. Four varieties, York Imperial, Stayman Winesap, Ben Davis, and Rome Beauty, were used to study the influence of temperature on the storage life of dehydrated apples. The York Imperial apples were obtained from commercial stocks of the American Fruit Growers, Inc., in the fall of 1942, and held at 33° F. until dehydration in February, 1943.

Ninety per cent of this material was estimated to be 2½ inches and up in size; 10 per cent, 2¼ to 2½ inches. The Rome Beauty, Stayman Winesap, and Ben Davis apples were brought to College Park from the cold storage houses of R. S. Dillon, Hancock, Maryland, on March 6, 1943, and dehydrated on March 13 and 14, 1943. Some scald was observed on Rome and Stayman, but the Ben Davis apples were in excellent condition. All three varieties consisted of fruit which was 2¼ inches or more in diameter.

All varieties were dehydrated in the tunnel dehydrator for 2½ hours at 175° F., followed by 2 hours at 165° F. The dehydrated material was conditioned for one week in shallow trays, thoroughly mixed, and sealed in No. 1 tin cans in air at the rate of 0.25 pounds per can. Three storage rooms were used: (1) a cold storage held constant at 33° F., (2) a common storage which fluctuated between 60° F. and 98° F., and (3) a warm storage, held fairly constant at 110° F. The dehydrated York apples were put in differential storages on February 26, 1943; the dehydrated fruit of the other three varieties was stored on March 21, 1943.

The color of the dehydrated fruit was very nearly the same as that of the fresh fruit. The final moisture content reached as a result of the same dehydration conditions was somewhat different for each variety. Ben Davis dried down to 12 per cent moisture; Rome Beauty, to 18 per cent. York Imperial and Stayman Winesap were intermediate at 16 and 15 per cent respectively. When the first samples were taken from storage at the end of one month, all lots which were stored at 110° F. had darkened completely, illustrated by stage V, figure 19. Subsequent investigation revealed that this darkening began in 8 days and was nearly complete at the end of the first two weeks. A musty, hay-like odor accompanied the darkening, and became stronger as the color became more intense. At the end of two weeks the odor of alcohol could be detected. Because of the

rapid deterioration of the samples stored at this temperature, further work at 110° F. could not be carried out with these lots, and the performance of the four varieties in common and cold storage was recorded for a one-year period.

In appendix tables 30 through 33 detailed results of cold and common storage, showing chemical changes during storage, are presented for the four varieties. No change in moisture content was found during the entire storage period in any of the samples. The pH of all varieties under both storage conditions consistently decreased. This decrease in pH was rather surprising since the darkened apples taken from the 110° storage and also those taken from common storage in later months had a flat taste entirely void of any acid flavor whatever. Titratable acidity determinations fluctuated rather widely and show no definite trend. These determinations involved some error in method, but they indicate that titratable acidity was not lost in storage.

Though the varieties were very similar in sugar content, dehydrated York Imperial apples contained the highest percentage of total sugars and the lowest amount of reducing sugars of the four varieties studied. Under cold storage conditions, total sugars in this variety remained constant while reducing sugars gradually increased from 47 to 54 per cent, with a corresponding decrease in non-reducing sugars from 23 to 16 per cent. Similarly in common storage, total sugars remained the same while reducing sugars increased 9 per cent during the year. The sugar content of the other varieties, though somewhat different in initial value, showed the same trend under both storage conditions, but, except for Ben Davis, the common storage resulted in greater changes of both non-reducing and reducing sugars than did cold storage. There was some indication of loss of total sugar in Rome Beauty, and in the case of this

variety the greatest increase in non-reducing sugars occurred. However, the reduction in total sugars could be within the range of variability in the material.

The oxidation of ascorbic acid in the four varieties through the storage period is plotted in figures 12 through 15. The greatest loss of ascorbic acid, ranging from 52 per cent in Rome Beauty apples to 75 per cent in Stayman Winesap apples, occurred in the first 6 months of common storage in all cases. The explanation of this rapid initial loss in common storage is found in the temperature levels for the first 6 months compared to those for the second half of the storage period. During the first half of the storage year, the hot summer temperatures prevailed, reaching the maximum of 98° F. The last 6 months, on the other hand, coincided with the cool fall and winter months when the temperature of the room remained near the minimum of 60° F. Thus the loss of ascorbic acid would seem to be directly related to the temperature of the storage room. In cold storage, York Imperial and Rome Beauty apples decreased in ascorbic acid at a somewhat constant, low rate, whereas Stayman Winesap and Ben Davis apples decreased at a more rapid rate in the first half of the year than in the second half of the storage period.

The summary of ascorbic acid loss, shown in table 3, indicates that during storage the destruction of ascorbic acid in these dehydrated apples was markedly influenced by the temperature, and less so by variety. In common storage, for example, the losses among the four varieties for the entire year ranged from 39 to 61 per cent whereas in cold storage the losses were only 16 to 31 per cent. Of the four varieties stored, Rome Beauty showed the greatest loss of ascorbic acid in cold storage and the least loss in common storage. More work, however, would be necessary

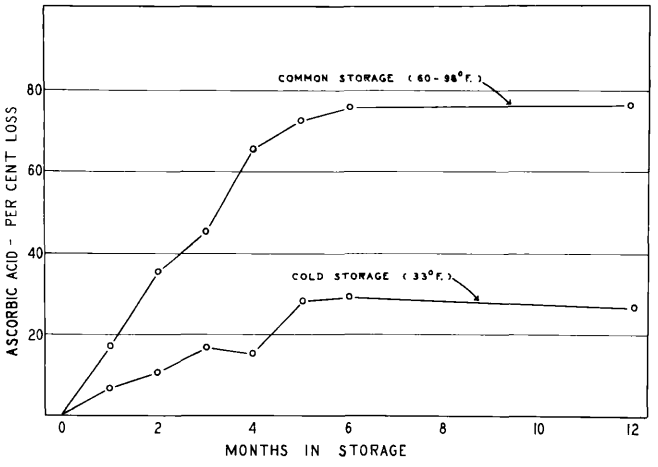

Figure 12. Loss of ascorbic acid in dehydrated Stayman Winesap apples stored for one year at two temperature levels.

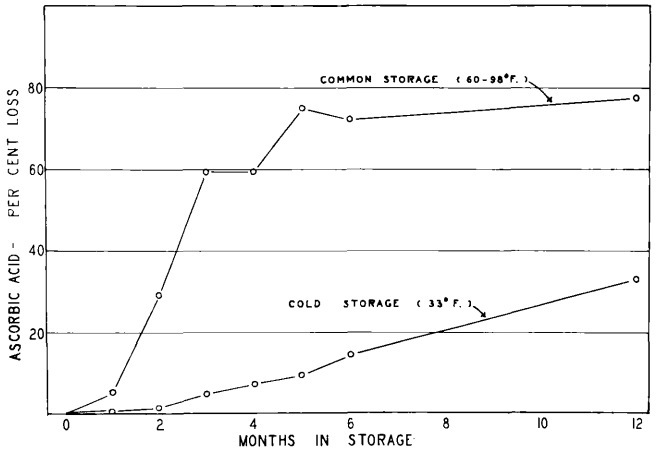

Figure 13. Loss of ascorbic acid in dehydrated York Imperial apples stored for one year at two temperature levels.

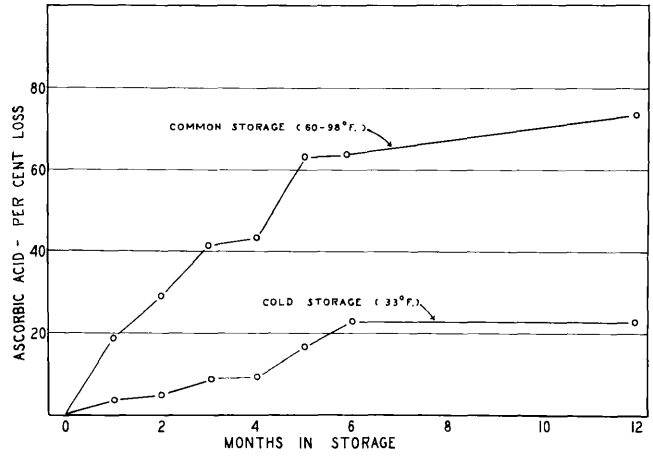

Figure 14. Loss of ascorbic acid in dehydrated Ben Davis apples stored for one year at two temperature levels.

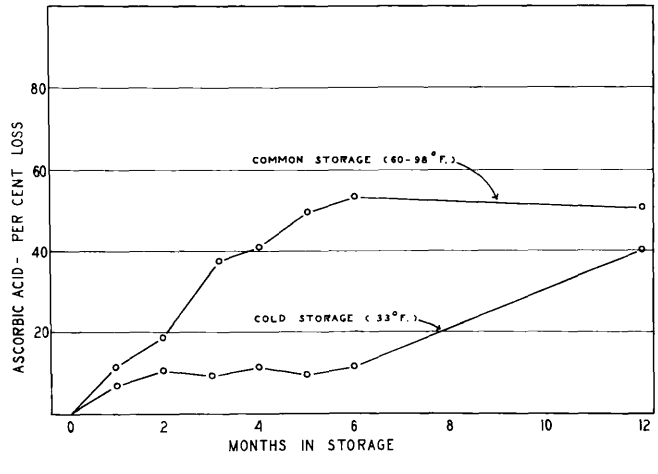

Figure 15. Loss of ascorbic acid in dehydrated Rome Beauty apples stored for one year at two temperature levels.

TABLE 3. Summary of ascorbic acid loss in the dehydration and storage of York Imperial, Ben Davis, Stayman Winesap, and Rome Beauty apples. (See appendix tables 30-33).

Variety	Per cent loss				
	Dehydration	Storage for one year		Dehydration and storage for one year	
		Common	Cold	Common	Cold
York	21.65	60.33	27.92	81.98	49.57
Rome	20.84	39.65	31.94	60.49	52.78
Stayman	20.91	60.69	21.25	81.60	42.16
Ben Davis	26.95	52.96	16.26	79.91	43.21

before this could be established as characteristic of the variety. In York Imperial apples the loss in common storage was nearly twice as much as in cold storage, and in Stayman Winesap and Ben Davis apples, the loss in common storage was nearly three times that in cold storage. Total loss of ascorbic acid, including that in both dehydration and storage for one year, ranged from 60 to 81 per cent when common storage was used, and from 42 to 52 per cent when cold storage was employed.

The percentage of ascorbic acid lost in dehydration, especially in York Imperial and Stayman Winesap apples, presents an interesting comparison to losses in the cabinet dehydrator recorded for these two varieties in previous work. (Tables 28 and 29) Whereas the loss of ascorbic acid from these two varieties when dried in the cabinet machine at 175° F. under low humidity conditions was 24 to 27 per cent, the loss when dried in the tunnel machine was only 21 per cent for each variety. Since the temperature used in primary drying was the same in both machines, this indicates that the low relative humidity of less than 10 per cent, which prevailed in the tunnel machine, was responsible for the reduced loss of ascorbic acid.

In cold storage no discoloration of any kind could be found during this investigation. In common storage, only bruised areas which had not been entirely removed before dehydration showed a tendency to turn brown at the end of six months of storage. York Imperial, Rome Beauty, and Stayman Winesap apples darkened only slightly in common storage by the end of the year, whereas Ben Davis apples retained almost completely the original white flesh color throughout the storage period. This superior appearance of Ben Davis apples was clear even when allowance was made for the white flesh characteristic of this variety. The better color of Ben Davis apples might have been due partially to the lower moisture content, which was reached by this variety in dehydration, compared to the moisture content reached by the other varieties.

1944 Studies. The four varieties of dehydrated apples used in the 1943 studies all showed discoloration after 8 days of storage at 110° F. Since the Quartermaster Subsistence Research Laboratory specified 100° F. as a test temperature for use in research work on high temperature storage of dehydrated foods, this temperature was used in place of the higher temperature employed in 1943. These studies were planned to place particular emphasis on increasing the storage life of dehydrated apples at 100° F. through methods of sulfuring, a combination of sulfuring and blanching, types of pack, and degree of drying. The variety Stayman Winesap was selected for this detailed work because of the high quality of dehydrated fruit of this variety, and because of the importance of Stayman among apple varieties grown in Maryland. The fruit was selected at picking time for good color as well as uniform size, placed in 33° F. storage on the day of harvest, and stored until December when an average pressure test of approximately 12 pounds indicated that the fruit was fully ripe.

The apples were dehydrated in December, 1943, in the tunnel dehydrator

for 105 minutes at 210° F. followed by 135 minutes at 165° F. Eleven days elapsed from the time the first lots were dehydrated until the total volume was sealed in tin cans. During this period, one lot, No. 124, was dehydrated to a low moisture content by an additional 8 hours in the cabinet dehydrator at 165° F. and immediately sealed in tin cans. The bulk of the material was turned daily in the conditioning trays until the last day of dehydration when the dried apples were pooled, thoroughly mixed, and segregated into 4 parts for further sulfuring treatment.

The several lots of dehydrated and resulfured apples were sealed in vacuum, carbon dioxide, and air in No. 2 cans, and the canned material was placed in storage at constant temperatures of 33°, 65°, and 100° F. in storage facilities already described. Due to unforeseen difficulties experienced in setting up the apparatus for sulfurous acid determination, the various lots of apples were not placed in differential storage until January 20, 1944; from the time of sealing in cans to placing under different storage temperature conditions, all lots were held in the 33° F. storage room. A summary of the sulfuring, blanching, and packing treatments is given in table 4, and for convenience in later discussion, these treatments will be referred to by the lot or code numbers.

Since this work was primarily concerned with preservation in high temperature storage, only air packs were placed in 65° and 33° F. storage. Further, it was known from previous work that deterioration would likely be rather slow in apples stored at these two temperatures, and therefore, samples for analyses of apples stored at 65° and 33° F. were taken at intervals of 90 days, whereas more frequent sampling was necessary for material stored at 100° F.

The results of analyses of apples stored for 9 months at 65° F. and 33° F. are presented in tables 5 and 6. From these data, it can be seen

TABLE 4. Treatments used for dehydrated Stayman Winesap apples stored at 100° F. (1944).

Code*	Rate of sulfuring before dehydration	Blanch before dehydration	Rate of sulfuring after dehydration	Atmosphere in sealed container
120 A	10 lbs./ton	none	none	air
120 C	"	"	none	CO_2
120 V	"	"	none	vacuum
121 A	"	"	10 lbs./ton	air
121 C	"	"	10 lbs./ton	CO_2
121 V	"	"	10 lbs./ton	vacuum
122 A	"	"	20 lbs./ton	air
122 C	"	"	20 lbs./ton	CO_2
122 V	"	"	20 lbs./ton	vacuum
123 A	"	30 seconds	20 lbs./ton	air
123 C	"	30 seconds	20 lbs./ton	CO_2
123 V	"	30 seconds	20 lbs./ton	vacuum
124 A**	"	none	none	air

*Note: A = air-pack
C = carbon-dioxide pack
V = vacuum pack

**Lot 124 was dried to low moisture content by 8 hours additional drying in the cabinet dehydrator.

[redacted]

TABLE 5. Analysis of dehydrated Stayman Winesap apples stored at 33° F. sealed in air.
(Stored January 20, 1944.)

Days stored	Moisture (per cent)	Ascorbic acid (mg./100 gr. dry wt.)	Sulfurous acid (p.p.m.)	Reducing sugar (per cent dry wt.)	Non-reducing sugar (per cent dry wt.)	Total sugar (per cent dry wt.)
		Lot 120 (sulfured 10 lbs./ ton)				
0	13.5	10.2	1321	50.8	22.0	72.8
90	14.2	8.7	1251	51.3	22.4	73.7
180	13.8	8.0	1193	50.6	21.9	72.5
270	13.2	7.6	1124	50.0	22.2	72.2
		Lot 121 (sulfured 10 lbs./ton, resulfured 10 lbs./ton)				
0	13.0	10.3	1351	50.2	20.8	71.0
90	13.9	8.9	1291	50.7	21.9	72.5
180	13.7	8.1	1301	50.7	21.8	71.8
270	13.3	7.6	1248	49.8	21.7	71.5
		Lot 122 (sulfured 10 lbs./ton, resulfured 20 lbs./ton)				
0	12.8	10.0	1407	48.4	18.1	66.6
90	13.9	9.1	1350	49.2	18.8	68.1
180	13.6	8.7	1310	49.1	20.6	69.7
270	12.9	8.0	1296	50.5	20.2	70.7
		Lot 123 (sulfured 10 lbs./ton, steam-blanched, resulfured 20 lbs./ton)				
0	11.0	9.6	1768	50.4	18.6	68.9
90	11.0	9.7	1610	51.3	19.8	71.0
180	10.9	9.5	1600	51.2	20.4	71.6
270	10.1	8.5	1537	51.0	20.7	71.6

[redacted]

TABLE 6. Analysis of dehydrated Stayman Winesap apples stored at 65° F. sealed in air.
(Stored January 20, 1944.)

Days stored	Moisture (per cent)	Ascorbic acid (mg./100 gr. dry wt.)	Sulfurous acid (p.p.m.)	Reducing sugar (per cent dry wt.)	Non-reducing sugar (per cent dry wt.)	Total sugar (per cent dry wt.)
			Lot 120 (sulfured 10 lbs./ton)			
0	13.5	10.2	1321	50.8	22.0	72.8
90	14.6	8.5	1179	50.6	19.7	70.3
180	14.1	7.8	1160	47.7	18.6	66.4
270	12.8	7.2	1172	50.7	22.0	72.7
			Lot 121 (sulfured 10 lbs./ton, resulfured 10 lbs./ton)			
0	13.0	10.3	1351	50.2	20.8	71.0
90	14.2	8.4	1220	49.9	19.6	69.5
180	14.0	8.5	1194	49.3	19.5	68.8
270	11.9	8.1	1124	50.2	21.3	71.5
			Lot 122 (sulfured 10 lbs./ton, resulfured 20 lbs./ton)			
0	12.8	10.0	1407	48.4	18.1	66.6
90	14.0	8.0	1200	51.2	19.8	70.9
180	13.8	8.3	1190	48.7	20.0	68.7
270	13.2	8.1	1172	50.7	21.7	72.4
			Lot 123 (sulfured 10 lbs./ton, steam-blanched, resulfured 20 lbs./ton)			
0	11.0	9.6	1768	50.4	18.6	68.9
90	11.5	9.3	1497	53.3	16.7	70.1
180	11.0	9.4	1510	47.6	21.6	69.2
270	10.4	8.4	1421	50.2	20.0	70.2

that there was a decrease in sulfurous acid in all lots at both temperatures. That these changes might be seen more clearly, cumulative losses are shown in table 7; variance analysis of these latter figures is given in table 34 (appendix). In nearly every case the greatest decrease in sulfurous acid occurred in the first 90 days of storage, as seen from the losses recorded in the first period. With the exception of lot 120 in 65° F. storage and lot 121 in 33° F. storage, all lots showed a constant decrease of sulfurous acid, and these losses are shown to be significant. It is evident, also, that decreases in sulfurous acid were influenced by temperature. With the exception of lot 120, all lots showed significantly higher losses in 65° F. storage compared to 33° F. storage. Although the variance analysis did not show significance for differences caused by treatments, it is interesting to note that in 65° F. storage the total losses of sulfurous acid were progressively greater as higher initial sulfurous acid contents were obtained. That is, the order of these treatments, in respect to sulfurous acid content at the beginning of storage, remained the same on the basis of cumulative losses.

The loss of ascorbic acid from the various samples stored at either 33° or 65° F. was not marked, and no significance can be attached to differences between temperature treatments, as determined by analysis of variance of cumulative losses in table 8. This indicates that ascorbic acid was not sensitive to the 65° F. temperature compared to 33° F. as was sulfurous acid, since significant differences were recorded for sulfurous acid decreases in the two temperature levels. When the ascorbic acid losses at 65° and 33° F. are compared to those at 100° F., shown in figure 16 which was made by plotting the losses of lot 120 sealed in air and stored at the three temperatures, it was apparent that high temperature storage at 100° F. resulted in a rapid and complete loss of ascorbic acid.

TABLE 7. Cumulative losses of sulfurous acid, shown by analysis at intervals during storage, in dehydrated Stayman Winesap apples as affected by storage temperatures and treatments* at the time of dehydration.

Storage interval (days)	Cumulative loss** of sulfurous acid (in p.p.m.)	
	33° F. storage	65° F. storage
	Lot 120	
90	70	142
180	128	161
270	197	149
	Lot 121	
90	60	131
180	50	157
270	103	227
	Lot 122	
90	57	207
180	97	217
270	111	235
	Lot 123	
90	158	271
180	168	258
270	231	347

*Treatments: Lot 120, sulfured @ 10 lbs./ton, dried; Lot 121, sulfured @ 10 lbs./ton, dried, resulfured @ 10 lbs./ton; Lot 122, sulfured @ 10 lbs./ton, dried, resulfured @ 20 lbs./ton; Lot 123, sulfured @ 10 lbs./ton, steam-blanched 30 seconds, dried, resulfured @ 20 lbs./ ton.

** Differences necessary for significance:
Between Temperatures - 100.58 at 5% point
Between storage intervals - 28.58 at 1% point

TABLE 8. Cumulative losses of ascorbic acid, shown by analysis at intervals during storage, in dehydrated Stayman Winesap apples as affected by storage temperature and treatments* at the time of dehydration.

Storage interval (days)	Cumulative loss** of ascorbic acid (in mg./100 g. dry weight)	
	33° F. storage	65° F. storage
	Lot 120	
90	1.5	1.7
180	2.2	2.4
270	2.6	3.0
	Lot 121	
90	1.4	1.9
180	2.2	1.8
270	2.7	2.2
	Lot 122	
90	0.9	2.0
180	1.3	1.7
270	2.0	1.9
	Lot 123	
90	-0.1	0.3
180	0.1	0.2
270	1.1	1.2

*Treatments: Lot 120, sulfured @ 10 lbs./ton, dried; Lot 121, sulfured @ 10 lbs./ton, dried, resulfured @ 10 lbs./ton; Lot 122, sulfured @ 10 lbs./ton, dried, resulfured @ 20 lbs./ton; Lot 123, sulfured @ 10 lbs./ton, steam-blanched 30 seconds, dried, resulfured @ 20 lbs./ton.

**Differences necessary for significance:
Between Treatments - 0.508 at 1% point
Between storage intervals - 0.252 at 1% point

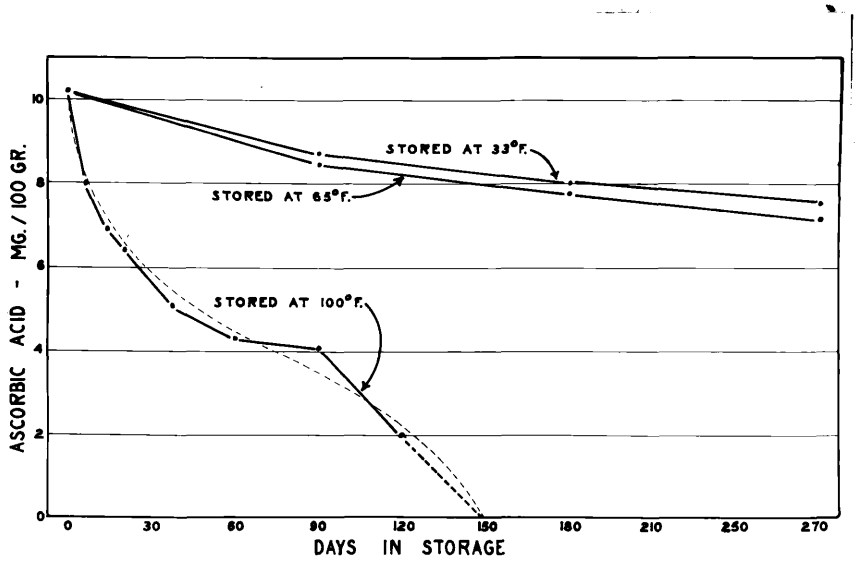

Figure 16. Loss of ascorbic acid in dehydrated Stayman Winesap apples stored for 9 months at 33°, 65°, and 100° F. sealed in air. (Lot 120, sulfured at 10 lbs./ton before dehydration.)

Thus at some point between 65° and 100° F. the losses of ascorbic acid would begin to rise significantly. The sulfur treatments, however, as well as the storage intervals did result in significant differences in ascorbic acid loss. The treatments which received the heaviest sulfuring resulted in the best retention of ascorbic acid, and differences in favor of treatments were highly significant, as were the differences produced by the length of time the samples were stored. Except for lot 123, the greatest loss of ascorbic acid occurred during the first 90-day period of storage, which was somewhat parallel to decreases of sulfurous acid in this period.

Sugar determinations of the samples stored at 65° and 33° F., recorded in tables 5 and 6, showed no significant changes in any of the treatments during the storage period. With some variation, reducing sugars remained essentially at a constant level as did non-reducing and total sugars. These data are not in agreement with the results of the 1943 storage work where a gradual accumulation of reducing sugars was found in dried apples stored in both cold and common storage. This can possibly be explained on a basis of the results of enzyme determinations. In all samples stored in the 1943 work, a positive peroxidase test was obtained; in all samples stored in the 1944 work, a negative peroxidase reaction resulted. Thus the treatment given the apples in this work resulted in destruction of any enzyme systems operating, and this could account for the little change which took place in the sugars in this material, whereas enzyme activity could be responsible for the accumulation of reducing sugars noted in the four varieties stored in 1943.

The flavor, color, and general appearance of all lots stored at both 65° and 33° F. were the same after 9 months of storage as compared to condition at the beginning of the storage period. No differences could be

detected in visible characteristics and no off-flavors or hay-like odors developed under either storage condition.

It was not known how rapidly changes would occur in dehydrated apples in the 100° storage box, and thus frequent analyses of this material were made in the early part of the storage period. Later these intervals between sampling were lengthened until the end of the 270th day when all but lot 124 had darkened to the inedible stage (figure 19) and the project was discontinued.

Table 9 presents the ascorbic acid content of samples taken at intervals from 100° storage. Retention of ascorbic acid correlated closely with decreases in sulfurous acid throughout the storage period. Lot 120, which was given only the standard sulfuring before dehydration, lost ascorbic acid at a considerably higher rate than did any of the other lots; lot 123, which had the highest sulfur content of the four lots at the beginning of storage, retained the most ascorbic acid on a percentage basis even though the apples in this treatment were lower in ascorbic acid after steam-blanching and dehydration. The inclusion of lot 124, dried an additional period to 2.9 per cent moisture, proved that the combination of low moisture and a relatively high sulfur content was necessary for retention of ascorbic acid in the high temperature storage. Throughout the storage period this treatment was consistently higher in ascorbic acid, and at the end of 9 months of storage this sample was only beginning to show the initial stages of darkening, compared to the complete discoloration in all other lots. At this point the loss of ascorbic acid from lot 124 was approximately 66 per cent compared to a loss of 100 per cent for all other samples.

In every comparison of lots of similar moisture content, the vacuum pack was more effective in ascorbic acid retention than the carbon dioxide

[redacted]

TABLE 9. Ascorbic acid content, expressed as mg./100 grams, of dehydrated Stayman Winesap apples stored at 100° F.
(Stored January 20, 1944)

Lot* no.	Nature of pack	Days stored										
		0	7	14	20	36	60	90	120	150	200	270
120	air	10.2	8.0	6.9	6.4	5.1	4.3	4.1	2.0	-	-	-
120	vacuum	10.2	9.2	7.9	8.0	7.1	4.8	5.0	4.4	-	-	-
120	CO_2	10.2	8.9	6.8	6.8	5.5	5.0	4.4	3.3	-	-	-
121	air	10.3	8.2	6.7	7.0	6.5	4.5	4.5	2.4	-	-	-
121	vacuum	10.3	9.2	9.1	8.2	7.7	6.0	6.4	4.7	-	-	-
121	CO_2	10.3	8.0	8.4	6.8	5.8	5.2	5.5	4.0	-	-	-
122	air	10.0	8.0	7.6	7.6	6.6	5.0	4.6	2.8	-	-	-
122	vacuum	10.0	8.9	8.7	9.1	8.3	7.2	6.8	6.0	4.3	-	-
122	CO_2	10.0	8.0	8.0	8.0	6.9	5.3	4.9	4.2	-	-	-
123	air	9.6	8.4	7.8	8.1	8.1	5.1	4.8	3.2	-	-	-
123	vacuum	9.6	9.6	9.5	9.0	9.0	7.8	7.4	6.4	5.2	-	-
123	CO_2	9.6	9.8	9.3	8.5	8.7	7.2	6.0	5.6	4.7	-	-
124	air	10.1	10.1	9.6	9.1	-	-	8.4	-	5.6	-	3.4

*Treatments: 120 - sulfured @ 10 lbs./ton, dried; 121 - sulfured @ 10 lbs./ton, dried, resulfured @ 10 lbs./ton; 122 - sulfured @ 10 lbs./ton, dried, resulfured @ 20 lbs./ton; 123 - sulfured @ 10 lbs./ton, steam-blanched 30 seconds, dried, resulfured @ 20 lbs./ton.
Initial sulfurous acid contents: Lot 120, 1321 p.p.m.; lot 121, 1351 p.p.m.; lot 122, 1407 p.p.m.; lot 123, 1768 p.p.m.; lot 124, 1466 p.p.m.

[redacted]

pack, whereas both were clearly superior to the air pack in this respect. The data show, however, that pack atmosphere was not as important as the moisture content of the apples in retention of ascorbic acid, illustrated by comparing lot 124 to all other treatments regardless of the nature of the pack. The apples making up lot 124 were not sealed in vacuum or carbon dioxide; therefore, the difference between the air-packed, low-moisture apples and other treatments which had been packed in gas or vacuum becomes of even greater importance. Sealing of low-moisture apples (3 per cent or less) in carbon dioxide or vacuum would offer the possibility of even greater ascorbic acid retention.

The sulfurous acid content of the dehydrated samples stored at 100° F. for 9 months is shown in table 10. The low-moisture treatment, lot 124, was clearly superior to all other treatments in that approximately 50 per cent of the sulfurous acid was retained in this fruit after 9 months of storage, whereas the other samples lost from 77 to 100 per cent of initial sulfurous acid. Differences among other treatments were apparent to the extent that increased sulfuring, and sulfuring plus blanching, definitely increased the retention of sulfurous acid in spite of relatively small differences in initial sulfur contents among lots 120, 121, and 122.

Retention of sulfurous acid seemed to be influenced by the pack atmosphere. As seen from the data in table 10, the vacuum packed apples retained the most sulfurous acid in each of the four treatments of comparable moisture content. The carbon dioxide pack resulted in intermediate retention of sulfurous acid by the apples whereas the air pack resulted in the poorest retention of sulfurous acid. The relationship between the three types of pack is illustrated in figure 17, made by plotting the curves for the air, carbon dioxide, and vacuum packs of the standard sulfur

TABLE 10. Sulfurous acid content, expressed as parts per million, of dehydrated Stayman Winesap apples stored at 100° F. (stored January 20, 1944)

Lot* no.	Nature of pack	Days stored										
		0	7	14	20	36	60	90	120	150	200	270
120	air	1321	980	906	917	875	405	259	0	0	0	0
120	vacuum	1321	1070	1040	1065	1099	798	538	226	186	181	173
120	CO_2	1321	1121	1084	936	888	585	353	82	0	0	0
121	air	1351	1091	1184	1164	964	746	571	123	0	0	0
121	vacuum	1351	1091	1181	1194	1152	949	757	277	192	144	88
121	CO_2	1351	1009	1068	1084	1035	666	552	205	93	94	0
122	air	1407	1111	1136	1144	1122	959	716	339	144	156	164
122	vacuum	1407	1162	1144	1294	1252	950	1067	534	361	281	299
122	CO_2	1407	1203	1049	1064	1099	899	622	216	199	244	164
123	air	1768	1335	1314	1274	1229	1040	823	441	268	256	279
123	vacuum	1768	1466	1389	1354	1388	1343	880	810	602	393	404
123	CO_2	1768	1456	1389	1554	1406	1403	1130	687	412	418	336
124	air	1466	1467	1427	-	-	-	1471	-	866	-	759

*Treatments: 120 - sulfured 10 lbs./ton; 121 - sulfured 10 lbs./ton, resulfured 10 lbs./ton; 122 - sulfured 10 lbs./ton, resulfured 20 lbs./ton; 123 - sulfured 10 lbs./ton, steam-blanched, dried, resulfured 20 lbs./ton.

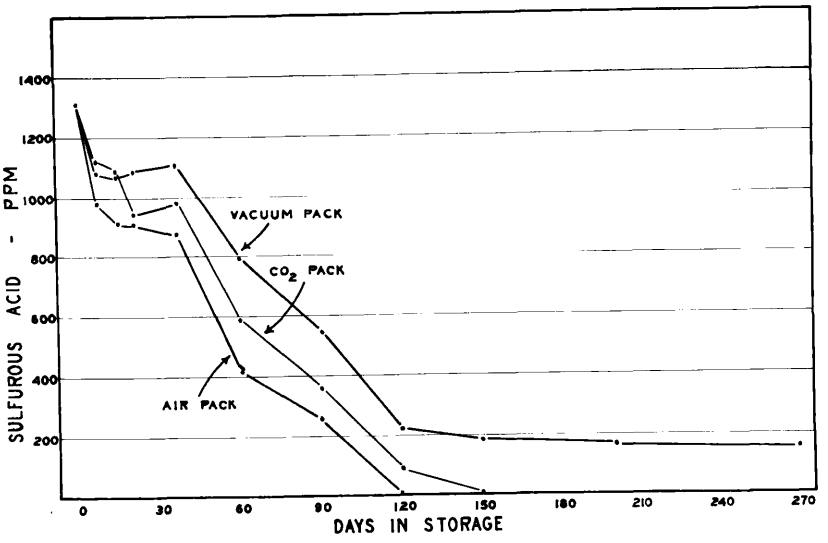

Figure 17. Effect of vacuum, carbon dioxide, and air packs on retention of sulfurous acid in storage of dehydrated Stayman Winesap apples. (Lot 120, sulfured at 10 lbs./ton before dehydration)

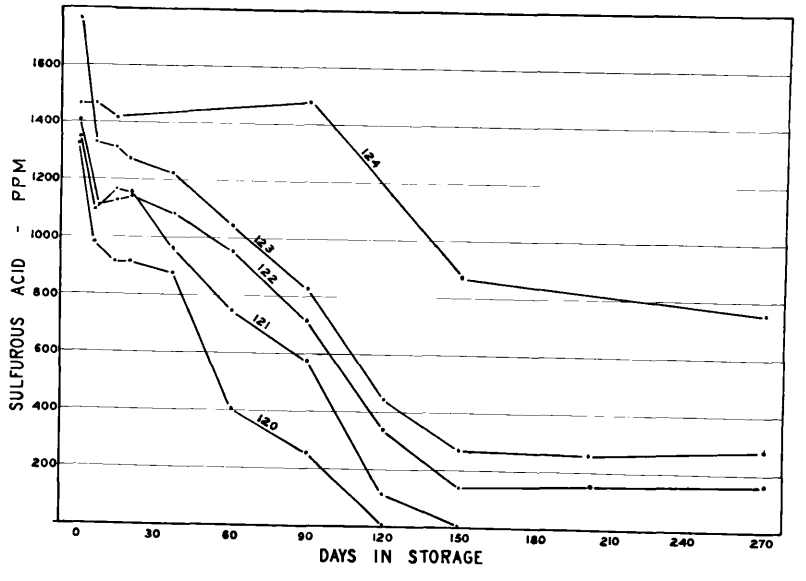

Figure 18. Loss of sulfurous acid in dehydrated Stayman Winesap apples stored at 100° F. sealed in air.

treatment, lot 120. Nichols and Christie (46) reported that sulfur dioxide in dehydrated apples might eventually disappear during storage. These data are in agreement with this statement as shown by the air and gas packs of lot 120 and lot 121, all of which resulted in a complete loss of sulfurous acid after 9 months of storage. Of these, the air pack of the control lot, lot 120, was the first to lose all sulfurous acid, the complete loss showing up after 120 days of storage.

Particular attention is called to the steam-blanched apples, those of lot 123, which showed very little loss of sulfurous acid in the last 120 days of storage regardless of type of pack. Although no definite conclusions are offered from these data, it is possible that steam-blanching might level out the curve after a certain percentage of initial sulfurous acid has been lost. This is suggested because the steam-blanched fruit always dried down to a lower final moisture content, and in doing so might result in a"locking in" of a certain amount of sulfur which would not be easily given up as illustrated with lot 124. If the loss-curve for sulfurous acid could be leveled out in this manner, and if this could be done at a high enough level, prolonged high temperature storage might be possible. However, more work is necessary to reveal the nature of sulfurous acid disappearance from dried fruit before this point can be fully developed.

Sulfurous acid content, as was the case with ascorbic acid content, was reduced markedly by high temperature storage compared to 65° and 33° F. storage. This rate of loss in the high temperature storage was in turn influenced by both moisture content of the apples and by the type of pack in which the apples were sealed. To emphasize the superiority of low moisture apples over others in this respect, the sulfurous acid contentsof the air packs of all lots were plotted in figure 18. In this

figure, the curve for lot 124 shows more clearly the strikingly lower sulfurous acid decreases in low-moisture apples compared to those of all other samples. That the initial sulfurous acid content of lot 124 did not dictate its order of sulfur disappearance among lots was illustrated, since lot 123, the steam-blanched apples, had an initial sulfurous acid content of over 1700 parts per million whereas the low moisture apples, lot 124, had an initial content of 1400 parts per million and this order was reversed after the first week of storage when the sulfurous acid content of lot 123 dropped to 1335 parts per million, or 132 parts per million lower than the sulfurous acid content of lot 124. When, however, only those lots of comparable moisture content are considered, the initial order in regard to sulfurous acid content was maintained throughout the 9 months of storage; that is, lot 120, which had the lowest initial sulfurous acid content was first to show a 100 per cent loss of sulfur; lot 121, next lowest at the start of the storage period, was next to lose 100 per cent, etc.

Quantitative sugar and starch analyses were made on the dehydrated apples stored at 100° F. at the same time when lots were sampled for sulfurous acid and ascorbic acid determinations. The complete results of sugar and starch determinations are given in table 36 in the appendix. Lot 120, the standard sulfuring treatment, showed the greatest changes of non-reducing sugars. However, the four lots of comparable moisture content, lots 120, 121, 122, and 123, showed somewhat similar sugar changes throughout the storage period. These figures from the four lots were averaged and are compared in table 11 to the sugar determinations of lot 124, the low-moisture apples. These data indicate a slow, continuous hydrolysis of the relatively low remaining starch in both the low-moisture apples and the fruit which was 10 to 14 per cent moisture. The data show

TABLE 11. Sugar and starch content of dehydrated Stayman Winesap apples sealed in air and stored for 270 days at 100° F. Averages of lots 120, 121, 122, and 123 compared to lot 124. (See appendix table 36.)

Days stored	Reducing sugars	Non-reducing sugars	Total sugars	Starch
	(Expressed as per cent of dry weight)			
	Averages of lots 120, 121, 122, and 123			
0	49.9	19.9	69.8	1.63
7	49.7	19.7	69.4	
14	49.6	19.0	68.6	
20	48.5	17.9	66.4	
36	50.0	16.0	66.0	
60	49.9	13.8	63.7	
90	50.2	10.0	60.2	1.56
120	52.9	8.8	61.7	
150	53.8	6.9	59.7	
200	57.9	10.9	68.8	1.49
270	62.7	7.3	70.0	1.41
	Lot 124			
0	50.1	20.1	70.2	1.45
14	48.1	16.8	64.9	
20	48.2	15.3	63.5	
90	50.6	13.0	63.6	
150	49.0	21.3	70.3	1.42
270	49.8	23.4	73.2	1.37

a gradual increase of reducing sugars after the 90th day to the end of the storage period when reducing sugars averaged 63 per cent compared to an average of 50 per cent at the beginning of storage. In the low-moisture apples, lot 124, this increase in reducing sugars did not take place; a very slight decrease was shown in the first 20 days of storage after which time the reducing sugar content remained around the original figure of 50 per cent. Total sugars in the four averaged lots decreased until the 150th day, after which there was an accumulation. At the end of the storage period total sugars averaged 70 per cent compared to 69.8 per cent at the beginning of storage. The low-moisture apples, lot 124,

also showed some initial loss of total sugars, but the increase which followed was greater and the final figure at the end of the storage period was 3 per cent higher than at the beginning of storage. Non-reducing sugars showed a steady decrease in the averaged lots, broken only by the figure obtained after 200 days of storage. In the low-moisture apples, however, the non-reducing sugars decreased from 20 to 13 per cent in the first 90 days, after which time non-reducing sugars increased to 23 per cent found at the end of the storage period. Starch hydrolysis could account for some of the increase in sugars after the initial decreases, but it does not account entirely for the accumulation of non-reducing sugars in the low-moisture apples. Apparently other factors were operating. To the author's knowledge these data are the first sugar determinations to be reported on dehydrated apples in relation to storage effects. Until further work is done on oxidative and hydrolytic reactions taking place in stored, dehydrated apples, the explanation of these sugar changes cannot be forthcoming.

To determine what effect packing in vacuum and carbon dioxide might have on sugar changes in dehydrated apples stored at high temperatures, sugar determinations were made on the vacuum, carbon dioxide, and air packs of the standard sulfuring treatment, lot 120. These results are presented in table 12. Reducing sugars increased in all three types of pack, but somewhat more slowly during the initial period in the air pack compared to the carbon dioxide or the vacuum pack. Non-reducing sugars decreased markedly in all packs during the storage period. In the air pack this reduction took place rapidly whereas in the gas and vacuum packs the decrease in non-reducing sugars was more gradual. Starch determinations indicated a continuous hydrolysis of starch which was somewhat more rapid and continued to a greater extent in the air-packed

TABLE 12. Effect of carbon dioxide, vacuum, and air packs on changes of sugars and starch in dehydrated Stayman Winesap apples stored at 100° F.

Days stored	Reducing sugars	Non-reducing sugars	Total sugars	Starch
	(Expressed as per cent of oven dry material)			
Air pack				
0	50.8	22.0	72.8	1.65
90	50.1	8.4	58.5	1.56
150	54.7	4.4	59.1	1.52
200	59.5	7.2	66.7	1.46
270	63.4	6.7	70.1	1.34
Vacuum pack				
0	49.4	18.8	68.2	1.64
90	55.4	15.7	71.1	1.67
150	59.9	11.4	71.3	1.47
200	63.0	7.5	70.5	1.45
270	61.4	11.0	72.4	1.47
CO_2 pack				
0	50.6	20.0	70.6	1.62
90	56.3	15.5	71.8	1.56
150	60.2	11.6	71.8	1.48
200	63.3	8.1	71.4	1.49
270	64.2	7.2	71.4	1.49

apples than in the gas or vacuum packed apples.

The stages of darkening observed in these dehydrated apples during storage at 100° F. are shown in figure 19. Stage I represents the apples as they appeared after dehydration and before any storage began. Stage II shows the first faint discoloration, which appeared in the early part of the storage period for some samples. No hay-like odor could be detected in apples showing this first darkening. Further darkening is represented by stage III. This further deterioration was distinguished from the previous stage by a darker color and frequently by the development of a slight but distinct hay-like odor. The discoloration in this stage did not

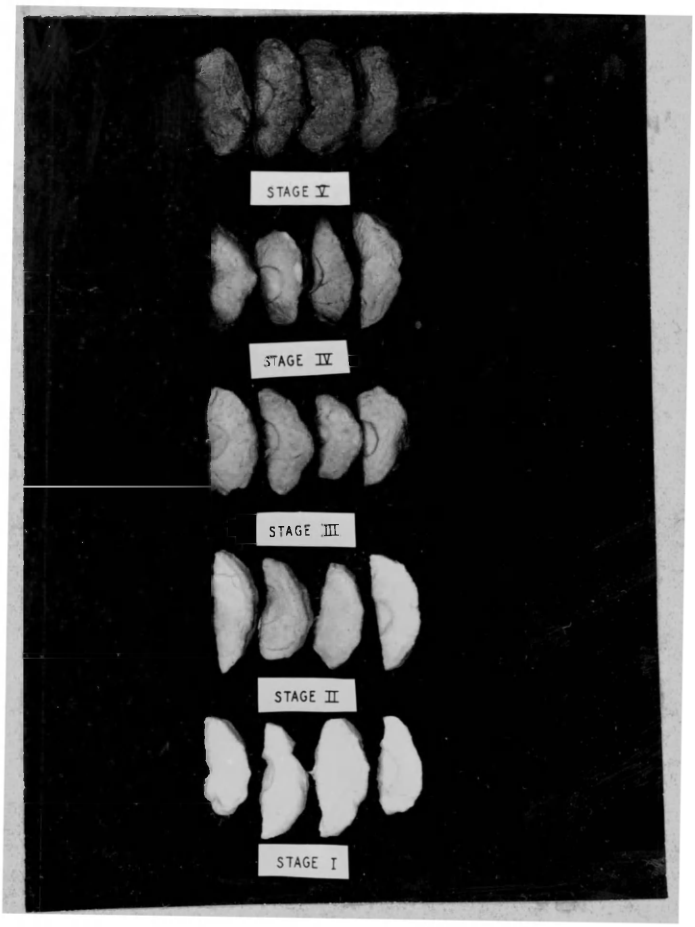

Figure 19. Stages of darkening observed during storage of dehydrated Stayman Winesap apples stored for 9 months at 100° F.

extend through to the interior of the individual sections, but was limited to the outer surfaces. Stage IV shows complete discoloration of the sections. In this case the darkened condition was uniform in the entire section, both interior and exterior, and the off-odors which were slightly discernible in stage III were pronounced in this stage. The final degree of discoloration, stage V, was characterized by a very deep brown color combined with a strong, offensive odor. At this stage the apples were considered inedible.

The time required for the various samples in 100° F. storage to reach the several degrees of discoloration is shown in table 13. The check lot, lot 120, sealed in air, reached the inedible stage after 90 days of storage. With the exception of lot 123 sealed in carbon dioxide and vacuum, and the low-moisture apples sealed in air, all other samples reached the inedible stage after 120 days of storage. The vacuum pack of the steam-blanched apples, lot 123 V, was classified in stage V only at the end of the 9 month storage period, whereas the low-moisture apples at this time showed only the first faint discoloration. The appearance of these samples after 9 months of storage compared to corresponding treatments stored at 65° F. is shown in figure 20.

Nichols and Christie (46) reported that dehydrated apples stored satisfactorily in common storage for 8 months if the sulfur content was 200 p.p.m. or more. This study presents some rather interesting comparisons when the darkening is associated with the sulfurous acid content of the fruit (table 10). The first samples to show initial discoloration, lot 120 sealed in air and carbon dioxide, had a sulfurous acid content at this time of 875 and 988 p.p.m. respectively; it is important to point out that this discoloration took place in only 36 days at 100° F. Of the group of samples (table 13) which showed initial discoloration in 60 days, the

TABLE 13. Appearance of discoloration in dehydrated Stayman Winesap apples stored at 100° F.

Lot* number	Nature of pack	Days to first discoloration (stage II)	Days to complete discoloration (stage IV)	Days to inedible condition (stage V)
120	air	36	60	90
120	vacuum	60	90	120
120	CO_2	36	60	120
121	air	60	90	120
121	vacuum	60	90	120
121	CO_2	60	90	120
122	air	60	90	120
122	vacuum	60	90	120
122	CO_2	60	90	120
123	air	60	90	120
123	vacuum	150	200	270
123	CO_2	90	150	200
124	air	270	-	-

*Treatments: 120 - sulfured @ 10 lbs./ton, dried; 121 - sulfured @ 10 lbs./ton, dried, resulfured @ 10 lbs./ton; 122 - sulfured @ 10 lbs./ton, dried, resulfured @ 20 lbs./ton; 123 - sulfured at 10 lbs./ton, steam-blanched 30 seconds, dried, resulfured @ 20 lbs./ton.

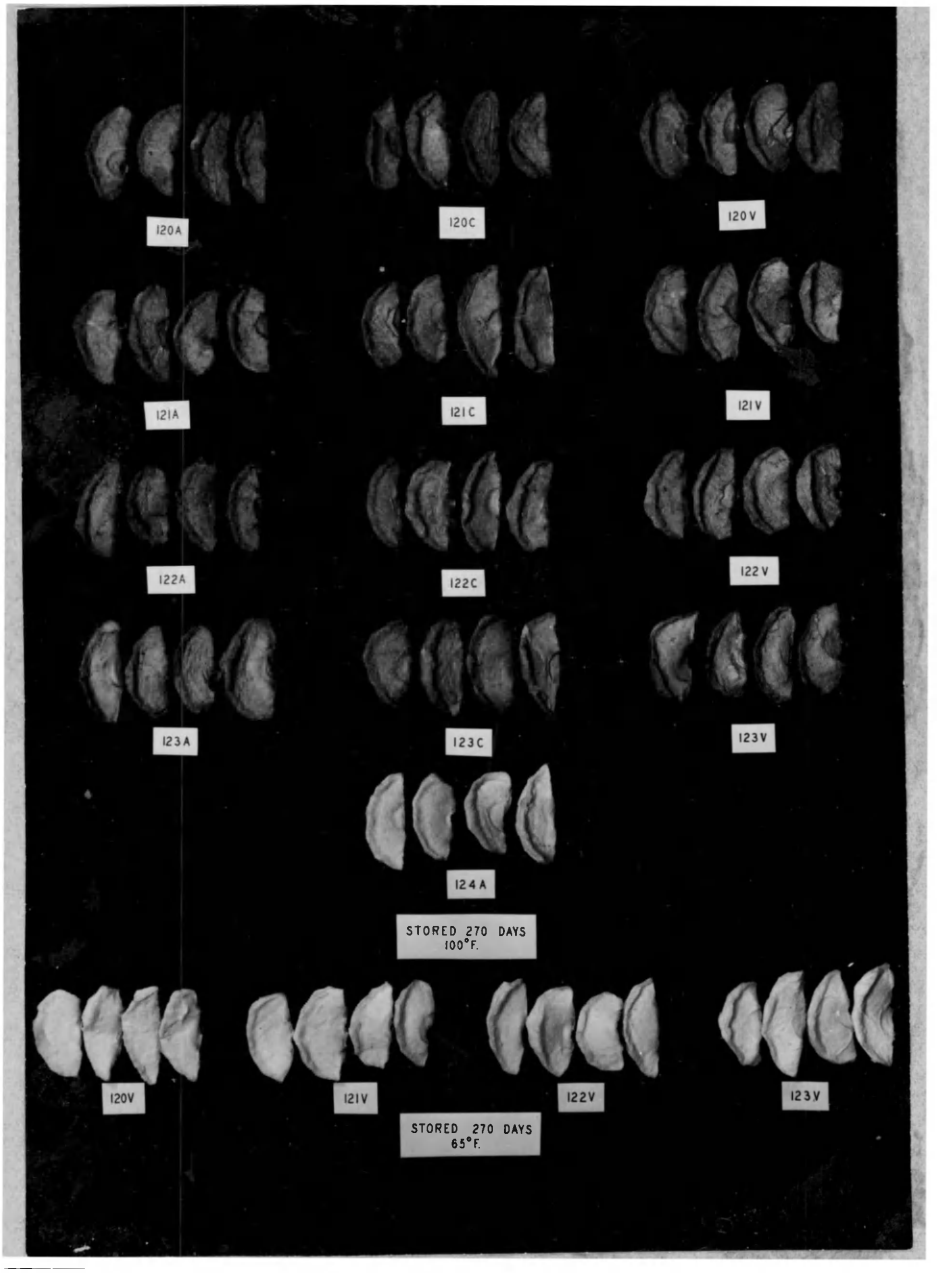

Figure 20. Appearance of dehydrated Staymam Winesap apples after 270 days of storage at 100° F., showing the effect of low moisture on keeping quality at high temperature.

average sulfur content was 913 p.p.m. at this period in storage. The steam-blanched apples packed in vacuum, lot 123 V, did not show discoloration until the 150th day, at which time the sulfurous acid content was only 402 p.p.m., whereas the carbon dioxide pack of this treatment showed discoloration in 90 days when the sulfurous acid content was 1130 p.p.m. These two samples represented the extremes in sulfurous acid contents of the various samples at the time of the first discoloration; however, the average sulfurous acid content of all samples at the time of first discoloration was 881 p.p.m. and at the time of complete discoloration (stage IV), the average sulfurous acid content was 620 p.p.m. Thus even though there was considerable variation in sulfurous acid content, appearance and development of discoloration was correlated in most lots with a reduction in sulfurous acid.

The differences in initial sulfurous acid content in the non-blanched apples had little influence on color retention in the apples during the storage period. The steam-blanched apples, however, sealed in vacuum and carbon dioxide, showed remarkable color retention compared to the other samples during storage. These differences are very similar to the sulfurous acid contents recorded for the steam-blanched samples compared to non-blanched apples through the 9 months, thus offering further evidence that color retention is very closely associated with sulfurous acid content.

Factors Involved in the Sulfuring of Apples

In the fall of 1944, Stayman Winesap apples were harvested in a local orchard and ripened for 15 days at room temperature before dehydration. Careful selection of the fruit in the orchard insured uniformity in size, maturity, and color of the material used in this study. The

apples were dehydrated in the tunnel dehydrator for 105 minutes at 210° F. followed by 135 minutes at 165° F. Various sulfur and blanching treatments prior to dehydration were planned to study the effect of: the time of the sulfuring period, the concentration of the gas in the sulfur box, the temperature in the sulfur box, a short steam-blanch, and a combination of the steam-blanch with a standard sulfuring preceding the blanch. Since the sulfurous acid and ascorbic acid contents of the dehydrated material were the important measures of the effect of the sulfuring treatments, sulfurous acid and ascorbic acid analyses were made on dehydrated apples after a 48-hour conditioning period. Moisture determinations were made on samples of apples taken from the dehydrator after the primary drying period and again when the apples were removed from the dehydrator after the secondary drying period. Variability in moisture content was so high in apple sections taken at these stages of dehydration, however, that these determinations were used as a rough estimate only of the moisture level. The moisture contents of the conditioned material were used as a basis for comparing the effect of the different sulfuring treatments.

Concentration of Sulfur. Increasing the concentration of sulfur dioxide gas in the sulfuring treatment of the fresh fruit resulted in increased sulfurous acid contents of the dehydrated apples, as shown in table 14. The greater sulfurous acid in the dried fruit was not directly proportional, however, to the increased concentration of the gas. The 10 pounds/ton treatment resulted in a sulfurous acid content more than double that gained by the 5-pound treatment. On the other hand, the 20 pounds/ton application resulted in an increase of only 41 p.p.m. of sulfurous acid or a small per cent of increase over the 10-pound treatment; this increase was probably not significant.

TABLE 14. Effect of sulfur dioxide concentration on the sulfur retention, moisture, ascorbic acid, and peroxidase activity in dehydrated Stayman Winesap apples.

Rate of sulfuring (lbs./ton)	Per cent moisture		Ascorbic acid (mg./100 g. dry wt.)	Sulfurous acid (p.p.m.)	Peroxidase
	after primary drying	after conditioning			
0	41.9	13.2	5.2	31	5 plus
2	39.4	10.6	11.6	337	2 plus
5	43.1	12.7	11.5	571	3 plus
10	46.2	11.4	11.5	1388	plus
20	45.9	13.3	11.8	1429	-

The ascorbic acid content of the dehydrated fruit was nearly the same for all sulfured apples, regardless of the amount of sulfuring or the amount of sulfur retained. The check treatment in which no sulfur was used resulted in a markedly lower retention of ascorbic acid. This is in agreement with the report of Morgan and Field (41), which presented evidence to show that unsulfured fruit lost most of the original anti-scorbutic properties in dehydration, whereas sulfured fruit lost very little in the same process of dehydration. The data in table 14 indicate that very little sulfur dioxide was necessary to reduce the loss of ascorbic acid during dehydration. According to these figures, all sulfur (as sulfur dioxide or sulfurous acid) over the amount which was absorbed and retained by the 2-pound application was in excess of that needed during dehydration to conserve ascorbic acid, and would be of use only under warm storage conditions. This is in agreement with the view of Morgan, Field, and Nichols (42) who established a minimum sulfur retention value of 450 to 500 p.p.m. for prunes and apricots, beyond which little protection of

vitamin C is afforded. These authors stated that conservation of vitamin C in prunes and apricots during dehydration is the only function of sulfur, and that this protection is of little importance in storage unless temperatures are unusually high.

According to Cruess (16) and others, sulfuring plasmolyzes the cells and renders sulfured fruit more subject to rapid drying. The data in table 14, however, indicate that the heavily sulfured apples dried more slowly in the primary period than the lightly sulfured material, as shown by the moisture contents at the end of the primary drying period. Whereas the apples sulfured at 10 and 20 pounds/ton had dried down to 46 per cent moisture at this point, the apples which received the 2-pound treatment and those which were not sulfured had dried down to 39 and 42 per cent moisture respectively. Since this slower drying in heavily sulfured apples is shown again in later data, it is apparent that the association of more rapid drying of other fruits with heavy sulfuring, as made in the sun-drying industry of the west, may not apply in dehydration of apples or even other fruits.

Moisture contents after conditioning do not reflect these differences which were found at the end of the primary period.

Time of Sulfuring. Increasing the length of time the apples are subjected to sulfur dioxide had the effect of increasing the absorption and retention of sulfur by the fruit, but only up to 60 minutes of sulfuring, as shown in table 15. The 60-minute treatment resulted in a 43 per cent increase in sulfurous acid content of the dehydrated fruit, whereas the 120-minute treatment did not result in any increase compared to the 60-minute treatment. Again, there is evidence of more rapid drying in the lightly sulfured fruit compared to the heavily sulfured apples as shown by moisture contents ranging from 42 to 51 per cent at the end of

TABLE 15. Effect of time of sulfuring on the sulfur retention, moisture, ascorbic acid, and peroxidase activity in dehydrated Stayman Winesap apples.

Sulfuring time (minutes)	Per cent moisture		Ascorbic acid (mg./100 g. dry wt.)	Sulfurous acid (p.p.m.)	Peroxidase
	after primary drying	after conditioning			
0	41.9	13.2	5.2	31	5 plus
30	42.6	14.7	11.4	1214	plus
60	46.9	14.2	11.5	1735	plus
120	51.0	13.0	12.0	1735	-

the primary drying period. At the end of the conditioning period all treatments reached a somewhat similar moisture content, which did not vary consistently compared to no sulfuring.

The sulfured apples, compared to the non-sulfured apples, showed marked reductions in the loss of ascorbic acid during dehydration. As measured by ascorbic acid content, there was no significantly increased protection afforded vitamin C as a result of increasing the sulfuring time; the differences shown in ascorbic acid content among sulfur treatments are assumed to be within the range of experimental error and therefore not significant.

It is interesting to note in tables 14 and 15 that the sulfuring at 20 pounds/ton and the 120-minute sulfuring at 10 pounds/ton resulted in material which gave a negative peroxidase test. In the dehydration industry it has been felt that no amount of sulfuring would destroy peroxidase, but here is evidence that heavy sulfuring will result in apples which will not produce a color reaction with guaiacol. This will be discussed more fully later.

Temperature During Sulfuring. Table 16 presents the results of sulfuring apples at increasing temperatures from 59° to 150° F. Increasing the temperature of the sulfur chamber from 59° to 108° F. resulted in a gradual increase in sulfurous acid content of the dehydrated apples. The 134° treatment, however, resulted in a slightly decreased sulfurous acid content compared to the 108° treatment, whereas the 150° treatment resulted in the highest sulfurous acid content obtained in this series of treatments, but the increase over the 108° treatment is not in proportion to the increases obtained in each temperature rise from 59° to 108° F.

TABLE 16. Effect of sulfuring temperature on sulfur retention, moisture, ascorbic acid, and peroxidase activity in dehydrated Stayman Winesap apples.

Temp. of sulfur chamber (°F.)	Per cent moisture		Sulfurous acid (p.p.m.)	Ascorbic acid (mg./100 g. dry wt.)	Peroxidase
	after primary drying	after conditioning			
59°	42.6	14.8	1214	11.4	plus
67°	46.2	11.4	1388	11.5	plus
86°	45.1	11.9	1469	11.5	plus
108°	34.9	10.2	1571	12.2	plus
134°	48.1	18.4	1520	9.2	plus
150°	52.3	15.6	1663	10.0	plus

Although the moisture contents of the dehydrated apples did not show any consistent proportional relation to temperature treatments during sulfuring, the apples sulfured at 134° and 150° dried the slowest of all treatments and had the highest final moisture content. The apples sulfured at all lower temperatures dried more rapidly and reached a lower final moisture content, but did not show a consistent trend towards the

slow drying and high moisture of the fruit sulfured at the highest temperatures. Since the fruit sulfured at the higher temperatures in the sulfur chamber went into the dehydrator in a warmed condition, it was expected to dry more rapidly than the fruit sulfured at lower temperatures, but the reverse was true. It is possible that the outer surfaces of the apple sections dried more rapidly in the initial stage of dehydration and formed a crust or hard layer of cells impervious to movement of water from the inside; if true, this is an example of "case hardening" as described by the industry.

Fisher, et al. (26) reported that prolonged, high-temperature sulfuring of soft fruits resulted in a mushy product which dried more slowly and stuck to drying trays. In this work, though no prolonged periods of sulfuring were used with high temperatures, the high temperature treatments resulted in a high quality product which showed no tendency whatever to stick to the drying trays, although somewhat slower drying was observed in apples sulfured at 134° and 150° F. When the trays were removed from the sulfur chamber, the apples which were subjected to temperatures above 108° F. were somewhat mushy on the outer surfaces of the individual sections. This breakdown of cells was limited to the surface cells and did not extend into the interior of the sections. From the viewpoint of handling, however, the high temperature treatments were not at all objectionable.

The ascorbic acid content of the dehydrated fruit showed no outstanding differences between the 59° to 108° treatments. The 134° and 150° treatments, however, resulted in dehydrated material of a lower ascorbic acid content. Though no ascorbic acid determinations were made on fresh, sulfured apples before dehydration, it is possible that some ascorbic acid was lost in the sulfuring process when the two highest temperatures were

used. This could be due to both the high temperatures and a relatively high humidity which usually prevailed in the sulfur chamber.

Steam-blanching. The effect of a steam blanch used with and without sulfuring is shown in table 17. The use of a standard 30-minute sulfuring followed by a 30-second steam blanch resulted in the highest sulfurous acid content in the dehydrated apples of all treatments used in this entire sulfuring study. This result was indicated in earlier work when a steam blanch was used in one of the treatments for the 1944 storage work already described. In addition to producing the highest sulfurous acid content,

TABLE 17. Effect of a standard 30-minute sulfuring at 10 pounds per ton compared to a 30-second steam blanch on ascorbic acid, moisture, sulfur retention, and peroxidase activity in dehydrated Stayman Winesap apples.

Treatment before drying	Per cent moisture		Sulfurous acid (p.p.m.)	Ascorbic acid (mg./100 g. dry wt.)	Peroxidase
	after primary drying	after conditioning			
No treatment	41.9	13.2	31	5.2	5 plus
30-sec. blanch	38.6	8.3	10	8.0	plus
30-min. sulfuring	42.6	14.8	1214	11.4	plus
30-min. sulfur plus blanch	45.5	11.4	1913	10.2	minus

the sulfur plus steam-blanch treatment resulted in fruit which showed no peroxidase activity whatever, and which had a somewhat reduced, but still high ascorbic acid content. A small amount of sulfurous acid, 31 and 10 p.p.m. respectively, was found in the check treatment and in the blanch-only treatment indicating that some sulfur was picked up in the dehydrator from the trucks which had been sulfured. Blanching alone resulted in the

most rapid drying and the lowest final moisture content of the four treatments considered. Blanching alone resulted in considerably more ascorbic acid than did no blanching, but sulfur was necessary for maximum conservation of ascorbic acid during dehydration. In the blanching treatments, it is recognized that some of the ascorbic acid was lost in the blanch treatment itself.

Samples of all treatments used in this entire study were reconstituted in cold water (17° C.) for two hours. Results calculated as per cent of initial moisture recovered showed no significant differences due to any of the sulfuring treatments, so the data are not given in this paper.

Effect of Ripeness of Fresh Apples on Quality, Yield, and Reconstitution of Dehydrated Apples

For this study apples were dehydrated at the following intervals during the storage season: (1) harvest, (2) the middle of the ordinary commercial storage period (December), (3) near the end of the commercial storage period (March), and (4) past the commercial season (June). Three varieties, Stayman Winesap, York Imperial, and Rome Beauty were dehydrated in this work, and, as an index of maturity in each variety, pressure tests were made before each dehydration. The prepared fruit was dehydrated in the cabinet dehydrator for two hours at 175° F. followed by 2½ hours at 165° F. All dehydrated apples were conditioned for 48 hours and sealed in tin cans in air for chemical analysis which was made as soon as possible after dehydration. Fresh apples were analyzed the same day the apples were dehydrated.

In table 18 is recorded the yield, moisture content, and ascorbic acid content of the dehydrated fruit of each variety. There was considerable

[redacted]

TABLE 18. Analysis of Stayman Winesap, York Imperial, and Rome Beauty apples dried at intervals during the storage period.

Date dried	Average pressure test (pounds)	Yield (dried lbs.)	Per cent moisture			Ascorbic acid		
			fresh fruit	after primary drying	dried and conditioned	fresh fruit (mg./100 g. dry wt.)	dried fruit (mg./100 g. dry wt.)	per cent loss in drying
Stayman Winesap								
10/12/43	-	3.50	79.3	56.5	9.8	15.4	12.9	16.6
12/ 2/43	12.4	3.60	83.9	58.7	9.6	8.1	6.3	21.6
2/29/44	8.9	3.82	83.1	58.4	11.0	7.3	5.3	27.7
6/14/44	8.7	3.60	82.8	58.9	12.6	7.3	5.9	18.2
Rome Beauty								
10/29/43	15.3	3.55	85.3	61.7	10.2	11.2	9.7	13.1
12/ 6/43	11.4	3.35	85.1	60.8	12.4	10.1	8.5	15.2
3/ 1/44	10.4	3.47	85.2	59.5	8.6	7.5	6.4	15.8
6/13/44	10.3	3.40	85.7	59.0	11.1	7.1	6.1	14.8
York Imperial								
10/29/43	19.5	3.60	83.1	56.2	8.9	19.8	14.8	25.4
3/ 1/44	15.6	4.10	82.3	55.0	9.3	9.0	7.5	16.9
6/13/44	12.2	3.70	83.4	55.0	11.9	10.3	8.4	18.1

[redacted]

variation in the yield within all three varieties, but no trend in relation to stage of ripeness is indicated by the data. Stayman and York on the average yielded somewhat higher than Rome, thus confirming earlier work. When moisture determinations of dehydrated and conditioned apples are considered, the less ripe York and Stayman dried down to consistently lower levels than the fully ripened apples of these two varieties. Rome Beauty, however, was variable in final moisture content. Considering the three varieties at all stages of ripeness, York Imperial apples dried more rapidly and reached a lower final moisture content than did either Stayman or Rome apples.

Although the ascorbic acid content of the fresh apples decreased as the storage season progressed, the percentage loss of ascorbic acid in dehydration at each level of ripeness was in general no greater than the percentage loss resulting from dehydration of freshly harvested apples. Stayman Winesap apples, however, lost increasing percentages of ascorbic acid with each dehydration up to February, but the last drying in June resulted in a loss of only 18 per cent, or very nearly that of the freshly harvested Stayman apples. In dehydration at harvest time, York apples lost 25 per cent of initial ascorbic acid, but dehydration in March and June resulted in losses of only 17 and 18 per cent respectively. Rome Beauty was slightly, but consistently lower in ascorbic acid loss than the other two varieties. This result is in agreement with the previous study in 1943 which showed lower loss in Rome, compared to York and Stayman, when dehydrated in the tunnel dehydrator for the storage work of 1943. There was no trend of losses in dehydration, however, associated with ripeness in Rome apples.

Table 19 presents the results of sugar determinations on the fresh and dehydrated apples dried at intervals during storage. With all three

[redacted]

TABLE 19. Sugar content of fresh and dehydrated apples dried at intervals during the storage period.

Date dried	Fresh						Dehydrated					
	As per cent of wet weight			As per cent of dry weight			As per cent of wet weight			As per cent of dry weight		
	Reducing sugars	Non-reducing sugars	Total sugars	Reducing sugars	Non-reducing sugars	Total sugars	Reducing sugars	Non-reducing sugars	Total sugars	Reducing sugars	Non-reducing sugars	Total sugars
Stayman Winesap												
10/12/43	6.9	2.8	9.7	33.0	13.7	46.7	40.6	13.2	53.8	45.0	14.6	59.6
12/ 2/43	8.0	2.9	10.9	49.3	18.5	67.8	46.0	17.0	63.0	50.9	18.8	69.7
2/29/44	7.9	3.3	11.2	46.8	19.6	66.4	42.8	16.8	59.6	48.1	18.9	67.0
6/14/44	8.6	2.3	10.9	50.2	13.1	63.3	46.2	8.8	55.0	52.9	10.0	62.9
Rome Beauty												
10/29/43	7.0	2.3	9.3	47.6	15.6	63.2	38.5	14.5	53.0	42.8	15.7	58.5
12/ 6/43	7.3	3.0	10.3	49.0	19.8	68.8	44.0	16.6	60.6	50.2	19.0	69.2
3/ 1/44	8.3	1.8	10.1	55.8	12.1	67.9	52.4	10.6	63.0	57.3	11.6	68.9
6/13/44	6.8	1.0	7.8	47.5	7.3	54.8	49.0	10.0	59.0	55.1	11.2	66.3
York Imperial												
10/29/43	8.1	2.3	10.4	47.8	13.8	61.6	36.9	10.5	47.4	40.7	11.5	52.2
3/ 1/44	10.0	2.9	12.9	56.1	16.5	72.6	47.4	14.6	62.0	52.2	16.1	68.3
6/13/44	10.1	0.7	10.8	60.8	4.4	65.2	46.6	5.4	52.0	52.9	6.1	59.0

[redacted]

varieties, the fresh apples showed an increase in total sugars from October to February, followed by a decrease. This was reflected in the dehydrated apples by corresponding changes. The dried apples showed a high total sugar content regardless of when the apples were dehydrated; this is in agreement, as to quantity, with the sugar data previously reported in this paper. Rome and Stayman apples showed a greater total sugar content after dehydration than before, whereas York apples decreased in total sugars in each dehydration of this variety. Two factors could be operating in dehydration to produce changes in sugars within the apples. It was expected that the heat of the dehydration process would step up respiration in the initial stages of drying, thereby reducing the sugar content in the apples. On the other hand, there could be hydrolysis of starch and hemicelluloses during dehydration to produce an increase in sugar content of the dehydrated material. These data, however, were not intended to present a detailed account of sugar changes in apples during dehydration. This work does indicate that changes in sugars take place during dehydration, but that these changes were not uniform in different varieties, or in the same variety dried at different intervals in the storage season.

The reconstitution of dehydrated York Imperial apples in cold water, reported in table 20, showed a tendency for increased recovery of initial moisture as the period of storage of fresh fruit was increased. Apples dried in October recovered 43 per cent of initial moisture in the 2-hour reconstitution period, whereas apples dried in June recovered 57 per cent. The reconstitution of Rome and Stayman apples, shown in tables 37 and 38 in the appendix, resulted in considerable variability in amount of moisture recovered. In each of these two varieties, there was no trend in moisture recovery associated with length of the storage period for the

TABLE 20. Reconstitution of dehydrated York Imperial apples dried at intervals during storage.

Time in water* (minutes)	Per cent of initial moisture recovered		
	Dried 10/29/43	Dried 3/1/44	Dried 6/13/44
0	1.94	2.19	2.68
20	21.39	25.98	28.04
40	28.62	33.11	36.49
60	32.52	40.24	43.25
80	35.85	45.01	47.76
100	39.74	48.57	52.27
120	43.08	52.14	56.78

*Temperature of water - 25° C.

fresh apples. Though more moisture is picked up by dehydrated apples when reconstituted from 2 to 12 hours, the relative differences between samples in amount of moisture recovered is not changed by extending the reconstitution period beyond 2 hours. Moreover, this period of 2 hours is double the soaking time required by the army (2) for cooking purposes.

All lots dried in this study were of excellent appearance and edible quality when dried and when reconstituted. This was true even of the apples dried in June, well past the commercial storage season for the fresh fruit. Perhaps the only difference between the last lots and those dried earlier in the storage season was the somewhat lighter color of the dried sections in the former. Also the apples dried in June had a tendency to stick to the drying trays more than firmer apples of the early part of the storage season. This characteristic, however, was not sufficient to be objectionable in handling the apples.

DISCUSSION

The primary objective of any method of food processing is to preserve as much of the fresh food quality, flavor, and appearance as possible; this preservation, of course, must be obtained not only in processing but in subsequent storage as well. The present study has shown that quality in dehydrated apples, measured by ascorbic acid and darkening, can be lost or retained to a considerable extent in both dehydration and storage.

During the dehydration of apples, oxidation of ascorbic acid in the fruit is influenced by the drying temperatures used, the drying rate, the relative humidity in the drying period, the variety of apples, and by pre-drying treatments. Ascorbic acid losses up to 80 per cent were recorded when high temperatures or high humidities were used in the cabinet dehydrator. In the tunnel machine, however, there was no greater loss of ascorbic acid when the primary temperature was held at 210° F. than was the case when the primary temperature was as low as 175° F. This difference between drying equipment was undoubtedly due to the more rapid drying rate associated with the lower humidity which prevailed in the primary tunnel, as compared to the unavoidable higher humidities in the cabinet dehydrator. Consequently, the home dehydrators of the cabinet type, with relatively low air velocities and high humidities, cannot be operated without considerable losses of ascorbic acid in the drying of foods. Moreover, application of results obtained in experimentation with small cabinet machines to commercial dehydration would at best be difficult. Maximum retention of ascorbic acid, therefore, seems to depend on attaining a rapid drying rate through use of high temperatures together with low relative humidity, maintained by high air velocity and controlled recirculation of air through the machine.

There has been considerable difference of opinion in the literature concerning various pre-drying treatments of fruits. As already pointed out (14, 46), blanching of fruits has been studied, but for one reason or another, investigators have failed to recommend blanching for general use with fruits. In the case of apples, however, this method of treatment has distinct advantages which cannot be ignored. Blanched apples gave some indication of more rapid drying than did non-blanched fruit. More conclusive evidence of this has been obtained (57) but is not included in this paper. A short, 30-second steam blanch, moreover, following the standard 30-minute sulfuring used in this work, markedly increased the sulfur retention in the fruit, an increase which was maintained through dehydration and into the storage period. Blanched samples had a longer storage life, as measured by ascorbic acid and darkening, than did non-blanched fruit of a comparable moisture content. Thus it would seem that blanching of apples after sulfuring is a very practical method of extending the storage life of this product.

Some objection has been raised (14) against blanching of soft fruits before dehydration because of a resulting lower grade of the dehydrated product. Where critical grades of dehydrated fruit are recognized, it must be admitted that blanched apples probably would not grade as high as apples that had been adequately sulfured, but not blanched. Though no marked discoloration could be detected in the blanched apples, the color was definitely not as white as the sulfured, non-blanched fruit. When blanched apples dried down to a lower moisture content than non-blanched apples within a given time, the dehydrated sections were bordered on the edges with a hard, transparent layer of cells which gave these sections a somewhat undesirable appearance. After a few months of storage, however, the superiority of blanched fruit over non-blanched apples would

more than compensate for the initial differences in color and general appearance, and therefore, the initial effect on color would not be sufficient to discard blanching as a pre-drying treatment.

Although Brown, et al. (10) recently proposed that blanching alone might be sufficient for preservation of fruits and vegetables, the present work showed that blanching without sulfuring is inadequate to preserve quality and color in dehydrated apples. Blanched apples which were not previously sulfured exhibited discoloration even before the apples were placed in the dehydrator. Blanching alone, moreover, did not result in the high degree of ascorbic acid retention during dehydration that was obtained by sulfuring alone. Sulfuring plus blanching, on the other hand, resulted in the longest storage life in apples of about 12 per cent moisture stored at 100° F. Thus some marked improvement of keeping quality as well as rate of drying of apples can be effected by a pre-drying treatment combining blanching with sulfuring.

Contrary to the report of Nichols and Christie (46), this paper presents evidence to show that high sulfur absorption and retention was relatively easy to accomplish in the dehydration of apples. The possible maximum of 450 parts per million, reported by Nichols and Christie as the greatest amount of sulfur possible to get into apples, was shown to be extremely low. By increasing the concentration of the gas in the sulfur chamber, the temperature of the sulfur chamber, or the length of time the apples are exposed to sulfur, or by combining sulfuring with a short steam blanch, the operator can easily get retention of 1800 parts per million or more of sulfur after dehydration. It must be emphasized also that sulfuring of apples up to this high level was done within commercial practicability. Thus if a commercial dehydrating plant were called upon to produce apples of increased sulfur content, this could be accomplished

by increasing the concentration of the sulfur dioxide gas together with raising the temperature of the sulfur chamber to perhaps 100° F. In this manner the sulfur content of the apples could be markedly raised without increasing the length of time of the sulfuring period for each unit of trays, as time is usually an important factor in handling of food prior to processing. The use of a steam blanch in addition to the sulfur treatment for further increasing sulfur retention has already been proposed.

Resulfuring of fruit after dehydration has been said to add nothing to the protection of vitamin C in prunes and apricots during storage (42). The resulfuring of dehydrated fruit, practiced in the west for many years to bleach fruit after certain periods of storage, is at best a very inefficient method of increasing the sulfur content, since dried fruit absorbs far less sulfur dioxide than fresh fruit. It would seem from this work, however, that some advantage was gained by additional sulfur obtained in resulfuring dried apples. In those treatments in which resulfuring was used, a longer storage life resulted in proportion to the amount of sulfur which was in the fruit at the beginning of storage. Though the blanched apples, lot 123, had the highest sulfur content in this study, it is doubtful that much of this sulfur was added in the resulfuring process. However, retention of sulfur was improved in this treatment by some means. It is apparent that a more practical method of preventing excess oxidation of ascorbic acid and of preserving color in dried apples would be to get the sulfur into the apples before dehydration rather than rely upon resulfuring to do even part of the job; this is especially true when apples are dried to a low moisture content. The data do not agree, however, with the contention that resulfuring can add nothing to ascorbic acid conservation in dried apples. Resulfuring does increase ascorbic acid retention, but only to the extent that sulfur content

is retained in subsequent storage.

The mechanism of the action of sulfurous acid in dehydrated apple tissue is little understood. Since sulfur content is correlated with color retention in dried fruits, and since enzyme systems are known to operate in fresh tissue to produce discoloration, there can be no doubt that sulfur - either in the form of sulfur dioxide or sulfurous acid - in dried fruit has some relationship to inhibition of enzyme activity. Although the enzyme systems in fresh apples have been studied, practically no information could be found in the literature concerning the enzyme activity in dehydrated apples. An attempt was made during the course of this work to study oxygen intake and carbon dioxide output in dried apples using the Warburg apparatus (59). With dehydrated Stayman Winesap apples which gave a positive qualitative peroxidase test, the following compounds were studied separately: catechol, L-tyrosine, hydroquinone, P-cresol, resorcinol, phenylenediamine, and guaiacol. Any oxidative reaction which might have taken place, however, was not measurable in this apparatus, so the attempt was abandoned and only qualitative determinations of peroxidase have been reported in this paper. All peroxidase tests made on fruit which was dehydrated in the cabinet drier were positive; many determinations of peroxidase made on fruit which was dried in the tunnel machine were negative. For example, all apples which were dried in the tunnel dehydrator using a primary temperature of 175° F. showed a positive peroxidase test; nearly all apples dried in the tunnel machine at a primary temperature of 210° F. showed a negative peroxidase test. Is it possible that high primary drying temperatures used in dehydration together with the sulfur in the fruit destroyed peroxidase during the dehydration process? Experience in the industry would indicate that this is not true, and in this work,

drying at 210° F. in the tunnel dehydrator did not always result in a negative peroxidase test. However, a detailed study of sulfur treatments in later work showed that sulfurous acid is a definite factor in breaking up enzyme systems in dehydrated apples.

Balls and Hale (5) stated that darkening of fresh apples is a reaction catalyzed by peroxidase, and that the formation of hydrogen peroxide by a respiration enzyme - which uses molecular oxygen - is a necessary preliminary step to the darkening reaction. They stated, further, that in the absence of air, the tissue darkens only until the peroxide present is completely utilized, and then continues further only upon the addition of peroxide or upon re-exposure to air when the peroxide is again produced enzymically. If a similar system operates in dehydrated apples, then it remains to be explained why darkening took place almost as rapidly in samples sealed in carbon dioxide and in vacuum as it did in samples sealed in air. Overholser and Cruess (52), in studying the darkening of fresh apple tissue, indicated that sulfur dioxide prevented the darkening by acting with the organic peroxide (considered by them to resemble hydrogen peroxide) rather than with the enzyme, peroxidase. If this action takes place in dehydrated apples, the actual decreases in sulfurous acid should be correlated with the appearance of darkening. A correlation of this sort was noted, but some variation existed and the association was not a close one with similar reductions of sulfurous acid for all samples which showed a certain stage of discoloration at a given time.

In the qualitative peroxidase test with various lots of dehydrated apples, variations in the color intensity of the reaction were produced by differential sulfuring. Considering the prevalent opinion of the industry, it was assumed at first that no amount of sulfuring would

destroy peroxidase. It was found, however, that sulfuring for 2 hours before dehydration or sulfuring at the relatively high rate of 20 pounds per ton produced a negative test in that fruit with guaiacol. Thus it was possible with sulfuring to get a negative test for peroxidase, just as it was possible to get quantitative differences in the extent of the enzyme inactivation. The application of this information, however, remains to be explored. Until a detailed study is made of the enzyme systems in dehydrated apples during storage, no statement can be made concerning the significance of negative or weakly positive peroxidase tests in relation to the storage deterioration of dried apples. It has been assumed that peroxidase activity is responsible for the off-odors and off-flavors in deteriorated, dehydrated foods, but as far as the author has been able to learn, this has not yet been proven for dehydrated apples.

The test for peroxidase as a measure of enzyme activity is not entirely satisfactory. Phaff and Joslyn (53) pointed out many inconsistencies in the test involving both worker and materials. Further, in some products such as corn, peas, and white potatoes, certain heat-stable catalysts exist which will produce a reaction with guaiacol regardless of the length of the blanching period. Applied to apples, the samples called plus, or weakly positive, showed a red coloration only in parts of the carpel and in some vascular bundles. Again, the significance of these localized effects is unknown. The peroxidase test has been advanced as a good indicator of enzyme activity in foods, but this test can be used only with utmost discretion, and further investigation is necessary before the role of enzymes in the deterioration of dehydrated apples can be fully illustrated.

Though the mechanism of preservation of ascorbic acid by sulfurous acid is not understood, losses of sulfurous acid and ascorbic acid were

correlated through the storage period. In the work on dehydrated apples stored at 100° F. the discoloration of the apples in the later stages of storage so colored the ascorbic acid extract that the determination of an end point in the titration was impossible. However, at this period of storage the sulfur content of the apples was reduced to a very small percentage of initial sulfur, or no sulfur at all, as was the case of some samples. Thus it is assumed that the association of sulfur and ascorbic acid would still hold for the last part of the storage season.

The disappearance of sulfur in stored, dehydrated apples has been studied by Nichols and Christie (46), who proposed a possible reciprocal relationship between moisture content of the dried fruit and the extent of conversion of sulfur to some other compound. In fruit of higher moisture content (about 24 per cent, or near the legal limit) they postulated that darkening was due to the formation of sulfuric acid by the reaction of sulfurous acid with oxygen in the fruit, but stated that the possible sulfuric acid concentration in the fruit with which they were working was probably not sufficient to cause the darkening by charring action. This leaves their further assumption that the darkening was due to changes in plant pigments. Some of the results obtained in storage of dehydrated Stayman apples at 100° F. support indirectly this theory of reciprocal action of sulfur and water. In this study, apples which were dried down to about 3 per cent moisture showed a loss of approximately 50 per cent of initial sulfurous acid compared to a loss of 81 to 100 per cent in all other treatments in which the moisture content of the apples was about 12 per cent. Thus the conversion of sulfur in the 3 per cent apples was roughly only half that which took place in the 12 per cent apples. It would seem, further, that the decreases in pH found in stored, dried apples would also support this reciprocal theory. These decreases might

have been brought about by oxidation of sulfurous acid to sulfuric acid, wherein the total acidity need not change but the sulfuric acid is more highly ionized. It was shown in later work, however, that sulfurous acid retention was markedly influenced by storage temperature. Thus it can be assumed that in the first storage work the common storage temperatures were high enough in initial months to produce a rather rapid decrease in sulfurous acid in the stored apples, whereas the cold storage would not show a corresponding rate of decrease of sulfurous acid. With this assumption as a basis, it is suggested, then, that oxidation of sulfurous acid to sulfuric acid could have had no relation to the reduction in pH in stored apples since the pH of all four varieties stored showed a similar rate of decrease in both cold and common storage. This suggestion is in agreement with the work of Morgan and Field (41), who found no relation between pH of dried fruit and sulfur content.

That sulfur content does not account entirely for color retention in dehydrated fruit has been reported by Mrak, et al. (45), who recorded a 50 per cent loss of sulfur dioxide in dried apricots during a 6-month period with no accompanying deterioration of color in the fruit. In the present work, the sulfurous acid content of apples when initial darkening was evident ranged from 400 p.p.m. to 1100 p.p.m. In apples of a comparable moisture content, a reduction in sulfurous acid was usually accompanied by darkening, but the specific sulfur content of the apples at the onset of darkening ranged considerably. In the low-moisture apples, however, darkening did not show a close correlation with reduction of sulfurous acid, since initial darkening was observed in these apples only after 9 months of storage; at this point the sulfurous acid had been reduced to about 51 per cent of the initial value. Thus it would seem that darkening is associated with sulfur content to a considerable extent, but only at a given moisture content.

Storage temperature is the most important factor in the preservation of dehydrated apples. A storage temperature just above freezing was the most satisfactory for long keeping of this product, but a constant temperature of 65° F. was nearly as effective in preserving the apples as the near-freezing temperature. When the common temperature was allowed to fluctuate widely from 65° F., however, the deterioration of apples took place more slowly or more rapidly, depending upon the direction and the extent of the temperature variations.

It is apparent that for preservation of color and quality of dehydrated apples in storage, high sulfurous acid content in the apples was more important than packing in vacuum or an inert gas in air-tight containers. Some differences were shown indicating a greater rate of deterioration in apples packed in air compared to fruit sealed in vacuum or carbon dioxide, but these differences were not as great as were the variations between treatments which produced differential sulfur contents in the fruit. With the exception of the low-moisture apples, the sulfured and blanched apples used in this study had the longest storage life correlated with the highest initial sulfur content. As already pointed out, it is not clear how much of the sulfur was added by the resulfuring after dehydration, but the fact remains that this fruit contained over 350 p.p.m. of sulfur more than lot 122, which was resulfured at the same rate, but not steam blanched prior to dehydration. Thus it is clear that the blanched apples were superior to the others of a comparable moisture content because of the higher sulfur retention. The effect of blanching on later storage behavior is uncertain beyond the influence of its greater sulfur content.

The combination of relatively high sulfur with low moisture is undoubtedly the answer to maximum retention of quality in dehydrated

apples in high temperature storage. By reducing the moisture content of apples in dehydration to 3 per cent, the storage life of dehydrated apples was extended to a minimum of 9 months compared to a few days at 100° F., which was the extent of the storage life of apples dried to about half of the commercial moisture content. It is interesting to note that the 3 per cent apples had an initial sulfurous acid content which was slightly higher than the sulfur content reported for apples which received the standard sulfuring and drying. It has been reported by Long, et al. (35) that most of the sulfur lost in dehydration is lost in the initial stages of drying, after which time the rate of loss is negligible. Presumably, the additional drying of apples used in the storage work removed little of the sulfurous acid from the fruit. Thus some of the higher sulfurous acid content reported for the low-moisture apples was due to a removal of more moisture in the additional drying, and consequently, there remained a higher dry matter content which would tend to raise the sulfurous acid content reported on a wet weight basis, on which basis all sulfurous acid determinations in this paper were calculated. The performance in 100° F. storage clearly shows that low moisture combined with a relatively high sulfurous acid content is paramount to keeping quality of dehydrated apples in high temperature storage. Packing such fruit in vacuum or in an inert gas would possibly extend even further the storage life of this product.

The practical implications of this information are obvious. The legal limit of moisture content for dehydrated apples is still 24 per cent. This is entirely too high for any extended storage period at temperatures much above 65° F., but is satisfactory for fruit which is to be shipped immediately to a vacuum dehydration plant for further processing into

apple nuggets*. For purposes of a lend-lease shipment and for purposes of a possible commercial domestic industry after the war, the necessary storage period and the temperatures to which the fruit will be subjected are very often unpredictable. In a study of tunnel drying under pilot plant conditions, Schrader and Thompson (57) have shown that apples can be dried down to 5 per cent moisture or less in a period of 5 hours using a primary temperature of 210° F. Thus to supply the future retail market with low-moisture apples of long shelf life, the processor has the possibility of drying apples down to a low moisture content in a tunnel machine without significantly increased operating time or costs. Under the present conditions of war, it is possible to supply the armed forces and lend-lease agencies with a product which is usable under hot tropical or sub-tropical conditions, and producible at rather low cost in existing tunnel dehydrators of this apple-producing area or similar areas so equipped. This work has demonstrated further that similar quality in dried apples can be produced at various stages of ripeness, although the storage behavior as affected by ripeness of the fresh fruit was not tested. However, it does show that apple dehydration can extend even beyond the commercial storage season for fresh apples.

It has been shown that the loss of ascorbic acid in apples can be held to relatively low levels in both dehydration and storage. Such information is of value in the vitamin fortification program put forth by the army for military rations. Though apples are not a good source of vitamin C, this vitamin, as measured by ascorbic acid, is relatively stable in dehydrated apples under optimum storage conditions. Therefore, it would be feasible to use dehydrated apples as a food to be fortified with vitamin C.

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*Dehydrated apples (24 per cent moisture) dried further in vacuum dehydrators to a moisture content of 1 per cent or less for exclusive use by the armed forces.

SUMMARY AND CONCLUSIONS

1. Four leading commercial varieties of apples, York Imperial, Stayman Winesap, Rome Beauty, and Ben Davis, were dehydrated in a small cabinet dehydrator and in a "pilot" tunnel at primary temperatures ranging from 145° F. to 210° F. High humidity and a high temperature of 190° F. in the cabinet machine were detrimental to retention of ascorbic acid and to rapid drying of the apples. In the pilot tunnel, where greater air velocity and hence low humidity throughout the dehydration period were possible, a primary temperature of 210° F. was found to be completely satisfactory with relatively low loss through oxidation of ascorbic acid or reduction in quality of the dehydrated product.

2. Loss of ascorbic acid in the dehydration of apples was held down to 25 per cent or less with proper humidity, temperature, and air velocity conditions. Excessive humidity or temperature, or both, resulted in loss up to 80 per cent of the original ascorbic acid. Optimum primary temperature for the cabinet machine was found to be 175° F., for the pilot tunnel, 210° F. Secondary temperature for both machines was held at 165° F.

3. Storage investigations resulted in satisfactory preservation of dehydrated apples at a constant temperature of 65° F. However, when wide fluctuations above this figure were used, darkening and ascorbic acid loss took place rather rapidly. Storage of apples at 100° F. or more resulted in a very rapid deterioration, especially when sulfurous acid retention was low. Storage at 33° F. was the best in all cases, but only slightly superior to 65° F. storage.

4. High sulfurous acid content was a very important factor in adequate preservation of dehydrated apples which have a moisture content of 12 per cent or more. Sealing apples in vacuum or carbon dioxide had

some influence in slowing down the rate of ascorbic acid oxidation, but this method was subordinate to increasing sulfur content.

5. Dehydrated apples of about 3 per cent moisture content retained quality and color longer than any other treatment. After 9 months of storage at 100° F. this treatment was only beginning to show initial stages of darkening, and at this point the fruit showed a loss of only 50 per cent of the original sulfurous acid, and a loss of about 60 per cent of the original ascorbic acid content, based on analyses of the dehydrated fruit at the beginning of storage.

6. Though apples are a poor source of vitamin C compared to citrus and other fruits, evidence is presented to show that this vitamin can be preserved in dehydrated apples in high temperature storage, and, therefore, vitamin fortification of dried apples is feasible.

7. The pH of dehydrated apples in storage gradually decreased in one year of both common and cold storage. The titratable acidity was variable and indicated no definite trend.

8. The moisture content of dehydrated apples in sealed cans in storage exhibited no definite change.

9. Total sugars in dehydrated apples remained fairly constant, but reducing sugars indicated a loss in the early stages of storage followed by a marked gain above the original percentage. Non-reducing sugars decreased steadily throughout the storage period.

10. Apples used for storage work were dehydrated in an edible ripe stage; starch content of the dehydrated fruit was therefore relatively low. A slow, but measurable hydrolysis of starch was determined in dehydrated apples through 9 months of storage at 100° F.

11. A short steam blanch after sulfuring resulted in more rapid drying, greater sulfur retention, and longer storage life presumably due

to the high sulfur retention.

12. The amount of sulfurous acid retained by apples can be increased by raising the temperature of the sulfur chamber during sulfuring, by increasing the concentration of the sulfur dioxide gas in the chamber, by increasing the length of the sulfuring period, and by steam blanching after a standard sulfuring. The highest amount of sulfurous acid, 1900 p.p.m., retained after dehydration was obtained by using the standard 30-minute sulfuring followed by a 30-second steam blanch.

13. No advantage as to quality or chemical content of the product was found by dehydrating apples at any one of four intervals from harvest to the following June, well past the commercial storage season for fresh apples. Yield, moisture content, ascorbic acid content, and sugar data showed some unexplainable variations, but no trend associated with ripeness of the fresh fruit. However, greater peeling loss, decay loss, and development of softness can be cited as reasons for attempting to get apples dehydrated before the end of the normal storage season for a particular variety of fresh apples.

14. Interpretation of qualitative peroxidase tests, as applied to storage deterioration of dehydrated apples, is considered impossible in view of the limited knowledge of enzyme activity in dried apples. Semi-quantitative peroxidase determinations are given using the qualitative guaiacol test, and evidence is presented to show that a negative test can be obtained by sulfuring alone. Also, varying degrees of coloration can be obtained with guaiacol in dried apples depending on the degree of sulfuring. However, the significance of this is not known. High temperatures in the tunnel dehydration resulted in some negative peroxidase tests, thus suggesting that dehydration may itself serve to destroy enzyme systems in sulfured fruit.

PART II

DEHYDRATION OF LIMA BEANS

REVIEW OF LITERATURE

No reports could be found in the literature concerning ascorbic acid in the dehydration of lima beans, and very few papers were found recording the ascorbic acid content of fresh beans. Walker (66) has reported lima beans to vary in ascorbic acid content from 16 to 29 milligrams per 100 grams whereas Kramer (29) found a range of 28 to 61 milligrams per 100 grams in six varieties grown in Maryland. That ascorbic acid is higher in green beans compared to white ones, and higher in small beans compared to large ones has been reported by Fellers and Stepat (24), Walker (66), Tressler, et al. (65), and by Fitzgerald and Fellers (28). Part of the work reported in this paper has been published by Thompson and Mahoney (61).

MATERIALS AND METHODS

Processing Procedure. The variety of lima beans used in both years of this study, 1943 and 1944, was Early Baby Potato, grown on the Maryland Horticultural Farm near College Park. The beans, after being cut and vined, were separated into sieve sizes, washed in a regular pea washer, and weighed out for dehydration at the rate of approximately 1.25 pounds per square foot on each tray. The beans were dehydrated in both the tunnel dehydrator and the cabinet machine already described in Part I. The primary temperatures used in this work varied from 170° F. to 200° F., and the secondary temperature was maintained at 160° F. regardless of the machine used or the type of investigation. Primary temperatures and

drying times used will be given in those sections where they apply. Dehydrated beans were thoroughly mixed and sealed in No. 1 tin cans in air until analyses could be made.

Sampling. Samples of fresh beans for analysis were taken immediately after washing. Before being chopped up and analyzed, these beans were rolled between two pieces of blotting paper until the outer surfaces appeared relatively dry. When samples of blanched, but not dehydrated beans, were obtained, the same blotting procedure was carried out. In all cases, the contents of a 400 ml. beaker were used as a sample of fresh beans. The contents of a No. 1 tin can were used as a sample of dehydrated beans. The dried samples were ground up in an ordinary household food grinder, thoroughly mixed, screened through 20 and 40 mesh screens, and the material held on the 40 mesh screen was taken for analysis.

Analytical Procedure. Moisture determinations were made in a vacuum oven at 70° C. for 12 hours. Ascorbic acid determinations were made using the modification of the Bessey and King (5) method already outlined. In macerating the tissue for ascorbic acid determinations, it was found that a minimum blending period of 1 minute was necessary for thorough extraction of ascorbic acid from fresh beans. Dehydrated beans, which were first partially reconstituted in the cold acid solution for 1 hour, required a blending period of 1½ minutes for ascorbic acid extraction. Duplicate determinations were made on all samples.

RESULTS

Standardization of Methods

In order to reduce the variability in moisture determinations apparently traceable to method, a comparison was made of moisture contents

between mesh sizes screened from ground-up samples and non-screened material. The contents of ten No. 1 cans were ground up separately and analyzed for moisture content. The mean weight of material held on each screen and the mean moisture content of each mesh size after 12 hours of drying in the vacuum oven are shown in table 21. More than 50 per cent

TABLE 21. Variability in moisture content of dehydrated lima beans.

Mesh size	Mean per cent moisture	Standard deviation of moisture	Mean weight held on each screen (grams)	Mean per cent of total weight
All sizes	4.69	0.549	-	-
20	3.89	0.632	7.1	6.3
40	4.70	0.324	59.8	52.5
60	4.94	0.388	19.8	17.3
80	5.00	0.489	9.9	8.9
100	5.21	0.506	8.4	7.4
100	5.75	0.897	8.6	7.5

of the ground material from each sample was held on the 40-mesh screen, and the proportion decreased progressively downward as finer mesh sizes were considered. Conversely, the moisture contents of the finer mesh sizes were higher, but they also exhibited the greatest variability as measured by the standard deviation. It was anticipated that the finer particles might be hygroscopic, so these sizes were weighed first after grinding the sample. Therefore, the higher moisture found in these finer sizes hardly can be due to any influence of the method used in preparing the sample. Though no one has ever investigated the

distribution of moisture within lima beans, it is probable that certain tissues are higher in moisture than others, and that this variation shows up in the mesh sizes screened from ground-up beans. In grinding and screening the samples, it was noted that the larger screens held a high proportion of seedcoat material, whereas the cotyledons broke up to a greater extent and were distributed in the smaller sizes.

Similar results on dehydrated carrots have been reported by Makower and Myers (37), but they found little difference in moisture content between mesh sizes after 44 hours of drying in the vacuum oven as compared to their original drying time of 6 hours. Undoubtedly, the most important factors governing vacuum-oven moisture determinations are the drying time and particle size. However, rather than discard the vacuum-oven method, as suggested by Makower and Myers, it would seem that careful standardization of this method for each kind of dehydrated food with respect to the above two factors would produce satisfactory results which would be comparable. Thus in this work constant weight for lima bean samples, ground to pass a 20-mesh, but not a 40-mesh screen, was obtained after 12 hours drying in the vacuum oven at 70° C., and this time and particle size was adopted as standard for all moisture determinations made on dehydrated beans reported in this paper.

Determination of ascorbic acid for each mesh size (table 22) shows that as smaller particles are used, the ascorbic acid content is reduced. It has been shown by many investigators that the distribution of ascorbic acid (or vitamin C) in vegetables and fruits is not uniform, but is concentrated in certain tissues. Though no work has been reported on lima beans in this respect, it is possible that this uneven distribution of ascorbic acid does occur in lima beans, and that this was reflected in the several mesh sizes screened from ground-up, dehydrated samples.

TABLE 22. Effect of mesh size in determination of ascorbic acid in dehydrated lima beans.

Mesh size	Moisture (per cent)	Ascorbic acid (mg./100 gr. wet weight)	Ascorbic acid (mg./gram oven dry material)
All sizes	6.65	39.8	0.43
20	5.59	45.3	0.47
40	6.32	39.0	0.42
60	6.80	40.0	0.43
80	6.76	38.8	0.42
100	7.00	37.5	0.40
100	7.45	34.8	0.38

Effect of Blanching on the Loss of Ascorbic Acid in Dehydration and Storage of Lima Beans

Blanching of vegetables prior to dehydration or canning has been practiced in the industry for many years. This experiment was designed to study in detail the effect of various methods of blanching on the retention of ascorbic acid in lima beans in subsequent processing and storage.

For this study only sieve sizes No. 2 and No. 3 were used, and before blanching the various lots, all white beans were discarded. After differential blanching the beans were dehydrated in the cabinet machine for 2¼ hours at 190° F. followed by 5-3/4 hours at 160° F. Dehydrated beans were mixed in the usual manner, sealed in No. 1 tin cans in air, and stored for 4 months at 65° F. Due to the time consumed in removing the white beans and carrying out the blanching treatments, it was impossible to analyze the fresh beans before blanching.

The results of this investigation are presented in table 23. There is no evidence to indicate an increased drying rate associated with increased blanching time. Although the moisture determinations made after

TABLE 23. Loss of ascorbic acid and moisture in dehydration and storage* of differentially-blanched lima beans.

Blanching time (minutes)	Per cent moisture			Ascorbic acid (mg./g. dry wt.)		
	Blanched	Dried	Stored	Blanched	Dried	Stored
No blanch	-	6.3	6.8	-	.249	.142
Steam (214° F.)						
1	71.0	5.5	6.8	.752	.262	.174
3	71.8	5.4	6.6	.649	.278	.171
5	72.5	5.2	6.2	.505	.277	.186
7	72.6	5.4	5.9	.492	.283	.173
Water (190-200° F.						
1	72.4	5.6	6.5	.572	.290	.192
2	75.8	5.5	6.1	.494	.263	.152
3	72.8	5.5	6.1	.503	.242	.146

*Stored 4 months at 65° F. sealed in air.

4 months of storage indicated that increased time used in steam and water blanching resulted in lower moisture, the moisture contents following dehydration are not consistent with this correlation. The increase in moisture content of dehydrated samples after storage is explained by faulty sealing of the cans by the closing machine, resulting in a very small hole at the point of intersection between the side seam and the lid seam of each can. This was not discovered until the samples were

taken from storage for analysis. On the average, blanching resulted in a lower final moisture content than did non-blanching. The water-blanched beans were somewhat higher in moisture content after dehydration than the steam-blanched beans.

Increasing the blanching time had a marked effect, as found in the reduced ascorbic acid contents of the blanched beans. The ascorbic acid content was decreased progressively in steam-blanched beans from .752 milligrams per gram in the 1-minute blanch to 0.492 milligrams per gram in the 7-minute blanch. The decrease in ascorbic acid resulting from the water-blanching was marked in the 2-minute blanch compared to the 1-minute blanch, but very little difference was found between the 2-minute blanch and the 3-minute treatment. When the beans were dried, however, the order of ascorbic acid contents was reversed for the steam-blanched samples. The beans which had been steam blanched for 7 minutes were slightly higher in ascorbic acid than those which had received the 1, 3, or 5-minute blanch. The dried samples which had received the water-blanching showed the same previous order in favor of the 1-minute blanch. That is, beans blanched for 1 minute in hot water were still higher in ascorbic acid at the end of dehydration than those which had received the 2 or the 3-minute water blanch.

After 4 months of storage, all steam-blanched samples had practically the same ascorbic acid content, though all of these samples showed a loss during the storage period. Thus it would seem that increased blanching time in steam had no advantage whatever from the standpoint of ascorbic acid conservation in lima beans, processed by dehydration. The data show, moreover, that increasing the time in the water blanch resulted in a definitely lower ascorbic acid content. Actually, the 3-minute water-blanched beans had the same ascorbic acid content after dehydration and

storage as did the non-blanched beans. Conversely, the beans which had received the 1-minute water blanch had the highest ascorbic acid content of all the treatments at the end of the storage period. It is doubtful, however, that this figure was significantly higher than those of the steam-blanched beans.

Peroxidase determinations were made in connection with all blanching treatments. In considering blanching, it was important to record the effectiveness of the various treatments on the destruction of enzyme systems in the beans. In addition, an attempt was made to correlate the semi-quantitative guaiacol procedure, as used with apples, and the quantitative assay of Lucas and Bailey (36). Though the peroxidase value for dehydrated, non-blanched beans (table 24) was only about one-fourth that

TABLE 24. Peroxidase determinations on blanched, dried, and stored lima beans.

Blanching time (minutes)	Qualitative peroxidase test			Peroxidase value*		
	Blanched	Dried	Stored	Blanched	Dried	Stored
No blanch	-	5 plus	5 plus	-	0.7	2.6
Steam (214° F.)						
1	3 plus	plus	plus	0.8	0.4	0.7
3	1 plus	minus	minus	0	0	0
5	1 plus	minus	minus	0	0	0
7	plus	minus	minus	0	0	0
Water (190-200° F.)						
1	3 plus	plus	plus	1.9	0.3	0.4
2	plus	minus	minus	0.2	0	0
3	plus	minus	minus	0	0	0

*Mg. of d-isoascorbic acid oxidized within 1 minute in 1 gram of enzyme extract at 38° C.

of the same sample stored for 4 months, the qualitative tests for the two periods were equally high. Similarly, in the steam-blanched beans, no quantative value could be obtained for those samples blanched for 3, 5, and 7 minutes, but the qualitative test was positive in the blanched beans in each case. The closest association between the two methods was found in the samples which were water-blanched for 1 and 2 minutes. Here the blanched beans were positive in both methods, but dried and stored beans were positive only when the 1-minute blanch was used in processing, and not in those beans which were blanched for 2 minutes.

These results suggest that the guaiacol test for peroxidase activity was less sensitive than the quantitative test based on the oxidation of a known amount of d-isoascorbic acid. However, the peroxidase test requires careful interpretation in the light of the cautions given by Phaff and Joslyn (53). These workers observed heat-stable catalysts in peas which oxidized guaiacol in the presence of hydrogen peroxide. Thus in lima beans it is possible that similar compounds exist, and therefore, that the positive reactions given by beans which had received extended blanching need not necessarily mean that the beans were insufficiently blanched. The beans which were given a weak positive rating showed a coloration only in localized areas of the ovary wall; after dehydration and storage, a negative test was produced by samples of the same treatment. Therefore, it would seem that steam-blanching for 3 minutes, or water-blanching for 2 minutes would be adequate for destruction of enzyme systems in lima beans.

Some indication of regeneration of the enzyme systems in dried beans is shown in the peroxidase value for the non-blanched beans after 4 months of storage, when a value of 2.6 was recorded compared to a value of only 0.7 at the beginning of storage. A similar trend was indicated in the beans which received a 1-minute steam blanch. Until more is known about

the application and limitations of these methods as applied to lima beans, the significance of this increase can hardly be interpreted.

Moisture and Ascorbic Acid Contents of Dehydrated Lima Beans in Relation to Various Pre-drying Treatments and Dehydration Temperatures

Freshly harvested beans were dried in the tunnel dehydrator using varying primary drying temperatures from 170° to 200° F. Standard drying time for all trucks of beans was 6 hours and 45 minutes. The several treatments and the moisture and ascorbic acid contents of each are recorded in table 25. As was found with apples, high primary drying temperatures did not increase the losses of ascorbic acid during the drying process. Actually, dried beans from the "test"* trucks dehydrated at 190° and 200° F. in the primary tunnel were on the average about 21 per cent higher in ascorbic acid than those dried at the two lower primary temperatures. This might mean that the humidity and temperature conditions prevailing in this machine were such that more ascorbic acid was oxidized during the slower drying at 170° and 180° F. than at the higher temperatures in the primary tunnel. However, a more detailed study of actual temperatures of the beans would be necessary to confirm such a statement.

The method of blanching, however, as well as the length of the blanch influenced the final ascorbic acid content of the beans. There was some evidence that the length of the steam blanch had an effect on the final ascorbic acid content, but not to the extent that was shown in the previous blanching study using the cabinet machine. Since ascorbic

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*The "test" truck, preceded and followed by buffer trucks, was run for each primary temperature used. Standard blanch for test trucks - 5 minutes in steam.

TABLE 25. Moisture and ascorbic acid content of dehydrated lima beans.

Pre-blanch treatment*	Blanch			Primary tunnel temp. (°F.)	Moisture (per cent)	Ascorbic acid (mg./100 g. wet weight)	Ascorbic acid (mg./gram dry weight)
	Time (min.)	Temp. (°F.)	medium				
-	4	214	steam	170	6.63	38.5	0.41
-	5	214	steam	"	6.45	36.3	0.39
-	6	214	steam	"	6.65	34.3	0.37
-	5	214	steam	"	6.67	42.0	0.45
-	4	212	water	"	5.98	24.8	0.26
-	6	212	water	"	4.65	20.0	0.21
-	8	212	water	"	4.48	19.3	0.20
cold, 2 min.	5	214	steam	"	6.20	39.0	0.42
cold, 4 min.	5	214	steam	"	6.52	37.8	0.40
cold, 6 min.	5	214	steam	"	6.37	38.8	0.41
-	5	214	steam	180	5.94	36.0	0.38
-	5	195	water	"	5.30	24.8	0.26
-	5	212	water	"	4.41	24.0	0.25
180° F., 30 sec.	5	214	steam	"	5.44	41.5	0.44
cold, 2 min.	5	214	steam	"	5.18	48.3	0.51
-	5	214	steam	190	4.85	46.8	0.49
180° F., 1 min.	5	214	steam	"	5.27	42.8	0.45
180° F., 1½ min.	5	214	steam	"	5.37	42.0	0.44
-	5.	212	water	"	4.70	29.3	0.32
-	5	214	steam	200	5.05	45.8	0.48

*Immersion in a 0.2 per cent sodium sulfite solution.

acid is water-soluble, blanching in water markedly reduced the amount of ascorbic acid compared to steam-blanching. Increasing the length of the water-blanch also reduced the final ascorbic acid content. The pre-blanching treatment, used primarily to extend the storage life of dehydrated products such as white potatoes and peas, had no measurable influence on the final ascorbic acid content of the beans. Although the highest ascorbic acid content was recorded for the sulfited beans dried at 180° F. in the primary tunnel, the significance of any effect from this pre-blanching treatment is questionable.

In every case, water-blanching resulted in a lower final moisture content than did steam-blanching. When the water-blanch was increased from 4 to 8 minutes, the final moisture content showed a progressive decrease from 6.0 to 4.5 per cent. There was no evidence that increasing the length of the steam-blanch produced corresponding decreases in final moisture content. Likewise, the pre-blanch treatment with sodium sulfite had no influence whatever on final moisture content.

The lower moisture content recorded for water-blanched beans compared to steam-blanched beans was not in agreement with the blanching study previously discussed. It is possible that the advantage of water-blanching shows up only under the low humidity, high temperature conditions possible in the tunnel rather than in the slower drying of the cabinet dehydrator. However, when both studies are considered, the only statement which can be made is that using a water-blanch compared to a steam-blanch may not always result in more rapid drying of lima beans.

Moisture and Ascorbic Acid in Fresh Lima Beans in Relation to Sieve Sizes and Brine Separation

The moisture and ascorbic acid contents of fresh beans used for tunnel dehydration described above are reported (table 26), according to

TABLE 26. Moisture and ascorbic acid contents of fresh lima beans.

Sieve size (diameter in inches)	Separation	Whites in sample (per cent)	Moisture (per cent)	Ascorbic acid (mg./100 gr. wet weight)	Ascorbic acid (mg./100 gr. dry weight)
22/64	none	2	83.2	33.5	1.98
"	floaters	1	78.6	36.6	1.71
22/64-28/64	none	4	79.8	27.8	1.38
" "	floaters	1	75.9	29.7	1.23
28/64-30/64	none	2	77.4	26.5	1.17
" "	floaters	1	75.2	25.8	1.04
" "	sinkers	2	70.0	24.3	0.81
30/64-34/64	none	3	71.4	22.7	0.79
" "	floaters	4	72.0	22.7	0.81
" "	sinkers	3	66.4	20.6	0.61
34/64	none	6	67.9	20.4	0.64
"	floaters	4	67.7	22.2	0.69
"	sinkers	7	61.8	15.0	0.39
all sizes	whites	-	60.5	9.6	0.24
all sizes	greens	-	71.2	27.0	0.94

sieve sizes and brine separation within sieve sizes. Each sieve size was separated into "floaters and sinkers" in a 15 per cent (60 degrees salometer) brine, and the percentage of white beans in each of the above classes was determined by actual count. As the sieve size was increased, the moisture content decreased progressively from 83 to 68 per cent. The floaters showed an inconsistent relation to non-separated beans in respect to moisture content, but the sinkers were lower in moisture content than floaters or non-separated lots in every case where sinkers were obtained. Comparison of white beans to green beans of all sizes showed that whites were significantly lower in moisture than green beans.

The ascorbic acid content of the non-separated beans showed a progressive decrease from 1.98 to 0.64 milligrams per gram as sieve size increased. As was shown in moisture contents, floaters were inconsistent in ascorbic acid content compared to non-separated beans. In the smaller sized beans, floaters were lower in ascorbic acid than non-separated beans, but in the larger sizes, floaters showed a slightly higher ascorbic acid content. Sinkers were in all cases the lowest in ascorbic acid within each sieve size group, as would be expected from the high percentage of white beans which were counted in this separation. It is interesting to note that when all sizes were considered, the green beans were nearly three times higher in ascorbic acid than the white beans. It would seem from these data that where quality packs of lima beans are desired in the food processing industry, separation by brine flotation might provide a method of eliminating over-mature beans (sinkers) within respective sieve sizes. The hard whites and the beans of lower ascorbic acid content would sink, whereas the greens, which are shown to be significantly higher in ascorbic acid, would float.

Relation of Sieve Size to the Loss of Ascorbic Acid in Dehydration and Storage of Lima Beans

After separation into sieve sizes and blanching for 5 minutes in steam, the various groups of beans were spread out for removal of all shriveled white beans before weighing on trays at the rate of 1.25 pounds per square foot. The beans were dehydrated in the cabinet machine for 2¼ hours at 190° F. followed by 5-3/4 hours at 160° F. Dehydrated beans were thoroughly mixed, sealed in No. 1 tin cans in air, and stored at 65° F. for 4 months.

The effects of dehydration and storage on moisture and ascorbic acid contents of the four sieve sizes compared to the non-sieved beans are shown in table 27. As would be expected from previous work, the smaller fresh beans were higher in moisture than the larger beans or the sample which consisted of all sizes. The non-sieved beans appeared unusually low in moisture content, but a second sample in duplicate confirmed this figure. The dehydrated beans showed the same order of moisture content as was found in the fresh beans; that is, the smallest beans dried down to 6.0 per cent moisture, whereas the largest beans dried down to 5.3 per cent. The non-sieved sample had a moisture content of 6.2 per cent after dehydration, or higher than any of the sieved beans.

The ascorbic acid contents of the fresh, blanched, and dried beans were inverse to the size of the beans. This relationship of ascorbic acid and sieve size held for each series of determinations made in this study. The ascorbic acid contents of the non-sieved beans were intermediate between those of the No. 2 and the No. 3 beans in each case.

The percentage losses of ascorbic acid due to blanching, dehydration, and storage are calculated for each sieve size group and the non-sieved beans. The losses due to blanching in relation to bean size are difficult

TABLE 27. Loss of ascorbic acid and moisture in dehydration and storage of lima beans as affected by sieve size of beans.

Sieve size	Per cent moisture				Ascorbic acid (mg./ gram, dry weight)				Ascorbic acid (per cent loss)			
	Fresh	Blanched	Dried	Stored 4 mo.	Fresh	Blanched	Dried	Stored 4 mo.	In blanching	In drying	In storage	Total
1	72.3	72.6	6.0	6.0	.937	.642	.359	.285	31.5	30.2	7.9	69.6
2	63.2	71.7	5.7	5.8	.662	.509	.332	.212	23.2	26.6	18.1	68.0
3	61.5	61.4	5.4	5.6	.491	.300	.243	.136	38.9	11.6	21.9	72.4
4	61.0	-	5.3	5.3	.372	-	.238	.158	-	36.2*	21.3	57.5
all sizes	60.5	62.7	6.2	5.9	.617	.333	.254	.168	46.1	12.8	13.9	72.8

*Includes loss in blanching plus dehydration.

to interpret on a basis of the three figures given, except to note that the percentage losses were extremely variable. No determination was made of blanching loss in the No. 4 beans due to insufficient quantities of this size being available for sampling. In dehydration, however, it seems safe to assume on the basis of determinations for three sieve sizes that smaller beans lost more on a percentage basis than did the large beans. This situation is reversed in the storage period, when the larger beans showed a greater loss of ascorbic acid than the smaller beans. Though additional work would be necessary to confirm the data reported here, it is surmised that the smaller beans lost higher percentages of ascorbic acid in blanching and drying compared to the losses in larger beans, but the smaller beans had a higher retention of ascorbic acid in the storage period compared to the larger beans.

Though the small beans lost a total of about 70 per cent of initial ascorbic acid, the two small sizes still contained from 40 to 100 per cent more ascorbic acid than the two larger sizes. Thus from the viewpoint of ascorbic acid content, the small beans maintained precedence nutritionally over the large beans throughout the processing and storage.

DISCUSSION

A critical analysis of fresh lima beans brought out the variability of the beans as they came from the field. It was realized that the commercial operator would not brine-separate fresh lima beans and dehydrate only part of the crop, but this work did illustrate the possibility of a high quality pack from part of a crop whether that pack be processed by dehydration, canning, or freezing. The great variability in moisture and ascorbic acid in beans segregated by brine separation of the various sieve sizes further showed the tremendous differences in quality involved

in fresh lima beans. When the beans were separated into two categories, it is interesting to note that green beans were three times as high in ascorbic acid as white beans on a wet weight basis, and nearly four times as high on a dry weight basis.

General losses of ascorbic acid in lima beans were rather high in blanching, dehydration, and storage, when compared to the minimum losses that were obtained in the apple work. Thus it becomes important to minimize the losses of ascorbic acid in the dehydration and storage of lima beans to retain as much as possible of the high vitamin quality originally present in this product.

The study of the influence of blanching on subsequent losses of ascorbic acid in dehydration and storage revealed unusually high oxidation of ascorbic acid in spite of any blanching effects. Thus it is imperative that blanching be intelligently used. If ascorbic acid is a measure of quality, as suggested by Tressler (64) and Fitzgerald (27), then little was gained by increasing the steam-blanch beyond 1 minute, for at the end of 4 months of storage, all differentially steam-blanched samples were nearly the same in ascorbic acid content. On the other hand, much was lost by increasing the time in the water-blanch beyond 1 minute, since ascorbic acid was thereby markedly reduced, and this effect was evident after 4 months of storage. However, it must be noted that blanching of some type was necessary, since the non-blanched beans were significantly lower in ascorbic acid in each set of determinations.

Since perhaps the major fundamental purpose of blanching vegetables has been to destroy enzyme systems naturally occurring in the fresh crop, the study of enzyme activity in blanched samples was of interest. According to the peroxidase determinations, nothing was gained by blanching in water more than 2 minutes, or by blanching in steam more than 3 minutes.

The application of this information, however, is dependent entirely upon the resultant storage life of the product as determined by ascorbic acid, by organoleptic methods, or by whatever yardstick is to be adopted to measure quality in dehydrated lima beans. For example, in the steam-blanched group, if the 1-minute blanch resulted in the retention of quality equal to the 3-minute treatment, then the 1-minute blanch was sufficient despite the fact that this treatment did not produce a negative peroxidase test in the blanched beans. As already pointed out, the steam-blanched samples all reached the same ascorbic acid content after 4 months of storage. Judging from this storage information, then, a 1-minute steam-blanch was sufficient, and longer periods of blanching in steam were unnecessary, unless a longer storage period would change the results in favor of the longer blanch. Considering both the ascorbic acid and peroxidase determinations on water-blanched beans, blanching more than 1 minute was excessive. A more detailed investigation of enzyme activity associated with length of storage life as well as with storage quality is necessary, however, to be able to predict with more reasonable assurance the time necessary in steam or water-blanching.

Further, a measure of quality in dehydrated lima beans must be standardized. Kramer (30) suggested that a non-specific reaction involving several substances in the product might show a closer correlation with quality in fresh, frozen, and canned lima beans than a specific reaction such as the ascorbic acid determination. He further stated that semi-quantitative peroxidase determinations were unsuitable as quality indices for the above-mentioned packs of beans. Whether or not these suggestions can be applied to dehydrated lima beans is not known.

The problem in dehydration of lima beans, then, is to blanch sufficiently to insure keeping quality in subsequent storage, but to avoid

overblanching which results in excessive losses of ascorbic acid and other nutrients.

SUMMARY AND CONCLUSIONS

1. Variability in moisture content of dehydrated lima beans was studied by screening ground-up beans into mesh sizes from 20 to 100 mesh. Least variability in moisture content was found in the material held on the 40 mesh screen, and this size was adopted as standard for all determinations made on dehydrated beans. Ascorbic acid was found to vary directly with mesh size of the particles.

2. To study the influence of blanching on ascorbic acid content, beans were differentially blanched in steam and hot water, dehydrated in the cabinet dehydrator, and stored for 4 months at 65° F. No advantage was gained by blanching more than 1 minute in steam, and considerable ascorbic acid was lost by blanching more than 1 minute in hot water. Quantitative and qualitative peroxidase tests on the blanched and dried beans, though not in complete agreement, indicated that of the blanching times used, 3 minutes in steam and 2 minutes in water was necessary to destroy the enzyme systems of lima beans. Thus the blanching time necessary for maximum retention of ascorbic acid was not the same as the time necessary for destruction of peroxidase. Evidence for regeneration of the enzyme during storage was presented in the quantitative peroxidase tests, but further work is necessary to confirm this as well as to correlate enzyme activity and loss of quality in storage of dehydrated lima beans.

3. Tunnel dehydration of lima beans, with primary temperatures ranging from 170° to 200° F., indicated that no greater loss of ascorbic acid occurred with high primary drying temperatures than with lower

temperatures. Water-blanching resulted in a lower ascorbic acid content of the beans, and this reduction was accentuated by increasing the time in the water-blanch. Water-blanching also resulted in a lower final moisture content, but this was exhibited only in tunnel-dehydrated beans. There was some evidence for reduced ascorbic acid content in the dried beans correlated with increased time in the steam-blanch, but this was not shown as clearly as in the blanching work with the cabinet dehydrator. A pre-blanching treatment, consisting of immersion in a 0.2 per cent sodium sulfite solution, had no measurable influence on either final moisture or ascorbic acid contents.

4. Early Baby Potato lima beans were graded into five sieve sizes and further separated by brine flotation in a 15 per cent salt solution. Moisture and ascorbic acid determinations, made on each group, showed that sinkers were invariably lower in moisture and ascorbic acid content than floaters or non-separated beans in each sieve size group. Floaters were inconsistent in moisture and ascorbic acid in relation to non-separated beans. The ascorbic acid and moisture content of the beans was inversely proportional to a sieve size.

5. To study the effect of sieve size on the loss of ascorbic acid in dehydration and storage of lima beans, four sieve sizes were dried in the cabinet machine and stored for 4 months at 65° F. Small fresh beans were higher in moisture and ascorbic acid content than the large beans, and this relationship was maintained through blanching, dehydration, and storage. Evidence is presented to show that total losses of ascorbic acid in each sieve size was high in each case, and that the largest sized beans were lower in percentage loss compared to the three smaller sieve sizes. No attempt is made to draw a definite conclusion in this respect without further work. After dehydration and storage, the No. 1 sieve size beans were still nearly 100 per cent higher in ascorbic acid than the No. 4 sieve size.

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APPENDIX

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TABLE 28. Loss of moisture and ascorbic acid during dehydration of Stayman Winesap apples under varying conditions of temperature and humidity.

Hours dried	High humidity				Low humidity			
	Moisture (per cent)	Per cent of initial moisture removed	Ascorbic acid (mg./100 g. dry wt.)	Ascorbic acid (per cent loss)	Moisture (per cent)	Per cent of initial moisture removed	Ascorbic acid (mg./100 g. dry wt.)	Ascorbic acid (per cent loss)
			Dried at 145°- 165° F.*					
0	85.9	-	10.7	-	86.3	-	13.0	-
1	82.4	23.0	13.2	-	77.3	45.7	13.7	-
2.5	70.4	61.0	9.6	10.0	59.8	76.3	11.6	11.0
4	39.1	89.5	5.1	52.3	28.1	93.8	7.2	44.3
5	12.0	97.8	4.6	57.3	8.8	98.5	6.6	49.2
			Dried at 175°- 165° F.					
0	86.1	-	11.8	-	86.9	-	13.7	-
1	79.6	36.8	11.2	5.1	76.6	50.6	12.1	12.2
2.5	59.6	76.1	6.4	45.4	49.5	85.2	10.4	24.2
4	23.4	95.1	3.6	69.1	17.9	96.7	9.9	28.3
4.5	10.2	98.2	3.6	69.1	11.2	98.1	10.0	27.2
			Dried at 190°- 165° F.					
0	86.6	-	11.8	-	86.4	-	14.1	-
1	76.9	46.0	9.2	21.4	81.3	31.4	13.7	2.8
2.5	53.2	81.6	4.6	61.2	51.1	83.5	7.1	49.5
4	21.2	95.7	3.3	72.4	9.7	98.3	5.0	64.4
4.5	9.6	98.3	2.2	81.5	9.3	98.4	5.0	64.4

*Drying temperatures indicate level held in primary drying followed by finishing temperature of 165° F.

[redacted]

TABLE 29. Loss of moisture and ascorbic acid during dehydration of York Imperial apples under varying conditions of temperature and humidity.

Hours dried	High humidity				Low humidity			
	Moisture (per cent)	Per cent of initial moisture removed	Ascorbic acid (mg./100 g. dry wt.)	Ascorbic acid (per cent loss)	Moisture (per cent)	Per cent of initial moisture removed	Ascorbic acid (mg./100 g. dry wt.	Ascorbic acid (per cent loss)
			Dried at 145°- 165° F.*					
0	85.7	-	17.1	-	85.4	-	17.8	-
1	82.5	21.7	19.4	-	80.6	28.7	20.7	-
2.5	74.3	51.8	17.6	-	65.7	67.3	17.5	1.9
4	40.9	88.5	9.5	44.7	38.8	89.2	12.3	31.2
5	17.1	96.6	8.6	50.0	12.6	97.5	8.6	52.9
			Dried at 175°- 165° F.					
0	86.0	-	17.8	-	85.8	-	16.9	-
1	80.2	34.1	17.7	0.4	75.7	48.5	16.4	3.9
2.5	68.7	64.2	16.2	5.4	50.2	83.3	14.5	14.6
4	26.8	94.0	7.5	57.2	13.8	97.4	12.6	25.0
4.5	12.2	97.7	3.6	80.0	9.8	98.2	12.9	24.4
			Dried at 190°- 165° F.					
0	86.0	-	17.8	-	86.1	-	18.8	-
1	81.0	30.2	15.7	11.8	77.2	45.7	19.3	-
2.5	54.2	80.7	9.8	45.2	52.6	82.1	10.7	42.7
4	22.1	95.4	6.2	65.4	18.0	96.5	7.0	62.6
4.5	9.7	98.2	5.5	68.9	10.1	98.2	7.0	62.6

*Drying temperatures indicate level held in primary drying followed by finishing temperature of 165° F.

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TABLE 30. Chemical changes in dehydrated York Imperial apples stored for one year (1943).

Months in storage	Moisture (per cent)	pH	Titratable acidity (ml. 0.1 N NaOH)	Ascorbic acid		Sugar content (as per cent of dry wt.)		
				mg./100 g. dry wt.	Per cent loss	Reducing sugars	Non-reducing sugars	Total sugars
				Cold storage				
0	16.5	3.69	6.4	15.6	-	47.5	23.7	71.2
1	15.9	3.72	6.4	15.5	0.7	47.8	23.8	71.6
2	16.6	3.75	6.3	15.3	1.6	47.9	24.0	71.9
3	16.4	3.50	6.3	14.8	4.8	50.5	21.8	72.3
4	16.5	3.36	6.3	14.5	6.9	52.7	18.9	71.6
5	16.4	3.38	6.4	14.2	8.6	52.9	18.4	71.3
6	15.6	3.54	6.4	13.4	14.1	53.1	18.0	71.1
12	16.2	3.35	6.5	10.0	35.7	54.9	16.7	71.6
				Common Storage				
0	16.5	3.69	6.4	15.6	-	47.5	23.7	71.2
1	16.3	3.62	6.0	14.8	4.8	47.3	24.4	71.7
2	16.0	3.64	5.9	11.1	29.0	48.8	22.6	71.4
3	15.9	3.53	6.3	6.4	58.9	50.7	20.9	71.6
4	14.9	3.45	6.6	6.6	57.7	51.5	18.6	70.1
5	16.4	3.40	6.7	3.9	75.0	54.5	16.8	71.3
6	15.8	3.55	6.6	4.2	73.0	54.6	15.3	69.9
12	16.2	3.32	6.0	3.6	77.0	56.8	14.8	71.6

[redacted]

TABLE 31. Chemical changes in dehydrated Rome Beauty apples stored for one year (1943).

Months in storage	Moisture (per cent)	pH	Titratable acidity (ml. 0.1 N NaOH)	Ascorbic acid		Sugar content (as per cent of dry wt.)		
				mg./100 g. dry wt.	Per cent loss	Reducing sugars	Non-reducing sugars	Total sugars
				Cold Storage				
0	18.0	3.64	6.2	10.3	-	53.2	18.4	71.6
1	18.5	3.61	6.2	9.6	6.9	53.5	17.9	71.4
2	18.5	3.55	6.9	9.2	10.2	53.8	17.2	71.0
3	18.5	3.58	6.4	9.3	9.5	54.5	15.6	70.1
4	19.1	3.37	6.2	9.1	10.9	54.4	15.8	70.2
5	19.3	3.38	6.2	9.3	9.5	54.3	17.3	71.6
6	18.8	3.34	6.0	9.1	10.9	54.2	13.3	67.5
12	18.3	3.34	6.2	6.1	40.4	57.0	12.8	69.8
				Common storage				
0	18.0	3.64	6.2	10.3	-	53.2	18.4	71.6
1	18.5	3.61	6.6	9.1	10.9	53.5	17.7	71.2
2	18.9	3.55	7.0	8.4	18.3	54.5	16.7	71.2
3	18.2	3.58	6.7	6.5	36.9	56.2	13.0	69.2
4	18.7	3.35	6.3	6.2	40.1	57.8	12.3	70.1
5	18.9	3.33	6.8	5.2	49.5	59.2	12.0	71.2
6	19.4	3.33	6.0	4.8	52.8	59.6	8.6	68.2
12	18.0	3.36	5.4	5.1	50.1	60.0	9.5	69.5

[redacted]

TABLE 32. Chemical changes in dehydrated Ben Davis apples stored for one year (1943).

Months in storage	Moisture (per cent)	pH	Titratable acidity (ml. 0.1 N NaOH)	Ascorbic acid		Sugar content (as per cent of dry wt.)		
				mg./100 g. dry wt.	Per cent loss	Reducing sugars	Non-reducing sugars	Total sugars
				Cold Storage				
0	12.7	3.70	6.0	16.6	-	48.9	19.3	68.2
1	12.7	3.65	6.4	16.0	3.5	48.1	20.4	68.5
2	12.9	3.65	6.5	15.8	4.7	50.0	19.3	69.3
3	12.4	3.56	6.0	15.2	8.7	51.6	16.9	68.5
4	12.2	3.45	6.2	15.3	8.2	52.4	16.2	68.6
5	12.6	3.47	6.4	13.7	17.4	56.1	12.1	68.2
6	12.8	3.37	6.0	12.8	22.8	56.2	14.4	70.6
12	12.5	3.45	5.4	12.9	22.3	56.3	12.5	68.8
				Common Storage				
0	12.7	3.70	6.0	16.6	-	48.9	19.3	68.2
1	12.5	3.68	6.3	13.5	18.9	48.9	21.9	70.8
2	11.8	3.65	6.5	11.8	28.8	49.1	20.9	70.0
3	13.3	3.65	6.0	9.7	41.7	52.4	18.7	71.1
4	12.7	3.47	6.1	9.4	43.5	53.6	15.4	69.0
5	13.5	3.47	5.9	6.1	63.2	55.5	13.4	68.9
6	13.0	3.41	6.0	6.1	63.2	51.5	12.0	63.5
12	12.4	3.45	5.5	4.6	72.5	54.8	13.4	68.2

[redacted]

TABLE 33. Chemical changes in dehydrated Stayman Winesap apples stored for one year (1943).

Months in storage	Moisture (per cent)	pH	Titrateble acidity (ml. 0.1 N NaOH)	Ascorbic acid		Sugar content (as per cent of dry wt.)		
				mg./100 g. dry wt.	Per cent loss	Reducing sugars	Non-reducing sugars	Total sugars
				Cold Storage				
0	15.5	3.60	6.7	11.7	-	50.9	18.1	69.0
1	15.4	3.50	6.1	10.9	6.3	51.5	17.5	69.0
2	15.4	3.42	7.0	10.4	10.7	50.6	17.9	68.5
3	15.5	3.43	6.7	9.7	16.7	50.2	18.2	68.4
4	15.3	3.28	6.7	9.9	14.9	50.3	19.1	69.4
5	15.3	3.29	6.4	8.4	28.2	50.7	16.3	67.0
6	15.7	3.24	6.5	8.3	28.8	52.0	15.6	67.6
12	16.7	3.30	6.2	8.5	26.9	53.8	14.8	68.7
				Common Storage				
0	15.5	3.60	6.7	11.7	-	50.9	18.1	69.0
1	15.2	3.52	6.4	9.6	17.9	49.5	18.9	68.4
2	14.9	3.45	7.0	7.5	35.5	50.4	17.6	68.0
3	15.2	3.47	6.5	6.4	45.0	51.9	16.1	68.0
4	15.7	3.30	6.2	4.0	65.9	54.1	14.4	68.5
5	14.9	3.34	6.6	3.3	72.1	53.6	13.2	66.8
6	16.0	3.30	6.4	2.9	75.5	54.5	13.6	68.1
12	15.2	3.32	5.4	2.7	76.7	54.3	12.0	66.3

TABLE 34. Variance analysis of cumulative losses of sulfurous acid in dehydrated Stayman Winesap apples stored for 270 days at 65° F. and 33° F. (See Table 7)

Source of variation	Degrees of freedom	Mean square	F
Treatments	3	16,084	4.49
Temperature	1	47,883	13.44*
Error (a)	3	3,564	
Storage intervals	2	8,461	11.72**
Interactions:			
Intervals x temp.	2	258	
Intervals x treat.	6	441	
Residual error	6	722	
Total	23		

*Significant at odds greater than 19:1

**Significant at odds greater than 99:1

TABLE 35. Variance analysis of cumulative losses of ascorbic acid in dehydrated Stayman Winesap apples stored for 270 days at 65° and 33° F. (See Table 8)

Source of variation	Degrees of freedom	Mean square	F
Treatments	3	3.748	40.60*
Temperature	1	0.240	2.60
Error (a)	3	0.092	
Storage intervals	2	1.640	29.44*
Interactions:			
Intervals x temp.	2	0.189	
Intervals x treat.	6	0.087	
Residual error	6	0.055	
Total	23		

*Significant at odds greater than 99:1

TABLE 36. Sugar and starch content of dehydrated Stayman Winesap apples stored at 100° F. sealed in air

Days stored	Reducing sugar	Non-reducing sugar	Total sugar	Starch
	(Expressed as per cent of dry weight)			
Lot 120				
0	50.8	22.0	72.8	1.65
7	49.3	20.7	70.0	
14	48.7	16.7	65.4	
20	48.4	16.5	64.9	
36	50.0	16.6	66.6	
60	49.9	14.6	64.5	
90	50.1	8.4	58.5	1.56
120	54.8	4.8	59.6	
150	54.7	4.4	59.1	
200	59.5	7.2	66.7	1.46
270	63.4	6.7	70.1	1.34
Lot 121				
0	50.2	20.8	71.0	1.67
7	49.8	21.6	71.4	
14	49.4	23.1	72.5	
20	48.9	19.0	67.9	
36	49.7	14.1	63.8	
60	51.0	12.5	63.5	
90	51.3	9.0	60.3	1.60
120	53.5	9.1	62.6	
150	55.0	5.1	60.1	
200	60.2	9.3	69.4	1.51
270	65.3	6.4	71.7	1.44
Lot 122				
0	48.4	18.2	66.6	1.62
7	48.7	19.0	67.7	
14	49.7	18.3	68.0	
20	48.7	18.0	66.7	
36	50.9	15.3	66.2	
60	50.8	15.5	66.3	
90	49.9	11.6	61.5	1.57
120	52.1	12.4	64.5	
150	51.2	8.2	59.4	
200	57.1	12.7	69.8	1.51
270	63.7	5.5	69.2	1.43
Lot 123				
0	50.4	18.5	68.9	1.59
7	51.0	17.4	68.4	
14	50.6	17.9	68.5	
20	48.0	18.2	66.2	
36	49.4	17.9	67.3	
60	47.8	12.7	60.5	
90	49.6	11.0	60.6	1.52
120	51.3	8.9	60.2	
150	54.3	6.0	60.3	
200	55.0	14.2	69.2	1.46
270	58.3	10.7	69.0	1.41
Lot 124				
0	50.1	20.1	70.2	1.45
14	48.1	16.8	64.9	
20	48.2	15.3	63.5	
90	50.6	13.1	63.7	
150	49.0	21.3	70.3	1.42
270	49.8	23.4	73.2	1.37

TABLE 37. Reconstitution of dehydrated Rome Beauty apples dried at intervals during storage.

Time in water* (minutes)	Per cent of initial moisture recovered			
	Dried 10/29/43	Dried 12/6/43	Dried 3/1/44	Dried 6/13/44
0	1.13	1.21	1.64	2.07
20	18.61	16.16	20.72	18.04
40	25.06	20.84	27.40	23.68
60	29.66	24.02	32.17	28.38
80	33.34	27.38	35.98	32.14
100	37.02	30.19	39.81	34.01
120	40.15	32.99	42.66	35.89

*Temperature of water - 25° C.

TABLE 38. Reconstitution of dehydrated Stayman Winesap apples dried at intervals during storage.

Time in water* (minutes)	Per cent of initial moisture recovered			
	Dried 10/12/43	Dried 12/2/43	Dried 2/29/44	Dried 6/14/44
0	2.41	1.54	2.50	2.99
20	28.15	21.30	25.29	24.38
40	38.16	27.54	33.26	30.33
60	45.31	30.66	40.10	36.27
80	51.03	34.82	43.52	41.02
100	55.32	38.98	46.94	43.40
120	58.90	41.06	50.35	46.96

*Temperature of water - 25° C.

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