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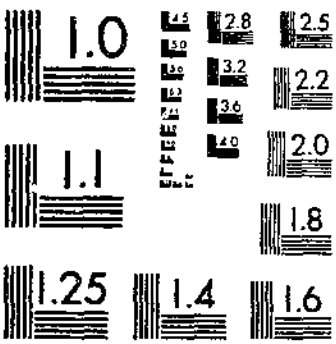

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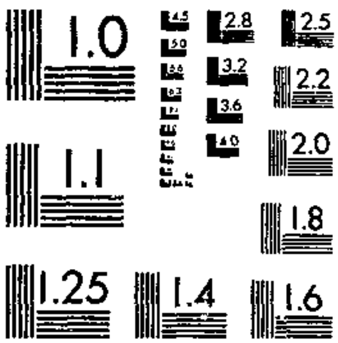

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Physiological Investigations on Fall and Winter Pears in the Pacific Northwest[1]

By Fisk Gerhardt, *physiologist*, and Boyce D. Ezell, *assistant horticulturist*, *Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*

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INTRODUCTION

Commercial production of fall and winter pears in the United States is largely confined to the warm, dry, irrigated valleys of the three Pacific Coast States, where approximately 14 percent of the California, 65 percent of the Oregon, and 32 percent of the Washington total pear acreage is planted to these varieties (*31*).[2] Production trends and estimated new plantings foreshadow a considerable increase in both acreage and tonnage. Although production has varied from season to season, carlot shipments of winter pears from the Pacific Northwest have more than doubled during the 10-year period 1929–39.[3]

The Anjou (Beurre d'Anjou) variety has shown a consistent gain in popularity and in 1934 comprised approximately one-half of the total commercial shipments of winter pears. The Bosc (Beurre Bosc) and Winter Nelis form the major portion of the remaining tonnage of fall and winter pears, and Flemish Beauty, Comice (Doyenne du Comice), and Howell represent varieties of lesser commercial production in the Pacific Northwest.

The winter-pear market is largely a fresh-fruit market and as such demands the utmost in appearance, condition, and dessert quality of the fruit. Improvement of these essential factors can be accomplished through intelligent harvesting, handling, storage, and marketing

[1] Submitted for publication May 10, 1940.
[2] Italic numbers in parentheses refer to Literature Cited, p. 63.
[3] Information obtained from the Wenatchee Valley Traffic Association, Wenatchee, Wash.

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practices. Because pears are decidedly more active physiologically than apples, handling delays and higher storage or transit temperatures are correspondingly more critical factors in the maintenance of maximum storage life and of best dessert quality.

Published work (*1*, *23*, *24*, *38*) relative to maturity standards and proper storage procedures for handling fall and winter pears has formed the basis for a continued improvement in the commercial handling of these varieties. The above factors have received attention in the present studies only insofar as they might affect the physiology or biochemistry of the experimental fruit.

Information relative to the physiological response of fall and winter pears to various handling, storage, and ripening practices was decidedly limited prior to the initiation of these studies in 1931. This publication presents information relative to the physiological and biochemical response of different varieties of pears picked at various maturities to handling, storing, and ripening procedures. The results of measurements of respiration, acetaldehyde, ethyl alcohol, carbohydrate, pectin, enzyme, and astringency served as criteria in following these responses. Certain of these determinations were also used in following the course of scald, core break-down, and loss of normal ripening capacity in pears. The results of these studies should lead to a better understanding of the physiology and biochemistry of the different varieties of fall and winter pears.

REVIEW OF LITERATURE

The following brief review of the experimental work with pears is confined to that dealing with physiological and biochemical changes. Maturity, storage, and ripening studies are reviewed only insofar as they relate to the physiology and chemistry of the fruit. For a detailed review of harvesting and storage studies, reference is made to the work and appended bibliographies of Hartman (*23*, *24*), Diehl,[4] Allen (*1*), and Pentzer (*38*).

Gore (*13*) studied the respiratory activity of Kieffer pears at temperatures from 2.9° to 34.4° C. He found the Q 10 (Van't Hoff temperature coefficient for a 10° difference in temperature) to be 2.24, since the respiratory activity doubled after each rise in temperature of 8.6°. He reported no stimulus in the rate of respiration due to picking from the tree. In studying the respiration of Kieffer pears at different storage temperatures, Lutz and Culpepper (*33*) obtained the greatest activity during storage at 15.5°. They found the rate of respiration to be directly associated with the rate of softening. Storage temperatures of 26.6° and 32.2° effected a diminution of both respiration and softening.

Kidd and West (*30*) studied the respiratory activity of Conference and Comice pears as influenced by maturity at time of harvest and after storage at 12° C. Respiratory activity was greater in the less mature fruit both at the time of gathering and at the peak of the climacteric rise. Carbon dioxide production, however, was remarkably similar for the two varieties of pears. The incidence of the respiratory climacteric at 12° was much earlier in the more mature fruit. The peak of the climacteric, irrespective of the maturity or

[4] DIEHL, H. C. HARVESTING PEARS TO OBTAIN BEST QUALITY. Rev. 1930. [Mimeographed.]

variety, always occurred when the fruit was eating ripe. Hansen and Hartman (*19*) found that ethylene increased the respiration of Anjou and Comice pears both at harvest and after short periods of cold storage at −0.5° and 2.8°. The magnitude of the stimulation, however, decreased as the length of storage increased, and after 2, 6, and 8 weeks, Bosc, Comice, and Anjou, respectively, failed to respond to ethylene treatment. This lack of further chemical stimulation was associated with a natural increase in the respiratory activity of the fruit.

Tindale and others (*44*) found that the carbon dioxide production of Bosc, Howell, and Winter Nelis pears stored at 32° and 37° F. increased to a maximum and eventually declined to a point where respiratory activity ceased. The latter point coincided with the death of the fruit through disintegration of the tissue. Similar results had previously been reported by Gerhardt and Ezell (*10*) for Comice at 32°. The respiratory climacteric of all the varieties studied by Tindale and others (*44*) appeared several weeks earlier in storage at 37° than at 32°. Furthermore, these authors found the initial rate of respiration and the storage life of Williams Bon Chretien [Bartlett] pears at 37° was not influenced to any extent by either size or maturity. At 32° the climacteric occurred 10 days earlier in the large-sized fruits than in the small and 22 days earlier in the more matured fruits than in the least mature. The storage life of the more mature fruit was only 1 week less than that of the least mature. In terms of storage life the authors stated that this meant a difference of only 3 and 7 days, respectively, a period of little practical importance.

Ezell and Gerhardt (*8*) found no correlation between respiration, oxidase, and catalase activity of Anjou pears at 32° F. They found the respiration rate of Bosc pears at 30° and 36° to be practically the same in fruit from three different producing areas on the Pacific coast, whereas the enzyme activity varied widely.

Emmett (5) concluded that total solids and sugars of Conference pears decreased at practically a constant rate during the entire storage life of the fruit. She found a close correlation between the rate of ripening and the rate of conversion of protopectin to soluble pectin. This author reported that pectic changes occurred more rapidly in pears than in apples at 12° C., whereas at 1° the reverse was true. She suggested that acids may be involved in the pectic conversions in apples, while in pears this process may be chiefly enzymatic. Martin (*36*) in a chemical study of the ripening process of Bosc pears, found a loss in weight of about 0.5 percent per day. Levulose and total sugars increased whereas sorbitol decreased during ripening. With the exception of an increase in sucrose, differences in maturity were not reflected in the results of carbohydrate analyses. When pears were ripened at harvest after treatment with ethylene, Hansen (*17*) found an increase in starch hydrolysis and a corresponding accumulation of sugars. Ethylene also catalyzed the hydrolysis of protopectin.

Lutz and Culpepper (*33*) reported that differences in quality of Kieffer pears, as influenced by various ripening temperatures, were not reflected in the results of chemical analyses for solids, sugars, and acids. Starch was not generally present, and in this respect the Kieffer variety differs from certain high-quality pears of which the sugar content increases through hydrolysis of starch. These authors found the rate of hydrolysis of protopectin to soluble pectin was closely associated with the rate of softening. This rate was highest at 60° F. and decidedly lower at 32° and 90°. Gerhardt and Ezell (*11*) found that carbohydrates in winter pears were influenced by maturity and by variety. Levulose and sucrose were the predominant sugars present, and their accumulation varied directly with the maturity of the fruit at harvest. Comice and Bosc varieties had a higher percentage of these sugars than did Anjou or Flemish Beauty.

Moore (*37*) found the mineral constituents highest in the Bosc variety and lowest in Winter Nelis, and an unusually low iron-copper ratio compared with other foodstuffs. The alkalinity of the ash of winter pears varied from 3.6 (cubic centimeter of N/1 Hcl per 100 gm. tissue) for Comice to 5.7 for Winter Nelis.

Epinastic responses of tomatoes confined with pears led Hansen and Hartman (*18*) to conclude that ethylene is produced by Anjou and Winter Nelis pears. Peelings as well as peeled pears produced epinasty, but pear tissue rendered inactive by freezing or by chloroform produced no response. These authors also presented chemical evidence to indicate that ethylene is present in winter pears.

Acetaldehyde and ethyl alcohol have been found as products of normal and abnormal metabolism of pear fruits (*10, 21, 22, 29, 44*). The accumulation of these volatiles in abnormal amounts has usually been associated with scald (*22*), core break-down (*21, 10*), over-ripeness (*44*), loss of ripening capacity (*10*), and artificial storage atmospheres (*27, 29*). It has been suggested by Hulme (*27*) that these volatiles accumulate as a result of the gradual failure of the oxidative mechanism to function in fruit during the latter stages of senescence. Tindale and others (*44*) concluded that acetaldehyde is formed as an intermediate substance of partial oxidation during respiration. The rate at which it increased was greatest in pears that failed to ripen normally at 65° F., and its concentration reached a maximum with the appearance of core break-down. Harley (*21*) found a similar correlation between acetaldehyde and core break-down in Bartlett pears. In advanced stages of senescence, cellular disintegration and general collapse of the tissue served to restrict the normal aerobic processes of oxidation, and with the onset of anaerobic or fermentative processes, ethyl alcohol was produced in increasing amounts (*44*).

Winter pears have a rather definite storage life, the length of which is dependent upon the variety, maturity, storage temperature, and prestorage handling practices. Under optimum conditions, the commercial storage life at 32° F. of the different varieties has been reported as follows: Bosc (*25, 44*), Comice and Seckel (*25*), and Kieffer (*25, 33*) 90 to 100 days; Anjou (*25*) 150 to 180 days, and Winter Nelis (*25, 44*) 160 to 180 days. In studying the length of the commercial storage life of winter pears, Tindale and others (*44*) found that with the exception of Winter Nelis this period was about three-fifths of the time required to reach the respiratory climacteric and two-fifths of the time before scald appeared. That the storage life of Comice, Conference, and Winter Nelis varieties can be materially extended by gas storage has been shown by the studies of Kidd and others (*29*). They found that subnormal concentrations of oxygen from 20 to 2 percent did not significantly retard ripening, but that 0.2 percent of oxygen caused a marked retardation. Carbon dioxide, in the presence of more than 2 percent of oxygen, greatly retarded ripening, and the degree of retardation was dependent upon the atmospheric concentration of this gas. Gerhardt and Ezell (*12*) have reported similar results for Bartlett pears.

The potential storage life of each variety of pears is directly dependent upon the storage temperature. For winter pears, Tindale and others (*44*) found this period decreased one-fifth for every 3° F. of increase in temperature between 32° and 37°, and Hartman et al. (*25*) estimated that 1 day's storage at 65° reduced the subsequent storage life at 32° by 10 days.

Studies on the ripening of winter pears have received the attention of several investigators. Most varieties of pears do not ripen properly when held continuously at 32° F., and in order to obtain the best dessert quality the fruit should be transferred to temperatures of 60° to 70° for ripening (*25, 33, 38, 44*).

Certain varieties fail to soften and ripen properly upon removal to temperatures of 60° to 70° F. after prolonged storage at lower temperatures (*25, 28, 44*). This loss of ripening capacity in pears has been described by Kidd and West (*28*) as a form of low-temperature injury. Such fruit may appear to be in excellent condition and yet upon removal to ripening temperatures it fails to soften normally, develops an abnormal flavor, and scalds badly or develops break-down at the core. This loss of ripening capacity sometimes results in heavy financial losses. Little is known concerning the physiology or biochemistry of this storage disorder.

MATERIAL AND METHODS

Source and Selection of Material

Flemish Beauty, Comice, Bosc, and Anjou pears were used in the studies reported herein. In 1931, 1932, and 1933, fruits of these varieties were harvested from typical, vigorous trees of full bearing age, grown in the Wenatchee Valley in Washington. The Anjou trees were growing in a heavy loam soil and the other varieties in a sandy loam. Cultural practices were standard for the district. The quantity of fruit required for the storage experiments varied from year to year, depending upon the particular studies being made. In work on the Bosc variety usually the entire crop from three trees was used, whereas in that on the other varieties fruit from a single tree of each was generally sufficient. In 1934 the work was expanded to include a comparative physiological and storage study of the Bosc variety as grown in the Wenatchee and Yakima valleys of Washington and in the pear district of Medford, Oreg. Representative fruit from three trees in each district was harvested at optimum maturity and brought together for storage at temperatures of 30° and 36° F. at Yakima, Wash.

Whenever maturity was studied in relation to biochemical and storage behavior, three pickings were made, the second usually coinciding with the commercial harvest when the pressure test met the recommendations of Pentzer and others (*38*). The first and third pickings were spaced so as to secure relatively immature and more mature fruit. In those seasons in which a single picking was made, ground color, finish, and firmness were used as indexes of maturity. Firmness was measured throughout by taking the pressure of the pared flesh of 10 representative pears by means of the United States Department of Agriculture pressure tester having a 5/16-inch plunger.

HANDLING, STORAGE, AND RIPENING

Unless otherwise specified, the fruit was harvested in the morning and the spray residue was removed by washing in a 1-percent hydrochloric acid solution at 90° F. in a single-process washing machine. It was then wrapped in either oiled or plain paper and placed immediately under the desired experimental storage environment. The fruit was stored at a temperature of 32° and a relative humidity of 80 to 85 percent unless otherwise stated. When delayed storage was used the fruit was held at 65° for the required number of days prior to storage at 32°. The time from harvest to storage was usually less than one-half of a day. During this interval representative samples were taken. Respiratory and enzymatic measurements at harvest were usually made within 24 hours from the time of picking. Ripening cabinets were maintained at a temperature of 65° and a relative humidity of 75 to 85 percent. All ripening data are based on the fruit after removal from low storage temperatures and after varying periods in the ripening cabinets except that ripened at harvest without being subjected to low-temperature storage.

PHYSIOLOGICAL METHODS

RESPIRATION

From 35 to 50 representative fruits (9 kg.) were placed in wide-mouthed, 5-gallon, glass pickle jars fitted with rubber sealed covers bearing a copper inlet and outlet tube. These tubes were left open between periods of aeration. The fruits were aerated at least 24 hours per week to minimize the effect of accumulated carbon dioxide on the respiratory activity of the fruit. Prior to respiratory determinations the fruit was aspirated with carbon dioxide-free air for 48 hours at a rate of 10 or 18 liters per hour (depending upon the storage temperature) by manipulation of calibrated flowmeters. The respired carbon dioxide was removed from the air stream as barium carbonate by passage through a solution of 0.3 N barium hydroxide in a Truog absorption tower. (See figs. 1 and 2.) The carbon dioxide equivalent was established by titration of the barium hydroxide solution with 0.2 N hydrochloric acid and expressed as mg. CO_2 per kg. per hour.

ENZYMES

Ten or more fruits were used at each sampling. The technique of preparing the fruit tissue for enzyme analysis was essentially that described by Ezell and Gerhardt (*8*). Two disks approximately 1 cm. thick were cut from each fruit through its greatest transverse diameter. The sections from the calyx half were used for the catalase measurements. They were weighed, sprinkled with 1-percent calcium carbonate, and ground in a food chopper with a nut-butter attachment. The juice was filtered through cheesecloth and held at 40° F. for 24 hours before its catalase activity was determined in duplicate by a water-displacement method similar to that described by Heinicke (*26*). A mechanical shaker (fig. 3) operating in a constant temperature bath at 25° C. caused a uniform flow of solution 108 times per minute from one arm of the catalase tube to the other. Catalase activity is expressed as cubic centimeters of oxygen liberated in 5 minutes.

FIGURE 1.—Arrangement of the containers, air scrubbers, and fruit in the respiration studies during storage.

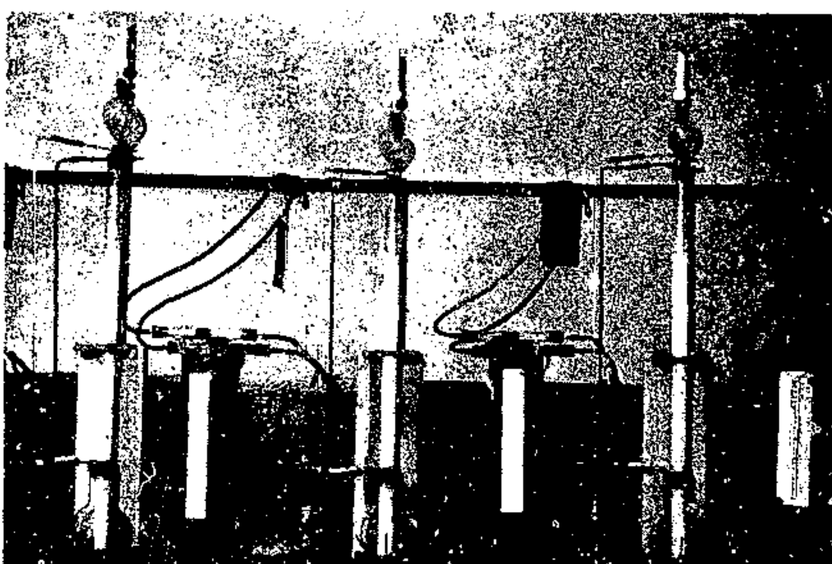

FIGURE 2.—Arrangement of the flowmeters and absorption towers in the respiration studies.

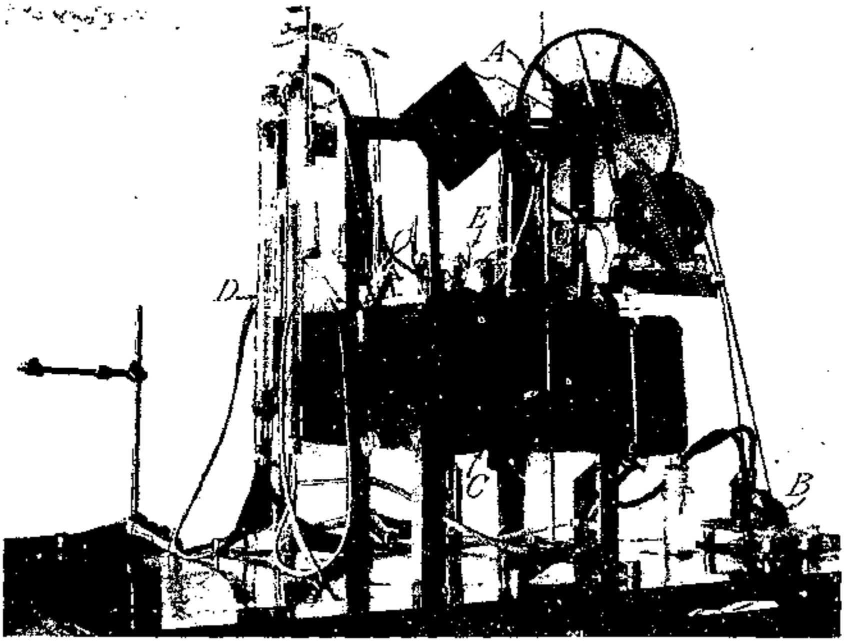

FIGURE 3.—*Apparatus for measuring catalase activity, showing: A, Shaking device; B, water pump; C, constant-temperature bath; D, water-jacketed manometers; and E, catalase-reaction tubes.*

Oxidase samples were obtained from the juice of sections from the stem half of the same fruits used in the catalase work. Oxidase activity was determined iodometrically as described by Guthrie (*15*) and expressed as cubic centimeters of N/100 sodium thiosulphate.

CHEMICAL METHODS

SUGARS AND SOLIDS

Samples for carbohydrate analyses were taken from 20 representative pears by passing a 7/16-inch cork borer through the greatest transverse diameter of each fruit. Following removal of the skin and core tissue, 100 gm. of this material were passed through a Clark press and immersed in boiling 95 percent ethyl alcohol. The samples were preserved for future analysis by boiling with sufficient 95 percent ethyl alcohol to produce a final concentration of approximately 80 percent alcohol.

The technique for handling the alcoholic extracts and the methods for the determination of reducing sugars, total sugars, alcohol-soluble, alcohol-insoluble, and total solids were essentially those as described in detail by Ezell and Diehl (*6*) for 1931. Sucrose was calculated by the difference in the copper reducing power of the clarified sugar solution before and after acid inversion with 5 cc. hydrochloric acid (sp. gr. 1.125) per 50 cc. of sugar solution after standing for 15 minutes at 70° C. The reducing power of the neutralized solution was determined by using the Quisumbing and Thomas (*39*) reduction procedure and the

Shaffer and Hartman iodometric titration method (*40*). Glucose and fructose were measured by using the iodine oxidation procedure as outlined by Lothrop and Holmes (*32*). Sugars and solids were expressed as percentages of fresh weight.

STARCH

The dried alcohol-insoluble-solids residue from the sugar sample was quantitatively transferred (including adhering filter paper) to a 500 cc. screw-top reagent bottle; 300 cc. of a 1-percent solution of potassium oxalate were added and then agitated in a motor-driven shaking machine for 6 to 8 hours. The finely divided, partly colloidal contents of the bottle were filtered through diatomaceous earth and washed free from oxalate with cold water. (The above procedure is essentially that of Widdowson (*45*) and has for its purpose the removal of pectic and other gelatinous substances that interfere with the enzymatic conversion of starch to soluble sugar.) The cold-water-washed residue was then transferred to a 400-cc. beaker, and after the addition of 200 cc. of water, gelatinization occurred after a few minutes of boiling. The contents of the beaker were cooled to 50° C. and, after the addition of a suitable amount of saliva (6–10 cc.), incubated at this temperature until plate tests indicated the disappearance of the characteristic starch-iodide color. If upon reboiling the solution the test remained negative, the clarified filtrate was made to volume and the reducing power determined as previously described for sugars. This reducing power expressed as glucose was multiplied by a factor 2.10 (the factor used being based on actual inversion of pure starch to maltose by trial in this laboratory) and the latter value by the conventional conversion factor of 0.9 for glucose-to-starch. The final value is expressed as percentage of starch in the fresh tissue.

PECTIC MATERIALS

Soluble pectins were determined as calcium pectate according to the method of Carré and Haynes (*8*), using 100 gm. of juice which had been clarified by filtration through diatomaceous earth. Preliminary trials substantiated the work of Haller (*16*) wherein he reported similar values for soluble pectin by using either 100 gm. of tissue or 100 ml. of juice.

Samples for total-pectin determinations were made in a manner similar to those for sugars; 100 cc. of N/30 hydrochloric acid were added to 100 gm. of the macerated pulp. After refluxing for 1 hour, the solids were compressed in a Carver hydraulic press and washed with 50 cc. of N/30 hydrochloric acid. This refluxing and washing procedure was repeated for an additional three times. After filtration through diatomaceous earth, aliquots representing 20 to 40 mg. of calcium pectate were carried forward as in the determination for soluble pectin.

Protopectin (insoluble pectin) was obtained by the difference between the total and soluble forms. The various forms of pectic materials are expressed as percentage of fresh weight.

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TOTAL ACIDITY, HYDROGEN-ION CONCENTRATION, "INDEX FIGURE"

Total acidity was measured by sampling 20 representative fruits with a 5/16-inch cork borer in a manner similar to that previously described for carbohydrate analysis. An equal weight of water was added to 100 gm. of the freshly macerated tissue and the mixture was boiled until the tissues became disintegrated. After cooling, the contents were diluted to 1 liter, filtered aliquots of which were titrated with N/10 sodium hydroxide, using phenolphthalein as an indicator. Total acidity was expressed on a fresh-weight basis as percentage of citric acid.

Hydrogen-ion-concentration measurements were made on the expressed juice from the same fruits that were used in the determination of the total acidity. Hydrogen-ion values were determined electrometrically, using a gold quinhydrone electrode and a saturated calomel cell.

The index figure (*4*) was obtained by dividing the gram-molecules of hydrogen-ions per liter by the millequivalents of H_2 per liter, and represents the ratio of dissociated to total acids present.

ACETALDEHYDE

Acetaldehyde and ethyl alcohol were extracted from the fruit tissue by steam distillation in a manner essentially similar to that described by Fidler (*9*). However, one modification was made that precluded the use of ice for the receptacle bearing the steam distillate. It was found that losses of standardized amounts of acetaldehyde during distillation were less than 2 percent (as found by Fidler to be optimum) when a condenser of sufficient cooling surface was used. The glass condensers used had a jacket length of 25 inches and a sealed-in bulbous inner tube. Duplicate 200-gm. samples of fresh macerated tissue, obtained by cutting disks (seeds removed) from the greatest transverse diameter of 20 fruits, were transferred to 1-liter, round-bottomed, Pyrex distilling flasks. The latter were connected to the steam-distilling apparatus and, after distillation for 2 hours, the distillates were each made to a volume of 1 liter. In those instances in which only acetaldehyde was measured, the steam distillate was led directly into a standardized solution of sodium bisulfite. Acetaldehyde in a 500 cc. aliquot of the original distillate or the entire amount of the bisulfite distillate was determined according to the Ripper method as described by Fidler (*9*). Acetaldehyde is expressed as milligrams per 100 gm. of fresh weight.

ETHYL ALCOHOL

The remaining 500-cc. portion of the original steam distillation was used for the determination of the total ethyl alcohol. Oxidation to acetic acid was accomplished with potassium dichromate and sulfuric acid (sp. gr. 1.8351) in amounts of 10 gm. and 15 cc., respectively. After standing at room temperature for at least 1 hour the mixture was distilled to a small volume, and after frequent additions of distilled water, until the total distillate approximated 750 cc. From the titration of this distillate against N/10 sodium hydroxide with phenolphthalein as an indicator, the total ethyl alcohol was calculated.

This total figure for ethyl alcohol represents that present as such in the tissue and that formed from the acetaldehyde during the dichromate oxidation. According to Fidler (*9*) it is necessary to subtract 1.05 times the acetaldehyde value to obtain the true amount of alcohol. These recommendations have been followed in the present work. Ethyl alcohol is represented as milligrams per 100 gm. of fresh tissue.

ASTRINGENT MATERIALS

Included under the classification of astringent materials is a large group of substances that reduce potassium permanganate under specific conditions. It includes tannin (gallic acid), its methylated derivatives or condensation products, coloring matters, and any of a number of organic reducing materials. The Loewenthal-Proctor method as described by the Association of Official Agricultural Chemists (*2*) was followed in this study, and the data under this heading are presented in three subclassifications, total astringency, tannins, and astringent nontannins. The former were determined by titration with potassium permanganate in the presence of indigo carmine; the latter were measured in the same manner after the removal of tannins by precipitation with gelatin and filtration with kaolin. Tannins were determined by the difference in the two titrations. All results are expresed on a fresh-weight basis as percentage of tannin.

In the studies on the distribution of astringent materials, 200 gm. each of peeling, flesh, and core tissue were macerated and boiled in 400 cc. of water for one-half of an hour. After filtering through diatomaceous earth the aqueous extracts were each brought to a volume of 1 liter. Duplicate 200-cc. aliquots were used for both total and nonastringent tannin determinations. Comparative studies of equal weights of juice and flesh tissue gave similar astringency values. Therefore, in obtaining all of the astringency data bearing on the influence of variety, storage, and ripening capacity, 200 gm. of filtered juice from the flesh tissue were used.

PRESENTATION OF DATA

Respiration of Fall and Winter Pears

The term "respiration" in the present work has reference to the final oxidation of a large heterogeneous group of respirable materials, and the authors have interpreted the carbon dioxide liberated as a measure of the respiratory intensity. Because the latter is a generally accepted index of metabolism, it has been used as an aid in studying the storage behavior of pears as influenced by variety, maturity, delayed storage, and certain handling practices.

Respiration of pears as influenced by varietal differences was studied in Bosc, Comice, Anjou, Flemish Beauty, and Winter Nelis pears that were harvested at their optimum maturity and stored immediately at 32° F. Respiratory determinations were made on fruits from the different varieties at irregular intervals during storage. Data typical of each variety are shown in figure 4.

Except during the first few weeks the respiration rates of all varieties but Winter Nelis gradually increased with the length of storage. Although this increase was small, it should not be overlooked that the metabolism of the fruit was greatly restricted at a temperature of

32° F., and if this increased respiratory activity were expressed on a percentage basis it would be large. The respiratory intensity of Bosc pears was the lowest of the five varieties studied, being similar to that of the Bartlett pear as reported by Magness and Ballard (*35*).

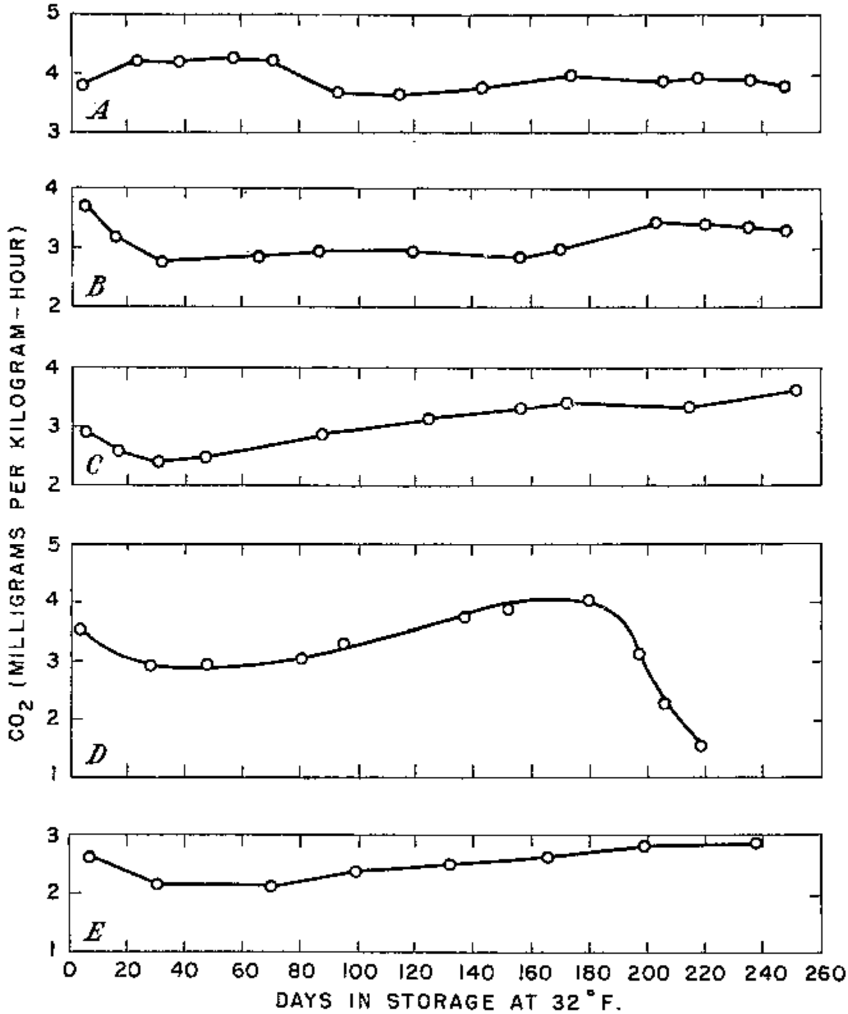

FIGURE 4.—Respiration of fall and winter pears during storage as influenced by variety. *A*, Winter Nelis, harvested October 9, 1931; *B*, Anjou, harvested September 14, 1931; *C*, Flemish Beauty, harvested August 15, 1932; *D*, Comice, harvested September 18, 1931; *E*, Bosc, harvested September 8, 1932.

The Anjou and Flemish Beauty varieties respired at a rate comparable to that of the Kieffer as reported by Lutz and Culpepper (*33*). Comice was the only variety in which surface scald and core break-down became apparent at temperatures of 32°. The restriction in respiratory activity of this variety late in the storage season, as shown in figure 4, *D*, was closely associated with the presence of the above storage disorders. A similar relationship between respiration and the presence of pear scald has been reported for Bosc by Tindale and others (*44*). That the rate of respiration is not a true indication of the potential storage life of pears when comparing one variety with another is shown in figure 4, *A* and *E*, wherein Bosc, with a relatively short storage life, is shown to respire more slowly than Winter Nelis, which at 32° has a storage life more than twice as long.

The life of pears in cold storage is directly dependent upon their handling between harvest and storage. Subjecting them to high

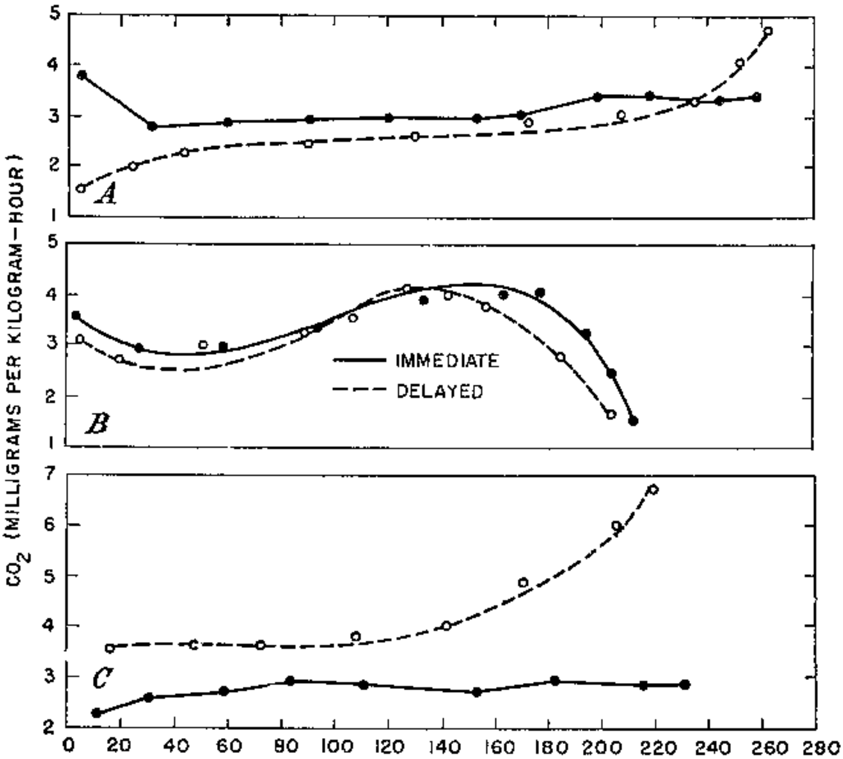

Figure 5.—Respiration of fall and winter pears during storage as influenced by immediate and delayed refrigeration after harvest. *A*, Anjou, harvested September 14, 1931; *B*, Comice, harvested September 18, 1931; *C*, Bosc, harvested September 27, 1933. In *A* and *B* the pears were held 7 days at 65° F.; in *C*, 2 days at 65° followed by 10 days at 45° (simulated transit conditions).

temperatures between harvest and storage is detrimental to fruit intended for extended storage (*44*). The effect of such temperatures during delay before cold storage is indicated by the data in figure 5, wherein the respiratory intensities of immediate and delayed storage lots of Anjou, Comice, and Bosc pears are compared.

The data in figure 5 indicate that during the normal commercial storage life of pears at 32° F. the rate of respiration is not directly correlated with the handling treatment immediately following harvest. In figure 5, *A* and *B*, delayed storage after harvest resulted in a lower respiratory activity of such fruit during the commercial storage period at 32°, whereas in *C* such treatment induced a more rapid rate of respiration.

After prolonged storage at 32° F., however, respiratory activity could be correlated with handling practice at harvest. In this case the respiration rate of Bosc and Anjou pears increased rapidly and reflected an advanced degree of ripeness, as indicated by color and texture of the fruit. In Comice, figure 5, *B*, scald and depression of the respiratory intensity occurred approximately 6 weeks earlier when the fruit was delayed for 7 days at 65° at harvest than when it was stored immediately at 32°.

Maturity at harvest is a vital factor in the storage life of pears destined for long storage at low temperatures (*24*). Usually fruit of more advanced maturity has a shorter storage life. Results in

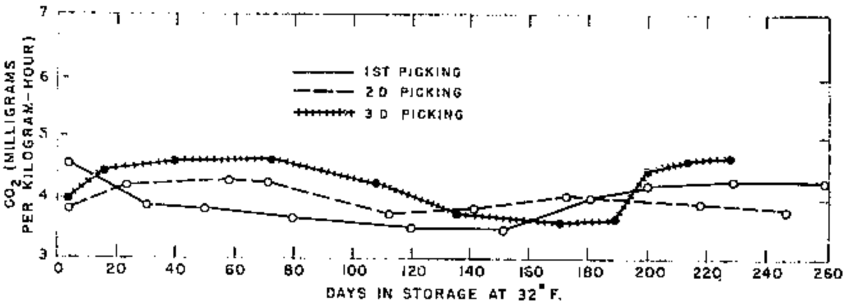

FIGURE 6.—Respiration of Winter Nelis pears during storage as influenced by maturity at harvest. Fruit stored immediately at 32° F. First picking harvested September 15, 1931; second picking harvested October 9, 1931; third picking harvested October 30, 1931.

figure 6 show that the maturity of Winter Nelis pears influences their rate of respiration during storage. Even when harvested within the range of marketable maturity, the fruit from the late picking generally had a higher respiratory intensity than did that of the two earlier pickings. Furthermore, after 180 days of storage at 32° F. the more mature fruit began to ripen rapidly. This change in ripening rate was also correlated with a marked rise in the respiration of such fruit. The increase in respiratory activity of the first picking after 150 days of storage was not accompanied by a similar accelerated ripening as noted for the third picking. The less mature fruit wilted badly and this factor may have influenced the rate of respiration. The relation between advanced maturity and respiration is substantiated by additional unpublished results with Bartlett, Comice, and Anjou pears. Tindale and others (*44*) have also reported that advanced maturity of Bartlett pears caused a greater respiratory intensity and a shorter storage life at 37°, whereas Magness and Ballard (*35*) found that early picked Bartlett pears respired at a lower initial rate and that this rate increased less rapidly after storage than in the later-picked fruit from the same tree. The data in figure 6, as well as those of the aforementioned authors, do not support the results of Kidd and West (*30*) who found a greater respiratory activity in the less mature Conference and Comice pears both at harvest and at their climacteric.

Obviously there is some accumulation of carbon dioxide in the respiration jars (fig. 1) between periods of aeration; the amount, however, could not be measured with a Hayes gas analyzer. That this accumulation might influence the respiration rate and also the ripening of the fruit therein is possible, because Willaman and Brown (*46*) observed a temporary higher output of CO_2 (due to the partial pressure of the dissolved CO_2 in the cell sap) from twigs and potato tubers during prolonged aeration following periods of storage in closed chambers.

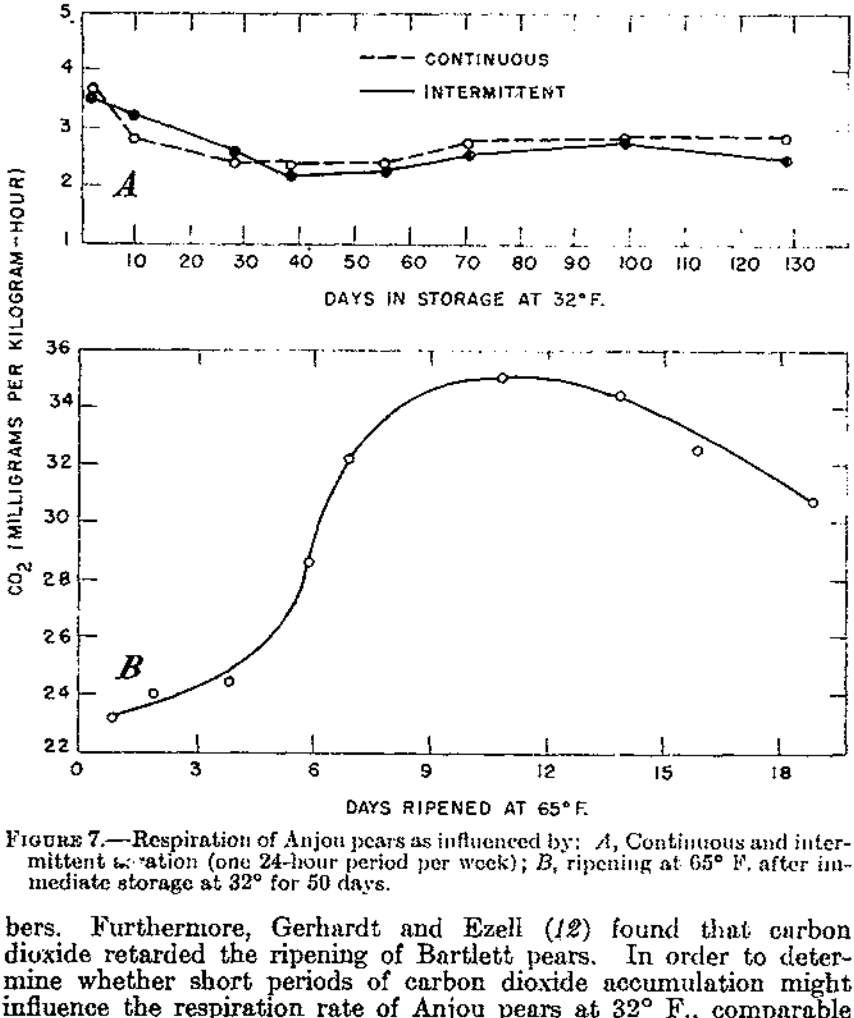

FIGURE 7.—Respiration of Anjou pears as influenced by: *A*, Continuous and intermittent aeration (one 24-hour period per week); *B*, ripening at 65° F. after immediate storage at 32° for 50 days.

Furthermore, Gerhardt and Ezell (*12*) found that carbon dioxide retarded the ripening of Bartlett pears. In order to determine whether short periods of carbon dioxide accumulation might influence the respiration rate of Anjou pears at 32° F., comparable lots of fruit were aerated either continuously or intermittently between runs during a period of 130 days. The respiration curves for this experiment are shown in figure 7.

There was no significant difference in respiratory intensity between the two lots of pears. Evidently a 24-hour period of aeration per week was sufficient to overcome the respiratory change in the fruit due to gaseous accumulation of carbon dioxide within the container.

During normal ripening pear fruits undergo decided changes. During the first 5 days in the ripening room little change in respiratory activity was noted in Anjou pears. Beginning with the sixth day, however, respiration increased rapidly, the climacteric being reached on the eleventh day of ripening. The shape of the respiratory curve of ripening Anjou is similar to that of Bartlett pears (*8*). The crest of the respiration rate was correlated with optimum dessert quality of the ripened fruit. Senescent changes after 11 days at 65° F. resulted

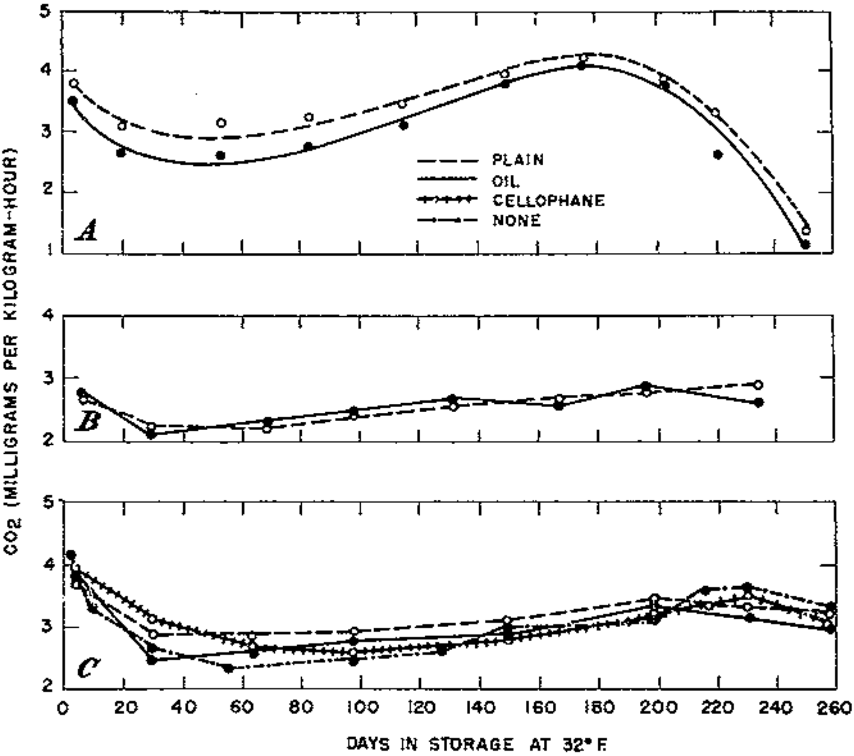

FIGURE 8.—Respiration of fall and winter pears during storage as influenced by type of fruit wrap. Immediate storage 32° F.: *A*, Comice, *B*, Bosc, *C*, Anjou. The oiled fruit wraps were of commercial stock and contained 17.5 percent oil. Cellophane wraps were of the moistureproof grade.

in over ripeness. The latter condition was associated with a diminution in respiratory intensity. A comparison of figures 7, *B*, and 24 indicates that acetaldehyde accumulation in ripened pears continued for approximately 7 days after the interval of greatest respiratory activity.

Some form of fruit wrap is used in packaging the major portion of the fall and winter varieties of pears grown in the Pacific Coast States. A comparative study was made of the respiration of Bosc, Comice, and Anjou varieties as influenced by the kind of fruit wrap. Data typical of this study are summarized in figure 8.

With the possible exception of Comice, use of plain or oiled paper or cellophane wraps did not influence the respiratory intensity of pears during storage at 32° F. With the exception of differences in loss of moisture and in the prevention of surface scald in the Anjou variety, storage and ripening responses were also similar.

Preliminary storage and ripening observations in 1933 suggested a variance in the quality of Bosc pears from different producing districts. A more comprehensive study of the storage behavior of this variety of pears, as grown in different localities, was initiated in 1934. Fruit from the Wenatchee and Yakima valleys of Washington and from the

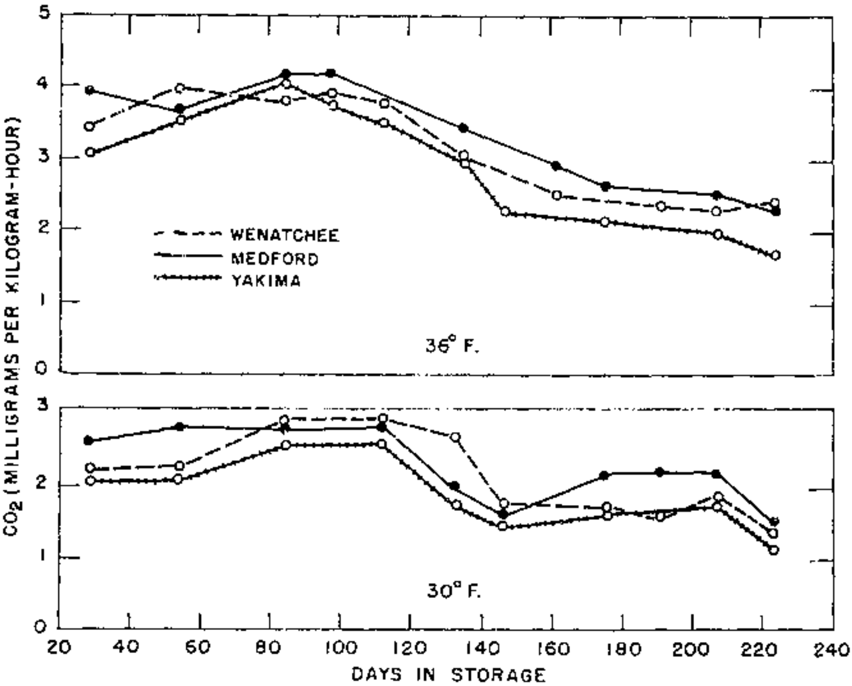

FIGURE 9.—Respiration of Bosc pears during storage as influenced by temperature and by producing district.

Medford district of Oregon was harvested at optimum maturity and stored immediately at 30° and 36° F. Cultural practice, tree age and load, and soil type were similar for the two districts of Washington. In Oregon, however, the trees were much larger and older, and bore a lighter load of smaller fruit. The soil types and irrigation practices also differed considerably from those of the other two districts.

The results of studies of the respiratory activity of fruit from the different districts during storage at 30° and 36° F. are presented in figure 9.

The respiratory intensity of Bosc pears from the three producing districts was similar. Although the magnitude of the respiratory climacteric was greater at 36° F., its time of inception was approximately the same at both temperatures. Bosc pears respired more rapidly during storage at 36° than at 30°, increased respiratory activity being correlated with a shorter storage life. However, this increased respiratory activity could not be correlated at either temperature with loss of ripening capacity or difference in the dessert quality of the ripened fruit. Differences in cultural practices and growing conditions of the three producing districts could not be correlated with differences in respiratory activity at low temperatures.

Enzyme Activity of Fall and Winter Pears

Because oxidase and catalase apparently play such an important part in the metabolism of fruits, it was thought desirable to study the effect of various factors on the activity of these enzymes at harvest, during storage, and at ripening. The activity of these enzymes in the different varieties was studied in relation to maturity, storage

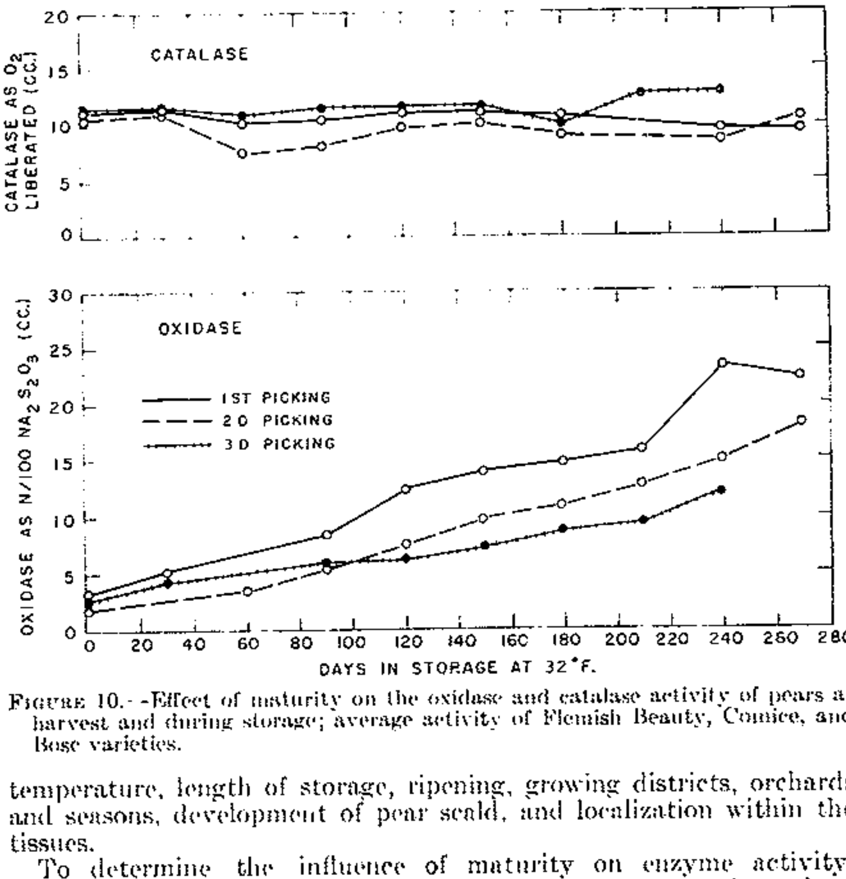

Figure 10.—Effect of maturity on the oxidase and catalase activity of pears at harvest and during storage; average activity of Flemish Beauty, Comice, and Bosc varieties.

temperature, length of storage, ripening, growing districts, orchards and seasons, development of pear scald, and localization within the tissues.

To determine the influence of maturity on enzyme activity, Flemish Beauty, Comice, and Bosc pears were harvested at three maturities. The second picking represented the optimum maturity for commercial harvesting; the first and third pickings were 2 weeks earlier and later, respectively. The fruit was stored at 32° F. immediately after harvest, and the oxidase and catalase activity were determined at harvest and at intervals during storage.

Figure 10 represents the average oxidase and catalase activity of the three maturities. There was a tendency for the oxidase activity to be greater in the immature fruit and this became more evident in storage. The authors (7) have previously reported the same to be true for Bartlett pears. The late-picked fruit showed greater oxidase activity at harvest and during early storage than did that picked at optimum maturity. However, during late storage the oxidase activity was least in the late-picked fruit. Catalase activity varied rather widely within a variety, nevertheless it averaged slightly less in fruit harvested at optimum maturity.

In order to study the influence of storage temperature on enzyme activity, Flemish Beauty, Comice, Bosc, and Anjou pears were picked

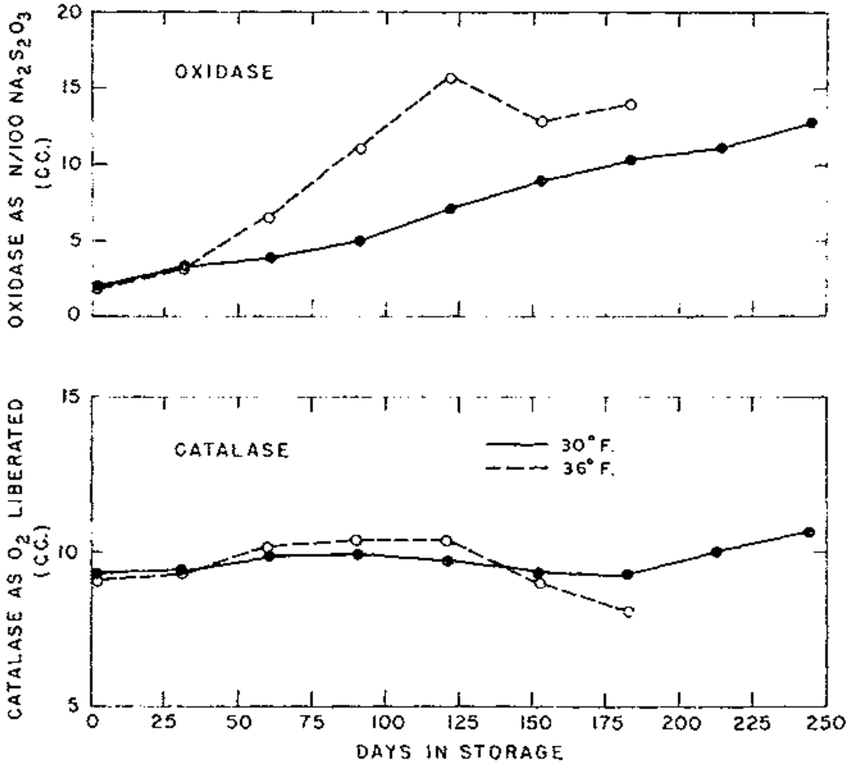

FIGURE 11.—Oxidase and catalase activity during storage of pears as influenced by storage temperatures of 30° and 36° F. Each curve represents the average of Flemish Beauty, Comice, Bosc, and Anjou varieties.

at their optimum maturity and stored immediately at 30° and 36° F. Results of oxidase and catalase determinations made on the fruit from each temperature at intervals throughout the storage season are presented in figure 11.

The oxidase activity was higher in fruit stored at 36° F. There was an increase in activity with length of storage at both temperatures. At 36° this activity reached its maximum in 125 days and then decreased toward the end of the storage season. Although fruit stored at 30° never showed as much oxidase activity as that stored at 36°, it attained a maximum at the end of the season and gave no indication of decreasing late in the storage season, except in the Flemish Beauty variety.

Catalase determinations showed less response to storage temperatures than did oxidase. Fruit stored at 36° F. reached a maximum in about 125 days and then declined slowly. At 30° the catalase remained fairly constant until near the end of the storage season when there was a gradual increase.

Oxidase activity at all maturities (fig. 10), at both temperatures (fig. 11), and in all varieties (fig. 13), increased with the length of storage. The increase was greatest in the earliest picked fruit with a maximum increase of 700 percent in the immature Comice. At 36° F. oxidase activity increased to a maximum and then declined late in the storage season. In fruit stored at 32° or lower, the increase

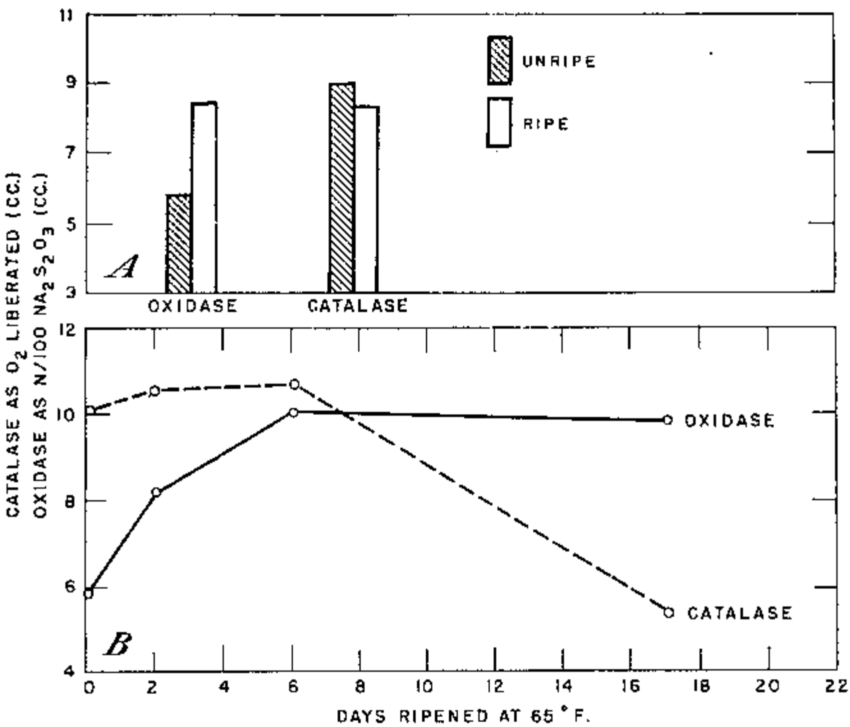

FIGURE 12.—Effect of ripening on the oxidase and catalase activity of pears. *A*, Average of 27 samples of Flemish Beauty, Comice, Bosc, and Anjou direct from cold storage and after ripening to prime eating condition; *B*, average enzyme activity of the same varieties direct from cold storage and at different intervals during ripening at 65° F.

continued throughout the storage season and never reached a maximum as great as in that stored at 36°. In general, length of storage had comparatively little effect on the catalase activity. (See figs. 10, 11, and 13.) It should be noted that these determinations extended over a longer period than the normal storage for Flemish Beauty, Comice, and Bosc varieties and beyond the period at which they will ripen normally. There was no definite break in the enzyme activity at the time the fruit failed to ripen. This would indicate that the failure to ripen is not due to a failure of the oxidase or catalase system to function normally.

For the purpose of studying the relation between ripening and enzyme activity, Flemish Beauty, Comice, and Bosc pears from the Wenatchee district were harvested at three maturities, early, commercial, and late, and stored at 32° F. In addition, Anjou pears from pickings at commercial maturity were stored at 30° and 36°, and Bosc pears from the Medford district of Oregon and from the Yakima district of Washington were stored at 30°. During the

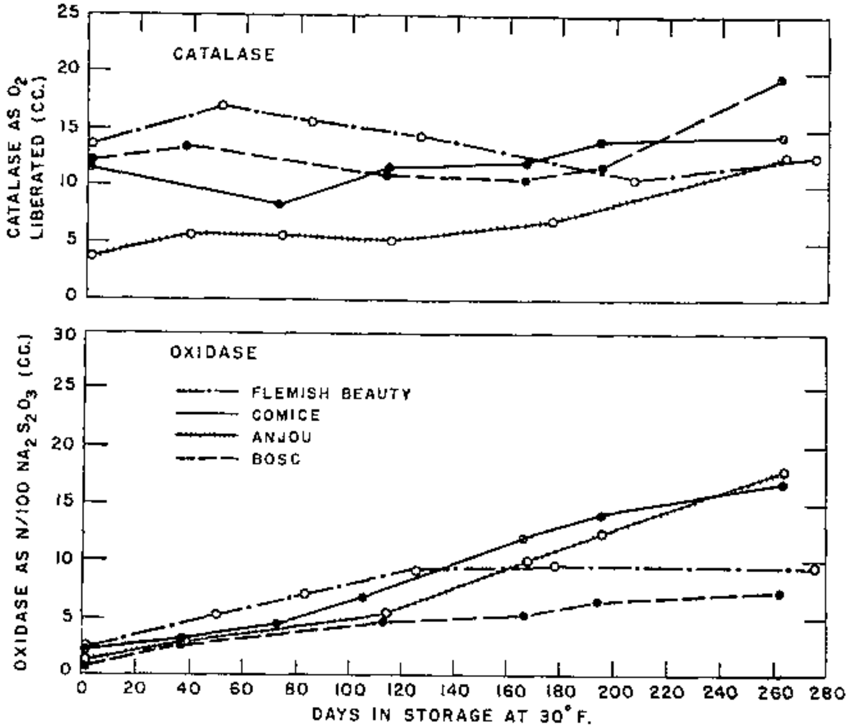

FIGURE 13.—Oxidase and catalase activity of different varieties of pears at harvest and during storage at 30° F.

storage season and while the fruit would still ripen normally, oxidase and catalase determinations were made on 27 samples of these lots, both before and after ripening to prime eating condition. As shown in figure 12, the oxidase activity was definitely higher in the ripened than in the unripened fruit and the catalase activity was somewhat lower. In all instances the ripe fruit was higher in oxidase than the unripe with the exception of Bosc stored at 30°, in which all lots showed less activity in the ripe fruit.

The enzyme activity of Flemish Beauty, Comice, and Bosc pears from 32° F. storage was determined at intervals during ripening (fig. 12, *B*). Both enzymes increased during the first few days at 65°. The oxidase activity then remained almost constant until the pears were long past prime eating condition, but the catalase activity decreased as ripening progressed.

Pear varieties differ greatly in the length of time during which they can be stored and ripened successfully. In order to determine whether this characteristic might be due to differences in enzyme content, the oxidase and catalase activity of Flemish Beauty, Comice, Bosc, and Anjou pears were determined at harvest and at intervals during the storage season of 1934–35. The oxidase content of all varieties was low at harvest (fig. 13) and gradually increased during storage at 30° F. Varieties showed a wide difference in catalase content at harvest but the dissimilarity became less during storage. Although the oxidase and catalase content of the fruit depends to some extent on

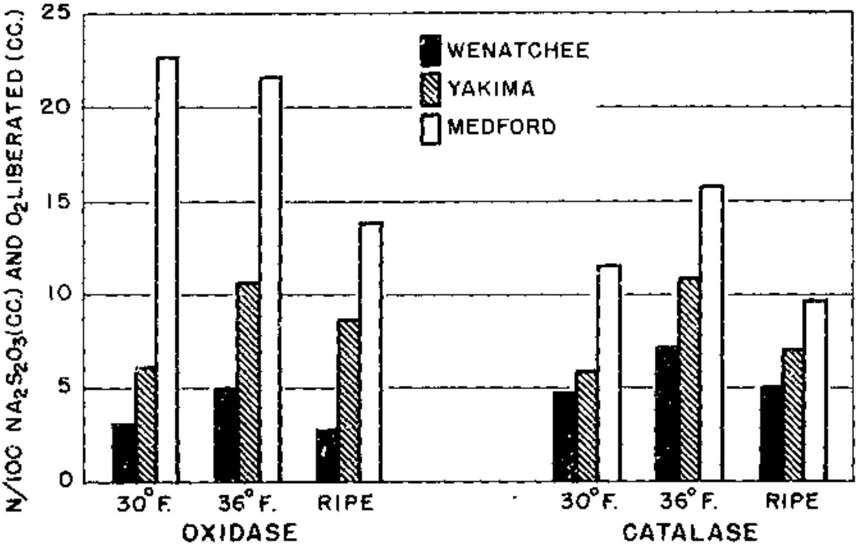

FIGURE 14.– Oxidase and catalase activity of Bosc pears from different producing districts as influenced by storage at 30° and 36° F. and by ripening at 65°.

the variety, it appears unlikely that these enzymes are responsible for the characteristic varietal behavior of pears in storage.

In order to determine whether the oxidase and catalase content was fairly constant in a variety or whether it varied with climatic or growing conditions, Bosc pears from the Wenatchee and Yakima districts of Washington, and from the Medford district of Oregon, were harvested at optimum maturity, as recommended by Pentzer et al. (*38*), and stored at 30° and 36° F. within 24 hours after harvest. Oxidase and catalase determinations made on fruit directly from the two storage temperatures, and on fruit removed from the 30° storage and ripened at 65°, showed that the Medford fruit contained about 5½ times as much oxidase as the Wenatchee fruit and about 3 times as much as that from Yakima (fig. 14). Medford Bosc pears also contained about twice as much catalase as Wenatchee Bosc and 60 percent more than the Yakima fruit.

Because it was shown that the enzyme activity varied widely in pears of the same variety when grown in different districts, the variation in the same variety grown within a single district was then studied. Anjou pears from three orchards and Bosc pears from two in the Wenatchee district were selected and oxidase and catalase activity determined at harvest and during storage. Two of the Anjou orchards were at an elevation of about 850 to 900 feet; one of them was on a sandy loam and the other on a heavy loam. The third orchard was on a heavy loam but situated at an elevation of approximately 2,400 feet. In one of the Bosc orchards (orchard F) the trees were growing on a medium loam soil and two lots of fruit were taken, one from a heavily loaded tree, and the second from a tree bearing a medium load. Both trees were in good vigor and the difference in load apparently was due either to unequal thinning or to

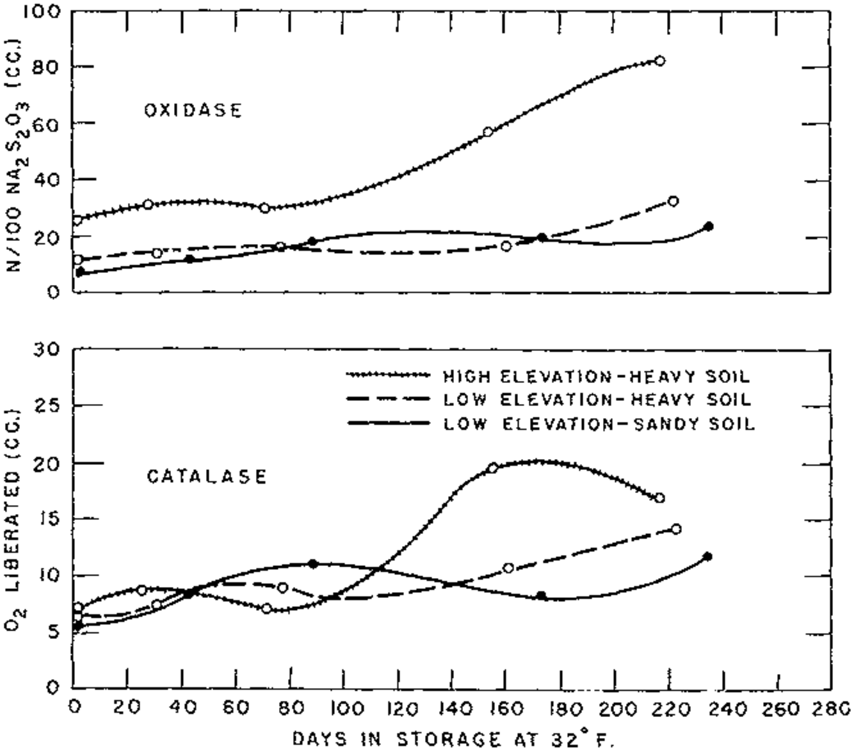

FIGURE 15.—Oxidase and catalase activity at harvest and during storage of Anjou pears from different orchards in the Wenatchee district.

the amount of fruit set. The second orchard (orchard D) located nearby was on a slightly heavier soil and many of the fruits failed to develop the normal number of seeds. The enzyme activity in the various lots of Anjou pears is shown in figure 15. Similar data for Bosc pears are shown in figure 16.

Anjou pears grown at the higher elevation were definitely higher in oxidase activity both at harvest and during storage. They also gave a higher pressure test at the time the fruit was harvested commercially. Oxidase activity was slightly greater on the heavy soil than on the sandy soil (average 17.9 against 15.4 cc., and only lower, 1.5 cc., at one key point on the curve) even though the pressure test at harvest was slightly greater on the sandy soil. However, the differences were not very great and may not be significant. The fruit from the higher elevation tended to show somewhat greater catalase activity, although the results were not conclusive.

At the time of harvest there was little difference in the oxidase content of Bosc pears from the two trees used, one bearing a heavy load and the other a medium load. During late storage (beyond the

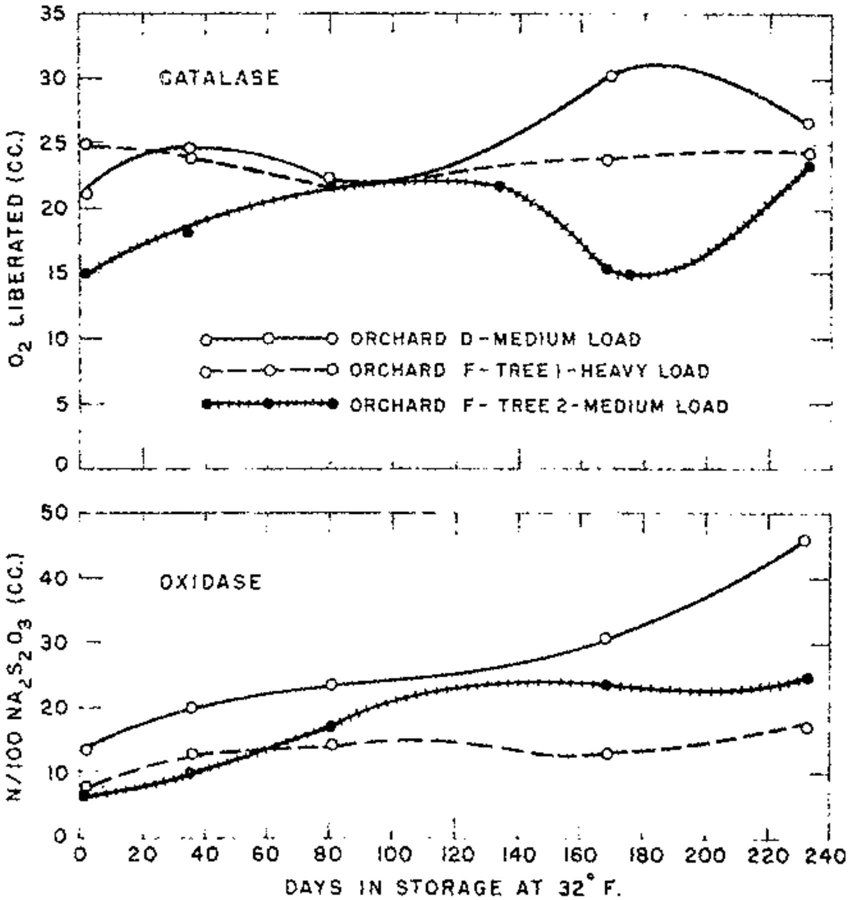

FIGURE 16.—Oxidase and catalase activity during storage of Bosc pears from different orchards and from trees bearing heavy and medium loads of fruit in the same orchard.

commercial storage season), the oxidase activity of the fruit from the heavily loaded tree was less than from the one that bore a medium crop. Fruit from the latter tree tested 1.7 pounds harder at harvest than fruit from the heavily loaded tree. Thus the increase in oxidase activity during storage might be due to this difference in firmness or maturity. The fruit from orchard D averaged higher in both oxidase and catalase than fruit from orchard F, but, as it was found that many of the fruits were abnormal in the number of seeds which they developed, the results may not be representative and their significance may be questioned. The fruit from the tree having a medium load in orchard D had about the same firmness at harvest as did fruit from the lightly loaded tree in orchard F.

Bosc pears from Medford, Oreg., grown on a light sandy soil and another lot grown on a clay adobe soil showed the same oxidase activity during storage in November, which was 50 percent greater than in fruit grown on a heavy loam soil in the Yakima district of Washington. Catalase activity of fruit from the Medford sandy soil at this time was 15.1 cc.; from the clay adobe soil, 22.2 cc.; and from the heavy loam at Yakima, 25.8 cc. This latter figure is slightly greater than for any of the Wenatchee lots at this time. In a previous publication (*8*) the authors have shown that the enzyme activity of Bartlett pears varies between orchards.

In order to obtain information relative to the seasonal variation in enzyme activity, Anjou, Bosc, and Comice pears were harvested from the same orchards in 1934 and 1935. The chief difference between these years was one of earliness of growing season. In 1934–35 Bosc and Comice were harvested on August 6 and Anjou on August 20, whereas in 1935–36 Bosc were picked on September 9 and Comice and Anjou on September 17. Using firmness of the flesh when measured by the pressure tester as an index of maturity, there was approximately 4 to 6 weeks' difference in time of harvest between the two seasons. The pressure tests at harvest for the 1934–35 and the 1935–36 seasons were as follows: Anjou, 11.4 and 11.6; Bosc, 12.9 and 12.2; and Comice, 10.9 and 10.1, respectively. Oxidase and catalase determinations were made at harvest and during storage at 32° F. At the time of harvest and for the most part during storage, oxidase and catalase activity were greater in the 1935–36 season (fig. 17) than in 1934–35. Although there was less variation in the catalase activity than in the oxidase activity in Anjou and Bosc pears in the two seasons, in most instances the former was definitely higher in 1935–36 than in 1934–35. In Comice pears the catalase activity fluctuated widely both in the 1934–35 and in the 1935–36 storage seasons. No explanation for this is offered.

A change made in the method of determining oxidase activity prevents comparison of oxidase content between fruit of the 1933–34 and the 1934–35 seasons. However, the results of catalase determinations on the fruit stored at 30° F. for these two seasons are comparable. Flemish Beauty, Comice, and Anjou pears from the Wenatchee district (Anjou taken from the same orchard both years) averaged 40 to 90 percent greater in catalase activity during the 1934–35 season. In Bosc pears from the same district, catalase was more than twice as active in 1933–34 as in 1934–35. As there was no marked difference in the condition of the fruit at harvest or in its behavior in storage during the different seasons, although differences in oxidase and catalase were found, it is evident that these enzymes as measured by present methods are not closely correlated with physiological behavior in storage.

Certain varieties of pears, if held at temperatures above 32° F. but low enough to prevent ripening, develop scald. To determine whether there is any relation between scald and oxidase and catalase activity in the fruit, Flemish Beauty, Comice, and Bosc pears were held at 36° until scald developed. Oxidase and catalase activity were then determined on the sound and on the scalded fruits. As

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indicated in table 1 the sound fruit showed greater oxidase and catalase activity than did the scalded fruit from the same lots. The enzyme activity diminished in proportion to the amount of scald present; in fact, in some badly scalded fruits there was no catalase activity at all.

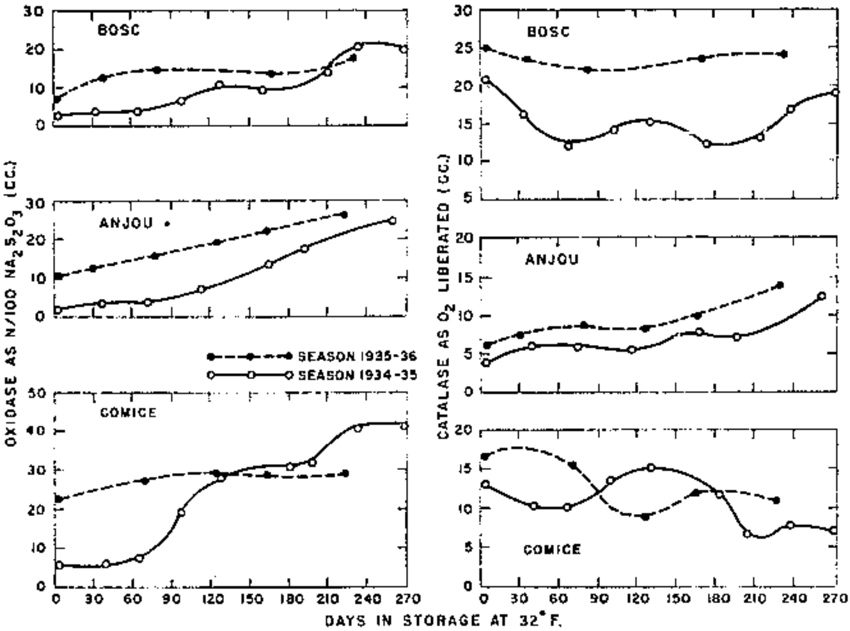

FIGURE 17.—Seasonal difference in oxidase and catalase activity during storage of Bosc, Anjou, and Comice pears.

TABLE 1.—*Enzyme activity of pears as influenced by scald and acetaldehyde*

Source and treatment	Oxidase activity (N/100 $Na_2S_2O_3$)	Catalase activity (O_2 liberated)
	Cc.	*Cc.*
Bosc:		
Sound	7.5	4.2
Scalded	3.8	1.2
Comice:		
Sound	20.4	6.8
Scalded	5.8	5.9
Flemish Beauty:		
Sound		8.2
Scalded		.0
Comice:		
Sound		9.4
Badly scalded		.0
Pear juice:		
Check	8.2	12.2
Plus 0.1 percent of acetaldehyde	7.3	7.6
Comice:		
Scalded after exposure to acetaldehyde for 2 weeks at 32° F	15.5	8.7
Normal, check	17.7	11.5

As acetaldehyde has been shown to be correlated with scald development (*22*), it appeared likely that acetaldehyde might be responsible for the decreased activity of enzymes in the scalded fruits; and this possibility was investigated. When acetaldehyde was added to prepared enzyme samples from normal fruits, such samples showed less activity than duplicate samples containing no acetaldehyde. Also, when sound fruit was exposed to acetaldehyde fumes at 32° for 2 weeks, surface scald developed and oxidase and catalase activity decreased.

In order to determine the distribution of the enzymes in the fruit, samples of Comice pears taken with a cork borer at right angles to the long axis and through the greatest diameter were divided into outer, middle, and core regions. The core consisted of the center part of the sample, including the seed cavity (but not the seeds) and closely adjoining tissues. The remaining part was divided equally into (1) outer region—part next to the surface but with the skin removed; and (2) middle region—part between core and outer region. The results are given in table 2.

TABLE 2.—*Localization of enzymes in Comice pears*

Part of fruit	Oxidase activity (N/100 $Na_2S_2O_3$)	Catalase activity (O_2 liberated)
	Cc.	*Cc.*
Outer region	13.3	5.1
Middle region	4.2	20.7
Core region	21.7	20.9

FIGURE 18.—Section of Comice pear showing the localization of greatest oxidase activity as indicated by the benzidine test.

The oxidase activity was greatest in the core region, being 63 percent more active than in the outer portion and five times as active as in the middle. This is in agreement with the benzidine colorimetric test applied directly to the tissue (fig. 18). The first visible indication of scald or core break-down is a browning of the tissues at the surface, or at the core. These are the areas in which there is the greatest oxidase activity, and the browning may well be brought about by the oxidase after the cells have been injured by certain products of respiration. Catalase activity was approximately the same in the core and middle regions, in both of which it was four times as active as in the outer region. These results are in general agreement with those reported by Harding (*20*) from work on Jonathan apples, in which he found the catalase activity highest in the center and decreasing progressively toward the outside.

Sugars, Starch, and Solids

In order to determine the degree to which maturity may influence the composition and condition [5] of winter pears at harvest and in storage, Winter Nelis fruits were picked from the same tree on September 15, October 9, and October 30 and placed immediately in storage at 32° F. Representative samples were taken for chemical analysis at harvest and after specified intervals of storage. Data from this study are presented in table 3.

There was an increase of approximately 6.8 percent in the total solids of Winter Nelis pears when harvested at intervals over a period of 6 weeks. During this time the alcohol-soluble solids increased 31.5 percent and the alcohol-insoluble fraction decreased 27.6 percent. The alcohol-insoluble solids of Winter Nelis, as shown in table 3, were considerably higher than those reported for Bartlett (*6*) and Kieffer (*33*), as were also the reducing sugar and total sugars. In the Winter Nelis pears these soluble carbohydrates increased approximately 32 and 67 percent, respectively, during the harvesting period of 45 days, and sucrose increased 213 percent during the same time. Martin (*36*) also found that the sucrose content of Bosc pears increased with maturity at harvest. The alcohol-soluble solids in table 3 are greater than the acids and total sugars, plus starch. This indicates the presence of some undetermined constituent in the alcohol-soluble fraction. Martin (*36*) recently reported the presence of sorbitol in Bosc pears in amounts as high as 3.72 percent. Starch, although present at each picking, decreased rapidly with advanced maturity at harvest.

Data in table 3 indicate that there was a more significant correlation between the carbohydrate composition and the maturity of Winter Nelis pears at harvest than after storage at 32° F. The pressure test for firmness of the tissue, however, could be correlated with maturity at harvest as well as after prolonged storage at 32°.

That the kind of fruit wraps used in packing pears has no significant influence on the chemical composition of the fruit after storage is shown in table 4, which presents data on Anjou pears harvested at their optimum maturity and wrapped in either plain, oiled, or cellophane papers, and stored immediately at 32° F.

[5] As used in this bulletin "condition" is a general term which embraces those factors that affect the appearance and keeping quality of the fruit, such as bruising, decay, scald, break-down, shriveling.

TABLE 3.—*Firmness, condition, solids, sugars, acids, and starch in Winter Nelis pears as influenced by maturity and length of storage. Fruits stored immediately at 32° F.*[1]

Picking	Storage at 32° F.	Condition and appearance	Firmness	Total acid (as citric)	Alcohol-soluble solids	Alcohol-insoluble solids	Total solids	Reducing sugar	Sucrose	Total sugars	Starch
	Days		*Lbs. pressure*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
First (Sept. 15, 1931)	0	Excellent	18.3	0.191	10.40	7.49	17.89	6.10	1.47	7.57	0.92
	28	do	15.0	.196	12.29	6.85	19.14	6.88	2.59	9.47	.32
	121	Slightly shrivelled, fair	13.5	.163	13.22	6.49	19.71	8.62	1.55	10.17	.00
	240	Severely shrivelled, slight scald.	8.5	.152	13.84	5.49	19.33	8.69	1.49	10.18	.00
Second (Oct. 9, 1931)	0	Excellent	15.0	.209	12.00	6.80	18.80	6.75	2.72	9.47	.35
	37	do	13.9	.185	12.61	7.01	19.62	7.10	2.62	9.72	.00
	129	do	11.3	.128	13.76	5.65	19.41	8.44	1.97	10.41	.00
	247	Poor, moderate scald	7.1	.108	13.27	5.48	18.75	8.15	2.03	10.18	.00
Third (Oct. 30, 1931)	0	Excellent	12.9	.223	13.68	5.42	19.10	8.04	4.61	12.65	.10
	22	do	12.6	.198	13.53	5.38	18.91	7.68	2.72	10.40	.00
	108	do	9.7	.182	13.32	5.45	18.77	8.79	1.38	10.17	.00
	226	Poor, moderate scald	5.4	.113	14.24	4.47	18.71	8.78	2.11	10.89	.00

[1] Expressed as percentage of fresh weight.

The changes in soluble carbohydates during storage were similar in Anjou (table 4) and the first and second pickings of Winter Nelis pears (table 3), but the quantity found was less in the Anjou than in the Winter Nelis. Alcohol-insoluble solids and total acids decreased during storage but could not be correlated with the kind of fruit wrap used. It should also be recalled that the type of fruit wrap did not influence the respiratory activity of comparable fruit (fig. 8).

TABLE 4.—*Firmness, condition, solids, sugars, acids, and starch in Anjou pears as influenced by type of fruit wrap and length of storage at 32° F.*[1] *Harvested Sept. 14, 1931, and stored immediately*

Type of wrap	Storage at 32° F.	Condition and appearance	Firmness	Total acid (as citric)	Alcohol-soluble solids	Alcohol-insoluble solids	Total solids	Reducing sugars	Sucrose	Total sugars	Starch
	Days		*Lbs. pressure*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Plain wrapped	0	Excellent	11.3	0.281	11.06	5.07	16.13	5.84	1.88	7.72	0.41
	27	do	11.7	.262	12.06	4.12	16.18	6.48	2.12	8.60	.00
	92	do	12.0	.213	12.62	3.27	15.89	7.07	1.66	8.73	.00
	154	Slightly shrivelled, fair.	8.0	.191	12.06	4.01	16.07	7.56	1.56	9.12	.00
	212	Ripening, yellow color.	7.0	.185	12.61	3.71	16.32	7.69	1.28	8.97	.00
	272	do	4.0	.143	12.87	3.94	16.81	7.59	1.53	9.12	.00
Oil wrapped	0	Excellent	11.3	.281	11.06	5.07	16.13	5.84	1.88	7.72	.41
	27	do	11.7	.280	12.13	4.06	16.19	6.48	2.32	8.80	.00
	92	do	11.3	.239	12.49	3.58	16.07	7.11	1.34	8.45	.00
	154	do	8.2	.194	12.09	3.95	16.04	7.38	1.59	8.97	.00
	212	Ripening, yellow color.	7.3	.176	11.51	4.20	15.71	7.62	1.19	8.81	.00
	272	do	5.0	.143	12.27	4.00	16.27	7.85	1.67	9.52	.00
Cellophane wrapped	0	Excellent	11.3	.281	11.06	5.07	16.13	5.84	1.88	7.72	.41
	27	do	11.3	.283	12.08	3.70	15.78	6.53	1.92	8.45	.00
	92	do	11.2	.217	12.32	3.39	15.71	7.11	2.01	9.12	.00
	212	Ripening, yellow color.	7.1	.162	12.09	3.35	15.44	7.40	1.86	9.26	.00
	272	do	6.7	.152	12.17	3.30	15.47	7.08	1.44	8.52	.00

[1] Expressed as percentage of fresh weight.

The influence of delayed storage at 65° F. on the composition of Comice and Anjou pears during subsequent storage at 32° is shown in table 5.

TABLE 5.—*Firmness, condition, solids, sugars, acids, and starch in Anjou and Comice pears as influenced by delayed storage at 65° F. and by length of storage at 32°.*[1] *Harvested Sept. 14 and 18, 1931, respectively*

Variety and type of storage	Storage at 32° F.	Condition and appearance	Firmness	Total acid (as citric)	Total solids	Alcohol-soluble solids	Alcohol-insoluble solids	Reducing sugars	Sucrose	Total sugars	Starch
	Days		*Lbs. pressure*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Anjou—immediate storage.	0	Excellent	13.3	0.281	16.13	11.06	5.07	5.84	1.86	7.72	0.41
	27	do	10.8	.281	15.98	11.89	4.09	6.59	2.14	8.73	.00
	93	do	10.7	.216	16.23	12.93	3.30	7.05	1.68	8.73	.00
	154	Slightly shrivelled, good.	8.5	.189	16.50	12.58	3.92	7.46	1.59	9.05	.00
	241	Severely shrivelled, poor.	6.0	.143	16.24	13.02	3.22	7.75	1.45	9.20	.00
	272	Light color, ripening, poor.	4.8	.143	16.67	12.94	3.73	7.67	1.45	9.12	.00
Anjou—delayed storage.	0	Excellent	12.9	.267	16.11	12.35	3.76	6.74	1.99	8.73	.10
	30	do	12.8	.296	16.42	12.61	3.81	7.12	1.75	8.87	.00
	85	Slightly shrivelled, good.	11.7	.232	16.55	13.03	3.52	7.20	1.77	8.97	.00
	147	Light color, ripening, poor.	8.6	.246	16.08	12.08	4.00	7.81	1.08	8.89	.00
	234	do	5.0	.191	16.35	12.34	4.01	7.85	1.43	9.28	.00
	265	do	4.0	.194	16.41	12.46	3.95	7.90	1.22	9.12	.00
Comice—immediate storage.	0	Excellent	9.5	.159	16.60	10.47	6.13	5.67	1.90	7.57	.28
	33	do	9.0	.171	15.94	10.14	5.80	6.32	1.24	7.56	.00
	88	do	8.7	.159	15.29	10.55	4.74	6.72	1.53	8.25	.00
	150	Fair, no scald	5.6	.150	14.93	10.64	4.29	6.30	1.19	7.49	.00
	177	Severe scald, poor	6.2	.131	14.97	10.94	4.03	6.38	1.27	7.65	.00
	208	Severe scald, tissue collapse.	6.2	.114	15.07	11.48	3.59	6.73	1.39	8.12	.00
Comice—delayed storage.	0	Excellent	9.1	.150	16.69	10.67	6.02	6.48	1.68	8.16	.30
	26	do	8.5	.183	16.33	11.12	5.21	6.92	1.33	8.25	.00
	92	Slightly shrivelled, good.	8.4	.171	15.08	11.01	4.07	7.10	1.00	8.10	.00
	143	Severe scald, poor	4.2	.147	14.67	10.75	3.92	6.48	1.57	8.05	.00
	201	Severe scald, tissue collapse.	4.7	.112	14.65	11.11	3.54	6.74	1.31	8.05	.00

[1] Expressed as percentage of fresh weight. Fruit delayed at 65° F. for 7 days prior to storage at 32°.

Delayed storage effected a greater change in the physical condition of both Anjou and Comice pears than in their chemical composition. Furthermore, the storage life of both varieties, as shown in column 3, table 5, was considerably curtailed by delayed low-temperature storage at harvest. Both varieties decreased from 3 to 4 percent in firmness during 7 days delay at 65° F.; they also lost approximately 5 percent of their total acids. However, delayed storage caused a much greater change in the composition of some of the Anjou pears than of the Comice. For instance, the alcohol-soluble solids in Anjou pears increased 11 percent during this delay, whereas those in Comice increased only 1.9 percent. Likewise, the insoluble solids decreased about 25 percent in Anjou and only 1.7 percent in Comice, while disappearance of starch was confined to the Anjou variety.

During storage at 32° F., the results of chemical analyses presented in table 5 indicated that differences in the composition of lots of fruit stored immediately at 32° and of others delayed at 65° prior to storage at 32° became less as the storage season progressed until little significant difference was evident, although on the basis of physical condition it was apparent that the delayed storage lots had ripened more at 32° than had the lots stored immediately. This agrees with the results of Lutz and Culpepper (*33*) for Kieffer pears. Data in table 5 show that Anjou pears had a greater acidity and a higher content of alcohol-soluble solids and total sugars than did Comice. Total acids and alcohol-insoluble solids in both varieties gradually decreased with prolonged storage at 32°, but there was no definite change in soluble carbohydrates.

Comice pears scalded severely when stored at 32° F. for 177 days following immediate storage, or for 143 days following delayed storage; after 208 and 201 days, respectively, both lots of fruit were completely scalded, and their flesh and core tissues became soft, discolored, and disorganized. The development of these conditions in the fruit could not be correlated with results of carbohydrate analyses, as shown in table 5.

During the season of 1933 a study was made of the different forms of free reducing sugars that comprise the soluble carbohydrate fraction of fall and winter pears. The distribution of these sugars was studied in relation to variety and maturity. Flemish Beauty, Bosc, Comice, and Anjou pears were harvested at three maturities. Chemical analyses were made at harvest on comparable fruits of each maturity. Data relative to this work are shown in table 6.

TABLE 6.—*Firmness, sugars, and acidity of fall and winter pears as influenced by maturity and by variety, 1933* [1]

Variety	Date harvested	Firmness	Glucose	Fructose	Sucrose	Total sugars	Ratio: fructose/glucose	pH value	Total acid (as citric)
		Pounds pressure	*Percent*	*Percent*	*Percent*	*Percent*			*Percent*
Flemish Beauty	Aug. 11	13.9	1.11	3.82	1.57	6.50	3.44	4.31	0.170
	Aug. 21	11.6	1.07	4.17	2.11	7.35	3.90	4.32	.148
	Sept. 6	10.8	.80	3.79	4.59	9.18	4.73	4.71	.114
Bosc	Aug. 28	14.6	1.26	3.71	2.68	7.65	2.94	4.65	.132
	Sept. 27	12.1	1.24	4.09	3.45	8.78	3.30	4.67	.122
	Oct. 16	9.7	1.24	4.74	6.45	12.43	3.82	4.79	.105
Comice	Aug. 30	12.4	1.19	4.39	2.12	7.70	3.69	4.38	.206
	Sept. 19	9.8	1.24	5.38	2.57	9.19	4.34	4.12	.224
	Oct. 4	9.2	.77	6.10	4.13	11.00	7.92	4.53	.148
Anjou	Aug. 28	15.6	1.35	3.94	.79	6.08	2.92	4.19	.245
	Sept. 19	11.0	1.17	4.77	2.09	8.03	4.08	4.04	.267
	Oct. 4	9.7	1.03	4.50	3.33	8.95	4.45	4.16	.106

[1] Compositional data expressed as percentage of fresh weight.

Glucose, sucrose, and fructose are the soluble sugars that constitute the total sugar fraction. Glucose was present in least amount and decreased as the fruit matured. Varietal differences in glucose content were small. Fructose was the predominant hexose sugar in all of the varieties included in table 6. In Bosc and Comice, this sugar increased approximately 27.7 and 38.9 percent, respectively, during the harvest period and attained its highest concentration in the Comice variety. Sucrose also increased with maturity and reached its greatest accumulation in the third picking of the Bosc variety. Evidently sucrose and fructose are the forms in which sugar accumulates in maturing pears. The ratio of fructose to glucose increased with maturity and attained its highest value in the Comice variety in which it was approximately 8 to 1. As both sucrose and fructose are sweeter than glucose, their increase, together with the gradual loss in acidity, doubtless explains on a chemical basis the increased sweetness of the more mature pears.

Certain varieties of fall and winter pears fail to ripen normally when removed to temperatures of 65° F. after prolonged storage at 32° (*10, 28, 44*). Experiments were conducted to determine whether this storage disorder can be correlated with carbohydrate composition. Bosc and Comice pears were harvested at optimum commercial maturity and stored immediately at 32°. Chemical analyses were made on both the cold-stored and the ripened fruit before and after the onset of abnormal ripening These data are presented in table 7.

TABLE 7.—*Carbohydrates and solids in Bosc and Comice pears as influenced by normal and abnormal ripening,*[1] *1934*

Variety	Date of sampling	Ripening capacity	Alcohol-soluble solids		Alcohol-insoluble solids		Total solids		Glucose	
			In storage	Ripened	In storage	Ripened	In storage	Ripened	In storage	Ripened
			Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Bosc	November	Normal	14.44	14.70	3.26	3.24	17.70	17.94	1.39	1.39
	March	Abnormal[2]	14.73	13.94	3.15	3.09	17.88	17.03	2.11	1.72
Comice	November	Normal	14.18	13.89	2.43	2.65	16.61	16.54	1.44	1.14
	March	Abnormal[2]	12.91	14.09	2.42	2.11	15.33	16.20	1.41	1.29

Variety	Date of sampling	Ripening capacity	Fructose		Sucrose		Total sugars		Ratio: fructose/glucose	
			In storage	Ripened	In storage	Ripened	In storage	Ripened	In storage	Ripened
			Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*		
Bosc	November	Normal	3.30	4.10	1.21	1.37	5.90	6.86	2.38	2.95
	March	Abnormal[2]	2.71	3.14	2.69	2.42	7.51	7.28	1.29	1.83
Comice	November	Normal	3.04	3.46	3.64	3.35	8.12	7.95	2.11	3.01
	March	Abnormal[2]	6.48	7.10	.75	.61	8.67	9.06	1.49	5.50

[1] Expressed as percentage of fresh weight.
[2] These lots failed to soften and ripen normally at a temperature of 65° F. Bosc remained hard and granular, and scald, tissue discoloration, and core break-down were present in Comice.

During normal ripening, pears undergo a marked change in physical condition. The color changes from dark green to varying shades of yellow. There is a marked softening of the flesh, which changes from a firm crisp texture to a butterlike consistency. Data in table 7, however, indicate that there is no concomitant change in the carbohydrates in Bosc and Comice pears during normal ripening. In this respect the data are similar to those reported for the Kieffer (*33*) and Bartlett varieties (*6*). There was some accumulation of fructose during normal ripening of Bosc and Comice pears, and in this respect the data in table 7 are similar to those reported by Martin (*36*).

The results of carbohydrate analyses gave no indication of any apparent change in the metabolism of the fruit that resulted in the loss of normal ripening capacity. Even the presence of scald, core break-down, or tissue discoloration was accompanied by little change in the carbohydrate content of the affected tissues. The data in table 7 indicate that the loss of ripening capacity in pears is brought about by physiological factors other than changes in carbohydrate content.

Acetaldehyde Content

The role of acetaldehyde in plant metabolism has received considerable attention since the earlier work of Thomas (*43*) on the relation of acetaldehyde to carbon dioxide zymasis, and that of Harley and Fisher (*22*) on the correlation between the severity of scald and break-down and the concentration of acetaldehyde in the tissues of Bartlett

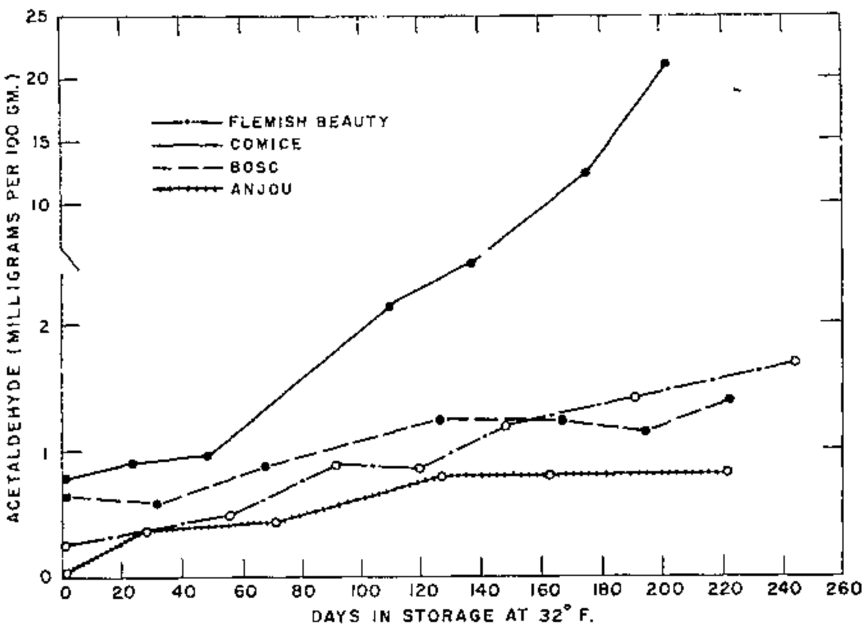

Figure 19.—Acetaldehyde content of tissues of fall and winter pears during storage at 32° F. as influenced by variety. Flemish Beauty, harvested August 15; Comice, September 19; Bosc, September 9; Anjou, September 13, 1932. All varieties were stored immediately at 32° F.

pears. Tindale and others (*44*) have recently reported that accumulation of ethyl alcohol and acetaldehyde in Bartlett pears could be correlated with a progressive replacement of the normal oxidative metabolism by one of an anaerobic type. This replacement was usually associated with overripeness or the presence of certain storage disorders.

Studies were initiated during the season of 1932 to evaluate the change in the acetaldehyde and ethyl alcohol content of different varieties of fall and winter pears as induced by diffe. ¬nt practices in handling, storage, and ripening. In general, the alcohol values varied directly with the acetaldehyde concentration and their incorporation here would offer little additional information. For these reasons and in the interest of brevity only the acetaldehyde data will be presented in graphic and tabular form. These data are representative of several additional experiments of a similar nature made during the years 1932 to 1935. Data in figure 19 are typical of the results obtained relative to the acetaldehyde content of fall and winter pears as influenced by variety and by length of storage at 32° F.

Data in figure 19 indicate that the acetaldehyde content of all four varieties of pears increased with the length of storage. This increase

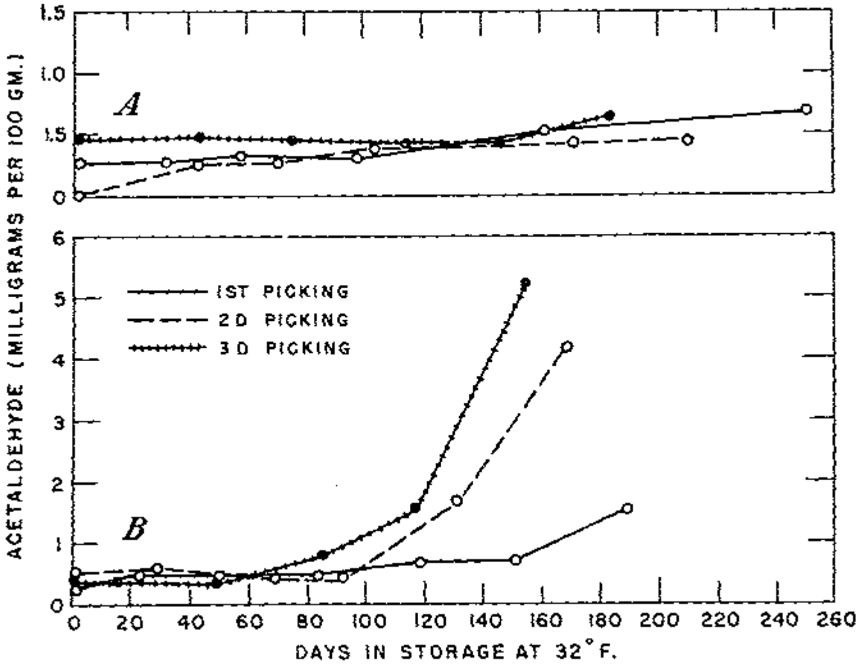

FIGURE 20. Acetaldehyde content of tissues of Flemish Beauty and Comice pears at harvest and during storage at 32° F. as influenced by maturity at harvest. *A*, Flemish Beauty: First picking August 11, 1933, at 13.9 pounds pressure; second picking August 21, 1933, at 11.6 pounds pressure; third picking September 6, 1933, at 10.8 pounds pressure. *B*, Comice: First picking August 30, 1933, at 12.4 pounds pressure; second picking September 19, 1933, at 9.8 pounds pressure; third picking October 4, 1933, at 9.2 pounds pressure.

was greatest in the Comice variety where its rapid accumulation after 140 days of storage was associated with scald and core break-down. In none of the other varieties were these storage disorders found during a similar period at 32° F.; the accumulation of acetaldehyde in their tissues was also correspondingly less.

The influence of maturity on the acetaldehyde accumulation in Flemish Beauty and Comice pears is shown in figure 20 and table 8.

TABLE 8.—*Firmness, acidity, acetaldehyde content, and condition of Comice and Flemish Beauty pears at 32° F., as influenced by maturity at harvest*

Date of harvest	Storage period	Firmness	pH value	Total acid (as citric)	Index figure	Acetaldehyde in 100 gm. of fresh tissue	Condition and appearance
COMICE							
	Days	*Pounds pressure*		*Percent*	10^{-}[illegible]	*Mg.*	
Aug. 31, 1933.	0	12.4	4.38	0.227	12.9	0.32	Excellent.
	22	10.7	4.14	.233	19.6	.42	Do.
	50	11.5	4.16	.229	19.1	.40	Shrivelled, slightly tough.
	83	12.1	4.24	.216	17.0	.43	Do.
	119	12.5	4.25	.199	17.8	.65	Do.
	152	9.2	4.35	.175	16.1	.68	Do.
	189	7.7	4.47	.158	13.6	1.54	Do.
Sept. 20, 1933.	0	9.8	4.12	.224	21.5	.42	Excellent.
	28	9.5	4.23	.208	17.9	.47	Do.
	68	9.5	4.32	.189	16.1	.41	Do.
	92	10.0	4.38	.173	15.1	.42	Good.
	132	8.9	4.45	.140	16.1	1.65	Do.
	168	8.1	4.52	.134	14.2	4.18	Slight surface scald.
	224	6.1	4.65	.102	14.0	14.64	Soft, severe scald, tissue collapse.
Oct. 4, 1933.	0	9.2	4.53	.148	12.7	.40	Excellent.
	16	8.6	4.33	.160	18.5	.36	Do.
	49	9.3	4.40	.156	12.0	.34	Do.
	85	9.5	4.42	.142	17.0	.74	Good.
	118	8.1	4.50	.122	16.4	1.51	Yellow color, some ripening.
	155	7.2	4.60	.116	13.9	5.21	Slight surface scald.
FLEMISH BEAUTY							
Aug. 11, 1933.	0	13.9	4.31	0.171	18.2	0.00	Excellent.
	42	10.9	4.29	.156	20.6	.26	Do.
	69	10.8	4.47	.138	16.0	.27	Shrivelled, slightly tough.
	103	11.0	4.48	.120	17.9	.38	Do.
	172	10.7	4.58	.104	16.0	.49	Do.
	209	10.9	4.68	.097	13.3	.44	Do.
Aug. 21, 1933.	0	11.6	4.32	.148	20.6	.28	Excellent.
	31	11.2	4.44	.146	15.9	.20	Do.
	57	11.2	4.47	.138	15.6	.30	Do.
	97	10.5	4.60	.120	13.6	.20	Do.
	161	11.5	4.74	.106	10.8	.51	Do.
	253	10.0	4.80	.094	10.4	.72	Good.
Sept. 6, 1933.	0	10.8	4.71	.118	10.8	.46	Excellent.
	43	10.3	4.88	.090	9.4	.49	Do.
	77	10.5	4.95	.080	9.0	.40	Do.
	113	10.2	5.17	.065	6.7	.40	Do.
	146	10.3	5.10	.065	7.9	.41	Do.
	183	9.8	5.47	.050	3.8	.61	Do.

Maturity at harvest was not a factor of importance in the accumulation of acetaldehyde in Flemish Beauty pears during storage at 32° F. Furthermore, this variety did not show scald, break-down, or ripening when held at 32°. In Comice also there was no difference until after 70 to 80 days' storage after which acetaldehyde accumulation was directly associated with maturity, being greatest in the more mature fruit. Similar results have been reported for Bartlett pears (*21*). Both Comice and Bartlett are subject to scald and break-down when stored at 32°.

Delay in storing the fruit after harvest also increased its acetaldehyde content. Data for Bosc and Comice are shown in figure 21 and table 9.

Because delaying the fruit at warm temperatures increased its rate of ripening and decreased its potential storage life (table 9), and because acetaldehyde accumulation is closely associated with senescence, a greater content of this volatile constituent in pears improperly handled at harvest would be anticipated.

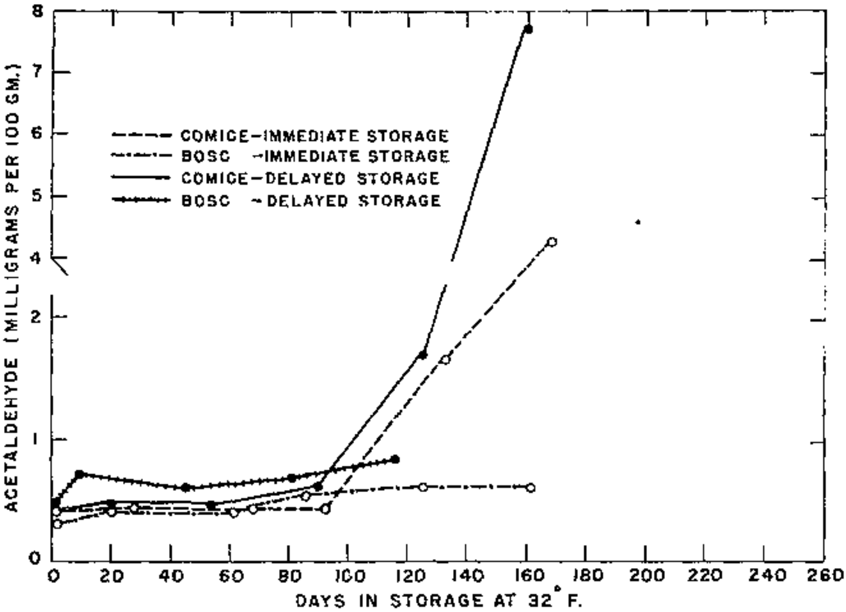

FIGURE 21.—Acetaldehyde content of tissues of Bosc and Comice pears during storage as influenced by delayed low-temperature storage at harvest. Delayed storage consisted of 2 days at 65° F. plus 10 days at 45° prior to storage at 32°.

TABLE 9.—*Firmness, acidity, acetaldehyde content, and condition of Bosc and Comice pears at 32° F., as influenced by delayed [1] storage at harvest. Picked Sept. 27 and 20, 1933, respectively*

Variety and type of storage	Storage at 32° F.	Firmness	pH value	Total acid (as citric)	Index figure	Acetaldehyde in 100 gm. of fresh tissue	Condition and appearance
	Days	*Pounds pressure*		*Percent*	10^{-1}	*Mg.*	
Bosc—immediate storage.	0	12.1	4.67	0.119	11.1	0.32	Excellent.
	20	12.0	4.67	.119	14.1	.46	Do.
	61	11.8	4.84	.099	9.2	.41	Do.
	85	11.3	4.80	.097	8.4	.55	Do.
	125	11.5	4.08	.083	7.9	.60	Do.
	161	11.5	5.06	.072	7.7	.56	Do.
	217	10.8	5.10	.061	6.7	.71	Good.
Bosc—delayed storage.	0	11.0	4.71	.110	11.3	.46	Excellent.
	9	7.9	4.70	.128	10.0	.75	Yellow color, some ripening.
	45	7.2	4.67	.112	12.1	.60	Firm ripe.
	81	7.2	4.89	.002	8.9	.67	Do.
	115	7.2	4.84	.092	10.0	.81	Do.
Comice—immediate storage.	0	9.8	4.12	.224	21.5	.42	Excellent.
	28	9.5	4.23	.205	17.9	.47	Do.
	68	9.8	4.32	.189	16.1	.41	Do.
	92	10.0	4.38	.173	15.1	.42	Good.
	132	8.9	4.45	.140	16.1	1.65	Do.
	168	8.1	4.52	.134	14.2	4.18	Slight surface scald.
	224	6.1	4.05	.102	14.0	14.64	Soft, severe scald, tissue collapse.
Comice—delayed storage.	0	9.5	4.18	.209	21.4	.48	Excellent.
	20	8.9	4.16	.219	21.1	.47	Do.
	54	6.9	4.31	.206	15.8	.46	Yellow color, some ripening.
	90	7.1	4.35	.190	15.7	.60	Do.
	124	4.7	4.33	.163	19.1	1.67	Severe scald, core breakdown.
	160	....	4.50	.155	13.6	7.70	Soft, severe scald, tissue collapse.

[1] *Delayed 2 days at 65° F. plus 10 days at 45° before storage at 32°.*

Oiled-paper fruit wraps for the control of scald in apples have been in commercial use for a long time. Although it is known that their use may not control scald on all varieties of pears, it appeared to be desirable to ascertain whether the presence of oiled fruit wraps would decrease the acetaldehyde content of pears. Data bearing on this study are shown in figure 22.

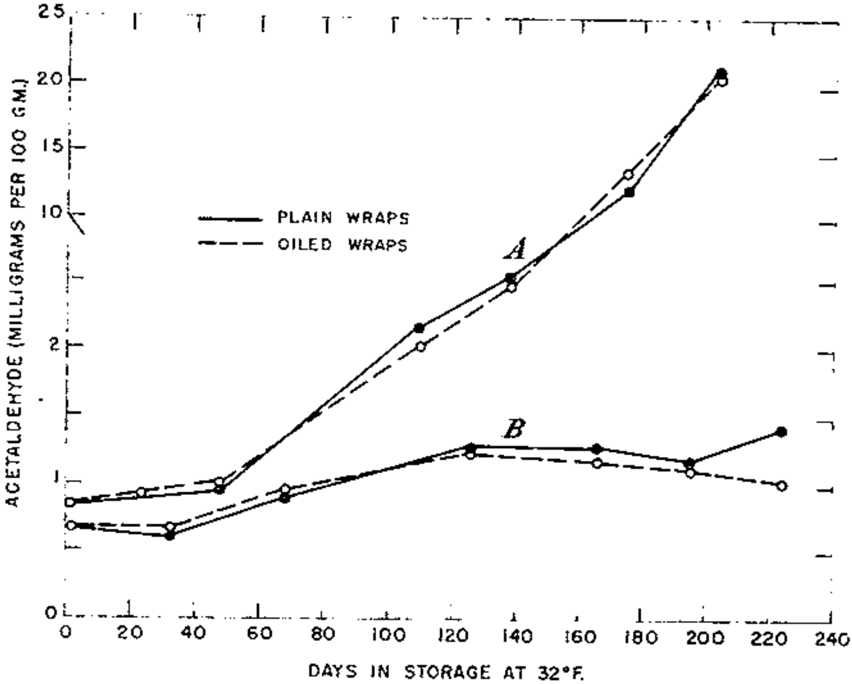

FIGURE 22.—Acetaldehyde content of tissues of Comice and Bosc pears during storage as influenced by the kind of fruit wrap. The wraps were of the regular commercial grade. Oiled wraps carried 18.7 percent oil. *A*, Comice; *B*, Bosc.

In neither Bosc nor Comice pears did the use of oiled fruit wraps influence the acetaldehyde content of the fruit or the development of pear scald.

The potential storage life of pears, as will be shown later (p. 57), is influenced to a large degree by the storage temperature. That the acetaldehyde content of pears bears a direct relation to storage temperature is shown in figure 23 and table 10.

There was little difference in the acetaldehyde content of Bosc pears during storage at 30° and 32° F., but at 34° the concentration of this volatile constituent was much greater than at 32° and 30° and much greater at 36° than at 34°. Changes in acetaldehyde concentration paralleled those of condition and appearance, as shown in table 10. Pear scald was present on Bosc pears during the latter period of storage at 34° and 36°; however, it was not present on comparable fruit at 32° and 30°.

TABLE 10.—*Firmness, acidity, acetaldehyde content, and condition of fall and winter pears as influenced by the length of storage at different temperatures* [1]

	COMICE							FLEMISH BEAUTY						
Storage temperature	Storage period	Firmness	pH value	Total acid (as citric)	Index figure	Acetaldehyde in 100 gm. of fresh tissue	Condition and appearance	Storage period	Firmness	pH value	Total acid (as citric)	Index figure	Acetaldehyde in 100 gm. of fresh tissue	Condition and appearance
° F.	*Days*	*Pounds pressure*		*Percent*	10^{-7}	*Mg.*		*Days*	*Pounds pressure*		*Percent*	10^{-7}	*Mg.*	
30	0	9.8	4.12	0.224	21.5	0.42	Excellent.	0	11.6	4.32	0.148	20.6	0.28	Excellent.
	63	10.3	4.30	.193	16.4	.40	Do.	92	11.2	4.62	.120	13.0	.36	Do.
	91	10.3	4.38	.193	13.7	.41	Do.	120	11.8	4.67	.123	11.3	.40	Do.
	131	10.7	4.50	.162	12.5	.42	Do.	160	11.3	4.67	.111	13.0	.38	Do.
	167	10.5	4.52	.152	12.5	3.20	Slight surface scald.	196	11.0	4.62	.111	13.6	.47	Do.
	222	8.6	4.74	.116	10.1	15.30	Severe scald, core break-down.	251	10.0	4.65	.102	13.9	.49	Do.
32	0	9.8	4.12	.224	21.5	.42	Excellent.	0	11.6	4.32	.148	20.6	.28	Do.
	28	9.5	4.23	.208	17.9	.47	Do.	31	11.2	4.44	.146	15.9	.29	Do.
	68	9.8	4.32	.189	16.1	.41	Do.	57	11.2	4.47	.138	15.6	.30	Do.
	92	10.0	4.38	.173	15.1	.42	Good.	97	10.8	4.60	.120	13.6	.29	Do.
	132	8.9	4.45	.140	16.1	1.65	Do.	161	11.5	4.74	.106	10.8	.51	Do.
	168	8.1	4.52	.134	14.2	4.18	Slight surface scald.	253	10.0	4.80	.094	10.4	.72	Good.
	224	6.1	4.65	.102	14.0	14.64	Soft, severe scald, tissue collapse.							
34	0	9.8	4.12	.224	21.5	.42	Excellent.	0	11.6	4.32	.148	20.6	.28	Excellent.
	29	9.5	4.14	.220	21.0	.45	Do.	30	11.2	4.45	.146	15.5	.27	Do.
	62	10.0	4.23	.204	18.4	.47	Good.	58	11.1	4.47	.140	15.4	.34	Do
	90	7.0	4.21	.187	21.1	.74	Yellow color, some ripening.	91	11.4	4.60	.128	12.6	.40	Good.
	128	([2])	4.40	.150	16.5	8.56	Slight scald, firm ripe.	119	11.3	4.40	.146	17.4	.53	Yellow color, hard.
	166	([2])	4.39	.140	18.5	14.21	Soft, severe scald, tissue collapse.	195	11.0	4.55	.128	14.0	1.10	Slight surface scald.
36	0	9.8	4.12	.224	21.5	.42	Excellent.	0	11.6	4.32	.148	20.6	.28	Excellent.
	28	9.5	4.23	.218	17.3	.50	Do.	30	11.1	4.41	.152	16.2	.46	Do.
	61	8.6	4.31	.206	15.1	.53	Yellow color, some ripening.	57	11.4	4.45	.150	15.0	.47	Good.
	89	4.3	4.30	.185	17.4	.62	Do.	90	11.2	4.49	.138	14.9	.58	Yellow color, hard.
	126	([2])	4.48	.150	13.8	12.76	Severe scald, core break-down.	118	11.6	4.48	.136	15.6	.60	Do.
	163	([2])	4.35	.177	15.9	13.77	Soft, severe scald, tissue collapse.	155	([2])	4.50	.123	16.7	18.87	Severe scald, core break-down.
								192	([3])	4.50	.117	17.9	14.52	Soft, severe scald, tissue collapse.

	ANJOU							BOSC						
30	0	11.0	4.04	0.267	21.7	0.28	Excellent.	0	12.1	4.67	0.119	11.1	0.32	Excellent.
	62	12.4	4.21	.231	17.1	.33	Do.	56	11.1	4.77	.099	10.9	.36	Do.
	90	11.5	4.21	.214	18.3	.30	Do.	84	11.6	4.89	.097	8.4	.42	Do.
	130	10.6	4.40	.183	13.5	.36	Do.	124	11.4	4.98	.081	8.2	.39	Do.
	166	9.9	4.45	.168	13.4	.42	Do.	160	11.1	5.01	.076	8.1	.42	Do.
	221	6.8	4.48	.129	16.2	.40	Good.	215	11.0	5.01	.061	10.1	.74	Do.
32	0	11.0	4.04	.267	21.7	.28	Excellent.	0	12.1	4.67	.119	11.1	.32	Do.
	28	11.6	4.23	.235	16.1	.25	Do.	20	12.0	4.67	.119	11.1	.46	Do.
	68	11.8	4.32	.190	15.9	.29	Do.	61	11.8	4.84	.099	9.2	.41	Do.
	92	11.2	4.25	.193	18.5	.38	Do.	85	11.3	4.89	.097	8.4	.55	Do.
	132	9.0	4.35	.181	15.7	.48	Do.	125	11.5	4.98	.083	7.9	.60	Do.
	168	8.4	4.38	.148	18.0	.44	Do.	161	11.5	5.06	.072	7.7	.56	Do.
	224	7.2	4.47	.120	18.0	.40	Good.	217	10.8	5.19	.061	6.7	.71	Good.
34	0	11.0	4.04	.267	21.7	.28	Excellent.	0	12.1	4.67	.119	11.1	.32	Excellent.
	28	11.4	4.17	.237	18.3	.25	Do.	20	11.1	4.77	.107	10.1	.32	Do.
	61	11.8	4.21	.226	20.3	.33	Do.	55	11.6	4.87	.097	8.8	.50	Do.
	89	8.8	4.21	.206	18.6	.39	Yellow color, hard.	83	11.2	4.87	.083	10.1	.64	Yellow color, hard.
	127	5.7	4.33	.181	16.4	.54	Yellow color, some ripening.	121	11.3	5.01	.077	7.8	1.20	Do.
	165	([2])	4.26	.169	20.5	1.10	Firm ripe.	159	11.5	5.14	.076	6.0	3.74	Slight scald, yellow color, hard.
36	0	11.0	4.04	.267	21.7	.28	Excellent.	0	12.1	4.67	.119	11.1	.32	Excellent.
	28	11.6	4.17	.245	17.6	.26	Do.	20	11.1	4.67	.117	11.2	.33	Do.
	61	9.7	4.19	.220	18.6	.27	Yellow color, hard.	54	11.4	4.84	.094	10.0	.50	Yellow color, hard.
	89	6.7	4.21	.206	18.8	.48	Do.	82	11.3	4.81	.094	10.7	.57	Do.
	126	([2])	4.26	.199	17.3	.79	Firm ripe.	119	11.3	5.00	.070	9.2	8.69	Slight scald, yellow color, hard.
	163	([2])	4.35	.166	17.1	2.20	Do.	156	......	5.17	.059	7.3	13.28	Severe scald.

[1] Comice and Anjou pears harvested Sept. 20, 1933; Flemish Beauty pears harvested Sept. 21, 1933; Bosc pears harvested Sept. 27, 1933.
[2] Too soft to record accurately on the U. S. pressure tester.

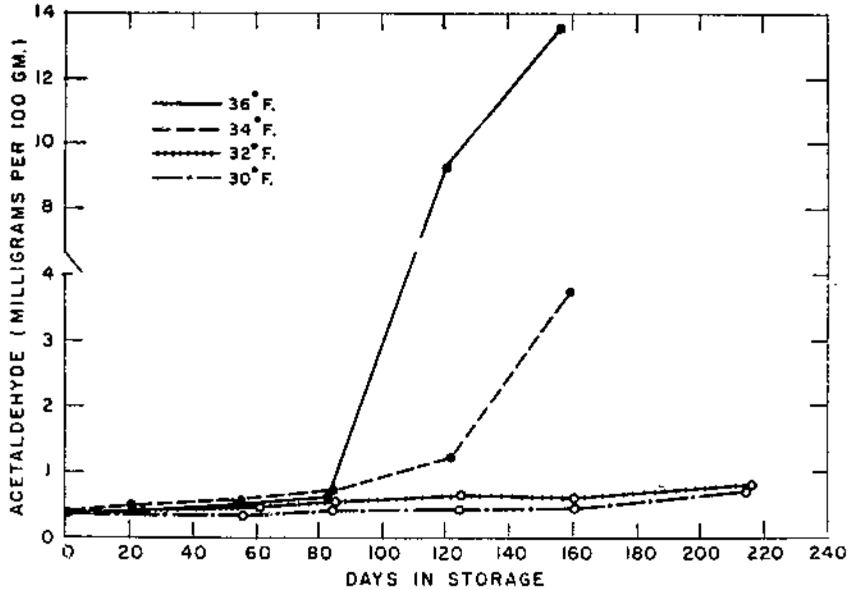

FIGURE 23.—Acetaldehyde content of tissues of Bosc pears during storage as influenced by storage temperature. Harvested September 27, 1933, at commercial maturity and stored immediately.

It has been reported (*21, 44*) that the acetaldehyde content of Bartlett pears increases as the fruit ripens, reaches a maximum with the appearance of scald and core break-down, and rapidly decreases with the onset of discoloration and collapse of the fruit tissue. During the season of 1931 a study was made of the acetaldehyde content of

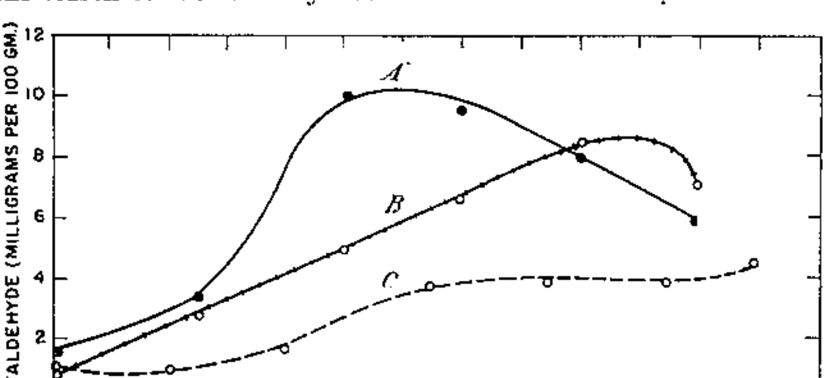

FIGURE 24.—Acetaldehyde content of Anjou and Comice pears during ripening after storage as influenced by variety and washing practice at harvest. *A*, Comice, harvested September 18, 1931. Washed with cold 0.5-percent hydrochloric acid and stored immediately at 32° F. until ripened on January 8, 1932. *B*, Anjou, harvested September 14, 1931. Handling and ripening procedure was similar to that of Comice. *C*, Anjou, duplicate fruit and handling practice with the exception of the addition of a 1-percent kerosene emulsion to the acid washing solution.

Comice and Anjou pears at different stages of ripeness. As experience in the removal of spray residue from pears has shown that they fail to color and ripen normally when a small amount of kerosene or mineral oil emulsion is added to the washing solution, the acetaldehyde-ripening study also included comparable fruit that was washed in this way. Data for these studies are shown in table 11 and figure 24.

TABLE 11.—*Acetaldehyde content of Comice and Anjou pears during ripening at 65° F., as influenced by variety and washing practice*

Variety	Storage at 32° F.	Ripened at 65° F.	Acetaldehyde in 100 gm. of fresh tissue	Condition, appearance, and dessert quality
	Days	*Days*	*Mg.*	
Comice [1]	112	0	1.65	Green color, hard.
		5	3.32	Excellent dessert quality.
		10	10.15	Past best dessert quality. Slight core discoloration.
		14	9.00	Soft, moderate core break-down, no scald.
		18	8.00	Severe core break-down, 70 percent surface scald.
		22	6.11	Tissue completely discolored and broken down.
Anjou [1]	116	0	.91	Green color, hard.
		5	2.95	Yellow color, softening, slightly under full ripe.
		10	4.88	Excellent dessert quality, no scald.
		14	5.97	Slightly past best dessert quality, no scald.
		18	8.40	Overripe, soft, slight core break-down.
		22	7.05	Badly scalded, severe tissue break-down.
Anjou [2]	116	0	1.02	Green color, hard.
		4	1.03	Do.
		8	1.65	Green color, firm.
		13	3.78	Green color, firm ripe, flat taste.
		17	3.89	Greenish yellow, best dessert quality.
		21	3.94	Greenish yellow, overripe, no scald or break-down.
		24	4.46	Do.

[1] Washed with 0.5-percent cold hydrochloric acid.
[2] Washed with 1-percent kerosene emulsion in 0.5-percent cold hydrochloric acid.

These data indicate that variety and kind of washing practice influence the magnitude of the acetaldehyde accumulation in pears. When normal ripening occurred, the acetaldehyde content of both Comice and Anjou pears increased until the fruit became overipe and broken down at the core. When this stage of senescence was reached, the acetaldehyde content of the fruit decreased as disintegration of the tissue progressed. In this respect the data are similar to those reported for the Bartlett variety (*22*). The results in table 11 show that Anjou pears failed to color and ripen normally when mineral oil was used in the washing solution. No scald or core break-down was produced during 24 days at 65° F., and the acetaldehyde content (fig. 24) was also much lower than in pears that had ripened normally.

Certain varieties of pears lose their capacity to ripen normally after prolonged storage at low temperatures (*10*, *28*). In some of the varieties used in these investigations (Comice at 32° F. and Bosc at 36°) this failure to ripen was associated with the presence of scald, core break-down, and a decline in respiratory activity. The relation between respiration and acetaldehyde accumulation is shown in figure 25.

The Comice pears (fig. 25, *A*) began to lose their ripening capacity between 120 and 140 days' storage at 32° F. Scald and core break-down became increasingly severe after this period. Acetaldehyde began to accumulate rapidly and was followed by a decline in the respiratory intensity. In Bosc pears at this temperature (fig. 25, *B*) loss of ripening capacity occurred between 100 and 120 days in storage.

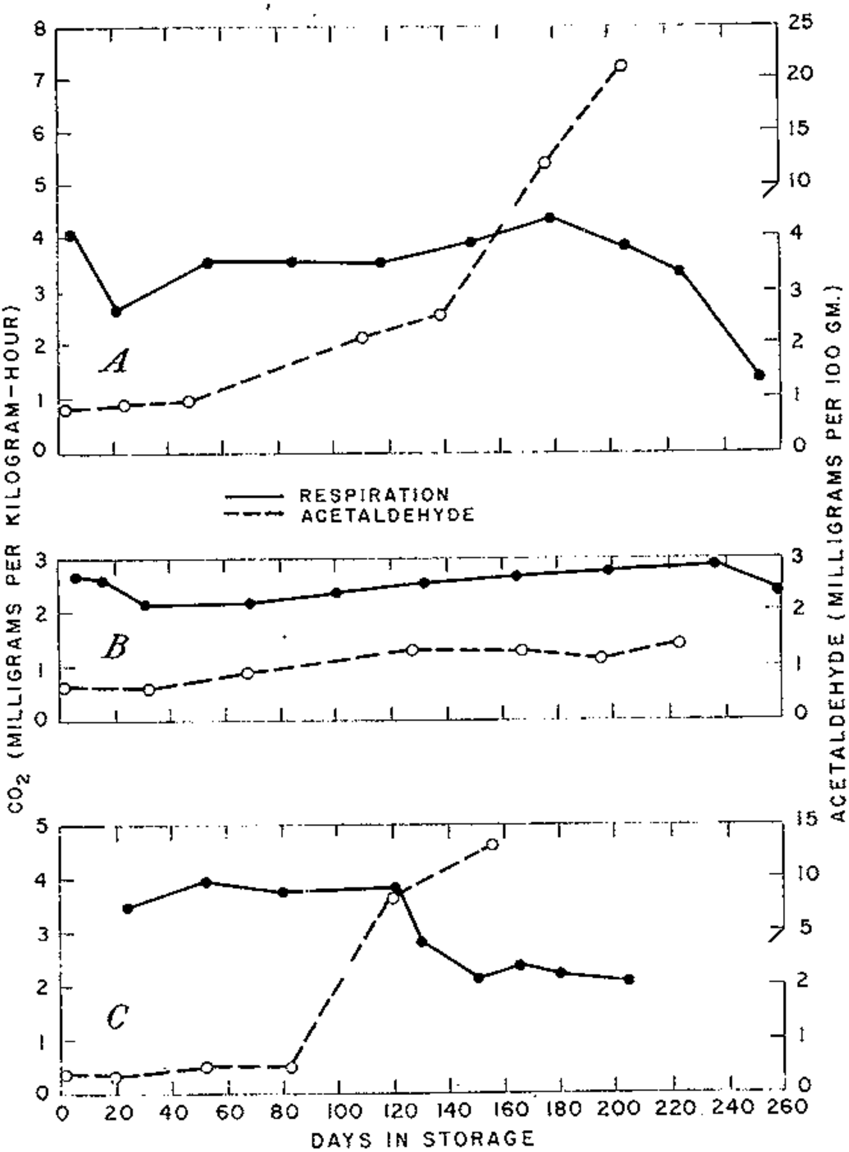

FIGURE 25.—Respiration (CO_2 respired) and acetaldehyde content of tissues in pears during storage as influenced by variety and storage temperature. All fruit received immediate storage: *A*, Comice at 32° F.; *B*, Bosc at 32°; *C*, Bosc at 36°.

In this test, however, scald or core break-down were not present and there was little change in either the acetaldehyde content or in the respiration rate of the fruit.

When Bosc pears were stored at 36° F., their normal storage life was much less than when stored at 32°. They began to lose their capacity to ripen normally after 70 to 80 days in storage at 36°. At this temperature such fruit began to evidence scald and discoloration of the flesh. Acetaldehyde began to accumulate rapidly with a subsequent decline in respiration. Therefore, the relation between acetaldehyde and respiration was similar for Comice at 32° and Bosc at 36°, but was quite different for Bosc at 32°. As all three lots of fruit lost their normal ripening capacity and only in lots *A* and *C* (fig. 25) was scald, core break-down, or tissue discoloration produced, it appears probable that accumulation of acetaldehyde is associated with the predisposition to and occurrence of such disorders, rather than from the loss of normal ripening capacity. The failure of Lutz and Culpepper (*33*) to observe any correlation between loss of ripening capacity and acetaldehyde accumulation in the Kieffer pear supports this interpretation.

Total Acidity, pH Value, and Index Figure

The influence of maturity on the total acid content of Winter Nelis, Comice, and Flemish Beauty pears is shown in tables 3 and 8. There was a slight increase of total acid in Winter Nelis pears as they were harvested through a period of 45 days. Magness (*34*) obtained similar results for Bartlett pears grown in Washington, whereas in those grown in California he found a loss of acidity as they matured. In the present study the total acidity of Comice and Flemish Beauty pears decreased 34 and 31 percent, respectively, between the first and the third picking and generally remained so during storage at 32° F. (See table 8.) Bosc and Comice pears lost some of their total acid during delayed storage (table 9), but lost it more slowly during subsequent storage at 32°, as the fruit receiving the delayed handling treatment generally had a higher acid content during storage at 32° than that which was stored immediately after harvest at 32°. There was a great difference at harvest in the total acidity of the four varieties of winter pears. The Anjou variety had the greatest acid content of 0.267 percent, and Bosc with 0.119 percent had the lowest (table 10). Total acids could not be correlated with loss of ripening capacity or the presence of scald or core break-down.

The pH value of the pear fruit tissues gradually increased with maturity, changing from 4.38 to 4.53 for Comice, and from 4.31 to 4.71 for Flemish Beauty (table 8). This value also increased in all varieties during storage at 32° F., but did not show significant differences in pear fruits stored at different temperatures (table 10). Furthermore, varietal influences and the presence of certain storage disorders were not reflected in the pH value of the fruit.

Du Toit and Reyneke (*4*) expressed the ratio of the dissociated acids (hydrogen-ion concentration) to the total undissociated acids as a single quantity which they termed the index figure. They found this value to be correlated with the maturity of fruit, storage behavior, physiological condition, and cultural practice. In tables 8, 9, and 10, the index figure has been calculated from the corresponding data for total acid and pH value.

Fruit from the second picking (table 8) was generally considered best for commercial storage. Fruit from this picking also had a higher index figure at harvest than did that from either the first or the third picking. Because a high index figure can be correlated with optimum maturity, the data in this respect support the results of Du Toit and Reyneke. However, the results indicated no significant influence on the index figure of handling practice, storage behavior, loss of ripening capacity, storage temperature, or presence of storage disorders. In the light of these results, it is exceedingly difficult to believe that the ratio between the total amount of acid and its degree of dissociation has any specific connection with the physiological condition of the fruit.

Astringent Materials

The term "astringent material" is used to designate a group of substances which have an astringent taste and certain characteristic physical and chemical properties. This term includes both the tannins and the nontannins, which are differentiated by the fact that the former can be precipitated with gelatin. Thatcher (*42*) has stated that tannins may represent intermediate products in cork formation. Gore (*14*) has shown that although fruits lose their apparent astringent taste during ripening, the tannin content of green and ripened fruit was quite similar, and that differences in astringency could be explained by the apparent "walling off" or condensation of the soluble tannin within the cell. Similar results were obtained by treatment with carbon dioxide.

It is conceivable that loss of ripening capacity in certain varieties of pears might be associated with changes in their tannin complex. Changes in astringent materials through condensation with acetaldehyde might also be associated with inhibition of the enzyme system responsible for the hydrolysis of pectic compounds during normal softening of the fruit. Because of these possibilities, studies were made of the amount and distribution of astringent materials in Bosc pears during different stages of maturity, and in Anjou, Bosc, and Comice pears during storage at 32° F., and after ripening at 65°. These data are shown in tables 12 and 13.

Table 12.—*Astringent material in Bosc pear tissues as influenced by maturity*

Astringent material	Tissue	Composition (fresh weight)			Distribution (whole fruit)		
		First picking [1]	Second picking [2]	Third picking [3]	First picking	Second picking [2]	Third picking [3]
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Tannin	Peel	0.0582	0.0386	0.1196	31.9	25.5	42.8
	Core	.0276	.0090	.0181	14.5	7.7	9.1
	Flesh	.0198	.0210	.0285	53.6	66.8	48.1
Nontannin	Peel	.1758	.1680	.1240	35.2	48.2	45.5
	Core	.0540	.0390	.0223	11.3	14.6	11.5
	Flesh	.0546	.0270	.0248	53.5	37.2	43.0
Total astringency	Peel	.2340	.2066	.2436	34.1	41.2	43.7
	Core	.0816	.0480	.0404	12.4	12.6	10.4
	Flesh	.0744	.0480	.0533	53.5	46.2	45.9

[1] Aug. 19, 1935, 16.5 pounds pressure.
[2] Sept. 9, 1935, 13.9 pounds pressure.
[3] Sept. 23, 1935, 11.0 pounds pressure.

TABLE 13.—*Astringent materials in Bosc, Comice, and Anjou pears as influenced by variety, length of storage, and ripening*[1]

Variety	Storage at 32° F.	In storage at 32° F.			Ripened at 65° F.					
		Tannin	Nontannin	Total astringency	Ripened	Tannin	Nontannin	Total astringency	Ripening capacity	Dessert quality and condition
	Days	*Pct.*	*Pct.*	*Pct.*	*Days*	*Pct.*	*Pct.*	*Pct.*		
Anjou[2]	0	0.0130	0.0347	0.0483						
	30	.0139	.0283	.0422	6	0.0181	0.0296	0.0477	Normal	Excellent.
	72	.0130	.0310	.0440	6	.0129	.0352	.0481	do	Do.
	105	.0076	.0375	.0451	7	.0131	.0363	.0494	do	Do.
	172	.0006	.0451	.0457	6	.0091	.0428	.0522	do	Very good.
Bosc[3]	0	.0210	.0270	.0480						
	45	.0167	.0333	.0500	8	.0247	.0283	.0530	Normal	Very good.
	82	.0102	.0350	.0452	9	.0106	.0362	.0468	do	Fair, granular.
	114	.0097	.0359	.0456	9	.0101	.0370	.0471	Abnormal	Poor, hard, granular.
	181	.0020	.0441	.0461	7	.0092	.0440	.0532	do	Do.
Comice[4]	0	.0204	.0248	.0452						
	36	.0126	.0246	.0372	6	.0157	.0283	.0440	Normal	Excellent.
	73	.0111	.0300	.0411	6	.0101	.0380	.0481	do	Do.
	105	.0101	.0310	.0411	4	.0093	.0370	.0463	do	Good.
	172	.0050	.0348	.0398	4	.0060	.0398	.0458	Abnormal	Poor, severe scald, core breakdown.

[1] Calculated as percentage of fresh weight.
[2] Harvested Sept. 17, 1935; 11.6 pounds pressure.
[3] Harvested Sept. 9, 1935; 13.9 pounds pressure.
[4] Harvested Sept. 17, 1935; 10.1 pounds pressure.

The data in table 12 show that in percentage composition the highest concentration of the tannins is found in the peeling. The tannin content of this tissue varied somewhat with the different pickings, being approximately 100 percent greater in fruit from the third picking than in that from the first. The tannin content of the flesh also increased, but to a lesser degree. In the core tissues, in which the stone cells are predominant, the tannin content showed considerable variation with maturity.

Nontannins were also present in significantly greater amounts in the peeling than in the other tissues, but decreased approximately 29 percent between the first and the third picking. In percentage composition the nontannins were similar in the core and flesh, and decreased more than 50 percent between the beginning and end of a harvest period of 35 days.

On the basis of percentage distribution in the whole fruit, the greater amount of all astringent materials was localized in the cortex. That this should be true is obvious because the cortex represents the greater part of the weight of the fruit. On this basis the peeling ranked second in astringent materials, and the core tissue third. Table 12 shows that the percentage distribution of total astringents in the fruit as a whole can be correlated with maturity. Approximately 53 percent of the total astringents were localized in the flesh at the first picking, but in the third they decreased to 45.9 percent; at the same time, however, the percentage distribution of total astringents in the peel increased approximately 28 percent. These results indicate either an outward diffusion of total astringents from the flesh to the peel, or the transformation of those in the flesh and the formation of additional amounts in the peel as the fruit matures on the tree.

The data in table 13 show no significant relation between the total astringents in fall and winter pears and the physiological condition of the fruit as affected by storage and ripening or by the presence of storage disorders. Similarly, no relation is indicated between the total astringency of the fruit and the variety tested, its ripening, the presence of scald and core break-down, or loss of ripening capacity. Either the methods of chemical analysis are not sufficiently sensitive to follow the change in distribution of the astringent materials, or these materials are not altered by the practices and conditions studied. However, the results indicate differences in the tannin and nontannin fractions as influenced by length of storage at 32° F. Data in table 13 show that tannins gradually decreased and nontannins increased with prolonged storage at low temperatures. In interpreting these results the possibility of addition compounds of tannin being formed with certain products of metabolism as suggested by Thatcher (*42*) and Gore (*14*) must be considered. The tannin fraction is measured by its capacity to precipitate gelatin from solution, and this property would become altered by the formation of tannin addition or condensation products. Chemical estimation by present methods would place this new stringent addition compound in the group of nontannins. The latter would thereby accumulate in the fruit tissue at the expense of the original tannins, as shown in table 13. Granting that reactions of the above type may occur, it would be difficult from a consideration of the data in table 13 to say that they caused the loss of ripening capacity in pears.

PECTIC MATERIALS

Emmett (*5*) has stated that differences in the keeping quality of Conference pears were in all probability due to differences in the rate of break-down of the pectic compounds, and the rate of ripening at different temperatures was closely associated with the rate of protopectin hydrolysis. Lutz and Culpepper (*33*) found a direct correlation between optimum ripening and maximum soluble pectin formation in Kieffer pears at 60° F. Soluble pectin changes have also been correlated with the storage behavior of Bartlett pears in artificial atmospheres containing carbon dioxide (*12*, *41*).

Because differences in the physiological metabolism of pear fruit often produce biochemical changes in the pectic materials, studies of these changes were undertaken in 1934. Four varieties of pears were harvested at their optimum maturity and stored immediately at 30° and 36° F. Comparable fruits of each variety were ripened to best dessert quality at 65° at time of harvest and after storage at 30° and 36°. Analyses of the pectic materials in the different lots were made at intervals throughout the storage season. These data appear in table 14.

TABLE 14.—*Pectic material in fall and winter pears as influenced by temperature, length of storage, and ripening, 1934* [1]

Variety	Stored fruit						Ripened fruit					
	Temperature storage	Length of storage	Condition in storage	Pectic material			Ripened at 65° F.	Dessert quality	Ripening capacity	Pectic material		
				Soluble pectin	Proto-pectin	Total pectin				Soluble pectin	Proto-pectin	Total pectin
	°F.	Days		Percent	Percent	Percent	Days			Percent	Percent	Percent
Flemish Beauty	At harvest	0		0.0275	0.6733	0.7008						
	30	50	Excellent	.0258	.6679	.6937	7	Excellent	Normal	0.3850	0.2120	0.5970
		126	do	.0200	.6300	.6500	6	Very good	do	.3850	.2150	.6000
		200	Very good	.0170	.6070	.6240	6	Poor	Abnormal	.3037	.2812	.5849
	36	50	Excellent	.0258	.6660	.6918	7	Excellent	Normal	.3875	.2525	.6400
		126	Showing color	.0375	.5925	.6300	6	Poor	Abnormal	.3100	.3000	.6100
		200	Scalded, poor	.0625	.5310	.5935	6	Poor, tissue collapse	do	.1950	.3467	.5417
Bosc	At harvest	0		.0437	.4500	.4937						
	30	38	Excellent	.0385	.4815	.5200	9	Excellent	Normal	.4700	.0200	.4900
		113	do	.0420	.4880	.5300	8	Fair	Subnormal	.3210	.1810	.5020
		180	Very good	.0300	.4783	.5083	7	Poor	Abnormal	.2587	.2169	.4756
	36	38	Excellent	.0428	.4674	.5102	8	Excellent	Normal	.4400	.0400	.4800
		113	Showing color	.0650	.5150	.5800	8	Poor	Abnormal	.2875	.2325	.5200
		189	Scald, poor				0	Poor, tissue collapse	do			
Comice	At harvest	0		.0525	.4300	.4825						
	30	37	Excellent	.0417	.4183	.4600	9	Excellent	Normal	.3750	.0650	.4400
		114	do	.0650	.4150	.4800	5	do	do	.3800	.1300	.5100
		188	Very good	.1600	.3120	.4720	5	Good	do	.2840	.1860	.4700
	36	37	Excellent	.0429	.4360	.4789	7	Excellent	do	.3625	.0595	.4220
		114	Soft, colored	.2980	.1620	.4600	3	Poor, scalded	Abnormal	.2800	.0800	.3600
		188	Scald, break-down				0	Poor, tissue collapse	do			
Anjou	At harvest	0		.0475	.6300	.6775						
	30	40	Excellent	.0392	.6279	.6671	9	Excellent	Normal	.5000	.1220	.6220
		115	do	.0375	.5835	.6210	6	do	do	.4650	.1750	.6400
		180	Very good	.0980	.5220	.6200	6	do	do	.4010	.2170	.6180
	36	40	Excellent	.0378	.6222	.6600	7	do	do	.5125	.1285	.6410
		115	Showing color	.2000	.4000	.6000	4	Very good	do	.5300	.1300	.6600
		189	Soft, colored				0	Poor, mealy	Overripe			

[1] Pectic material is expressed as percentage of fresh weight.

The content of protopectin and total pectin of unripened Flemish Beauty pears at harvest was greater than that of the Comice, Bosc, or Anjou. Evidently the high protopectin and low soluble-pectin content in Flemish Beauty pears is not closely correlated with firmness, as in Bosc the relative proportion of the protopectin is much less, although this variety is generally firmer than Flemish Beauty. On the other hand, general commercial experience, and pressure-test measurements as well, indicate that the flesh of unripened Comice pears is softer and therefore more subject to bruising injury than that of the other varieties. This variety also possesses a greater amount of soluble pectin and a smaller quantity of protopectin at harvest than any of the other varieties.

Flemish Beauty and Bosc pears did not soften or ripen appreciably at 30° F. Changes in soluble pectin also were small. The Comice and Anjou varieties, on the other hand, softened considerably at this temperature, this change being associated with the hydrolysis of protopectin into the soluble form. This varietal response to storage temperature was more marked at 36°. At this temperature, Flemish Beauty and Bosc fruits softened but little and there was only a small increase in soluble pectin, whereas the Comice and Anjou pears ripened to a marked degree and their content of soluble pectin increased proportionately through hydrolysis of protopectin.

Data in table 14 show that pectic compounds play an important role in the biochemical changes that occur in the pear fruit as it ripens to prime dessert quality. Normal ripening is associated with a progressive change in the physical texture of the fruit, which passes from firmness and crispness to a soft, smooth, and butterlike consistency. This change in texture is directly associated with the hydrolysis of the insoluble protopectin compound into soluble pectin and pectic acid. The soluble pectins, as shown in table 14, increase as much as tenfold during normal ripening. During prolonged storage of all varieties of pears at low temperature there was no significant difference in the total pectin, but during normal ripening at 65° F. it decreased.

Previous storage studies showed that certain varieties of fall and winter pears lose their capacity to ripen normally after prolonged storage at low temperatures. Biochemical data relative to this type of storage disorder are presented in tables 14 and 15.

TABLE 15.—*Pectic material in Comice and Flemish Beauty pears as influenced by normal and abnormal ripening at 65° F., 1935* [1]

Variety	Date ripened	Ripened at 65° F.	Ripening capacity	Soluble pectin		Protopectin		Total pectin	
				32° F.[2]	Ripened[3]	32° F.	Ripened	32° F.	Ripened
		Days		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Flemish Beauty	Nov. 5	7	Normal	0.0325	0.3752	0.5175	0.0450	0.5500	0.4202
	Apr. 8	10	Abnormal[4]	.0687	.1150	.4733	.3250	.5420	.4400
Comice	Dec. 15	5	Normal	.1212	.3700	.3388	.0300	.4600	.4000
	Mar. 9	4	Abnormal[4]	.1237	.2600	.3160	.1400	.4397	.4000

[1] Expressed as percentage of fresh weight.
[2] Direct from cold storage at the time of removal for ripening studies.
[3] After ripening the specified number of days.
[4] Fruit remained hard and granular and failed to soften and ripen normally at 65° F.

These data show a direct correlation between the loss of ripening capacity and the inactivity of the hydrolytic system responsible for the formation of soluble pectin. In other words, during normal ripening the rapid softening and concomitant disintegration of the tissue structure depends upon the chemical or enzymatic hydrolysis of the insoluble intercellular, tissue-binding, protopectin material. A large amount of soluble pectin is formed during this time and the ripened fruit acquires a butterlike texture. When pears fail to ripen normally, protopectin hydrolysis and soluble pectin formation are greatly restricted and the fruit remains firm and crisp. As has been previously shown (*10*), scald and core break-down may also be associated with this loss of ripening capacity. Respiratory measurements and carbohydrate analyses, however, afford no indication of the loss of ripening capacity in all varieties of pears susceptible to these physiological disorders. This is shown in table 7, figure 4, *C* and *E*, and figure 9. Protopectin changes, as shown for Flemish Beauty and Comice pears in table 15, however, indicate that loss of ripening capacity is associated with smaller quantities of soluble pectin and the presence of large amounts of protopectin.

The question arises as to why prolonged storage should disrupt normal ripening and probably inactivate the enzyme system responsible for the hydrolysis of protopectin. It is possible that this apparent inactivation may result from low-temperature injury, as suggested by Kidd and West (*28*). However, this should not preclude the use of 30° to 32° F. in the commercial storage of pears because the injury is not directly proportional to the decrease in temperature. Its inception is earlier and more severe at 36° than at 30°. Furthermore, it is difficult to conceive that anaerobiosis and the accumulation of the products thereof, i. e. acetaldehyde and ethyl alcohol, could be the sole causative factor involved (*44*), because in certain varieties of pears, particularly Bosc and Flemish Beauty, this loss of ripening capacity occurs without the accumulation of abnormal amounts of acetaldehyde and ethyl alcohol.

Ripening Studies

Earlier experiments (*25*, *33*, *38*, *44*) have shown that fall and winter pears stored at 30° to 32° F. attain optimum dessert quality when they are ripened at 65° to 70°. Fruit of each variety has a more or less definite span of life in cold storage during which it will ripen properly if removed to a suitable environment. However, when certain varieties of pears are held at low temperatures beyond their normal storage life, they lose their capacity to soften and attain a satisfactory dessert quality although retaining an apparently normal external appearance while under refrigeration. After removal to higher temperatures, however, the pears may also develop severe surface scald and core break-down.

In connection with the physiological and biochemical studies of fall and winter pears, summarized data obtained in this investigation on ripening capacity, dessert quality, condition, and appearance of comparable lots of Anjou, Bosc, Comice, Flemish Beauty, and Winter Nelis pears are presented in tables 16, 17, 18, and 19.

Table 16.—*Ripening capacity, dessert quality, and condition of fall and winter pears as influenced by maturity at harvest and by length of storage at 32° F.*

WINTER NELIS

Harvest date	Firmness at harvest	Storage at 32° F.	Ripened at 65° F.	Ripening capacity	Dessert quality	Condition and appearance
	Pounds pressure	*Days*	*Days*			
Sept. 15, 1931	18.3	88	10	Normal	Good	Good, some shrivelling.
		127	10	do	do	Fair, slight scald.
		193	8	do	Fair	Do.
		224	8	do	do	Do.
		288	6	Subnormal	Poor	Moderate scald, poor.
Oct. 9, 1931	15.0	74	10	Normal	Excellent	Excellent.
		103	10	do	do	Do.
		138	8	do	do	Do.
		171	8	do	do	Very good.
		200	8	do	Very good	Slight scald.
		233	6	do	do	Do.
Oct. 30, 1931	12.9	43	10	do	do	Slightly mealy, good.
		82	10	do	do	Do.
		117	8	do	Good	Do.
		150	8	do	do	Do.
		187	8	do	Fair	Overripe, mealy.
		221	6	do	do	Do.

COMICE

Harvest date	Firmness at harvest	Storage at 32° F.	Ripened at 65° F.	Ripening capacity	Dessert quality	Condition and appearance
Aug. 31, 1933	12.4	57	10	Normal	Very good	Good, slight shrivelling.
		82	7	do	Good	Do.
		110	5	do	Fair	Slight scald, shrivelled.
		147	5	Subnormal	Poor	Do.
		187	7	Abnormal	do	Do.
		244	0	do	do	Severe scald, core break-down.
Sept. 20, 1933	9.8	0	18	Normal	Excellent	Excellent.
		24	10	do	do	Do.
		52	7	do	do	Do.
		80	6	do	do	Very good.
		117	5	do	Good	Good.
		157	7	Abnormal	Poor	Severe scald, core break-down.
		224	0	do	do	Do.
Oct. 1, 1933	9.2	22	8	Normal	Excellent	Excellent.
		47	7	do	do	Do.
		75	5	do	do	Do.
		112	5	do	do	Mealy, overripe.
		152	7	Abnormal	Poor	Slight scald, core break-down.
		209	0	do	do	Completely scalded, core break-down.

BOSC

Harvest date	Firmness at harvest	Storage at 32° F.	Ripened at 65° F.	Ripening capacity	Dessert quality	Condition and appearance
Aug. 6, 1934	13.0	0	13	Normal	Good	Slightly shrivelled, poor color
		94	8	do	do	Do.
		138	7	do	Fair	Do.
		168	7	Abnormal	Poor	Granular, hard, shrivelled.
		203	10	do	do	Do.
Aug. 22, 1934	11.3	0	12	Normal	Excellent	Excellent.
		36	8	do	do	Do.
		70	7	do	do	Do.
		120	8	Subnormal	Fair	Granular, fair.
		150	9	Abnormal	Poor	Hard, granular, fair.
		185	10	do	do	Do.
Sept. 5, 1934	11.3	0	10	Normal	Excellent	Excellent.
		64	8	do	do	Do.
		108	7	Abnormal	Poor	Granular, mealy.
		138	7	do	do	Do.
		173	10	do	do	Granular, core break-down.

TABLE 16.—*Ripening capacity, dessert quality, and condition of fall and winter pears as influenced by maturity at harvest and by length of storage at 32° F.*—Continued

FLEMISH BEAUTY

Harvest date	Firmness at harvest	Storage at 32° F.	Ripened at 65° F.	Ripening capacity	Dessert quality	Condition and appearance
	Pounds pressure	*Days*	*Days*			
Aug. 11, 1933	13.9	76	8	Normal	Good	Good, some shrivel.
		101	8	do	Fair	Slightly granular, shrivelled.
		129	7	Abnormal	Poor	Granular, tough.
		166	8	do	do	Shrivelled, tough.
		206	8	do	do	Do.
Aug. 21, 1933	11.6	29	14	Normal	Excellent	Excellent.
		53	9	do	do	Do.
		91	7	do	Very good	Do.
		119	8	do	Good	Very good.
		156	7	Abnormal	Poor	Tough, hard, poor.
		196	7	do	do	Do.
		227	7	do	do	Core break-down.
Sept. 6, 1933	10.8	47	8	Normal	Excellent	Excellent.
		72	7	do	do	Do.
		100	8	Subnormal	Fair	Good, slightly granular.
		137	7	do	Poor	Hard, granular.
		177	7	Abnormal	do	Core break-down.

TABLE 17.—*Ripening capacity, dessert quality, and condition of fall and winter pears as influenced by season and length of storage at 32° F.*[1]

ANJOU

Harvest date	Firmness at harvest	Storage at 32° F.	Ripened at 65° F.	Ripening capacity	Dessert quality	Condition and appearance
	Pounds pressure	*Days*	*Days*			
Sept. 14, 1931	13.3	46	8	Normal	Excellent	Excellent.
		89	9	do	do	Do.
		113	9	do	do	Do.
		185	7	do	Very good	Very good.
		216	6	do	do	Do.
		248	6	do	Good	Fair, mealy.
Sept. 13, 1932	11.5	0	13	do	Excellent	Excellent.
		28	9	do	do	Do.
		71	7	do	do	Do.
		126	7	do	do	Do.
		162	7	do	do	Do.
		222	7	do	Good	Good, slightly mealy.
Sept. 19, 1933	11.0	0	14	do	Excellent	Excellent.
		24	10	do	do	Do.
		62	8	do	do	Do.
		127	8	do	do	Do.
		198	7	do	Very good	Very good.
		224	7	do	Good	Good.
Aug. 20, 1934	11.4	0	14	do	Excellent	Excellent.
		40	9	do	do	Do.
		72	7	do	do	Do.
		115	6	do	do	Do.
		163	5	do	Very good	Do.
		189	6	do	do	Very good.
Sept. 17, 1935	11.6	30	8	do	Excellent	Excellent.
		72	8	do	do	Do.
		105	7	do	do	Do.
		172	6	do	Very good	Very good.

[1] Harvested at optimum maturity and stored immediately.

TABLE 17.—*Ripening capacity, dessert quality, and condition of fall and winter pears as influenced by season and length of storage at 32° F.*—Continued

BOSC

Harvest date	Firmness at harvest	Storage at 32° F.	Ripened at 65° F.	Ripening capacity	Dessert quality	Condition and appearance
	Pounds pressure	*Days*	*Days*			
Sept. 8, 1932	11.8	0	13	Normal	Excellent	Excellent.
		32	11	do	do	Do.
		68	7	do	Very good	Do.
		126	14	Abnormal	Poor	Hard, granular, fair.
		160	10	do	do	Hard, granular, poor
		195	10	do	do	Do.
Sept. 27, 1933	11.1	16	10	Normal	Excellent	Excellent.
		54	9	do	do	Do.
		82	11	Subnormal	Fair	Slight granular, fair
		119	9	Abnormal	Poor	Do.
		159	9	do	do	Do.
		190	10	do	do	Do.
Aug. 22, 1934	11.3	0	12	Normal	Excellent	Excellent.
		36	8	do	do	Do.
		70	7	do	do	Do.
		120	8	Subnormal	Fair	Granular, fair.
		150	9	Abnormal	Poor	Hard, granular, fair.
		185	10	do	do	Do.
Sept. 9, 1935	13.9	45	8	Normal	Excellent	Excellent.
		82	10	Subnormal	Fair	Slightly hard, granular.
		114	9	Abnormal	Poor	Do.
		181	11	do	do	Granular, fair.

COMICE

Harvest date	Firmness at harvest	Storage at 32° F.	Ripened at 65° F.	Ripening capacity	Dessert quality	Condition and appearance
Sept. 18, 1931	9.5	42	9	Normal	Excellent	Excellent.
		84	9	do	Very good	Very good.
		114	4	do	Good	Slight scald.
		156	5	Abnormal	Poor	Tough, hard, scald.
		190	7	do	do	Severe scald, core break-down.
Sept. 19, 1932	10.3	0	16	Normal	Excellent	Excellent.
		23	8	do	do	Do.
		48	6	do	do	Do.
		109	6	do	Good	Very good.
		138	7	Subnormal	Poor	Hard, slight scald.
		175	10	Abnormal	do	Severe scald, core break-down.
		203	10	do	do	Do.
Sept. 20, 1933	9.8	0	18	Normal	Excellent	Excellent.
		24	10	do	do	Do.
		52	7	do	do	Do.
		80	6	do	do	Very good.
		117	5	do	Good	Good.
		157	7	Abnormal	Poor	Severe scald, core break-down.
		224	0	do	do	Do.
Aug. 21, 1934	8.7	0	17	Normal	Excellent	Excellent.
		37	8	do	do	Do.
		71	5	do	do	Do.
		126	4	do	Good	Good.
		155	4	Abnormal	Poor	Severe scald, core break-down.
		191	4	do	do	Do.
Sept. 17, 1935	10.1	36	6	Normal	Excellent	Excellent.
		73	6	do	do	Do.
		105	5	do	Very good	Good.
		172	4	Abnormal	Poor	Severe scald, core break-down.

FLEMISH BEAUTY

Harvest date	Firmness at harvest	Storage at 32° F.	Ripened at 65° F.	Ripening capacity	Dessert quality	Condition and appearance
Aug. 15, 1932	10.5	0	23	Normal	Excellent	Excellent.
		55	8	do	do	Do.
		91	7	do	Very good	Do.
		119	7	Subnormal	Poor	Granular, fair.
		147	7	Abnormal	do	Hard, granular, poor
		191	7	do	do	Do.
Aug. 21, 1933	11.6	29	14	Normal	Excellent	Excellent.
		53	9	do	do	Do.
		91	7	do	Very good	Do.
		119	8	do	Good	Very good.
		156	7	Abnormal	Poor	Tough, hard, poor
		196	7	do	do	Do
Aug. 9, 1934	10.9	0	15	Normal	Excellent	Excellent.
		49	9	do	do	Do.
		83	7	do	do	Do.
		134	7	Subnormal	Good	Slightly granular.
		164	7	do	do	Granular, hard.
		199	7	Abnormal	Poor	Granular, poor.

TABLE 18.—*Ripening capacity, dessert quality, and condition of Bosc pears as influenced by storage temperature and by producing districts, 1934* [1]

Producing district	Storage	Storage temperature of 30° F.				Storage temperature of 36° F.			
		Ripened at 65° F.	Ripening capacity	Dessert quality	Condition and appearance	Ripened at 65° F.	Ripening capacity	Dessert quality	Condition and appearance
	Days	*Days*				*Days*			
Wenatchee	0	12	Normal	Very good	Very good	12	Normal	Very good	Very good.
	36	8	do	do	do	8	do	do	Good.
	70	8	do	do	do	7	Subnormal	Fair	Granular, tough.
	113	10	Subnormal	Fair	Firm, slightly granular	10	Abnormal	Poor	Slight scald, core break-down.
	161	12	Abnormal	Poor	Hard, granular	3	do	do	Severe scald, core break-down.
	187	10	do	do	do				
Yakima	0	10	Normal	Very good	Very good	10	Normal	Very good	Very good.
	29	8	do	do	do	8	do	do	Good.
	63	8	do	do	do	8	Subnormal	Poor	Granular, tough.
	106	10	Subnormal	Fair	Firm, slightly granular	10	Abnormal	do	Moderate scald, core break-down.
	154	12	Abnormal	Poor	Hard, granular	3	do	do	Severe scald, core break-down.
	180	9	do	do	do				
Medford	0	10	Normal	Excellent	Excellent	10	Normal	Excellent	Excellent.
	29	8	do	do	do	8	do	do	Do.
	63	7	do	do	do	7	do	Good	Some shrivelling, good.
	106	7	do	Very good	Very good	7	Subnormal	Fair	Some shrivelling, fair.
	154	12	Abnormal	Poor	Firm, slightly granular	12	Abnormal	Poor	Scald, core break-down.
	180	10	do	do	Hard, granular.	0			

[1] Harvested at optimum maturity and stored immediately.

TABLE 19.—*Ripening capacity, dessert quality, and condition of fall and winter pears as influenced by length of storage at different temperatures, 1933* [1]

Storage: Temperature	Storage: Period	COMICE: Ripened at 65° F.	COMICE: Ripening capacity	COMICE: Dessert quality	COMICE: Condition and appearance	ANJOU: Storage	ANJOU: Ripened at 65° F.	ANJOU: Ripening capacity	ANJOU: Dessert quality	ANJOU: Condition and appearance
°F.	Days	Days				Days	Days			
30	62	8	Normal	Excellent	Excellent	62	8	Normal	Excellent	Excellent.
	90	6	do	do	do	90	7	do	do	Do.
	127	6	do	do	do	127	6	do	do	Do.
	167	7	Subnormal	Fair	Granular, tough	167	7	do	Good	Do.
	198	7	Abnormal	Poor	Severe scald, core break-down	224	7	do	do	Good.
32	0	18	Normal	Excellent	Excellent	0	14	do	Excellent	Excellent.
	24	10	do	do	do	24	10	do	do	Do.
	52	7	do	do	do	90	7	do	do	Do.
	80	6	do	do	do	127	6	do	do	Do.
	117	5	do	do	do	198	7	do	Good	Good.
	157	7	Abnormal	Poor	Slight scald, core break-down	224	7	do	do	Do.
	224	0	do	do	Severe scald, tissue collapse					
34	24	10	Normal	Excellent	Excellent	24	10	Normal	Excellent	Excellent.
	62	7	do	do	do	62	7	do	do	Do.
	90	3	do	Good	do	90	5	do	do	Do.
	127	4	Abnormal	Poor	Moderate scald	127	5	do	Fair, astringent	Good.
	167	0	do	do	Severe scald, core break-down	167	0	do	do	Do.
36	24	10	Normal	Excellent	Excellent	24	10	do	Excellent	Excellent.
	62	7	do	do	do	90	5	do	do	Do.
	90	3	do	Good	Very good	127	3	do	Fair, astringent	Good.
	127	0	Abnormal	Poor	Severe scald, core break-down	167	0	do	do	Do.

	FLEMISH BEAUTY					BOSC				
30	91	8	Normal	Excellent	Excellent	54	11	Normal	Excellent	Excellent.
	119	8	do	Good	do	82	11	do	do	Do.
	196	7	Abnormal	Poor	Granular, hard	119	10	do	Very good	Do.
	227	8	do	do	do	159	10	Subnormal	Fair	Granular.
						190	10	Abnormal	Poor	Granular, hard, tough.
32	29	14	Normal	Excellent	Excellent	16	10	Normal	Excellent	Excellent.
	91	7	do	do	do	54	9	do	do	Do.
	119	7	do	Good	do	82	10	do	do	Do.
	156	8	Subnormal	Fair	Granular, hard	119	9	Subnormal	Fair	Granular.
	196	7	Abnormal	Poor	do	159	10	Abnormal	Poor	Granular, hard, tough.
	227	7	do	do	do	190	9	do	do	Do.
34	29	12	Normal	Excellent	Excellent	16	10	Normal	Excellent	Excellent.
	54	7	do	do	do	54	9	do	do	Do.
	91	7	do	do	do	82	11	Subnormal	Poor	Granular, hard, tough.
	119	7	Abnormal	Poor	Granular, hard	119	9	Abnormal	do	Do.
	156	8	do	do	do	159	10	do	do	Severe scald, core break-down.
	196	7	do	do	Moderate scald, granular, tough					
36	29	12	Normal	Excellent	Excellent	16	10	Normal	Excellent	Excellent.
	53	7	do	do	do	54	9	do	do	Do.
	91	7	do	do	do	82	11	Abnormal	Poor	Granular, tough.
	119	8	Abnormal	Poor	Slightly granular, hard	119	6	do	do	Slight scald, core break-down.
	156	0	do	do	Severe scald, core break-down	159	0	do	do	Severe scald, tissue collapse.
	196	0	do	do	Severe scald, tissue collapse					

[1] All varieties were harvested at optimum maturity and stored immediately.

The data in table 16 indicate that maturity at harvest is an important factor in determining the storage life and ripening capacity of fall and winter pears. If harvested too early, the fruit has a tendency to develop surface scald and become excessively shrivelled. It is usually somewhat astringent in taste and seldom attains the full characteristic flavor of the variety. If harvest is delayed too long, mealiness and core break-down become serious in storage. In Bosc, Flemish Beauty, and Comice, where loss of normal ripening capacity occurs after prolonged storage, proper harvest maturity is an important factor, advanced maturity usually resulting in an earlier loss of ripening capacity. This is illustrated by the data on the third picking of Bosc and Flemish Beauty pears in table 16.

Pears ripen rapidly at temperatures of 60° to 70° F. The length of the previous storage period apparently has little significant influence on the time required to reach full ripeness at these higher temperatures. There was a difference of only 2 days in the ripening time of Winter Nelis pears at 65° (table 16) after having been stored previously at 32° for 74 to 200 days. Storage at low temperature also resulted in a greater uniformity in ripening of pears harvested at different degrees of maturity. Ezell and Diehl (*6*) obtained similar results with Bartlett pears.

Table 17 summarizes the data on the ripening capacity and dessert quality of four varieties of pears as they were influenced by seasonal differences. As firmness of the flesh as measured by the pressure tester is one of the recognized indices of pear maturity, it was used as the basis for establishing optimum harvest maturity. Except in 1934, the date of harvest varied only a few days from year to year. The length of the growing period for these years also varied but little, except in 1934 when the bloom was approximately 3 weeks earlier and the harvest 4 weeks earlier than in the other years.

In each of the 5 years, Anjou, Flemish Beauty, and Comice pears retained their characteristic ripening behavior at 65° F. after removal from storage at 32°. There was some variation in dessert quality from year to year, but in general approximately the same number of days were required each season for each variety to ripen after storage. The appearance of scald, core break-down, and loss of ripening capacity was likewise correlated with the time in storage. The data in table 17 indicate that Bosc pears were more variable in their ripening during different seasons than the other three varieties. Each year after prolonged storage Bosc pears failed to ripen normally but the seasonal variation in the time of inception of this physiological disorder was wide. Bosc pears also varied from season to season in the degree of development of the characteristic varietal flavor. Allen (*1*) also has reported that "of all the pears observed, Bosc has proved the most variable in quality."

Data in table 18 show that the ripening capacity of Bosc pears may vary between producing districts. Cultural practices, growing conditions, age and vigor of trees were similar in the Wenatchee and Yakima districts. There was also a similarity in the ripening behavior and dessert quality of the fruit from these districts. On the other hand, fruit from the Medford district was grown under clean cultivation, where irrigation was somewhat limited, and the soil was of a much heavier type. The trees were larger and older than those used in the Wenatchee and Yakima districts and bore a lighter crop of smaller-sized pears. Fruit from Medford was superior in texture and flavor to that from the other 2 districts. Its ripening capacity was still normal after 106 days of storage at 30° F., but fruit from the other districts failed to ripen satisfactorily at this time. Data in table 18 show that Bosc pears have a much shorter storage life at 36° than at 30°. Further evidence that loss of ripening capacity may vary within a variety is indicated by the fact that Bosc pears from the Medford district had a longer storage life at 36° than did those from the 2 Washington districts. The comparative respiratory measurements shown in figure 9 and carbohydrate analyses not included in this report failed to suggest significant chemical differences between the fruit from the 3 districts. Oxidase and catalase measurements (*8*), however, proved that the Medford fruit contained 3 to 5 times as much oxidase, and 1½ to 2 times as much catalase as that from the other 2 districts.

Data pertaining to the ripening capacity, dessert quality, and condition of fall and winter pears as influenced by storage temperature are presented in table 19 and show that the storage life of pears is dependent upon the storage temperature. For example, Comice could be ripened normally after 127 days of storage at 30° F., but after a similar period at 36°, normal ripening did not occur and severe scald and core break-down were present. Judged by condition and appearance, the potential storage life of Anjou pears was greater after 224 days at 30° than after 90 days at 36°. Comice and Anjou varieties softened and ripened at 34° to 36°, but Bosc and Flemish Beauty failed to soften at these temperatures.

Varieties that lost their capacity to ripen normally did so irrespective of the temperature at which they were stored, but the inception of the disorder was much earlier in lots held at 34° and 36° F. than at lower temperatures. Bosc pears, for instance, could be ripened normally after 119 days at 30°, whereas at 36° the successful storage period was less than 80 days. Scald and core break-down appeared earlier in fruit from the higher storage temperatures ripened at 65° than in similar fruit from 30°; in fact, Flemish Beauty and Bosc pears from storage temperatures of 30° and 32° remained entirely free from these disorders.

Data in table 19 indicate that for maximum storage life and for best dessert quality after ripening, fall and winter pears should be stored at 30° F. If the fruit is stored immediately after harvest at this temperature Comice and Flemish Beauty pears can be ripened satisfactorily at 65° after 120 to 130 days of storage; Bosc, after 100 to 120 days; Anjou, after 180 to 200 days. These are maximum storage periods found in experimental procedure and are slightly longer than those recommended for commercial practice by Hartman (*25*) and Pentzer (*38*) who employed storage temperatures of 31° and 32°.

Physiological Storage Disorders

The more common physiological disorders that limit the storage life of fall and winter pears are pear scald, Anjou scald, core break-down, and loss of ripening capacity, and these disorders are to a large degree associated with the senescence of the fruit. Their appearance is hastened by improper handling and storage practices. In the commercial handling of pears, any one of them may cause large financial losses.

PEAR SCALD

Most varieties of pears are subject to scald (fig. 26). In pear scald the skin of the affected fruit becomes dark brown, soft, watery, and sloughs off easily under pressure. In severe cases the peripheral flesh tissues also are involved. Unlike apple scald, pear scald cannot be controlled by oiled-paper wraps. It is usually characterized in severe cases by a foul odor and a disagreeable taste, doubtless due to

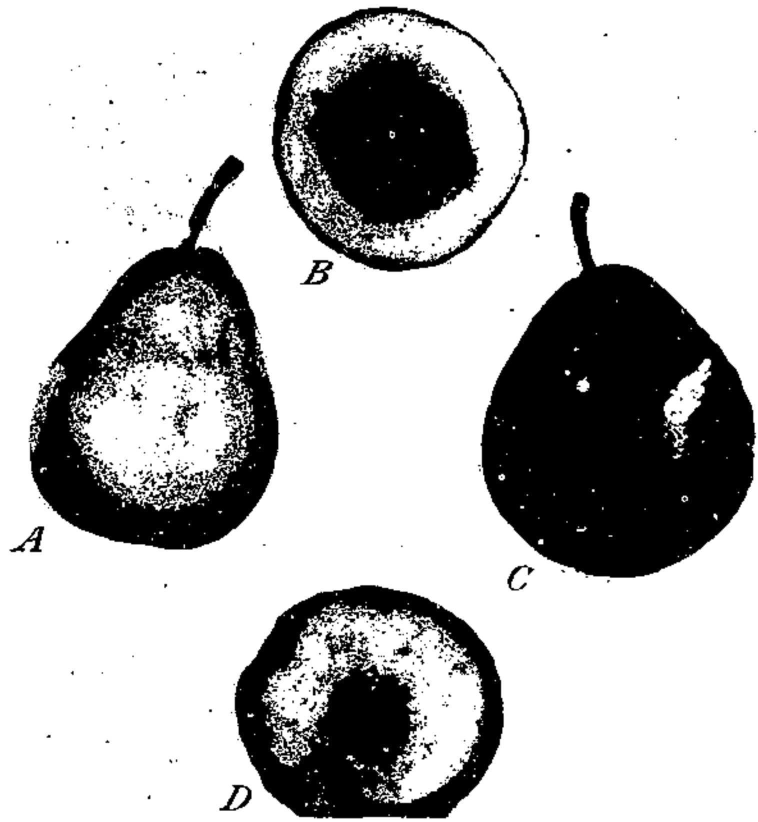

FIGURE 26.—Pear scald and core break-down in Flemish Beauty pears in storage at 36° F.: *A*, Sound fruit; *B*, core break-down; *C*, pear scald; *D*, pear scald and its extension into the flesh.

the accumulation of acetaldehyde, ethyl alcohol, and butyric esters in the diseased tissues. Susceptibility to pear scald can be lowered by harvesting the fruit at proper maturity and storing it immediately at 30° to 32° F. (*38*); by the use of "gas storage" (carbon dioxide) (*12*); and by limiting the length of storage at low temperature.

ANJOU SCALD

Anjou scald has been described by Hartman [6] as a mottled surface browning or blackening of the skin of the fruit of this variety. It

[6] HARTMAN, HENRY. INVESTIGATIONS RELATING TO THE HANDLING OF ROGUE RIVER VALLEY PEARS ON EASTERN MARKETS. [N. D.] [Mimeographed.]

differs from common pear scald in being confined to the surface tissue and in not being characterized by a hydration or sloughing off of the skin or by the accumulation of volatile chemicals that affect the odor or dessert quality of the scalded fruit. It resembles apple scald in being controlled by the use of oiled paper wraps. Early harvested fruit is more susceptible to Anjou scald than that picked when it is more mature. Scald is rarely present on the fruit in cold storage but often develops quickly when the fruit is removed to warm temperatures for ripening. It is limited to the Anjou variety and, although its presence may detract from the appearance of the fruit, the dessert quality is not impaired. Commercial control of Anjou scald can be accomplished by harvesting the pears at proper maturity and wrapping the fruit in oiled paper wraps.

CORE BREAK-DOWN

Core break-down in pears is illustrated in figures 26, *B*, 27, and 28. In its incipient form (fig. 27) this disease is characterized by an excessive softening and hydration of the core tissue that often results in "core slip." Severe disintegration and a marked browning or blackening of the tissues in the core region and the adjacent vascular and flesh area (fig. 28) mark the final stages of core break-down. This disorder is also associated with an accumulation of acetaldehyde (*21*), and like pear scald is more prevalent in senescent fruit. Allowing the fruit to become overmature before harvest and overripe after storage are important factors in its occurrence. It is also frequently present in unripened fruit that has been held too long in storage at low temperatures. Overmature pears sometimes are affected with core break-down while they are still attached to the tree.

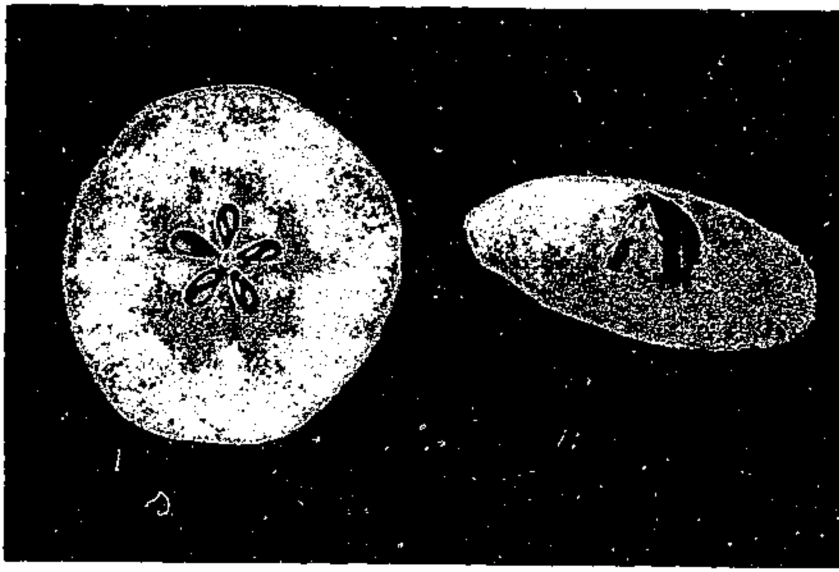

FIGURE 27.—Early stages of core break-down in Comice pears: *A*, Soft waterlogged area surrounding the core region; *B*, "core slip" in which the carpels separate readily from the surrounding flesh.

All commercial varieties of pears grown in the Pacific Northwest are susceptible to core break-down. Bartlett, Comice, Flemish Beauty, and Bosc are the most susceptible, whereas Anjou and Winter Nelis are fairly resistant. A variety grown in the hotter producing districts is less susceptible to core break-down than is the same variety grown in the cooler producing districts. Harvesting at optimum maturity, prompt storage at low temperature, avoidance of prolonged storage or overripening after storage are measures which can be used to reduce losses from core break-down.

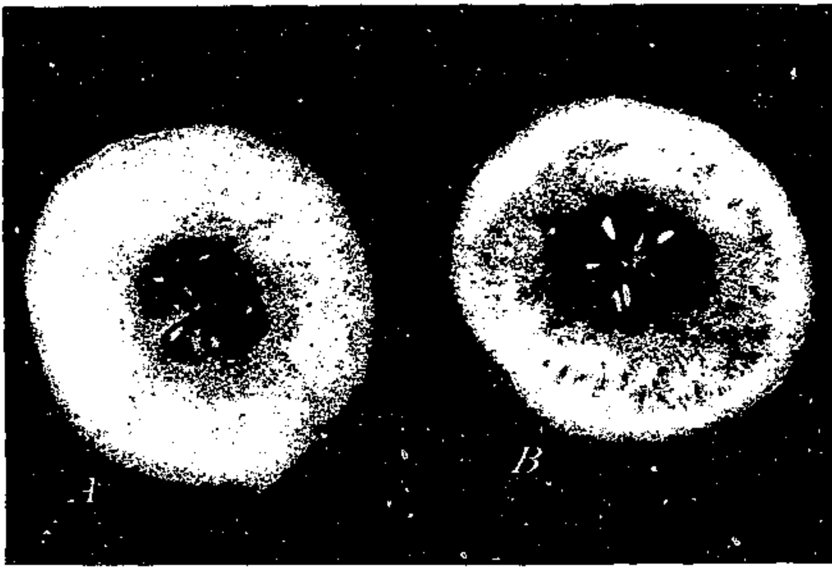

FIGURE 28. Advanced stage of core break-down in Comice pears: *A*, Discoloration of the waterlogged core area; *B*, discoloration of the core region and general break-down of the surrounding flesh.

LOSS OF RIPENING CAPACITY

Loss of ripening capacity in pears should be classified as a physiological disturbance characterized by failure of the fruit to soften and attain its characteristic dessert quality under favorable ripening conditions. This disorder develops while the fruit is still in storage at low temperature, but it cannot be detected by visible symptoms and for this reason it is difficult to diagnose before attempts are made to ripen the fruit.

It has been suggested (*28*) that the loss of normal ripening capacity in pears may be a form of low-temperature injury. However, if low temperature alone were the controlling factor it would seem that the lower the temperature the earlier would be the incidence of this storage disorder and the more severe would be its manifestation. That such is not always the case, however, is shown by the data in table 19 wherein Bosc, Flemish Beauty, and Comice lost their ripening capacity much earlier at 36° than at 30° F.

In Comice, loss of ripening capacity is closely associated with scald and core break-down; in Bosc and Flemish Beauty it is not. Following prolonged storage at 32° F., these three varieties may appear harvest green in color and apparently in excellent physical condition, yet upon removal to higher temperatures for ripening, they acquire a golden-yellow color but remain as firm and crisp as they were while under refrigeration. Of the fall and winter pears considered in this study, the Anjou and Winter Nelis varieties alone are not subject to this storage disorder.

No evidence of the loss of ripening capacity is obtainable in the respiratory activity of the fruit in cold storage. Oxidase and catalase measurements do not reveal its presence, nor can it be correlated with changes in carbohydrates and astringent materials. Pectic changes, however, offer a clue as to the probable mechanism involved when pears lose their capacity to ripen in a normal manner. Normal ripening is associated with a rapid hydrolysis of the insoluble protopectin into soluble pectin, which accumulates in copious amounts. Loss of ripening capacity is associated with a restriction of this hydrolytic process and is believed to be enzymatic in nature. If further work proves this to be true, loss of ripening capacity in pears doubtless can be explained by the inactivation of the protopectinase system.

SUMMARY AND CONCLUSIONS

Studies were made on five varieties of fall and winter pears after these had been subjected to various procedures in harvesting, handling, storage, and ripening. These studies involved determinations of the respiration, oxidase and catalase activity, carbohydrates, acids, acetaldehyde, astringents, and pectic material, accompanied by observations on the behavior of the fruit during ripening and when affected by physiological storage diseases.

The respiratory intensity at 32° F. was not directly correlated with: The storage life of the different varieties of pears, the delayed handling procedure prior to storage, the kind of fruit wrap used in packaging, the incidence of loss of ripening capacity, nor the dessert quality or storage life of Bosc pears from different producing districts. It was, however, directly associated with maturity at harvest and severity of pear scald and core break-down. Furthermore, normal ripening at 65° F. was correlated with an increased respiratory activity, and the intensity of the two processes paralleled each other until the fruit acquired prime dessert quality.

Fruit picked at the stage of maturity recommended for best dessert and storage qualities showed less oxidase activity than fruit picked earlier; the catalase content also averaged slightly less at this picking.

The oxidase activity increased during storage at 30° and 36° F., the greatest increase being at the higher temperature. Catalase activity showed comparatively little change at either temperature.

Fruit ripened to prime eating condition showed greater oxidase and less catalase activity than comparable fruit before ripening. When pears failed to ripen after prolonged storage at low temperatures no concomitant change in oxidase or catalase activity took place.

The oxidase and catalase of a variety varied widely when the fruit was grown in different districts and in different orchards in the same district. Their activity also varied between seasons.

Scalded fruits showed less oxidase and catalase activity than fruits not scalded.

Carbohydrate analyses indicated no significant difference in composition between pears stored immediately at 32° F. and those delayed at high temperatures before placing under refrigeration. Similar analyses failed to indicate differences in the composition of pears as influenced by scald, break-down, or loss of ripening capacity. Maturity at harvest, however, was associated with an increase in total solids and soluble carbohydrates.

Glucose, sucrose, and fructose are the soluble sugars in pears; fructose was present in predominant amounts and together with sucrose is the sugar that accumulates in maturing pears.

The acetaldehyde content of each variety of fall and winter pears increased with the length of storage. It increased to a maximum in Comice where it was closely associated with scald and core break-down. Its increase with maturity at harvest was dependent upon varietal characteristics, but delayed storage after harvest was conducive to the production of greater amounts of this volatile constituent. The acetaldehyde content of pear fruits during storage at 32° F. could not be correlated with the type of fruit wrap or the loss of ripening capacity unless scald or core break-down was present.

The acetaldehyde content of pears was correlated with scald, core break-down, and storage temperature, being decidedly greater in fruit held at 36° F. than in similar fruit at 32°. It increased in Comice and Anjou pears during normal ripening and attained its peak with the onset of scald and core break-down.

Total acids could not be correlated with loss of ripening capacity or the presence of scald and core break-down. The pH value of the fruit tissues gradually increased with maturity and duration of storage but was not correlated with varietal differences. In most instances, the "index figure" bore no direct relationship to handling practice, storage temperature, loss of ripening capacity, or the presence of scald and core break-down.

Tannin and nontannin compounds were present in greater concentration in the peeling than in other portions of pear fruits.

Changes in astringent components of the fruit could not be correlated with variety, storage temperature, ripening, scald, core break-down, nor loss of ripening capacity. They were, however, correlated with length of storage at 32° F., nontannins gradually increasing at the expense of tannins. These changes might be influenced by the production of addition compounds of tannin with certain products of metabolism such as acetaldehyde. Granting that condensation products of this nature may occur, information at hand does not justify a conclusion that when pears lose their ripening capacity these products inhibit the enzyme system which normally hydrolyzes the pectic compounds.

The ripening response of different varieties of pears was directly associated with the hydrolysis of protopectin into soluble forms. There was a significant correlation between the degree of ripeness and the formation of soluble pectin when pears were ripened normally at 65° F. This constituent increased tenfold during the process of normal ripening to prime dessert quality.

Data are presented to show that the loss of normal ripening capacity in certain varieties of pears is directly associated with the failure of the hydrolytic mechanism responsible for the formation of soluble pectin. The possibility is suggested that this mechanism may be largely enzymatic.

Pear-ripening studies demonstrated the importance of maturity at harvest in avoiding excessive shrivelling, scald, and the astringency that characterize immature fruit, and the mealiness and core break-down usually found in overmature fruit. In Bosc, Comice, and Flemish Beauty varieties overmaturity at harvest was generally associated with earlier onset of loss of normal ripening capacity.

Storage and ripening behavior, loss of ripening capacity, and the appearance of scald were singularly uniform from season to season except in the Bosc variety where these factors varied with the season and district in which the fruit was produced.

The storage life of fall and winter pears was dependent upon the storage temperature. At 36° F. Comice and Anjou ripened slowly, but Bosc and Flemish Beauty although acquiring a golden-yellow color did not soften. The latter varieties likewise lost their normal ripening capacity much earlier at 36° than at 30°. Scald and core break-down were excessive at 36°.

For maximum storage life and optimum dessert quality after ripening, pears should be stored at 30° F. Comice and Flemish Beauty pears stored at this temperature immediately after harvest could be ripened satisfactorily after 120 to 130 days; Bosc, after 100 to 120 days; Anjou and Winter Nelis, 180 to 200 days. These are maximum periods of safe storage which would be difficult to achieve in commercial practice.

Pear scald, Anjou scald, core break-down, and loss of normal ripening capacity are described. Preventive and control measures for minimizing losses from these troubles are suggested.

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Bureau of Plant Industry	E. C. AUCHTER, *Chief.*
Division of Fruit and Vegetable Crops and Diseases.	H. P. GOULD, *Principal Horticulturist, in Charge.*

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