PHYSIOLOGICAL RESPONSES AND QUALITY CHANGES OF WAXED AND UNWAXED STAYMAN WINESAP APPLES AS INFLUENCED BY DIFFERENT POST-STORAGE TEMPERATURES

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INTRODUCTION

The efforts of the apple industry and many research workers have been long directed towards the production and marketing of fruit of the highest possible quality. Today there is an increasing number of fresh fruit and vegetable products in sales competition with the apple. It is, therefore, of great importance to the grower that the quality of the apple be maintained at the highest level possible so that it may continue to successfully compete for the consumer's dollar.

The research efforts aimed at aiding the apple industry in presenting such a quality product, from planting to marketing, may be roughly grouped into the following categories: (a) the production, selection, and distribution of superior varieties; (b) the development of superior cultural practices; (c) the development of systems of grading and packaging to produce a more attractive and uniform product; (d) the development of methods of storage and treatment for prolonging the life and quality of the fruit. Only limited work has been directed, however, to methods of maintaining the quality of the apple once it has entered into commercial channels, as heretofore there was little or no possibility of controlling the environmental temperature that the apple might encounter during retail distribution or during the period of consumer holding. Recently, however, the advent of new refrigerated distribution equipment; i.e., merchandizing cabinets, vending machines, and retail display counters, have made it possible to control, within certain limits the environmental conditions, particularly the temperature which the apple as a retail product will encounter. It is now also feasible for the consumer to better control the temperature to which the fruit may be subjected since mechanical refrigeration has become increasingly commonplace in the American home.

Experimental evidence and conventional procedures have established 31^{o} - 32^{o}F. as the ideal temperature range for the long time storage, of one to six months or more, for most commercial apple varieties. The maintenance of such a low temperature range during retail distribution or in the home, while ideal, would be nevertheless impractical when considered in the light of the cost of the special equipment required and the length of the probable post-storage period. It remains highly desirable, therefore, to more accurately determine the effect of the temperature factor during the post-storage periods of retail distribution or in the home in relation to the maintenance of acceptable fruit quality.

This investigation was undertaken to determine the quality and physiological responses of the Stayman Winesap apple to various post-storage temperatures, with the purpose of establishing the post-storage temperature most satisfactory for maintenance of quality of this variety. Also included in this investigation was a study to determine the effect of wax applications on the post-storage keeping quality.

LITERATURE REVIEW

A preliminary study dealing entirely with the effect of temperature on quality changes in the apple fruit in post-storage was reported by Haut (26) in 1946. Other workers have studied the various quality and physiological factors of the apple under consideration here, but none have related their work entirely to its post-storage life. Since there is little in the literature relating directly to these changes in post-storage, the present review will concern itself with the quality and physiological factors under consideration.

Weight Loss. The weight loss of apples in storage is generally attributed (34, 46, 47, 55) to moisture loss although it is realized that some is due to a loss of carbohydrates in the respiration processes. The loss in moisture, weight, is explained by some workers (20, 55) on the basis of the vapor pressure deficit between the atmosphere which surrounds the apple and the internal atmosphere of that fruit. On this basis, it is shown that even at the same relative humidity, if less than 100 per cent, fruits stored at higher temperatures may be expected to lose more weight in a given period than those stored at a lower temperature (55). Theoretically weight losses in the storage room could be reduced by the maintenance of a saturated atmosphere. Such a solution to the problem of weight loss in storage, however, has proved unsatisfactory due to the difficulty encountered in maintaining a saturated atmosphere and to the development of certain diseases and surface molds under such conditions causing off-flavored and unsightly fruit. The importance of weight loss in storage cannot be overlooked as it has been indicated (55) that when an apple has lost as much as five per cent of its original weight, it is so shrivelled that the eating quality has been seriously impaired and the fruit is unattractive because of a wrinkled appearance of the skin. Christopher et al. (11) also emphasized the effect of weight loss on the quality of fruit, stating that 5-7 per cent weight loss results in an undesirable fruit.

Several factors have been shown to influence the amount of weight lost by apple fruit while in storage. Pieniazek (46) has shown that in the case of fruit stored at 32°F. and 85 per cent humidity, those approaching over maturity transpired more rapidly than did less mature fruits. He also noted marked increases in transpiration in fruits of the Yellow Transparent variety as they approached breakdown. Work done in Pennsylvania by Linde and Kennard (34) showed that the degree of the coloration of the fruit influenced the amount of water loss through transpiration. These workers (34) reported that fruit of the Stayman Winesap and Rome Beauty varieties, which were low in color, suffered greater weight loss than did highly colored fruits while stored for sixteen days at room temperature.

The use of wax applications have been shown (20, 34, 46, 47) to significantly reduce weight loss of apples in storage. Hitz and Haut (30) showed that with Grimes Golden, wax application resulted in a thirty per cent reduction in weight loss over comparable unwaxed fruit. A similar reduction in weight loss due to waxing with this variety was reported by Linde and Kennard (34). The reduction in weight loss brought about through wax application is again shown by Hitz and Haut (30) when they state, "For the three years, the weight losses during the storage period for all unwaxed apples average fifty-six per cent greater than for the comparable waxed samples."

Respiration. An excellent review of the general topic of respiration in apples while in storage has been presented by Smock (55). Therefore only those phases of the respirational activities which are particularly related to this study will be covered in this review of literature.

Morse (44) in 1908 reported the effect of storage temperature upon the respirational rate of stored apples and suggests that through reduced storage temperatures the life of the apple could be extended. Later workers Gore (17) and Burroughs (6) confirmed these findings and showed that Van't Hoff's law applied to the respiration rate of apple fruits in storage. Since these reports, many investigations have been conducted concerning the respirational activity of fruits (12, 14, 23, 39) while in storage.

It has been shown by Harding (23) that the rate of respiration increases with maturity of the fruit when held at a uniform temperature. He also showed that at the higher storage temperatures the increased state of maturity affects the respiration rate causing it to be more rapid. Ezell and

Gerhardt (14) also have shown the effect of maturity on respiration. Magness et. al. (39) have also noted that there is an association between the degree of softening of the fruit or maturity and the rate of respiration. However, Degmen and Weinberger (12) in their studies found no correlation to exist between the respiration rate and the storage life of the fruit.

The effect of alternating temperatures upon the subsequent respiration of apples has been tested to determine any possible deleterious after effects of cold storage. Results of work done in Iowa by Harding (24) show that the shifting of Grimes fruit from 30° to 50°F. had no affect upon respiration rates. The results show that after the fruit samples had reached temperature equilibrium, the respiration rate was neither stimulated nor depressed further than was the respiration rate of fruit held constantly at 50°F. Work by Eaves (13) and Smock (54) substantiate these findings. Burroughs (6) however found that with fruits tested immediately after harvest, there was a stimulatory effect resulting from moving immature fruits from 32° to 68.50°F. He reported no such response when mature fruits were used.

Respiration can be retarded in the same way as can the maturation processes. Fisher and Britton (16) have shown that the application of wax to winter varieties will reduce the respiration rate as much as fifteen per cent of that of unwaxed fruit. The reduction in storage temperature has also been shown (6, 17, 39, 44) to reduce respiration rates concurrently with retardation of the decline in fruit firmness and storage maturity. The rate of respiration has also been reduced by the use of controlled atmosphere storage by Smock (54) and others.

Firmness Evaluation. One of the major changes that occurs as the apple matures in storage is the reduction of fruit firmness. Due to the differences in human judgment, the determination of these firmness changes is one of the most difficult problems with which the fruit grower or handler is faced. An attempt to substitute objective measurements to overcome these judgment differences in determining the softening and thus maturity of the fruit was reported in use in Oregon by Morris (43) as early as 1917. Since that time much effort has been expended in developing a mechanical device which could ascertain the degree of softness or maturity of the apple tissue.

The first such device (43) consisted of a common marble mounted to one half its diameter in a hardwood block. The block with marble exposed was placed upon the pan of a kitchen scale and the fruit to be tested was forced against the marble until it penetrated far enough for the hardwood block to contact the fruit. The firmness value was then read directly in pounds from the face of the scale. This method of determining the storage maturity of the fruit was used successfully with apples and pears. Other early devices for evaluating fruit firmness were reported by Lewis, Murneek, and Cate (33) and Murneek (45).

The adaptation of these early mechanical guides to fruit firmness into the present day pressure testers was made by Magness and Taylor (38). This device is simple in design, portable, inexpensive, easy to use, and relatively accurate. It measures fruit firmness as the pressure required to cause a 7/16-inch plunger to penetrate 5/16 of an inch into the tissue of the fruit against the force of a self-contained spring. The firmness value of the fruit is read directly as pounds pressure from a gauge on the instrument. The pressure tester is such that the fruit to be tested may be held in one hand, while the tester is operated by the other. Many adaptations of the pressure tester have since been introduced, including the pistol type (1) used in this study for use with the various fruit and vegetable crops. An excellent review of the various types of pressure testers and their uses is presented by Haller (19).

The registered firmness value of the apple fruits as determined by the pressure tester, may be influenced by one of several factors. Experimental evidence (33) has shown, as would be expected, that the size, shape, and depth of penetration of the plunger affects the registered firmness of the fruit. Haller (19) reports the adaptation of the pressure tester for use with various crops by changing the size of the plunger. Magness and Taylor (38) found the use of a rounded plunger 7/16-inch in diameter penetrating to a depth of 5/16 of an inch to be very satisfactory for the testing of apples particularly in determining the storage maturity of the fruit. The use of this plunger and penetration depth has now become standard for use with apples.

The size of the individual apples has been shown (33) to cause a variation in the firmness value of a given lot of fruit. Morris (43) found that after a period of storage the larger apples, size 88, were as much as two pounds less firm than smaller apples, size 175. It has also been shown (43, 61) that highly colored fruits may be firmer than poorly colored fruits. By selecting for study only fruits which are uniform as to size and color, present day workers (26) are overcoming the possibility of these variables affecting fruit firmness studies.

The temperature of the fruits at the time the firmness evaluations are made has been shown by Hartman (25) to affect the registered value with pears. He found that comparable pears would register ten per cent firmer at 51°F. than at 97°F. Other workers (19) have reported similar results from tests conducted on strawberries, raspberries, and cherries. Haller (19), however, did not find any such affect of temperature upon the registered firmness value of apples. He conducted studies to determine the effect of temperature of the flesh upon the expressed firmness value of the apple with three varieties including Stayman Winesap. Fruits of a comparable maturity were placed in constant temperature chambers from 32° - 80°F. from three to six hours or until the fruit had reached the temperature of the chamber. Upon testing the fruit with a standard pressure tester he found that there was no significant difference in firmness value due to the temperature of the fruit at the time of the test.

The reliability of the pressure tester in indicating the true firmness value of the apple fruit partially depends upon whether the fruit under test is peeled or unpeeled. Early in the development of these devices they were used without the removal of the skin. The employment of the testers in such a manner was justified by Murneek (45) in that as the season progressed, increases in the pliability of the epidermis resulted in a greater increase in resistance that was partially and later totally overcome by the rapid increase in the ripeness of the tissues of the cortex. Later studies by Magness and Taylor (38) however, showed that with apple and pear fruits the skin had to be removed for the most accurate reading as it tended, particularly during or after storage, to mask the true firmness of the flesh. Results of these studies showed that with the Stayman Winesap variety at harvest the unpeeled fruit registered 19.4 pounds and with the peel removed 16.2 pounds. A comparable sample upon reaching prime eating condition registered 18.1 pounds before the peel was removed, while the peeled fruit registered almost fifty per cent less, 9.8 pounds. The removal of the peel or skin of the apple fruit before the application of a pressure tester has today become standard practice.

There has been some discussion as to the better technique in the use of the pressure tester as to whether the more accurate reading could be obtained by a slow or rapid penetration of the fruit by the plunger. When tests were made to determine the proper procedure, it was shown (38) that as long as it was possible to make accurate readings from the gauge of the tester, little variation would result from differences in the rate of penetration of the plunger.

Unexpected variation in the firmness values of harvested apples and pears have been reported by many workers (25, 39, 43, 45) when the firmness value of a lot of fruits increased as they matured rather than decreasing as would be expected. Hartman (25) and Morris (43) attributed this increase in firmness value to a decrease in turgidity of the fruit which results in a somewhat wilted "rubbery" specimen. Haller (19), however, states that this unexpected increase in registered fruit firmness after harvest may be due in part to some factor other than turgidity since he had observed such increases in firmness of fruits held at high humidities.

There is also an apparent difference in the firmness value of fruit of the same variety which are grown in different areas and in fruit produced in the same area over a period of years. Magness et al. (39) observed that apples grown in areas with long growing seasons are generally softer at harvest than those grown in districts of shorter growing seasons. They attributed this in part to greater maturity at time of harvest where long seasons occurred, but Haller (19) suggested that it might be due to the difference in temperature at the time of ripening. Degmen and Weinberger (12) failed to show differences in firmness and keeping quality of the apple due to application of nitrogen and potassium, but did show marked differences in firmness value of the same variety produced in different areas the same year and in the same area in different years. They showed with Stayman Winesap a difference of as much as three pounds in firmness between fruits grown in the same area in different years and as much as one and one-half pounds pressure between fruits of different areas the same year. Magness et al. (39) showed similar differences from year to year and area to area. Thus it can be seen that factors other than maturity may influence the firmness value of a given fruit of any variety.

There is much evidence (18, 25, 37, 39, 49) to indicate the lack of reliability of the pressure tester for use as a guide to picking maturity. Yet its use for establishing the firmness value of fruits in storage and post-storage has been shown to present a reliable index to storage maturity or to ripeness of fruit after harvest (19, 20, 26, 43).

Mealiness. After harvest as the apple softens and eventually approaches senescence its cells tend to become less firmly cemented together and to separate one from the other as the protopectin is hydrolyzed into soluble pectin (20, 21, 22). When the ease of separation has reached such a point that the separation may be ascertained organoleptically, the fruit is considered to be mealy. The degree of mealiness which is encountered in a given lot of fruits is used by the U. S. Bureau of Agricultural Economics as a guide in grading apple fruit. These regulations (59) state that ripe fruit are "mealy and soon to become soft for the variety" while overripe fruit is "dead ripe, very mealy, soft and past commercial utility." The development of mealiness is generally considered to indicate the approach of the end in the life of the apple fruit. Haller, Lutz, and Mallison (21) have attempted to determine the firmness value at which mealiness would develop in sixteen varieties of eastern grown apples. The results of this investigation showed that mealiness could not be expected to develop at a single given point with any lot of fruit of given variety. Rather the results of these workers showed that mealiness occurred anywhere within a range of firmness values which differed from three to six pounds with the different varieties. In the case of Stayman Winesap, mealiness was found to occur within a range of five pounds with the extremes at the seven and twelve pounds values. Earlier workers (38) had placed the point where mealiness occurred in this variety at eight pounds pressure.

Workers (20, 38) with different varieties have been uncertain in stating at what exact firmness value mealiness occurs, due, no doubt, to the differences in personal judgment and to the variability of the material. There have been no reports in which attempts have been made to distinguish between the various degrees of mealiness encountered.

Sugar Determinations. The principal sugars found in apples were first reported to be glucose, fructose, and sucrose (58). Later work from Illinois (34) has reported the sugars as levulose, dextrose, and sucrose. The quantity of these sugars present in fruits of a given variety has been shown to vary from year to year and orchard to orchard (4). These differences in sugar content within a variety have been partially explained (4, 34) on the basis of the difference in the leaf area supporting the growth of the various fruits.

In general the sugar content of apple fruits in storage, total and reducing, increases as the fruits approach maturity and then begins to decrease (4, 12, 27, 39, 49). The increase in sugar content has been explained by the hydrolysis of starch in the tissue (5, 12, 39). The changes in the sugar content of the fruit have been shown to be influenced in the same way as any other maturation processes by storage temperature (39) and modification of storage atmosphere (39, 40).

Smock (55) states that it is very difficult in every case to associate storage treatment with sugar content insofar as total amounts are concerned. Lutz and Culpepper (36) working with pears stated that there was no association between storage temperature and the sugar content of ripening pears. These workers further stated that although there is a great difference in quality of pears held at different temperatures, these differences were not reflected by sugar analysis. Magness et al. (39) found that comparable fruit in a comparable state of maturity contained practically the same amount of sugar, both total or reducing, regardless of the temperature at which it was held.

Soluble Pectin. Fremy, an early French worker is credited by Appleman and Conrad (2) as having first reported, 1840, an increase in what is now termed soluble pectin during the ripening process in fruits. This early worker suggested that this increase in soluble pectin was due to a transformation or digestion of an insoluble substance, now termed protopectin, associated with the cellulose of the cell wall. Although it was generally assumed after the report of Fremy that pectic changes connected with ripening were chiefly responsible for the softening of fruit, it was not until the work of Carré and Haynes (8) that methods were available by which a quantitative study of these changes could be made.

The first quantitative study of the pectic changes was conducted in England (7) in 1922. The results of this study showed that as apple fruits mature, the soluble pectin content increases until the apple breaks down at which time the soluble pectin content declines. Included in this early study was a comparison between the increases in soluble pectin in fruit held in cold and common storage. It was found that the lower temperature found in cold storage reduced the rate of development of the soluble pectin but that the total amount of pectin produced was the same regardless of storage temperature. Work by Fisher (15) confirms these findings.

Many workers (12, 15, 18, 39, 48, 49, 55) have shown a close relationship between the development of soluble pectin and the loss of firmness occurring with apple fruits while in storage. Haller (18) stated that softening in storage is apparently due to the conversion of insoluble pectic substances principally protopectin into a soluble form. He also showed that the rate of this conversion from the insoluble form to the soluble form at different temperatures was proportional to the rate of softening. Further work (55) suggested that with those fruits containing abundant amounts of pectic material, the change from pectose (protopectin) to soluble pectin presented a good criterion of the rate of softening of those fruits.

Since the degree of softening of fruits in storage is closely associated with the stage of storage maturity and hence quality, the quantity of soluble pectin has been used quite often as a rather accurate gauge of the value of a given storage treatment in maintaining fruit quality. This use of soluble pectin was used by Van Doren (60) to evaluate various gas mixtures for prolonging storage life of fruits in controlled atmosphere storage with McIntosh by comparing the rate of soluble pectin development in fruits stored in air and in various gas mixtures.

Wax Applications. Applications of wax to apple fruits were first made in an attempt to artificially replace the natural wax coating of the fruit which had been injured in the process of removing spray residues. Early studies with waxed fruit produced evidence of the possibility of prolonging the storage life of the fruit by use of wax applications and stimulated much interest in the waxing of apples. The effects of applications of various kinds of waxes to fruit have been demonstrated by a number of workers (10, 16, 29, 30, 31, 37, 39, 52, 53). Waxes are also used with various nursery and vegetable crops (31, 39, 49).

Early reports by Magness and Diehl (37) using oils and paraffines and by Smock (52) using a water soluble wax with a carnuaba-paraffine base, showed that the applications of these materials caused the development of undesirable flavors in apples resulting from anerobic respiration. Later studies (10, 16, 30, 39, 53) using other waxes at greater dilutions have shown that undesirable flavors or odors need not develop in fruit as a result of wax applications.

Wax applications have been shown by Magness and Diehl (37), Smock (52, 53), Fisher and Britton (16), and Hitz and Haut (30) to retard the ripening processes. The reduction of post-storage breakdown due to waxing has also been reported by Hitz and Haut (30). Magness and Diehl (37) report that by coating apples with oils or paraffines to reduce the permeability of the epidermis that respiration, rate of softening, ground color changes, and other changes indicative of the ripening process could be retarded. Smock (53) and Fisher and Britton (16) have also reported a reduction in the respiration rate due to wax application. Further indications of the retardation of the ripening process by waxing were presented by Fisher and Britton (16) when they reported a delay in the development of mealiness in waxed Delicious, of coreflush in waxed McIntosh and Jonathan spot in waxed

Jonathan, all of which generally occur with overripeness in these varieties. Other workers (16, 52, 53) report that waxing delays the development of ground color, another indication of fruit maturity.

Waxing of fruits will reduce the amount of wilting and shrivelling in storage and cause a reduction in the weight loss. The value of waxing in reducing shrivelling in storage, attributed to a reduction in water loss, has been shown by Jones and Richey (31), Hitz and Haut (30), Smock (52), Miller et. al (40), Hemphill and Murneek (29), and Pieniazek and Christopher (47). The retardation in water loss resulting from waxing has also been found to be accompanied by a corresponding preservation of the quality of the fruit (10). Claypool (10) suggested that the principal benefit of waxing fruit results from the reduction in water loss by those fruits thereby maintaining them in good condition and edible quality longer than would be normally expected. He found that the thinner the cuticle of the fruit the more effective the wax application would be. He noted that the keeping quality or appearance of apples, as well as pears, peaches, nectarines, and cherries are greatly improved by wax applications. Wax applications are now in commercial use with various fruit, vegetable, and ornamental crops.

MATERIALS AND METHODS

The investigations were conducted at the University of Maryland, College Park, Maryland; the storage phases of the post-storage studies being accomplished during the storage seasons of 1946-47 and 1947-48, with the laboratory analysis continued in the 1948-49 season. The fruits used in the study were of the Stayman Winesap variety, one of the leading apple varieties in the Cumberland-Shenandoah area and the fifth most important in the national production. The fruits were all harvested from the same commercial planting located in the apple producing area near Westminster, Maryland.

On the day of harvest, the fruit was returned to College Park in standard bushel baskets and placed immediately in storage at 32°F. As soon as practicable within 72 hours after harvest, the fruit was carefully handgraded and the fruits which were of uniform size, good color, and free from bruises, stem puncture and other blemishes, were selected. These fruits were then separated into two comparable lots. One lot was designated as unwaxed fruit, the other lot as waxed fruit which was treated by hand with Brytene 489A, a commercial waxing preparation designed for use with fruits and vegetables. As soon as the waxed fruit had dried, the fruits of both lots were packed in standard bushel baskets with shredded oil paper added to aid in the control of storage scald. Both lots of fruit were then stored in the same cold storage room which was maintained at a temperature of

30° - 31°F. with a relative humidity of 85-90 per cent. The average pressure reading for the fruits used for these studies at the time of storage for the 1946-47 season was 13.96 pounds and for the 1947-48 season, 14.50 pounds.

Following storage periods of two and one-half, three and one-half, and four and one-half months in 1946-47 and one and one-half and two and one-half months in 1947-48, random bushel samples of both waxed and unwaxed fruits were removed from the storage and placed in post-storage units held at 45°, 50°, 55°, and 65°F. The use of these temperature levels was indicated by the findings of Haut (26) in a work of a similar nature done with the variety Delicious. In addition it was felt that this range of temperatures would approximate the conditions which the fruits might encounter under distribution and retail marketing conditions.

These post-storage units, used to simulate distribution and retail marketing conditions, were well insulated cabinets located in a cold storage room, maintained at 32°F. with a relative humidity of 80-90 per cent. The temperature in these cabinets was maintained by individual thermostatically controlled heating units with circulating fans. The thermostats which controlled the post-storage units were capable of maintaining the temperature within plus or minus 0.5°F. The humidity of the units was kept as high as possible by means of exposed wicks continually saturated with water.

Each of the four units used in this study measured 38 by 30 by 25 inches on the interior surfaces and was separated horizontally into two equal size sections by a shelf made of strips of wood with a 1-inch space between the strips so that the circulation of the air would not be impeded. A similar shelf was located at the base of each unit so that objects placed in the storage chamber would not interfere with the air circulation within the unit. The upper section of each unit contained four respiration chambers which were connected to absorption towers located in an adjacent room, in a manner which will be described later. The lower section, or storage chamber, was large enough to hold two standard orchard boxes, one for waxed and one for unwaxed bulk fruit and two trays of fruit for the weight-loss study.

Commencing 24 hours after the fruits were placed under the differential post-storage conditions just described, samples of the fruit were withdrawn at three-day intervals and tested to determine the quality changes and physiological responses of the fruit to the different post-storage temperatures. Testing at regular three-day intervals continued until a total of six evaluations were made during the 1946-47 season and five evaluations during the 1947-48 season. Each sample consisted of twenty waxed fruits and twenty unwaxed fruits during the 1946-47 season and eighteen waxed and eighteen unwaxed fruits during the 1947-48 season, unless otherwise noted. These samples were then allowed to reach room temperature and used to determine the firmness and mealiness values, the reducing and non-reducing sugar levels, and the soluble pectin content.

Weight loss and respirational activity were determined on additional samples stored expressly for these readings in the same post-storage units. The results of the various studies for each post-storage period were compared by an analysis of variance (57). Correlation coefficients were determined between the different quality and physiological changes studied. The procedures used in determining the above-mentioned values were as follows:

Weight Loss. At the start of the storage period in 1946, 12 lots of 18 waxed fruit and 12 lots of 18 unwaxed fruit were selected at random for the sample to be used in the study. Each fruit was tagged, given a number, weighed, and placed in a storage flat designed for this purpose. These flats were stored with the rest of the fruit and at the beginning of each post-storage study, four flats of each treatment were removed from the storage room at random and placed one at each temperature, following the weighing and recording of the weight of each individual fruit. The fruit was then left undisturbed until the end of the post-storage period when it was weighed for the last time. The loss of weight was expressed as the per cent of weight loss during the post-storage period. The weight loss data was then compared by an analysis of variance after being transposed according to the tables prepared by C. I. Bliss as given by Snedecor (57).

The procedure followed in 1947-48 was modified from that of the previous season in that the fruits used in the study were selected just prior to the start of each post-storage period. Except for this modification, the study was carried out in a manner identical to that of the previous season.

Respiration Activity. For the determination of respirational activities during post-storage, duplicate waxed and unwaxed samples of five fruits, approximately 900 grams, were selected at random for each of the four temperatures. These samples were stored in separate respiration chambers located in the upper section of the post-storage unit. A diagramatic drawing of one of these respiration chambers with the line connections to the absorption tower is shown in Figure 1.

Each of the sixteen respiration chambers was connected to its corresponding absorption tower in a manner similar to the apparatus first described by Gore (17) and later used with some modifications by Kimbrough (32), Appleman and Brown (3), and Scott and Tewfik (51).

Each of the absorption towers was 24-inches high, one inch in diameter and filled for two-thirds of its height with 3/16-inch glass beads to increase the absorption surface. To aid in the adjustment of the flow of air, a manometer working as a flowmeter was placed in each line after the absorption tower. As nearly as possible the flow of air was maintained through all the lines at 80-100 ml. per minute so that the atmosphere of the respiration chambers was completely changed hourly. It was found that this speed was fast enough to prevent any accumulation of carbon dioxide in the

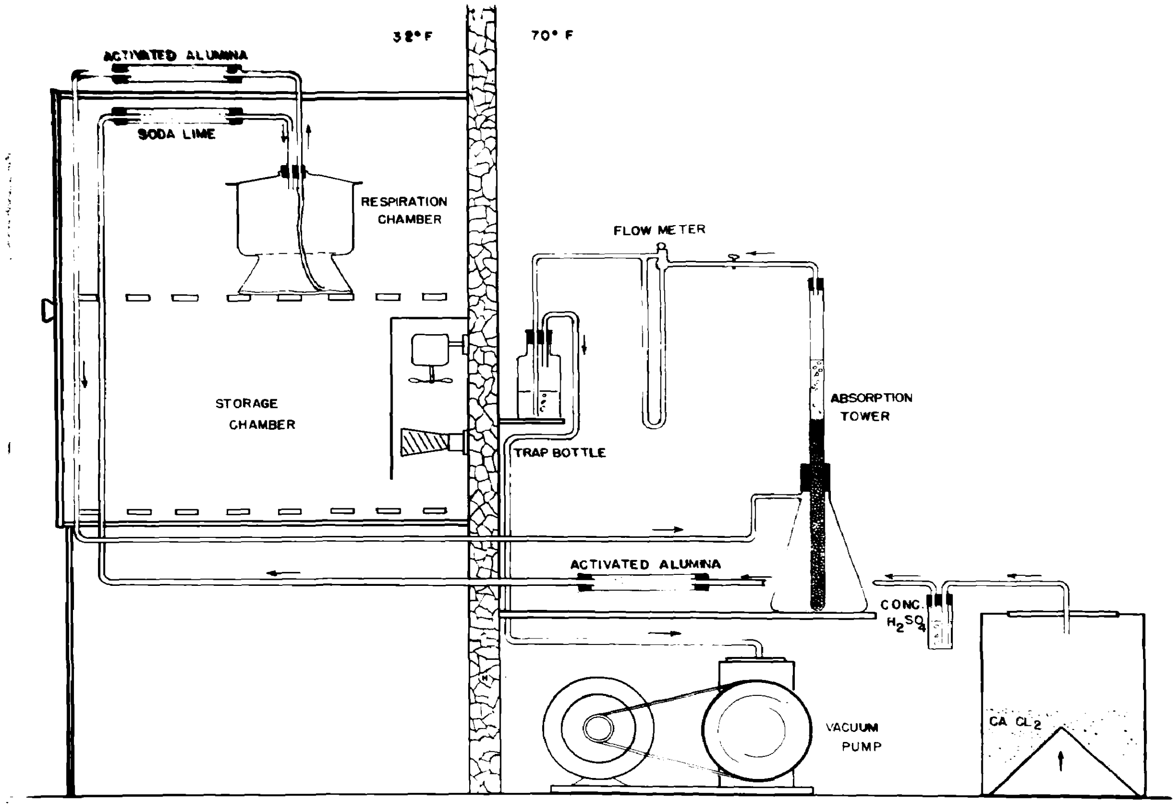


Figure 1. Diagramatic view of post-storage unit used in maintaining the fruit at the desired post-storage temperature. Note location and line connections of the respiration chamber.

respiration chambers and slow enough to insure its complete absorption in the towers. To eliminate the factor of humidity as affecting respiration, water was placed in each of the respiration chambers resulting in an almost saturated atmosphere.

The determination of respirational activity was accomplished concurrently with the other values. The method of determination of this value was by the double titration method outlined by Kimbrough (32). Results were calculated and expressed as the milligrams of carbon dioxide produced per kilogram of tissue for each three-day respiration period.

Firmness Evaluation. Throughout the study firmness evaluations were obtained by use of a King pistol-type pressure tester (1) with a standard 7/16-inch plunger. Three pressure test readings were taken for each of the eighteen or twenty fruit in any given sample. These readings were made on three approximately equal spaced areas on the apple cheek after the skin had been removed. All of the individual readings obtained from a given fruit sample were grouped and the mean of the fifty-four or sixty readings selected as the firmness value for that sample. In all cases the firmness value for the fruit was determined before any tissue was removed from the fruit for the determination of the other physiological or quality changes.

Mealiness Value. A segment was removed from each apple of a given sample and used to evaluate organoleptically the mealiness of that fruit after the pressure reading had been made. Each apple was rated only as mealy or not mealy and no attempt was made to differentiate between the various degrees of mealiness encountered in the different fruits. The value for mealiness for each post-storage sampling was expressed as the percentage of mealy apples for that sample.

Sugar Determinations. Another segment of unpeeled flesh was removed from each apple in a given sample for use in determining the reducing and non-reducing sugar values. A composite sample of 100 grams of tissue was made up from each group of fruit removed from the post-storage units at each sampling date. This 100 grams of tissue was blended in a Waring Blendor with 100 ml. of water for five minutes. After blending, 150 ml. of 80 per cent ethyl alcohol was added to duplicate 20 gram aliquots of the blend and the mixture boiled for one hour under a reflux condenser. Following the refluxing the material was filtered and the residue was washed with hot 80 per cent ethyl alcohol. The filtrate was then placed in No. 1 plain cans, sealed by a commercial closing machine and stored for analysis at a later date. The actual analysis of the sample was accomplished after the adaptation of Heinze and Murneek (28) of the Shaffer-Somogyi method.

Soluble Pectin. Soluble pectin values were obtained in the same manner during both storage seasons concurrently with the other determinations at regular three day intervals on both the waxed and the unwaxed fruits. For this determination a segment of unpeeled flesh was removed from each apple in a given sample. For each lot of fruit removed from each post-storage unit duplicate 50 gram composite samples were used. The determinations were made according to the methods described by Carré and Haynes (8) and Appleman and Conrad (2) with modifications as to the method of extraction. Extraction was accomplished by blending the sample with 50 ml. of cold water in a Waring Blendor for one minute. The blend was then removed from the blendor-cup and filtered through ordinary cheesecloth. After the filtering was complete the pulp was returned to the blendor-cup with an additional 50 ml. of cold water, blended and filtered as before. In all, each sample was blended and filtered three times to insure the complete extraction of the soluble pectin. The filtrate was then placed in a 250 ml. volumetic flask and the above-mentioned procedures followed. All results are expressed on a fresh weight basis as per cent calcium pectate since it was precipitated and weighed as that salt.

RESULTS

The results of these investigations will be presented by the quality and physiological factors studied rather than by individual post-storage periods since the reaction of the fruits to both temperature and treatment was quite similar during each of these periods.

Weight Loss. The results of these studies presented in Table 1 and Figure 2 show that during each post-storage period the fruits at the higher temperatures lost significantly more weight than did those fruits at the lower temperature when fruit stored at 45°, 55°, and 65°F. are compared. These results also show that there was no significant difference in the amount of weight lost between fruits held at post-storage temperatures of 45° and 50°F. When both seasons' results were averaged, it was found that fruits held at a post-storage temperature of 65°F. lost approximately three times as much weight as did comparable fruits held at 45°F. over a 17.5 day period, while those held at 55°F. lost two times as much and at 50°F. one and one-fourth times as much weight as did fruit held at 45°F. Thus the amount of weight loss of fruits stored at higher temperatures was not found to be proportional to the amount of temperature increase. The relationship of weight loss to temperature for each post-storage period is expressed graphically in Figure 2.

The effect of the waxing treatment as measured by the rate of weight loss at the various post-storage temperatures for all post-storage periods is shown in Figure 2. It will

Table 1. The Per Cent Weight Loss of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Post-Storage Temperatures During the 1946-47 and 1947-48 Storage Seasons.

Temperature	Treatment	1946-47 Season*				1947-48 Season**		
		Jan. '47	Feb. '47	Mar. '47	Mean	Dec. '47	Jan. '48	Mean
45°F.	Waxed	0.44	1.08	1.85	1.27	0.38	1.26	1.03
	Unwaxed	0.84	1.49	1.95		1.08	1.41	
50°F.	Waxed	1.00	1.82	1.70	1.57	0.64	1.08	1.07
	Unwaxed	1.36	1.97	1.58		0.98	1.59	
55°F.	Waxed	1.72	2.02	2.62	2.44	2.12	1.93	2.09
	Unwaxed	2.31	2.73	2.96		2.27	2.06	
65°F.	Waxed	3.24	3.44	3.50	3.69	3.63	2.59	3.27
	Unwaxed	3.75	4.55	3.68		3.91	2.98	
LSD 5% level					0.42			0.26

*Mean weight loss of all waxed treatments of the 1946-47 season, 2.04% and of unwaxed treatments, 2.42%. LSD at 5% level 0.29%.

**Mean weight loss of all waxed treatments of the 1947-48 season, 1.73% and of unwaxed treatments, 2.04%. LSD at 5% level 0.48%.

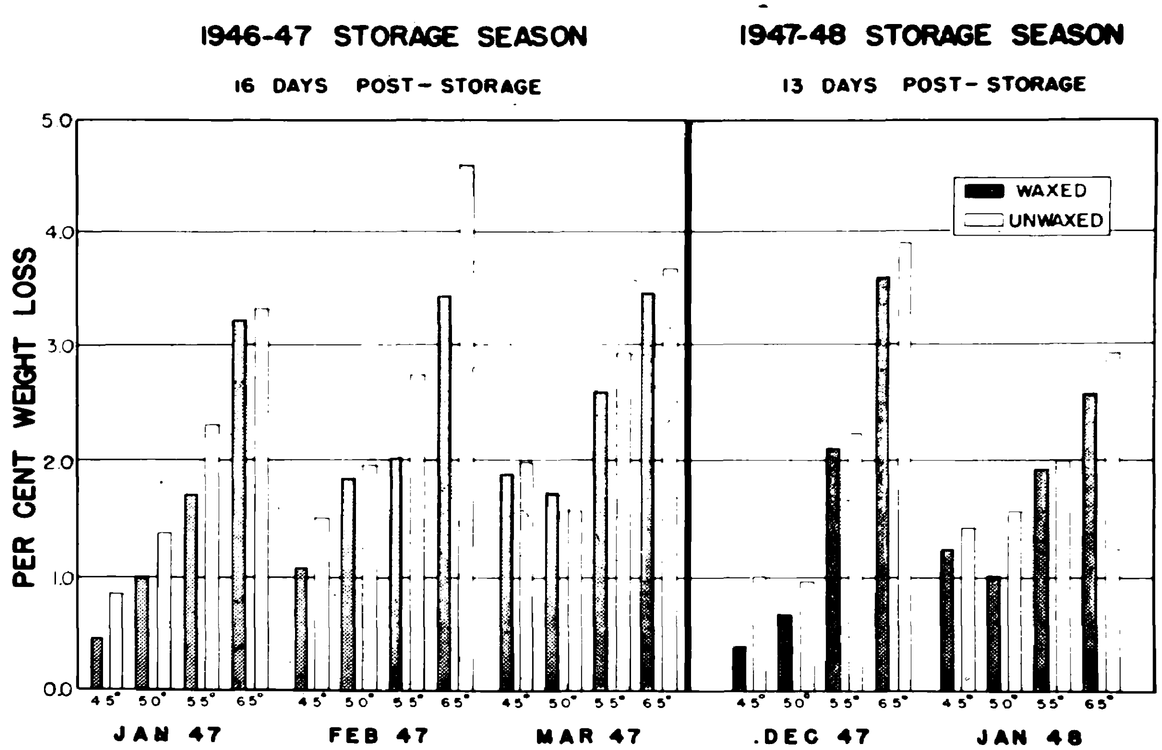


Figure 2. Per cent weight loss of waxed and unwaxed Stayman Winesap apples stored at different post-storage temperatures during the 1946-47 and 1947-48 storage seasons.

be noted that the wax application resulted in some decrease in the amount of weight lost by the fruit at all temperatures during all post-storage periods with the exception of the 50°F. temperature during the March 1947 period. The reduction in the amount of weight loss due to the wax application during the 1946-47 storage season was shown, Table 1, to be statistically significant. However, in the second season, although there was a difference in the actual amount of weight loss due to the waxing treatment, it was not sufficient to prove statistically significant. It is felt that this difference in the value of the waxing treatment was due to the delay in beginning the comparative post-storage studies in the 1946-47 season and to the better natural finish of the fruit in the second season. The value of the wax application in reducing weight loss in post-storage was shown by statistical analysis to be the same at all temperatures studied. When all post-storage temperatures and periods were considered, it was found that the average weight loss of the waxed fruit was sixteen per cent less than that of the unwaxed fruit.

Respiration. The results of the respiration studies with fruits subjected to the various post-storage temperatures are presented in Appendix Tables 3 and 4 and Tables 2 and 3.

The average accumulative production of carbon dioxide per kilogram of tissue for the sixteen days in the 1946-47 season's studies is depicted in Figure 3 and for the thirteen days in the 1947-48 season in Figure 4. The close similarity of the respirational activities of the two seasons should be

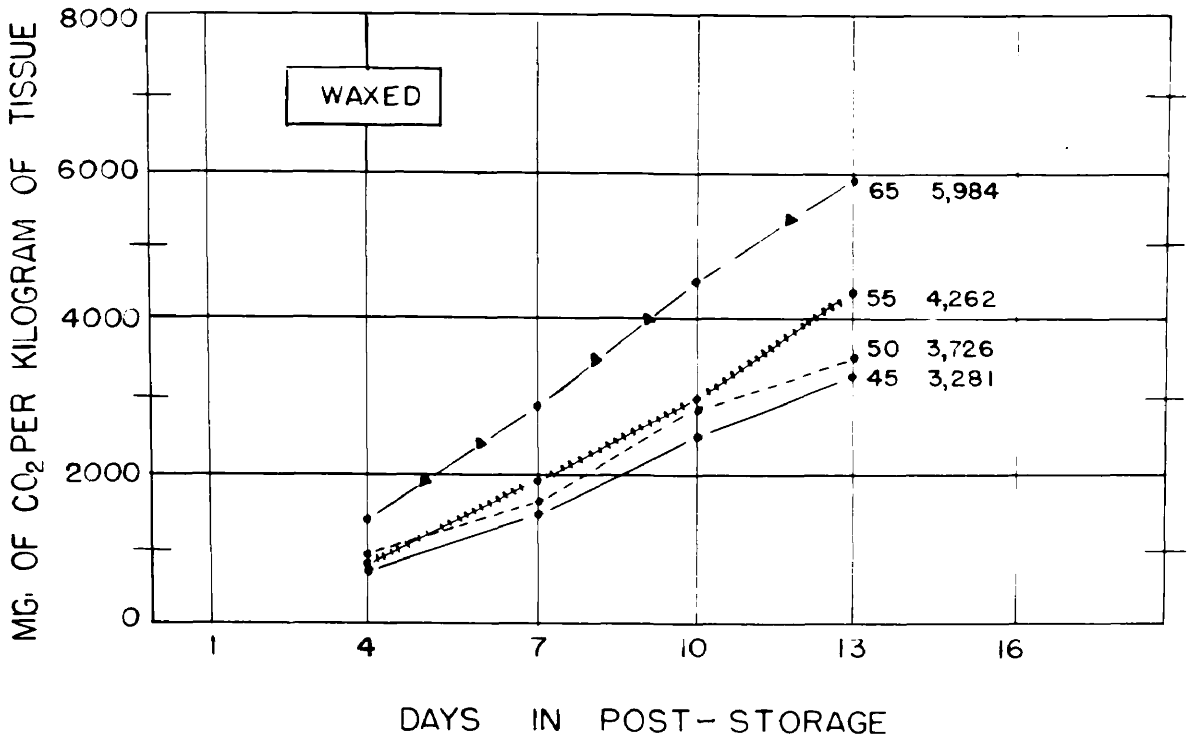
Table 2. Average Respiration Rates (Expressed as Mg. of CO_2/Kilo/Hr.) of Stayman Winesap Apples Stored at Different Post-Storage Temperatures During the 1946-47 and 1947-48 Storage Seasons.*

Temperature	Post-Storage Periods					
	Jan. '47	Feb. '47	Mar. '47	Dec. '47	Jan. '48	Mean
45°F.	10.64	8.94	14.19	11.22	12.14	11.77
50°F.	12.48	10.90	14.33	12.62	13.17	12.74
55°F.	14.70	12.46	19.42	15.61	15.12	15.44
65°F.	20.21	18.09	26.31	21.39	20.26	21.25
LSD 5% level	2.69	1.67	2.07	2.73	1.30	

*Mean value of both waxed and unwaxed fruit.

Table 3. Average Respiration Rates (Expressed as Mg. of CO_2/Kilo/Hr.) of Waxed and Unwaxed Stayman Winesap Apples while in Post-Storage During the 1946-47 and 1947-48 Storage Seasons.

Treatment	Post-Storage Periods					
	Jan. '47	Feb. '47	Mar. '47	Dec. '47	Jan. '48	Mean
Unwaxed	14.43	13.42	19.05	15.45	15.75	15.62
Waxed	14.58	11.78	18.07	14.92	14.87	14.82
LSD 5% level	1.90	1.16	1.46	1.93	0.44	



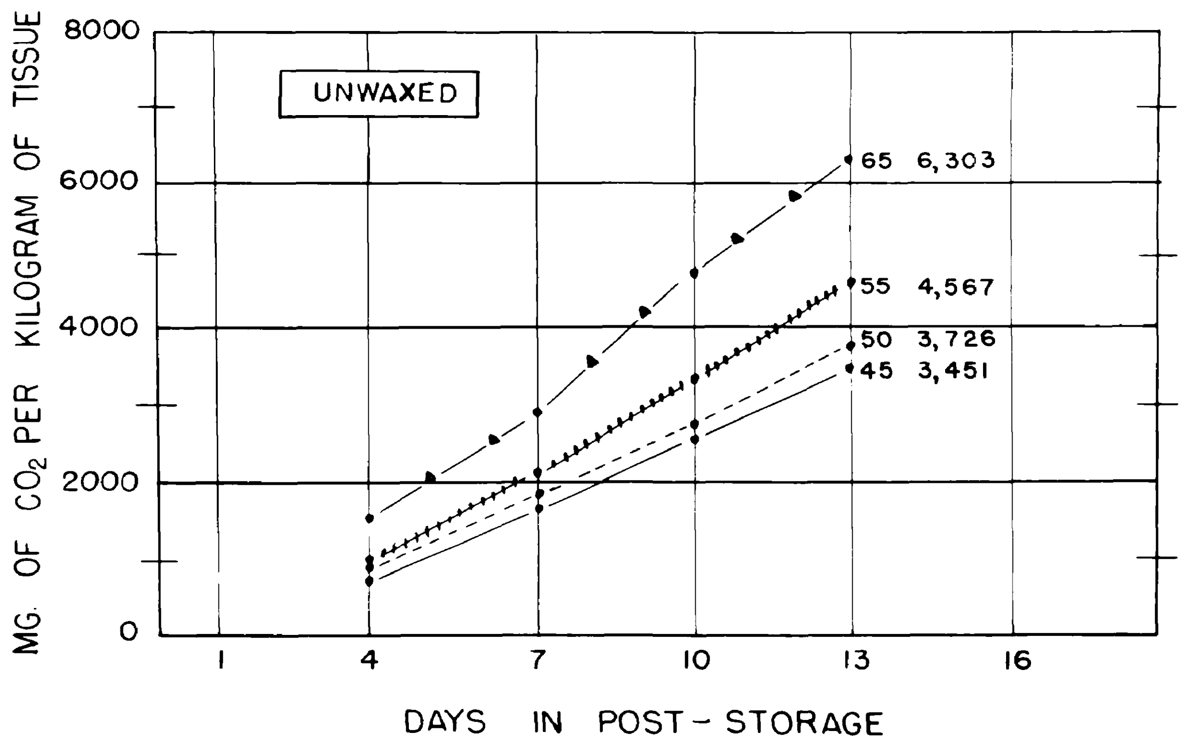


Figure 3. Average accumulative production of carbon dioxide in milligram per kilogram of tissue of waxed and unwaxed Stayman Winesap apples while in post-storage at different temperatures during the 1946-47 storage season.

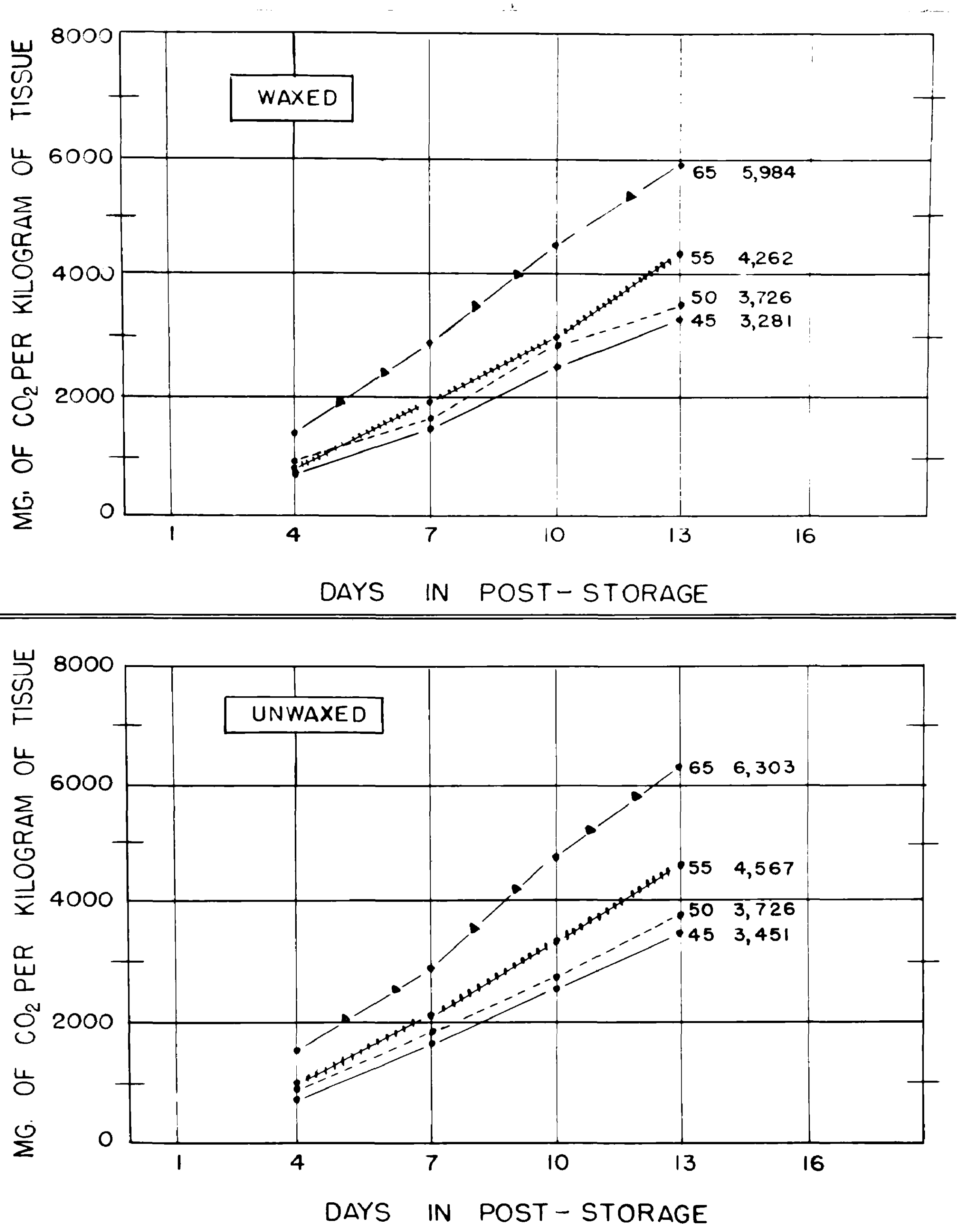


Figure 4. Average accumulative production of carbon dioxide in milligram per kilogram of tissue of waxed and unwaxed Stayman Winesap apples while in post-storage at different temperatures during the 1947-48 storage season.

noted from these figures. The data presented show that a major break in the respirational activities occurred between 55° and 65°F.

The difference in respiration rates of the fruit at the different temperatures for the five post-storage periods are presented in Table 2. These results show that there was a marked decrease in the average amount of carbon dioxide produced per kilogram of tissue per hour at the lower temperatures when fruit stored at 45°, 55°, and 65°F. were compared during each period. No significant difference was found to exist between the respirational activities of fruit held at post-storage temperatures of 45° and 50°F. except during the February 1947 period. The mean respirational rates for all temperatures studied, Table 2, show that the 10°F. increase in temperature from 45° to 55°F. increased the respiration rate thirty-one per cent and that the increase between 55° and 65°F. increased the rate thirty-seven per cent, an indication that the rate of respiration in post-storage is a function of temperature.

When all post-storage results were averaged, the fruits which had been waxed were found to have respired at a rate approximately five per cent slower than that of the unwaxed fruit. The waxed fruit did not, however, respire at a significantly slower rate than did the unwaxed fruit during all the post-storage studies, Table 3. Waxing significantly reduced the respiratory activity of the fruit during only two of the five post-storage studies, those of February 1947 and

January 1948. The effect of the waxing treatment was shown statistically to be the same at all of the temperatures studied. Although the waxing treatment was not indicated to be significantly of greater value at one temperature than another, within the range studied, there is a suggestion from the accumulative curves that the waxing treatment tended to be of more value at the lower temperatures. When the difference in the cumulative carbon dioxide output between the unwaxed fruit is compared with the difference in output of the waxed fruit at the same temperatures, Figures 3 and 4, there is a marked difference in favor of the waxed fruit at the lower temperatures while this difference is not so marked when the higher temperatures are compared in like manner.

Firmness Evaluation. The changes in fruit firmness which occurred at the different post-storage temperatures during the five post-storage periods are graphically presented in Figures 5-9 and are in complete form in Appendix Tables 1 and 2. These results show that in every instance, except for the waxed fruit of the December 1947 period, the major break in the retention of fruit firmness occurred between 50° and 55°F. The slight irregularities in the decline of fruit firmness during the early part of the post-storage periods is attributed to the slight variation in the material sampled. The apparent increase in firmness during the March 1947 period is attributed to the "rubbery" condition which had developed with shriveling in some of the fruits at their last samplings which caused the pressure readings to fluctuate

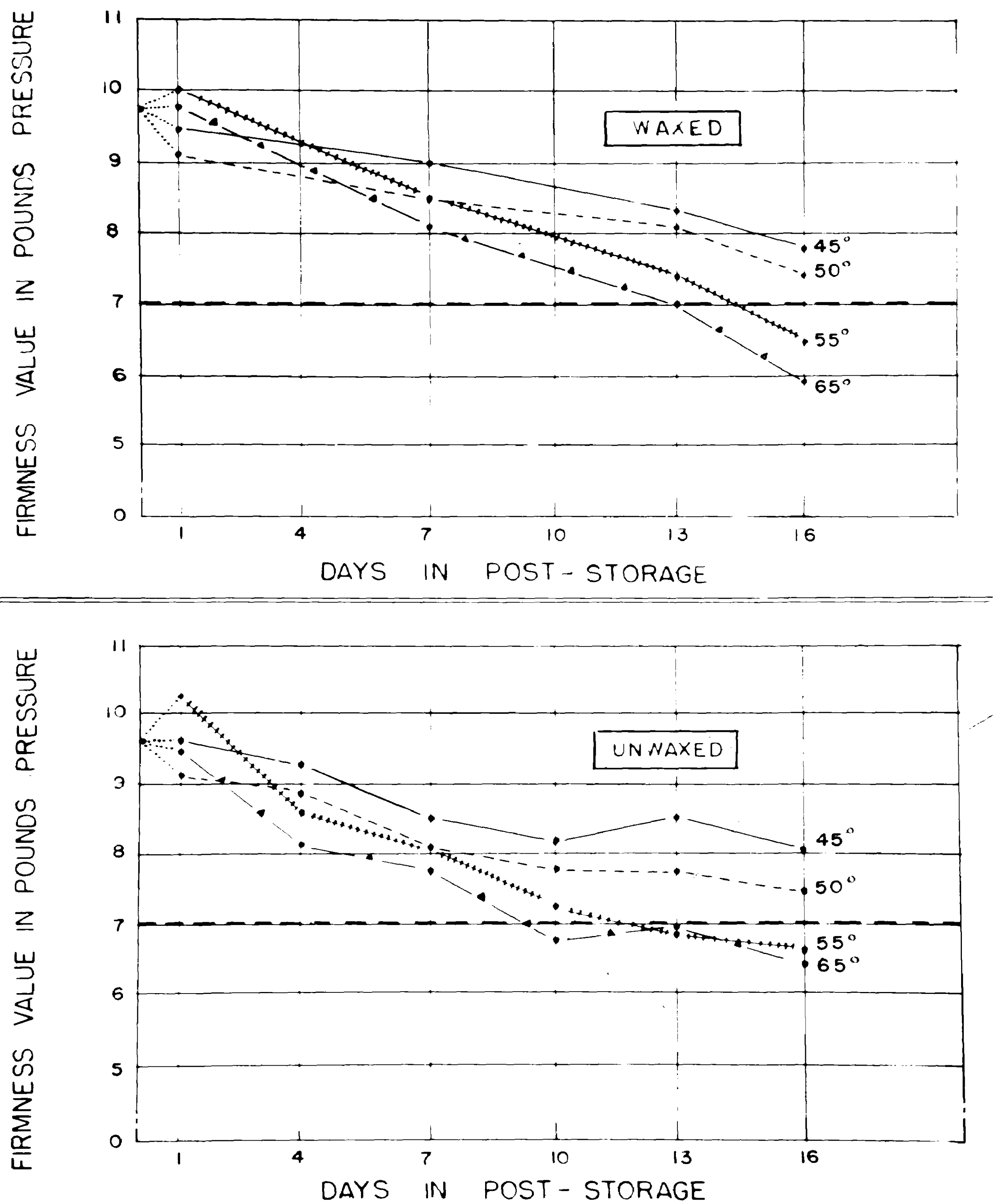


Figure 5. Firmness decline of waxed and unwaxed Stayman Winesap apples while in post-storage at different temperatures during the January 1947 period. Those values falling below the seven pound level indicate mealy fruits.

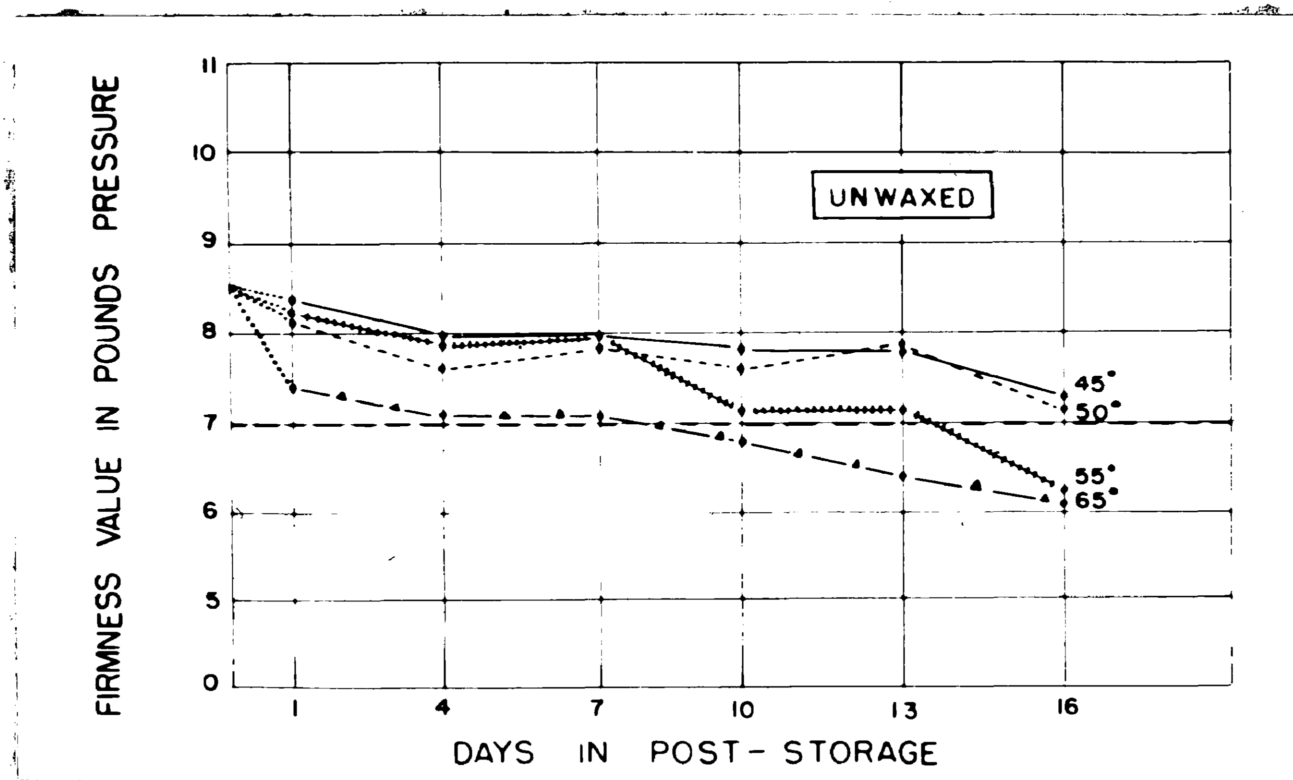
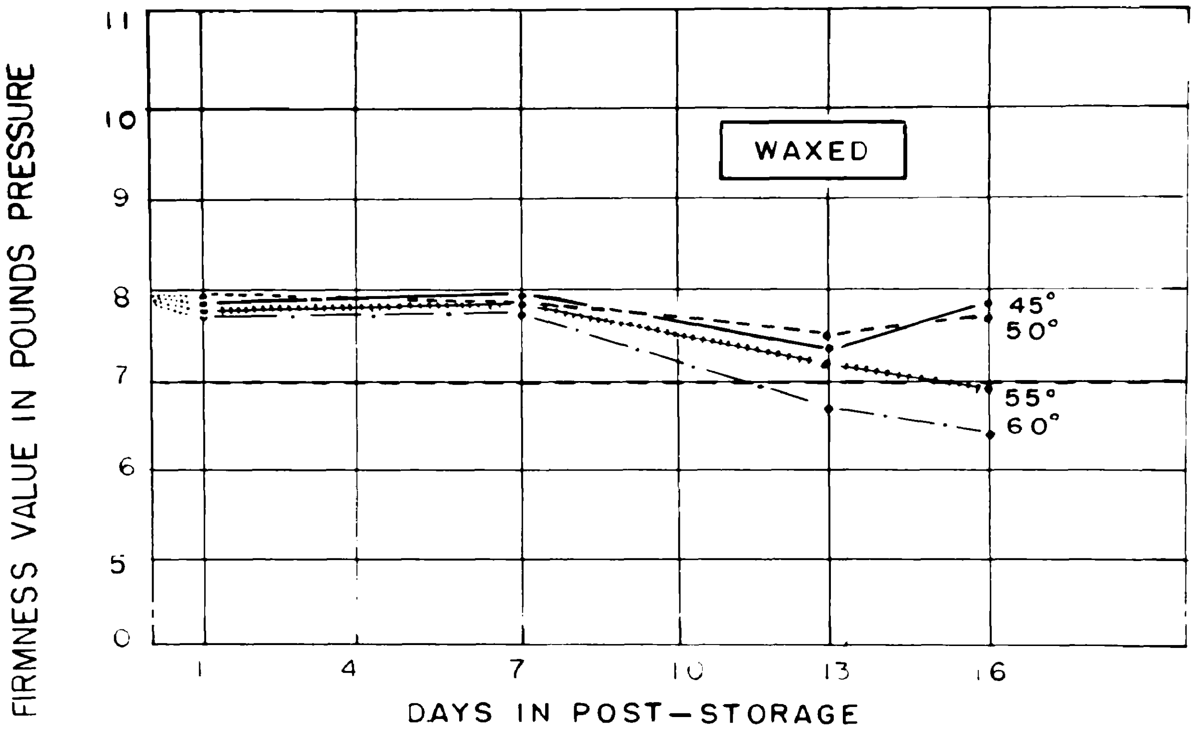


Figure 6. Firmness decline of unwaxed Stayman Winesap apples while in post-storage at different temperatures during the February 1947 period. Those values falling below the seven pound level indicate mealy fruits.



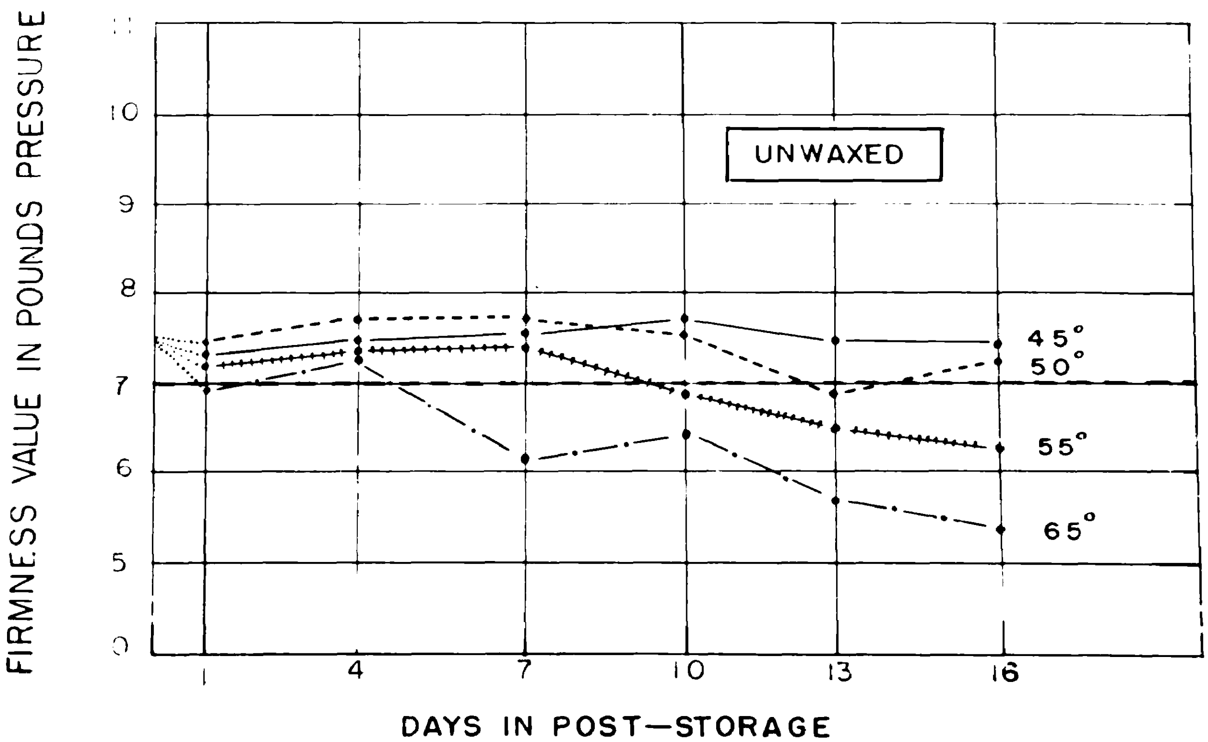


Figure 7. Firmness decline of waxed and unwaxed Stayman Winesap apples while in post-storage at different temperatures during the March 1947 period. Those values falling below the seven pound level indicate mealy fruits.

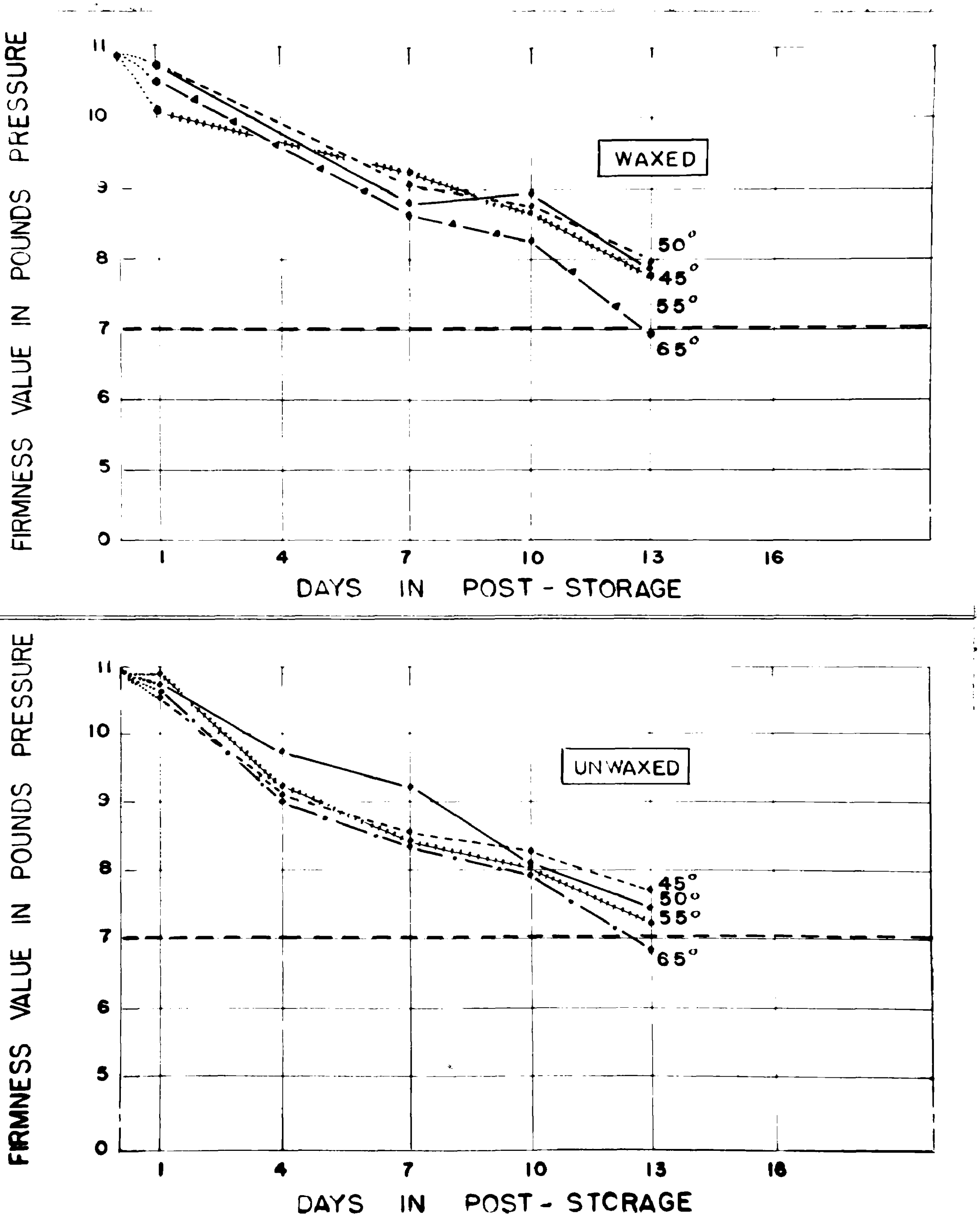
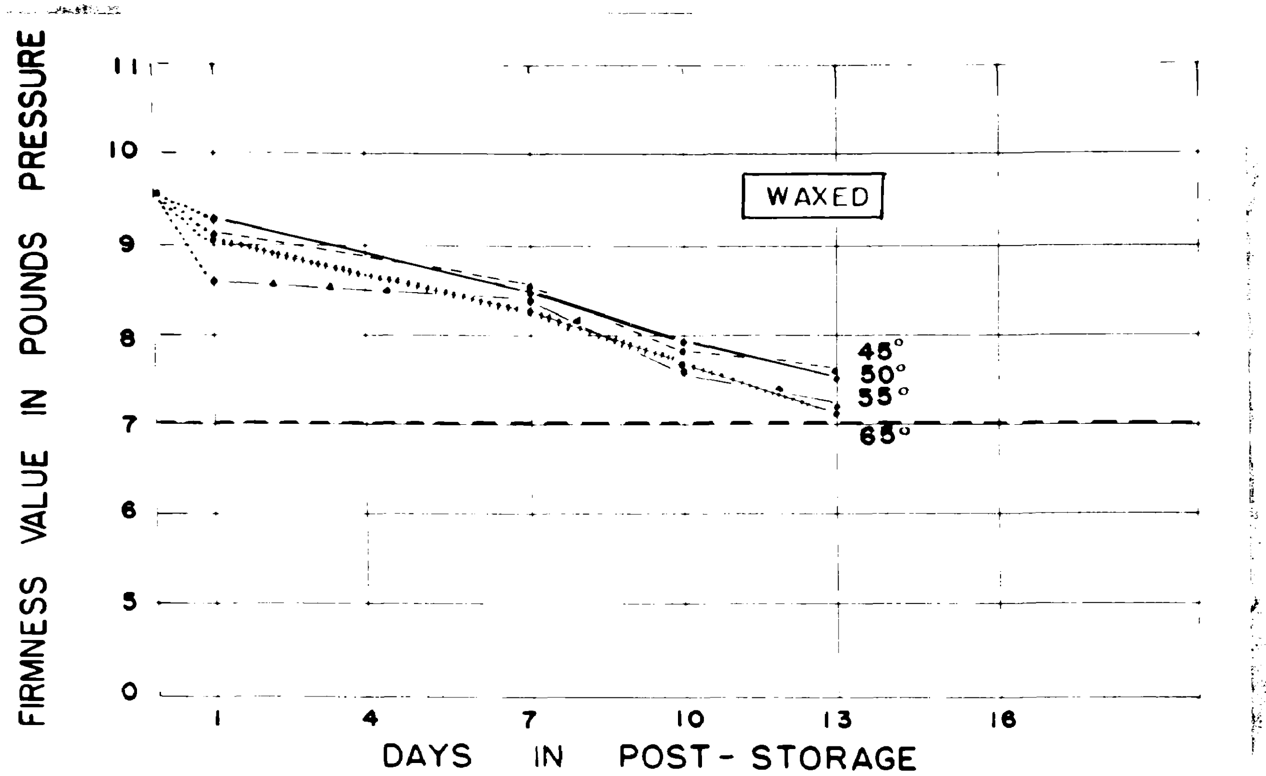


Figure 8. Firmness decline of waxed and unwaxed Stayman Winesap apples while in post-storage at different temperatures during the December 1947 period. Those values falling below the seven pound level indicate mealy fruits.



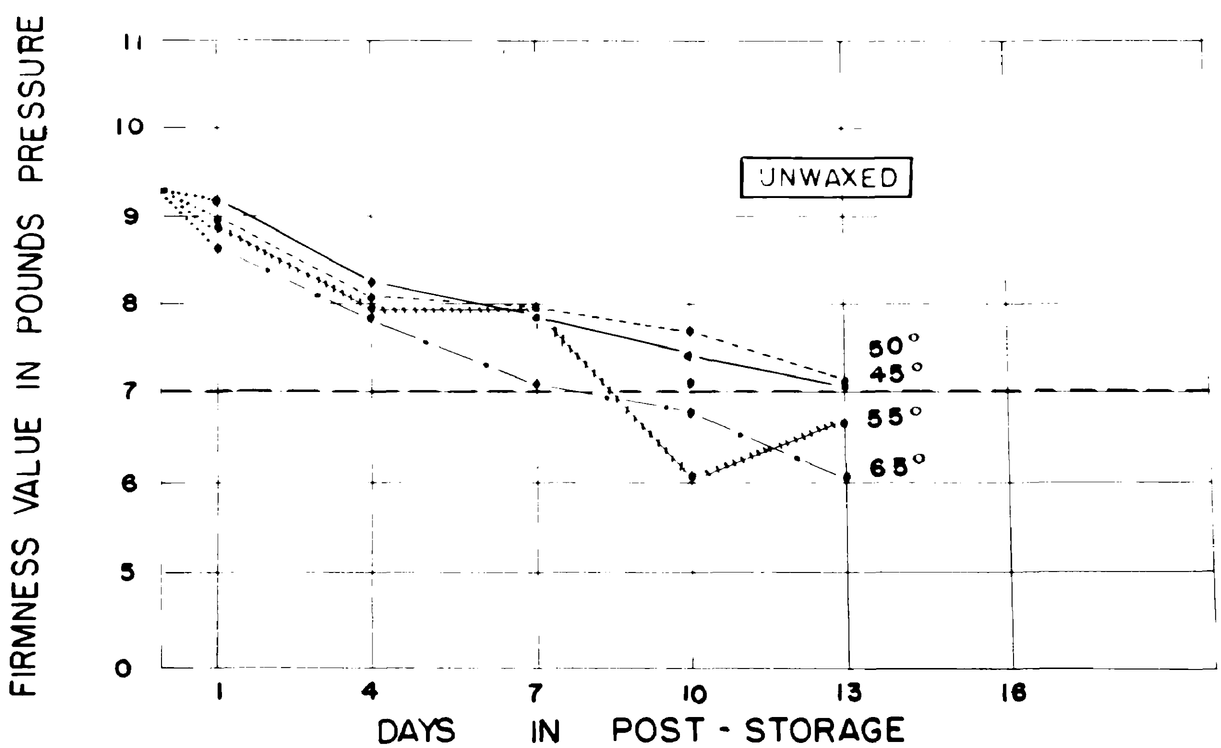


Figure 9. Firmness decline of waxed and unwaxed Stayman Winesap apples while in post-storage at different temperatures during the January 1948 period. Those values falling below the seven pound level indicate mealy fruits.

somewhat.

These findings also show that for the 1946-47 season, the average unwaxed fruit stored at 65°F. reached the same quality condition, as measured by firmness value, 12.5 days earlier than did similar fruit stored at 45°F. When waxed fruits are compared in the same manner during the 1946-47 season, those stored at 65°F. reached an equivalent firmness value 8.5 days sooner. Less marked but similar differences were found to exist between the fruit stored at 50° and 55°F. that season. The second season's results, Figures 8 and 9, confirmed these findings on effect of temperature as it affects post-storage firmness.

The average daily rate of firmness decline for both waxed and unwaxed fruits during post-storage was markedly greater during the earlier phases in the storage life of the fruit than in the later phases, Table 4. The average daily rate of firmness decline for each of the temperatures studied was in the same relative order, however, during each of the post-storage periods. When the average rate of firmness decline for both waxed and unwaxed fruit for both seasons were compared, the major break in firmness retention was again exhibited between 50° and 55°F. There was no difference in the daily rate of firmness decline between 45° and 50°F. when mean rates of decline were compared.

The mean firmness values of both waxed and unwaxed fruits for the various temperatures and post-storage periods are presented in Table 5. These values are presented in this

Table 4. Average Daily Decline in Firmness, Pounds Pressure, of Waxed and Unwaxed Stayman Winesap Apples While in Post-Storage for Sixteen Days During the 1946-47 Season and Thirteen Days During the 1947-48 Season.

Temperature	Treatment	Post-Storage Period					
		Jan. '47	Feb.* '47	Mar. '47	Dec. '47	Jan. '48	Mean
45°F.	Waxed	0.10	....	0.02	0.24	0.15	0.14
	Unwaxed	0.12	0.08	0.02	0.27	0.17	0.15
50°F.	Waxed	0.14	....	0.02	0.24	0.15	0.14
	Unwaxed	0.15	0.09	0.02	0.25	0.17	0.15
55°F.	Waxed	0.19	....	0.06	0.25	0.18	0.17
	Unwaxed	0.20	0.14	0.08	0.29	0.20	0.19
65°F.	Waxed	0.20	....	0.11	0.31	0.18	0.20
	Unwaxed	0.24	0.15	0.14	0.32	0.25	0.24

*Data for waxed fruit of the February 1947 period excluded.

Table 5. Average Firmness Value, Pounds Pressure, of Stayman Winesap Apples Stored at Different Post-Storage Temperatures During the 1946-47 and 1947-48 Storage Seasons.*

Temperature	1946-47 Season			1947-48 Season	
	Jan. '47	Feb.** '47	Mar. '47	Dec. '47	Jan. '48
45°F.	8.68	7.86	7.56	8.94	8.06
50°F.	8.22	7.70	7.48	8.88	8.07
55°F.	8.06	7.41	7.09	8.72	7.69
65°F.	7.68	6.81	6.63	8.47	7.52
LSD 5% level	0.51	0.28	0.34	0.29	0.32

*Mean value of both waxed and unwaxed fruit.

**No waxed fruit included for firmness evaluation.

Table 6. Average Firmness Value, Pounds Pressure, of Waxed and Unwaxed Stayman Winesap Apples While in Post-Storage During the 1946-47 and 1947-48 Storage Seasons.

Treatment	1946-47 Season		1947-48 Season	
	Jan. '47	Mar. '47	Dec. '47	Jan. '48
Waxed	8.20	7.49	8.88	8.12
Unwaxed	8.12	6.89	8.64	7.55
LSD 5% level	0.36	0.24	0.21	0.22

No waxed fruit included for firmness evaluation in the February 1947 study.

manner since statistical procedures showed that there was no interaction effect of temperature and treatment. It will be noted that in no instance was there a significant difference in the retention of firmness between fruits held at 45° and 50°F. In every case the fruits subjected to 45° or 50°F. during post-storage maintained firmness values higher than did fruits held at a post-storage temperature of 65°F. The difference in firmness retention between fruits held at 45° and 55°F. was also significant with the exception of those fruits in the December 1947 period. The initial period of each season showed that there was no difference in the retention of firmness between the fruits in post-storage at 55° and 65°F., however, a significant difference between fruit held at these temperatures occurred during the later periods each season. The average firmness value for fruit stored at 65°F. for nineteen days during the 1946-47 season was twelve per cent less than that of fruit stored at 45°F. while fruits stored at 50° and 55°F. were respectively three and six per cent less firm as those stored at 45°F.

The value of the waxing treatment in the retention of fruit firmness during post-storage is shown in Table 6. In all cases, except that of January 1947, the waxing treatment increased significantly the firmness value of the fruits in post-storage. The value of the wax application is also shown by comparison of the means in Table 4. Further statistical analysis showed that this value of the waxing treatment in the maintenance of fruit firmness was the same for all the temperatures under test. The value of the waxing treatment at the various temperatures during the post-storage periods is also shown in Figure 10.

Mealiness. Organoleptic determinations indicated that during both seasons some mealiness became evident when the average pressure reading of the fruit, used in this study, fell below seven pounds. As the average firmness value of a given sample of fruits fell increasingly below the approximate seven pound level, the per cent of mealy apples in that sample increased rapidly. It was found that when the average firmness value of any sample of fruits fell below 6.50 pounds that the sample would contain sixty per cent or more mealy fruits.

The data in Tables 7 and 8 reveal that the waxing treatment generally reduced the incidence of mealiness at all temperatures. The greatest value of waxing for reducing mealiness is evident in the later stages of the storage life of the fruit. These results also show that there was a marked break in the percentage of mealiness occurring in fruits in post-storage between those stored at 50° and those at 55°F. There is little or no difference between the per cent of mealiness that may be expected to develop in fruits stored at 45° and 50°F.

The results of these mealiness studies, Tables 7 and 8, substantiate the findings of the other studies conducted in this investigation in regards to both the value of the waxing treatment and the responses of the fruit to the several

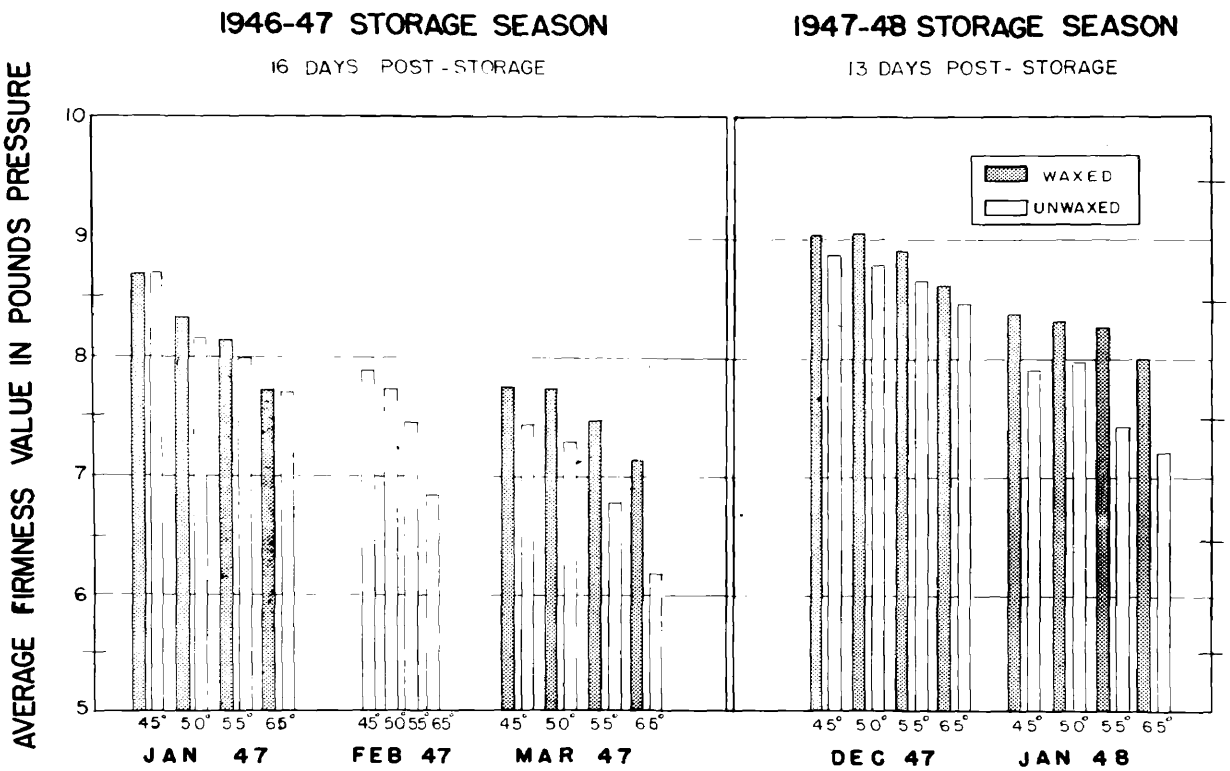


Figure 10. The average firmness value in pounds pressure of waxed and unwaxed Stayman Winesap apples stored at 45°, 50°, 55°, and 65°F. during the post-storage periods of the 1946-47 and 1947-48 storage seasons.

Table 7. Per Cent of Waxed and Unwaxed Stayman Winesap Apples Which Developed Mealiness While Stored at Different Post-Storage Temperatures During January, February, and March 1947.

Temperature	Unwaxed Fruit Days in Post-Storage						Waxed Fruit Days in Post-Storage			
	1	4*	7	10*	13	16	1	7	13	16
					January 1947					
45°F.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50°F.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55°F.	0.0	0.0	0.0	5.0	10.0	35.0	0.0	0.0	0.0	35.0
65°F.	0.0	0.0	5.0	25.0	35.0	60.0	0.0	0.0	5.0	85.0
					February 1947*					
45°F.	0.0	0.0	0.0	0.0	0.0	0.0				
50°F.	0.0	0.0	0.0	0.0	5.0	20.0				
55°F.	0.0	0.0	0.0	15.0	15.0	60.0				
65°F.	5.0	10.0	15.0	30.0	55.0	70.0				
					March 1947					
45°F.	10.0	0.0	5.0	0.0	0.0	5.0	10.0	0.0	0.0	0.0
50°F.	0.0	0.0	0.0	5.0	20.0	15.0	0.0	0.0	0.0	0.0
55°F.	0.0	0.0	20.0	40.0	45.0	60.0	0.0	0.0	15.0	20.0
65°F.	15.0	15.0	55.0	60.0	75.0	90.0	5.0	5.0	45.0	60.0

*No waxed fruits included in sampling.

Table 8. Per Cent of Waxed and Unwaxed Stayman Winesap Apples Which Developed Mealiness While Stored at Different Post-Storage Temperatures During December 1947 and January 1948.

Temperature	Unwaxed Fruit Days in Post-Storage					Waxed Fruit Days in Post-Storage			
	1	4*	7	10	13	1	7	10	13
					December 1947				
45°F.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50°F.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55°F.	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0
65°F.	0.0	0.0	0.0	0.0	16.6	1.0	0.0	0.0	22.2
					January 1948				
45°F.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50°F.	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0
55°F.	0.0	0.0	0.0	5.5	22.2	0.0	0.0	0.0	11.1
65°F.	0.0	0.0	5.5	27.7	50.0	0.0	0.0	0.0	11.1

*No waxed fruit included in sampling.

post-storage temperatures.

These data concerning the per cent mealiness should be compared with Figures 4-8 depicting the rate of firmness decline of these same fruits during post-storage. The line drawn at the seven pound level in these figures separates the fruits into desirable and mealy classes. Those fruits with firmness values falling below this indicated level are undesirable due to the occurrence of mealiness.

Reducing Sugar Determinations. The changes in the reducing sugar content of the fruits during post-storage are shown in Appendix Tables 7 and 8. The general trend of the changes in the content of these substances is presented in Table 9 and graphically expressed in Figure 10. These trends in reducing sugar content in Figure 11 are plotted from the means of the various sampling dates as shown in Table 9. The close parallelism of the trends of the soluble pectin and the reducing sugars should be noted. A correlation study of the two substances, Appendix Table 11, has shown that reducing sugars and soluble pectin are positively correlated to a highly significant degree.

The mean reducing sugar content of the waxed and unwaxed fruit stored under different post-storage temperatures is shown in Table 10. During the storage season of 1946-47 there was no statistical difference in the amount of these sugars present due to temperature. There was, however, a difference exhibited in reducing sugar content of the fruit stored at the different temperatures during the 1947-48 season. This

Table 9. Average Reducing Sugar Content (Expressed as Per Cent) of Unwaxed Stayman Winesap Apples After Different Periods of Post-Storage at 45°, 50°, 55°, and 65°F. During the 1946-47 and 1947-48 Storage Seasons.

Period	Days in Post-Storage						
	1	2	3	4	5	6	Mean
Jan. '47	11.27	11.20	10.72	12.08	11.93	13.26	11.74
Feb. '47	10.36	10.88	11.46	10.65	12.10	12.45	11.32
Mar. '47	11.72	12.90	11.92	12.40	12.86	12.86	12.44
Dec. '47	7.25	7.72	7.95	8.43	8.82	.....	8.03
Jan. '48	8.99	8.81	8.74	9.50	9.35	.....	9.08
Mean	9.92	10.30	10.16	10.61	11.01	12.86	

Table 10. Average Reducing Sugar Content (Expressed as Per Cent) of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Post-Storage Temperatures During the 1946-47 and 1947-48 Storage Seasons.*

Temperature	Post-Storage Period					
	Jan. '47	Feb.** '47	Mar. '47	Dec. '47	Jan. '48	Mean
45°F.	11.99	11.45	11.99	8.12	8.39	10.39
50°F.	11.55	10.94	12.75	8.33	9.40	10.59
55°F.	11.66	11.39	12.16	7.64	9.17	10.40
65°F.	11.68	11.48	12.01	8.41	8.89	10.49
LSD 5% level	1.06	0.68	1.06	0.43	0.43	

*Mean value of both waxed and unwaxed fruit.

**No waxed fruit included for reducing sugar determinations.

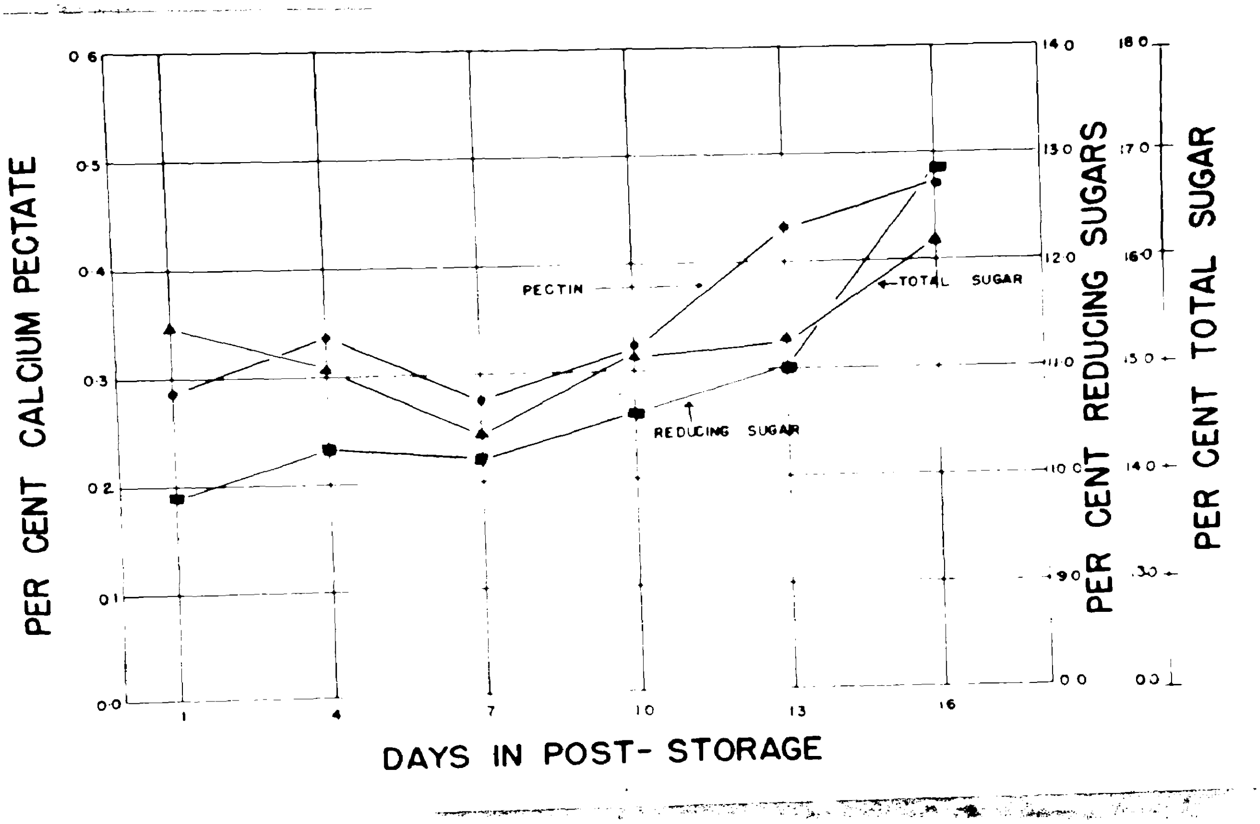


Figure 11. Representative trends in the total sugar, reducing sugar, and soluble pectin as calcium pectate content of Stayman Winesap apples while in post-storage during the 1946-47 and 1947-48 storage seasons.

difference appeared in the December 1947 study when the reducing sugar content of the fruits stored at 55°F. was lower than that of the fruits stored at either 45°, 50°, or 65°F. In the January 1948 study the reducing sugar content of the fruit stored at 45°F. fell below that of the fruit stored at either 50°, 55°, or 65°F. and the fruit held at 50°F. was lower in reducing substances than the fruit stored at 65°F. It will be noted that these results are again similar to those of the soluble pectin study.

The differences in reducing sugar content between waxed and unwaxed fruit in post-storage are shown in Table 11. There was no apparent effect of the wax application on the reducing sugar content of the fruit except in the case of the January 1948 study in which the wax application significantly reduced the content of these substances. Statistical analysis of the data further showed that the value of the wax application was the same at all of the post-storage temperatures.

Correlation studies, Appendix Table 11, showed that when both seasons results were studied, no significant correlation existed between respiration and the reducing sugar content of Stayman Winesap apples while in post-storage.

<u>Total Sugar Determinations</u>. The changes in the total sugar content which occurred while the fruits were in post-storage are presented in Appendix Tables 9 and 10. The general trends of the changes of these substances are shown in Table 12 and are graphically presented in Figure 11. These trends in total sugar content in Table 11 are plotted

Table 11. Average Reducing Sugar Content (Expressed as Per Cent) of Waxed and Unwaxed Stayman Winesap Apples While in Post-Storage During the 1946-47 and 1947-48 Storage Seasons.

Treatment	Post-Storage Period				
	Jan. '47	Mar. '47	Dec. '47	Jan. '48	Mean
Waxed	11.65	12.10	8.14	8.78	10.17
Unwaxed	11.79	12.34	8.11	9.14	10.35
LSD 5% level	0.43	0.43	0.37	0.24	

No waxed fruit included for reducing sugar determinations in the February 1947 study.

Table 12. Average Total Sugar Content (Expressed as Per Cent) of Unwaxed Stayman Winesap Apples After Different Periods of Post-Storage at 45°, 50°, 55°, and 65°F. During the 1946-47 and 1947-48 Storage Seasons.

Period	Days in Post-Storage						
	1	4	7	10	13	16	Mean
Jan. '47	16.43	14.49	14.85	16.71	14.75	15.52	15.46
Feb. '47	15.44	15.97	14.23	14.17	15.06	16.22	15.18
Mar. '47	17.25	16.32	15.81	15.80	16.50	16.46	16.36
Dec. '47	14.43	14.71	14.25	14.94	15.51	.....	14.76
Jan. '48	13.90	13.79	13.62	14.12	14.56	.....	13.99
Mean	15.49	15.06	14.55	15.15	15.28	16.20	

from the means of the total sugar content of the unwaxed fruit of each sampling period. The changes in total sugar content were shown by a correlation study, Appendix Table 11, to be unrelated to the changes in the soluble pectin content during three of the five post-storage periods but positively correlated with the soluble pectin changes during the other two periods. When, however, a correlation coefficient was determined from the data of all five periods, the correlation coefficient between total sugar and soluble pectin proved them to be positively correlated.

The effect of temperature upon total sugar content of the fruit is presented in Table 13. During the 1946-47 storage season it was found that there was no difference in the total sugar content of the fruits stored at the different post-storage temperatures. During the second season there was a difference in the total sugar content of the fruits stored at the different temperatures. These differences occurred in the December 1947 study when the fruits stored at 50°F. contained a significantly higher total sugar content than did the fruits stored at 45°, 55°, and 65°F. A difference in total sugar content due to temperature was also shown the second season when in the January 1948 study the fruits stored at 55°F. contained a lower total sugar level than did fruits stored at 45°, 50°, and 65°F.

The affect of the wax application on the total sugar content of Stayman Winesap apples while in post-storage is shown in Table 14. There was no significant difference be-

Table 13. Average Total Sugar Content (Expressed as Per Cent) of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Post-Storage Temperatures During the 1946-47 and 1947-48 Storage Seasons.*

Temperature	Post-Storage Period					
	Jan. '47	Feb.** '47	Mar. '47	Dec. '47	Jan. '48	Mean
45°F.	14.96	15.54	16.95	14.86	14.72	15.41
50°F.	15.36	14.35	16.89	16.50	14.32	15.48
55°F.	15.33	15.57	16.11	14.36	12.90	14.85
65°F.	15.01	14.60	15.84	14.49	14.30	14.85
LSD 5% level	0.93	1.24	0.93	0.73	0.73	

*Mean value of both waxed and unwaxed fruit.

**No waxed fruit included for total sugar determinations.

Table 14. Average Total Sugar Content (Expressed as Per Cent) of Waxed and Unwaxed Stayman Winesap Apples While in Post-Storage During the 1946-47 and 1947-48 Storage Seasons.

Treatment	Post-Storage Period				
	Jan. '47	Mar. '47	Dec. '47	Jan. '48	Mean
Waxed	14.94	16.34	15.32	14.07	15.17
Unwaxed	15.39	16.54	14.78	14.05	15.19
LSD 5% level	0.62	0.62	0.51	0.51	

No waxed fruit included for reducing sugar determinations in the February 1947 study.

tween the total sugar content of the waxed and unwaxed fruits while in post-storage.

Further correlation studies showed that in every study the correlation coefficient of total sugars and respiration was negative but only to a significant degree during the March 1947 period.

Soluble Pectin. The changes in soluble pectin content of the fruits during the different post-storage periods are presented in Appendix Tables 5 and 6. A representative trend of the pectin changes in post-storage is presented in Figure 11. The data from which this figure is plotted is the means of the average soluble pectin content of the unwaxed fruit for all the temperatures for each sampling date. These means are presented in Table 15. It should be noted that the difference in pectin content between dates proved to be statistically significant.

The average soluble pectin content of both waxed and unwaxed fruits stored at the various temperatures and post-storage periods are presented in Table 16. These values are presented in this manner since statistical procedures showed there was no interaction effect. It will be noted that during the 1946-47 season there was no significant difference in the pectin content of the fruit stored at the different post-storage temperatures. During both post-storage periods of the second season, there was, however, a significantly greater amount of pectin at 65° than at 45°F. With this exception, the results of the second season were similar to

Table 15. Average Soluble Pectin Content (Expressed as Per Cent Calcium Pectate) of Unwaxed Stayman Winesap Apples After Different Periods of Post-Storage at 45°, 50°, 55°, and 65°F. During the 1946-47 and 1947-48 Storage Seasons.

Period	Days in Post-Storage					
	1	2	3	4	5	6
Jan. '47	0.260	0.268	0.263	0.239	0.382	0.437
Feb. '47	0.273	0.316	0.253	0.257	0.306	0.341
Mar. '47	0.352	0.625	0.389	0.379	0.717	0.648
Dec. '47	0.268	0.199	0.223	0.383	0.363	.....
Jan. '48	0.303	0.389	0.259	0.340	0.382	.....
Mean	0.291	0.339	0.276	0.319	0.430	0.475

LSD between means at 5% level 0.049

Table 16. Average Soluble Pectin Content (Expressed as Per Cent Calcium Pectate) of Stayman Winesap Apples Stored at Different Post-Storage Temperatures During the 1946-47 and 1947-48 Storage Seasons.*

Temperature	Post-Storage Period					
	Jan. '47	Feb.** '47	Mar. '47	Dec. '47	Jan. '48	Mean
45°F.	0.299	0.269	0.488	0.287	0.259	0.321
50°F.	0.299	0.286	0.510	0.301	0.297	0.339
55°F.	0.306	0.306	0.507	0.303	0.321	0.349
65°F.	0.312	0.303	0.514	0.330	0.329	0.357
LSD 5% level	0.064	0.051	0.064	0.035	0.035	

*Mean value of both waxed and unwaxed fruit.

**No waxed fruit included for pectin determinations.

the results of the first season.

When the comparison of the soluble pectin content of the fruits was limited to only the later stages of the post-storage periods, namely the tenth and thirteenth day samplings, Table 17, a significantly greater pectin content was found in the fruits stored at 65°F. than in those held at 45°F. with the exception of the March 1947 sampling. On this same basis, there also occurred a significantly greater amount of pectin in fruits stored at 55°F. than in those held at 45°F. in two of the five periods. Whether the comparison was made over the entire post-storage period or for only the later stages, it was found that no difference occurred between the pectin content of the fruits stored at 45° and 50°F.

The fruits which had received the waxing treatment contained on the average during each post-storage period lesser amounts of soluble pectin than did comparable unwaxed fruits, Table 18. The mean pectin content of the waxed fruits was found to be ten per cent less than the mean pectin content of the unwaxed fruit. The reduction in soluble pectin content of the waxed fruits was shown by statistical analysis to be significantly different during the January periods of both storage seasons, but no significant difference in soluble pectin was exhibited by the fruit during other post-storage periods. The same analysis showed that the effect of waxing was the same at all the temperatures studied.

The results of a correlation study, Appendix Table 11,

Table 17. Average Soluble Pectin Content (Expressed as Per Cent Calcium Pectate) of Stayman Winesap Apples After Ten and Thirteen Days Post-Storage During the 1946-47 and 1947-48 Storage Seasons.*

Temperature	Post-Storage Period					
	Jan. '47	Feb. '47	Mar. '47	Dec. '47	Jan. '48	Mean
45°F.	0.238	0.235	0.519	0.320	0.293	0.321
50°F.	0.321	0.274	0.565	0.354	0.364	0.375
55°F.	0.346	0.296	0.520	0.377	0.401	0.388
65°F.	0.338	0.321	0.588	0.408	0.387	0.408
LSD 5% level	0.083	0.883	0.108	0.083	0.083	

*Unwaxed fruit only.

Table 18. Average Soluble Pectin Content (Expressed as Per Cent Calcium Pectate) of Waxed and Unwaxed Stayman Winesap Apples While in Post-Storage During the 1946-47 and 1947-48 Storage Seasons.

Treatment	Post-Storage Period*				
	Jan. '47	Mar. '47	Dec. '47	Jan. '48	Mean
Unwaxed	0.336	0.526	0.307	0.319	0.372
Waxed	0.272	0.484	0.303	0.284	0.336
LSD 5% level	0.045	0.045	0.025	0.025	

*No waxed fruit included for pectin determinations in the February 1947 period.

showed that there was a very high negative correlation between the pectin content and the firmness values of the fruit. Another correlation study, Appendix Table 11, showed that during the 1946-47 season there was no correlation between respiration and pectin but that the two were correlated during the second season.

DISCUSSION

The physiological and quality changes of the apple occurring in post-storage, under consideration in this investigation, can be separated into two classes; one class consisting of changes which are closely associated to the post-storage temperature, i.e. weight loss, respiration, firmness, and mealiness; the other class includes changes in sugar and soluble pectin which are not particularly affected by post-storage temperature.

The post-storage temperature at which the fruits were held influenced the amount of weight loss that occurred while the fruits were in post-storage even though the same high relative humidity was maintained. This amount of weight lost was too great to be accounted for by only the respirational activity. Much of the weight loss is therefore attributed to water loss, as other workers (34, 46, 47, 55) have reported. The greater amount of weight loss occurring at the higher temperatures has been reported and explained by Smock (55) on a basis of vapor pressure deficits. The value of the wax application in reducing the amount of weight loss should not be overlooked.

The occurrence of mealiness appeared to be closely related to the post-storage temperature at which the fruits were held. The relationship of temperature to mealiness is quite similar to that of temperature to firmness, in that the rate of development of mealiness was practically the same at 45° and 50°F., whereas marked differences in the amount of mealiness occurred when fruit stored at 45°, 55°, and 65°F. were compared. This similarity is not unusual when both firmness and mealiness are used as guides to storage maturity.

During both storage seasons, mealiness appeared when the fruits had an average firmness value of seven pounds. The development of mealiness at this firmness value approximates the point found by Magness (38) who indicated that with Stayman Winesap apples, mealiness occurred when the fruits reached a firmness value of eight pounds. The work of Haller, Lutz and Mallison (21) indicates, however, that mealiness may occur with this variety anywhere within the range of seven to twelve pounds pressure. The important point here is not the relationship of firmness to the development of mealiness but rather the fact that these fruits may be maintained in post-storage temperatures as high as 50°F. for reasonable periods of time without the development of mealiness causing undesirable fruits.

The rates of decline in firmness values of the fruits held in post-storage at 45°, 55°, and 65°F. are quite similar to the results reported by Haut (26) for Delicious. In this study, as in the preliminary study (26), the major break in the rate of the firmness decline occurred between 45° and 55°F. when only the three temperatures were considered. The intermediate temperature of 50°F. was added in this study to determine more closely if possible where the major break in fruit firmness decline would occur. The results revealed that this break occurred between 50° and 55°F. with the Stayman Winesap variety. The results of these studies further showed that fruit firmness with the Stayman Winesap variety can be maintained equally well at 50° as at 45°F. for reasonable periods of time.

The rates of reduction in fruit firmness at the various post-storage temperatures following 32°F. storage, were found not to differ materially from the decline in firmness occurring at different storage temperatures as reported by Magness et al. (39). These workers showed that fruits stored at higher temperatures declined in firmness or matured in storage in a non-lineal manner. They showed that with several apple varieties, the rate of firmness decline at 40°F. was more than double the rate at 32°F. At 50°F. the rate of softening was more than double the rate at 40°F. and at 70°F. the rate of softening was approximately twice as fast as at 50°F. The same workers (39) also reported that the relationship to the rate of firmness decline and temperature was not due to previous low storage temperature. The results of these studies (39) showed that there was no influence on the rate of softening when fruits stored at low temperature, 32°F., were moved to higher temperatures, 50° - 70°F.

The application of wax to the apple fruits generally retarded the ripening process in post-storage to about the same degree and in much the same manner as has been reported by other workers for fruit in storage. Although the difference between the various quality and physiological factors of the unwaxed and waxed fruits was not always great enough to prove statistically significant, with few exceptions these factors of the waxed fruits indicated them to be slightly less mature than did comparable unwaxed fruits. This effect of the waxing treatment was shown to be the same at all temperatures studied.

The fruits which were treated with wax retained higher firmness values than did those fruits which were unwaxed. During the entire study, the waxed fruits averaged four per cent firmer than did the unwaxed fruit. This retention of fruit firmness is in line with the earlier reports of Magness and Diehl (37), who worked with fruits in storage.

The retention of firmness in the waxed fruits as compared with the unwaxed fruits was reflected by lower soluble pectin content in these treated fruits. This relationship of soluble pectin and firmness value in the fruits in post-storage is in agreement with the findings of other workers (12, 15, 18, 39, 48, 49, 55) who also reported this relationship to occur in apple fruits in cold storage. Emphasis is given to the suggestion of Smock (55) that the development of soluble pectin presented a good criterion for the rate of softening of fruits while in storage.

Magness and Diehl (31), Fisher and Britton (15), and Smock (53) have all reported effects of waxing similar to those herein reported upon the reduction in respiration rate. This reduced respiration rate may be a secondary effect of delayed maturity in the light of the work of

Harding (23), Ezell and Gerhardt (14), and Magness et al. (39) who report that the rate of respiration increases with the maturity of the fruit. The main point is, however, that the rate of this process is reduced in apple fruits which have been waxed before being placed in post-storage. Whether this reduction of respiration activities of waxed fruit in post-storage is due to the wax directly or to the retardation of maturity of the fruit itself is questionable.

A further advantage of waxed fruit over unwaxed fruit in post-storage is evident when the matter of weight loss is considered. The amount of weight lost by the waxed fruit was less than the amount of weight lost by the unwaxed fruit. This value of waxing has been reported many times (10, 30, 31, 40, 47, 52) with stored fruit. The reduction in weight loss is considered to be due to a retardation of moisture loss which has been associated (10) with a corresponding preservation of fruit quality. Claypool (10) has stated that this reduction in the amount of water loss is the principal advantage to be gained by treating fruits with wax.

The value of the waxing treatment in delaying the maturation process is also demonstrated by the delayed development of mealiness generally associated with the later stages of storage life in fruit. This effect of waxing in reducing the incidence of mealiness in stored fruit has been reported by Fisher and Britton (15).

Summarizing the effect of the wax application upon the post-storage quality and physiological changes of the Stayman

Winesap apple, it is evident that waxing aided in retaining fruit quality and slowed the physiological responses of the fruit in post-storage in much the same manner as has been previously reported for apple fruits in storage. In no case, did a deleterious effect of the wax application exhibit itself in these studies, where commercial waxes were employed. Even though there was not always a statistically valid difference between the responses of the waxed and unwaxed fruits, waxing exhibits definite possibilities for the prolonging of the quality of apple fruits while in post-storage. The advantages offered by this treatment should not be overlooked and further investigations are warranted in order that the information can be obtained for completely exploiting the advantages of the waxing treatment.

The respiration of the fruits while in post-storage was closely related to the temperature at which the fruits were held, with the fruits held at the higher temperatures respiring at a more rapid rate than those held at lower temperatures. Similar effects of temperature upon the respiration rates of apples during regular storage has been reported previously by a number of workers (6, 17, 44). When the respiration data were studied, it was noted that, as with the other factors associated with temperature, namely, firmness, weight loss, and mealiness, no statistical difference in respiration activity occurred between the fruits held at 45° and 50°F. Unliked those other factors, however, it was found that there was no major break in the respirational activities exhibited. This lack of a major break is quite understandable in that respiration of apples is reported by Burroughs (6) to follow Van't Hoff's Law. Further, Harding (24) has also shown that the shifting of apple fruits from low to high temperatures has no effect upon the subsequent respiration of those fruits.

The changes in the soluble pectin content of the fruits stored at various post-storage temperatures was not great enough to show statistical differences in soluble pectin content due to temperatures. Haller (18) reports a difference in the soluble pectin content between fruits stored at different temperatures. However, in the latter study (18), storage periods were employed which were two and three times as long as those under consideration here. It is not unlikely that had these post-storage studies been extended, a difference in soluble pectin content due to temperature would have been observed.

The soluble pectin content of the fruits in post-storage did not follow the ever increasing trend as the fruits matured in post-storage as might be expected from the behavior of apples in regular storage (7, 12, 15, 18, 39, 48, 49, 55) indicating that as fruits matured or became less firm, the pectin content increased. Rather the soluble pectin increased at first, then fell off sharply after seven days in post-storage, after which it increased in a manner indicated by the above mentioned work. The reducing sugar content roughly paralleled the soluble pectin content of the fruit including the marked decrease in content the seventh day. This marked seventh-day activity was not reflected by any other physical or chemical test made on the fruits. As a possible explanation of the unexpected trend in soluble pectin content, it is suggested that for some reason there was not enough substrate for respiration at that point in the post-storage life of the fruits and that in order to satisfy the demands of respiration, a certain amount of pectin was broken down into simple sugars for use in respiration. When the physiological balance was again restored, the soluble pectin was again able to build up as more regular substrate material for respiration was made available. This irregular trend of the soluble pectin content of the fruits in post-storage should be further investigated.

Total and reducing sugar content of the fruit also appeared to be unaffected by the post-storage temperature at which the fruits were held. This lack of association between the sugar content and the post-storage temperature is supported by the work of Smock (55), Lutz and Culpepper (36), and Magness et al. (39). The results of these workers is expressed by Smock (55) when he states that it is very difficult to associate storage treatment with the sugar content of the apple.

There has been much emphasis placed upon the maintenance of storage conditions which would suppress the rate of the various physiological and quality changes of the apple in storage in order that a high quality product may reach the market. It now appears that these same factors are operative in the same or a similar manner during the post-storage life of the fruits. With the advent of new equipment, both in the home and in the commercial outlets, it is now feasible for the suppression of the physiological and quality changes associated with the maturation processes to continue for a longer period of time. If the apple industry can foster the post-storage handling of their fruit within the temperature range of 45° - 50°F., it will facilitate the consumer receiving a more acceptable, higher quality product and place the industry in a more advantageous position in our present competitive market.

SUMMARY AND CONCLUSIONS

This investigation was conducted with waxed and unwaxed fruits of the Stayman Winesap variety during the 1946-47 and 1947-48 storage seasons to determine the physiological and quality changes at different post-storage temperatures and to attempt to determine the optimum post-storage temperature for this variety. During both seasons fruit selected for uniformity of size, color and freedom from blemishes was stored at 32°F. for various periods of time from one and one-half to four and one-half months. After the storage period, fruit samples were removed and placed in post-storage in constant temperature chambers for periods of thirteen to sixteen days. While in post-storage, the rate of firmness decline, respirational activities, incidence of mealiness, amount of weight loss, and changes as to content of total and reducing sugars and soluble pectin were carefully studied.

From the results of this study, the following conclusions are justified:

1. The fruit of this variety may be held in post-storage for reasonable lengths of time equally well at 50° as at 45°F. so long as the pressure reading is higher than seven pounds without an unusual decline in fruit quality.

2. There is a major break in the rate of firmness decline, the rate in the development of mealiness, and the amount of weight loss by fruits in post-storage between 50° and 55°F. Concurrently there appears to be no significant difference insofar as these factors are concerned between fruits stored at

45° and 50°F.

3. There is no consistent significant difference in the soluble pectin, total sugar, or reducing sugar content of the fruits due to the post-storage temperature at which the fruits are held.

4. The quality and physiological changes which occurred in post-storage are similar in type to the changes which occur during normal storage.

5. The respiration rate of apples in post-storage is in a lineal relationship to temperature.

6. There is much to be gained as far as fruit quality is concerned by reducing the post-storage temperature of the fruit below 65°F. For limited periods there is little to be gained from reducing the post-storage temperature from 50° to 45°F.

7. The critical post-storage temperature occurs between 50° - 55°F.

8. The best guide for post-storage quality as used in this study is the pressure tester.

9. Waxing is beneficial in delaying the development of maturity in post-storage. The efficacy of the wax application in delaying maturity was found to be the same at all temperatures.

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APPENDIX

Appendix Table 1. The Firmness Value, Pounds Pressure, of Waxed and Unwaxed Stayman Winesap Apples at Different Temperatures During the Post-Storage Periods of the 1946-47 Storage Season.

Temperature	Treatment	Days in Post-Storage 1	4*	7	10*	13	16	Mean
		January 1947						
45°F.	Waxed	9.56	....	9.06	....	8.30	7.81	8.68
	Unwaxed	9.62	9.28	8.50	8.23	8.58	8.06	
50°F.	Waxed	9.18	....	8.52	....	8.10	7.45	8.22
	Unwaxed	9.13	8.95	8.10	7.87	7.87	7.45	
55°F.	Waxed	10.08	....	8.55	....	7.42	6.50	8.06
	Unwaxed	10.37	8.67	8.08	7.27	6.92	6.59	
65°F.	Waxed	9.78	....	8.10	....	7.00	5.92	7.68
	Unwaxed	9.48	8.10	7.82	6.82	6.98	6.43	
		February 1947						
45°F.	Unwaxed	8.40	7.97	7.97	7.78	7.78	7.27	7.86
50°F.	Unwaxed	8.13	7.63	7.85	7.60	7.83	7.18	7.70
55°F.	Unwaxed	8.17	7.87	7.98	7.12	7.15	6.22	7.41
65°F.	Unwaxed	7.42	7.08	7.07	6.78	6.37	6.15	6.81
		March 1947						
45°F.	Waxed	7.75	....	7.92	....	7.43	7.78	7.56
	Unwaxed	7.23	7.48	7.53	7.73	7.43	7.42	
50°F.	Waxed	7.77	....	7.88	....	7.48	7.73	7.48
	Unwaxed	7.33	7.68	7.57	7.53	6.88	7.27	
55°F.	Waxed	7.78	....	7.88	....	7.13	6.93	7.09
	Unwaxed	7.26	7.36	7.12	6.80	6.42	6.23	
65°F.	Waxed	7.83	....	7.68	....	6.60	6.32	6.63
	Unwaxed	6.96	7.30	6.12	6.38	5.68	5.35	

LSD between means at 5% level January 0.51, February 0.28, March 0.34.

*No waxed fruit included for firmness evaluation.

Appendix Table 2. The Firmness Value, Pounds Pressure, of Waxed and Unwaxed Stayman Winesap Apples at Different Temperatures During the Post-Storage Periods of the 1947-48 Storage Season.

Temperature	Treatment	Days in Post-Storage 1	4*	7	10	13	Mean
		December 1947					
45°F.	Waxed	10.64	....	8.77	8.92	7.83	8.94
	Unwaxed	10.66	9.72	9.22	8.05	7.44	
50°F.	Waxed	10.64	....	9.05	8.66	7.87	8.88
	Unwaxed	10.51	9.09	8.53	8.24	7.61	
55°F.	Waxed	10.03	....	9.12	8.61	7.68	8.72
	Unwaxed	10.85	9.16	8.35	8.01	7.16	
65°F.	Waxed	10.46	....	8.59	8.18	6.96	8.47
	Unwaxed	10.53	9.00	8.31	7.94	6.83	
		January 1948					
45°F.	Waxed	9.26	....	8.48	7.94	7.53	8.06
	Unwaxed	9.12	8.19	7.81	7.37	7.01	
50°F.	Waxed	9.12	....	8.50	7.83	7.57	8.07
	Unwaxed	8.94	8.02	7.95	7.64	7.03	
55°F.	Waxed	9.05	....	8.24	7.65	7.13	7.69
	Unwaxed	8.92	7.98	7.96	6.02	6.59	
65°F.	Waxed	8.59	....	8.37	7.61	7.15	7.52
	Unwaxed	8.62	7.83	7.09	6.75	6.00	

LSD between means at 5% level December 0.29, January 0.32.

*No waxed fruit included for firmness evaluation.

Appendix Table 3. Average Respiration Rates (Expressed as Mg. of CO_2/Kilo/Hr.) of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Temperatures During the Post-Storage Periods of the 1946-47 Storage Season.

Temperature	Treatment	Days in Post-Storage 1-4	4-7	7-10	10-13	13-16	Mean
				January 1947			
45°F.	Waxed	11.62	6.74	12.60	10.71	8.85	10.64
	Unwaxed	14.19	8.50	12.33	11.82	9.05	
50°F.	Waxed	11.76	7.18	18.55	12.63	12.70	12.48
	Unwaxed	13.91	7.17	14.95	14.33	11.58	
55°F.	Waxed	15.43	10.85	16.88	13.62	14.25	14.70
	Unwaxed	20.27	12.90	14.76	12.95	15.04	
65°F.	Waxed	30.20	11.50	23.31	24.05	18.62	20.21
	Unwaxed	25.72	9.85	15.78	25.69	17.92	
				February 1947			
45°F.	Waxed	8.25	7.13	6.61	7.15	9.16	8.94
	Unwaxed	9.50	11.25	10.98	9.96	9.43	
50°F.	Waxed	9.77	12.84	9.91	9.85	7.27	10.90
	Unwaxed	13.98	13.17	12.54	11.65	8.05	
55°F.	Waxed	14.17	14.12	12.11	10.48	9.59	12.46
	Unwaxed	14.50	15.04	14.68	10.44	9.51	
65°F.	Waxed	23.14	15.51	18.52	17.30	12.67	18.09
	Unwaxed	20.39	21.13	17.05	20.33	14.82	
				March 1947			
45°F.	Waxed	11.63	12.99	13.33	11.31	13.25	14.19
	Unwaxed	12.73	15.95	15.82	19.02	15.82	
50°F.	Waxed	13.36	16.39	13.52	14.11	16.91	14.33
	Unwaxed	12.50	11.51	15.08	14.80	15.16	
55°F.	Waxed	23.41	22.26	19.13	17.51	17.58	19.42
	Unwaxed	21.04	20.19	15.86	18.43	18.77	
65°F.	Waxed	28.48	27.33	26.13	22.96	19.83	26.31
	Unwaxed	28.99	30.33	25.97	26.63	26.47	

LSD between means at 5% level January 2.69, February 1.67, March 2.07.

Appendix Table 4. Average Respiration Rates (Expressed as Mg. of CO_2/Kilo/Hr.) of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Temperatures During the Post-Storage Periods of the 1947-48 Storage Season.

Temperature	Treatment	Days in Post-Storage 1-4	4-7	7-10	10-13	Mean
		December 1947				
45°F.	Waxed	9.18	7.87	14.23	12.26	11.22
	Unwaxed	10.74	11.80	11.48	11.20	
50°F.	Waxed	12.39	14.01	13.79	11.68	12.62
	Unwaxed	11.98	11.45	12.34	13.30	
55°F.	Waxed	12.05	13.85	13.19	21.41	15.61
	Unwaxed	10.13	17.24	15.36	20.99	
65°F.	Waxed	16.94	24.41	19.28	20.45	21.39
	Unwaxed	21.14	18.19	26.62	24.14	
		January 1948				
45°F.	Waxed	10.80	10.30	15.08	10.36	12.14
	Unwaxed	10.80	12.54	14.72	12.58	
50°F.	Waxed	12.58	11.89	15.05	12.06	13.17
	Unwaxed	12.76	13.52	14.88	12.65	
55°F.	Waxed	12.48	15.24	16.40	14.16	15.12
	Unwaxed	14.70	15.81	17.84	14.35	
65°F.	Waxed	20.55	17.74	23.38	17.88	20.26
	Unwaxed	21.90	19.22	24.15	19.68	

LSD between means at 5% level December 2.73, January 1.30.

Appendix Table 5. Average Soluble Pectin Content (Expressed as per cent Calcium Pectate) of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Temperatures During the Post-Storage Periods of the 1946-47 Storage Season.

Temperature	Treatment	Days in Post-Storage 1	4*	7	10*	13	16	Mean
		January 1947						
45°F.	Waxed	0.263	.....	0.293	.....	0.205	0.398	0.299
	Unwaxed	0.250	0.342	0.326	0.219	0.256	0.404	
50°F.	Waxed	0.177	.....	0.253	.....	0.197	0.343	0.299
	Unwaxed	0.218	0.318	0.276	0.238	0.403	0.424	
55°F.	Waxed	0.209	.....	0.280	.....	0.168	0.405	0.306
	Unwaxed	0.242	0.241	0.210	0.225	0.467	0.464	
65°F.	Waxed	0.170	.....	0.270	.....	0.225	0.399	0.312
	Unwaxed	0.332	0.720	0.241	0.273	0.403	0.454	
		February 1947						
45°F.	Unwaxed	0.300	0.339	0.220	0.217	0.252	0.287	0.269
50°F.	Unwaxed	0.284	0.345	0.245	0.266	0.281	0.294	0.286
55°F.	Unwaxed	0.265	0.283	0.309	0.247	0.344	0.387	0.306
65°F.	Unwaxed	0.244	0.298	0.238	0.296	0.346	0.398	0.303
		March 1947						
45°F.	Waxed	0.212	.....	0.311	.....	0.633	0.630	0.488
	Unwaxed	0.335	0.660	0.408	0.329	0.708	0.670	
50°F.	Waxed	0.273	.....	0.341	.....	0.602	0.617	0.511
	Unwaxed	0.390	0.649	0.428	0.396	0.734	0.700	
55°F.	Waxed	0.246	.....	0.375	.....	0.770	0.671	0.507
	Unwaxed	0.349	0.597	0.381	0.398	0.645	0.622	
65°F.	Waxed	0.303	.....	0.364	.....	0.698	0.691	0.514
	Unwaxed	0.332	0.594	0.337	0.394	0.782	0.601	

LSD between means at 5% level January 0.064, February 0.051, March 0.064.

*No waxed fruit included for soluble pectin determinations.

Appendix Table 6. Average Soluble Pectin Content (Expressed as per cent Calcium Pectate) of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Temperatures During the Post-Storage Periods of the 1947-48 Storage Season.

Temperature	Treatment	Days in Post-Storage 1	4*	7	10	13	Mean
			December 1947				
45°F.	Waxed	0.262	.....	0.269	0.276	0.290	0.287
	Unwaxed	0.246	0.164	0.275	0.372	0.308	
50°F.	Waxed	0.262	.....	0.294	0.304	0.333	0.301
	Unwaxed	0.303	0.222	0.201	0.369	0.339	
55°F.	Waxed	0.240	.....	0.259	0.324	0.392	0.303
	Unwaxed	0.254	0.174	0.202	0.359	0.395	
65°F.	Waxed	0.288	.....	0.254	0.390	0.412	0.330
	Unwaxed	0.269	0.237	0.212	0.403	0.412	
			January 1948				
45°F.	Waxed	0.232	.....	0.221	0.262	0.320	0.259
	Unwaxed	0.274	0.282	0.179	0.239	0.346	
50°F.	Waxed	0.271	.....	0.226	0.331	0.340	0.297
	Unwaxed	0.284	0.309	0.199	0.351	0.377	
55°F.	Waxed	0.261	.....	0.249	0.277	0.371	0.321
	Unwaxed	0.334	0.315	0.272	0.396	0.405	
65°F.	Waxed	0.268	.....	0.200	0.320	0.394	0.329
	Unwaxed	0.318	0.251	0.357	0.374	0.400	

LSD between means at 5% level December 0.035, January 0.035.

*No waxed fruit included for soluble pectin determinations.

Appendix Table 7. Changes in Reducing Sugar Content (Expressed as per cent) of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Temperatures During the Post-Storage Periods of the 1946-47 Storage Season.

Temperature	Treatment	Days in Post-Storage 1	4*	7	10*	13	16	Mean
		January 1947						
45°F.	Waxed	11.27	.....	12.28	.....	13.37	11.94	11.99
	Unwaxed	10.99	10.80	11.10	12.23	12.17	12.82	
50°F.	Waxed	10.88	.....	11.11	.....	12.11	11.72	11.55
	Unwaxed	10.03	10.61	10.96	12.11	12.33	13.22	
55°F.	Waxed	10.61	.....	12.29	.....	10.80	12.00	11.66
	Unwaxed	11.26	11.22	10.30	11.44	12.40	13.61	
65°F.	Waxed	12.28	.....	10.94	.....	10.95	11.79	11.68
	Unwaxed	12.79	12.15	10.52	12.55	10.83	13.37	
		February 1947						
45°F.	Unwaxed	11.29	10.59	11.28	10.50	12.27	12.80	11.45
50°F.	Unwaxed	10.47	10.44	10.22	10.32	12.11	12.05	10.94
55°F.	Unwaxed	9.92	11.00	12.44	10.66	12.22	12.11	11.39
65°F.	Unwaxed	9.79	11.47	11.88	11.11	11.78	12.83	11.48
		March 1947						
45°F.	Waxed	10.15	.....	11.53	.....	12.00	11.99	11.99
	Unwaxed	11.79	13.39	12.26	12.53	12.97	13.20	
50°F.	Waxed	11.27	.....	12.75	.....	13.22	11.70	12.75
	Unwaxed	12.05	13.28	12.87	12.66	14.17	14.00	
55°F.	Waxed	10.67	.....	12.63	.....	13.62	13.00	12.16
	Unwaxed	11.65	12.53	11.67	12.33	12.05	12.02	
65°F.	Waxed	11.33	.....	12.51	.....	12.06	13.20	12.01
	Unwaxed	11.38	12.40	10.89	12.06	12.26	12.21	

LSD between means at 5% level January 1.06, February 0.68, March 1.06.

*No waxed fruit included for reducing sugar determinations.

Appendix Table 8. Changes in Reducing Sugar Content (Expressed as per cent) of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Temperatures During the Post-Storage Periods of the 1947-48 Storage Season.

Temperature	Treatment	Days in Post-Storage 1	4*	7	10	13	Mean
		December 1947					
45°F.	Waxed	7.76	....	7.94	8.24	7.98	8.12
	Unwaxed	7.83	7.78	7.89	8.40	8.95	
50°F.	Waxed	7.67	....	7.61	8.11	9.42	8.33
	Unwaxed	7.17	7.72	8.50	9.11	9.01	
55°F.	Waxed	7.28	....	6.73	7.94	9.58	7.64
	Unwaxed	6.62	6.51	6.77	7.39	8.81	
65°F.	Waxed	7.80	....	8.69	8.42	9.00	8.41
	Unwaxed	7.39	8.88	8.67	8.81	8.50	
		January 1948					
45°F.	Waxed	7.89	....	8.24	8.71	8.11	8.39
	Unwaxed	8.65	8.47	7.50	9.17	8.90	
50°F.	Waxed	9.39	....	8.83	9.27	9.67	9.40
	Unwaxed	8.89	9.22	9.33	9.83	9.95	
55°F.	Waxed	8.83	....	8.78	9.05	9.05	9.17
	Unwaxed	9.33	9.39	9.45	9.61	9.28	
65°F.	Waxed	7.95	....	8.11	9.17	9.50	8.89
	Unwaxed	9.08	8.17	8.66	9.39	9.27	

LSD between means at 5% level December 0.43, January 0.43.

*No waxed fruit included for reducing sugar determinations.

Appendix Table 9. Changes in Total Sugar Content (Expressed as per cent) of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Temperatures During the Post-storage Periods of the 1946-47 Storage Season.

Temper-ature	Treat-ment	1	4*	7	10*	13	16	Mean
				January 1947				
45°F.	Waxed	13.20	.....	15.38	.....	14.73	16.11	14.96
	Unwaxed	15.22	14.65	13.65	17.77	16.22	15.13	
50°F.	Waxed	14.89	.....	14.82	.....	14.69	15.78	15.36
	Unwaxed	17.33	14.00	14.82	16.82	15.00	15.55	
55°F.	Waxed	15.45	.....	14.70	.....	14.10	15.50	15.33
	Unwaxed	17.11	14.66	16.33	16.69	13.78	15.62	
65°F.	Waxed	13.44	.....	15.99	.....	14.55	15.69	15.01
	Unwaxed	16.07	14.64	14.59	15.59	13.99	15.77	
				February 1947				
45°F.	Unwaxed	16.00	15.62	14.89	15.56	15.40	15.78	15.54
50°F.	Unwaxed	15.80	15.17	11.89	13.33	13.33	16.55	14.35
55°F.	Unwaxed	15.29	15.85	15.88	14.67	15.51	16.22	15.57
65°F.	Unwaxed	14.67	13.22	14.26	13.11	16.00	16.33	14.60
				March 1947				
45°F.	Waxed	16.33	.....	16.95	.....	17.11	16.84	16.95
	Unwaxed	17.60	17.29	17.02	16.18	17.22	16.72	
50°F.	Waxed	15.77	.....	16.84	.....	17.33	16.56	16.89
	Unwaxed	17.56	17.18	17.22	16.72	17.22	16.62	
55°F.	Waxed	15.24	.....	15.96	.....	16.84	16.51	16.11
	Unwaxed	17.11	15.46	15.24	15.27	15.77	16.18	
65°F.	Waxed	16.62	.....	16.18	.....	14.69	16.66	15.84
	Unwaxed	16.72	15.33	13.77	15.02	15.77	16.33	

LSD between means at 5% level January 0.93, February 1.24, March 0.93.

*No waxed fruit included for total sugar determinations.

Appendix Table 10. Changes in Total Sugar Content (Expressed as per cent) of Waxed and Unwaxed Stayman Winesap Apples Stored at Different Temperatures During the Post-Storage Periods of the 1947-48 Storage Season.

Temperature	Treatment	Days in Post-Storage 1	4*	7	10	13	Mean
		December 1947					
45°F.	Waxed	14.89	.....	15.03	15.22	14.50	14.86
	Unwaxed	14.72	14.81	14.48	14.78	15.22	
50°F.	Waxed	15.33	.....	16.99	18.19	18.40	16.50
	Unwaxed	14.33	15.44	15.22	16.22	17.33	
55°F.	Waxed	14.73	.....	14.23	14.56	14.61	14.36
	Unwaxed	14.28	14.72	14.26	14.33	13.94	
65°F.	Waxed	15.17	.....	14.22	14.44	14.66	14.49
	Unwaxed	14.39	13.89	13.05	14.44	15.55	
		January 1948					
45°F.	Waxed	15.39	.....	16.06	14.66	14.78	14.72
	Unwaxed	14.55	14.72	12.79	14.50	15.00	
50°F.	Waxed	14.94	.....	13.91	13.06	14.70	14.32
	Unwaxed	14.77	12.55	13.89	14.44	14.81	
55°F.	Waxed	12.78	.....	12.17	12.45	12.83	12.90
	Unwaxed	12.95	12.61	13.28	13.27	13.50	
65°F.	Waxed	14.39	.....	14.39	13.56	15.00	14.30
	Unwaxed	13.34	15.28	14.50	14.27	14.94	

LSD between means at 5% level December 0.73, January 0.73.

*No waxed fruit included for total sugar determinations.

Appendix Table 11. Correlation Coefficients Between Different Physiological and Quality Changes in Stayman Winesap Apples During the Post-Storage Period of the 1946-47 and 1947-48 Storage Seasons.

Physiological and Quality Changes	Post-Storage Periods Jan. '47	Feb. '47	Mar. '47	Dec. '47	Jan. '48	All Periods
Soluble Pectin Total Sugar	+.357*	+.181	+.161	+.149	+.482**	+.434**
Soluble Pectin Reducing Sugar	+.816**	+.423*	+.680**	+.523**	+.558**	+.658**
Soluble Pectin Respiration	+.084	+.001	-.108	+.464**	+.548**	+.626**
Soluble Pectin Firmness	-.469**	-.527**	-.394**	-.604**	-.866**	-.658**
Respiration Reducing Sugar	+.057	-.658**	-.395*	+.363*	+.583**	+.088
Respiration Total Sugar	-.088	-.397	-.461*	-.351	-.066	-.172*

*Significant at 5% level.
**Significant at 1% level.