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Title PHYSICAL AND BIOCHEMICAL CHANGES IN PEARS DURING STORAGE AND RIPENING

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A study has been made of the interrelations between certain of the physical and biochemical changes in three varieties of pears during storage and ripening. The metabolic changes which occurred in the fruit during cold temperature storage were found to influence the development of certain characteristics associated with dessert quality of the ripened fruit. The nature of these changes varied according to variety.

The rate and degree of softening at a temperature favorable for ripening (68-70°F.) varied considerably according to variety and according to length of the storage period. Bartlett pears decreased rapidly in pressure test when ripened in October and November. Bosc pears softened slower and to a lesser degree. Both varieties failed to soften and ripen normally after prolonged periods of storage. This condition was not observed in Anjou pears, but this variety ripened in April tended to have a mealy texture.

The amounts of both protopectin and total pectin increased during storage in all the three varieties. Anjou pears contained more total and protopectin than the other two varieties. The data on pectin changes indicate a possibility of synthesis of protopectin during storage. A possible explanation for such phenomenon is discussed. There is a fairly significant correlation between per cent protopectin and pressure test.

The percentage of extractable juice was inversely correlated with fruit firmness, and increased rapidly during ripening. Highest yields of extractable juice were obtained from Anjou and Bartlett pears, and the percentages decreased in all varieties with increase in length of the storage period. Low extractable juice content was correlated with the loss of ripening capacity in Bartlett and Bosc pears and the occurrence of mealy texture in Anjou pears. The relative viscosity of the juice increased during the ripening process and was highest in all varieties ripened after short periods of storage.

Total acid content of all varieties varied to some extent but no consistent trends were observed.

In all varieties total solids increased with ripening, and were lower in Bartlett and Bosc than in Anjou pears.

The use of activated carbon treatment of the storage atmosphere retarded the rate of loss of green color. No effect on the metabolism of pectic substances was apparent in Bartlett and Bosc pears, while the data for Anjou pears were not consistent.

PHYSICAL AND BIOCHEMICAL CHANGES IN PEARS DURING STORAGE AND RIPENING

by

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Chapter I

INTRODUCTION

Because of certain characteristics which are different from those of other fruits, the commercial handling of pears presents special problems in harvesting, storage, transportation and marketing. Unlike most fruits, pears do not develop desirable flavor and texture prior to natural abscission. In order to obtain long storage life and desirable eating qualities, they must be harvested at an optimum stage of maturity while still firm and green in color, and kept as nearly as possible in this condition until ripening is desired. When stored at low temperatures (30-32°F.), progressive ripening to an edible condition such as occurs in apples does not take place. At intermediate temperatures (35-50°F.), the storage life is shortened and in some varieties abnormal changes occur which prevent the fruit from ripening properly when removed to warm temperatures. Desirable eating qualities including a melting, buttery or juicy condition of the flesh depending upon the variety, together with good flavor, are developed only when the fruit is removed from storage while still green in color and firm in texture and ripened within a comparatively narrow warm temperature range. Recommended practices consist of storage at 30-31°F. and ripening at 68-70°F.

At the present time the retention of optimum fruit quality over the maximum period of time is best obtained by close maintenance of the storage temperature at slightly above the freezing point of the tissues. Recent investigations have given some indications that the keeping quality can be further enhanced by the use of activated carbon in the storage rooms for adsorption of the physiologically active volatiles emanating from the fruit.

Even under the best storage conditions, however, certain physiological changes occur which later may have an adverse effect on the quality of the ripened fruit. Anjou pears, for example, tend to become dry and mealy rather than soft and juicy after removal from storage late in the season. The ability of the fruit to ripen may become completely inactivated in Bartlett, Bosc and Comice pears after prolonged periods of storage. The development of these conditions is a serious handicap to successful storage and marketing programs and often results in serious financial loss to the pear fruit industry.

Considerable information is available relative to the physical and biochemical changes which occur in pears and other fruits. The inter-relationships of the reactions in the tissues during storage and especially the effect of the resulting changes on the behaviour of the fruit during ripening have been studied to only a limited extent. The effect of fruit volatiles on the biochemical changes in the fruit while stored at low temperatures has not been determined. This investigation was undertaken as an endeavor to obtain information on some of these problems, especially:

(1) The possible interrelationships of the changes which occur in the tissues and juice during storage to the nature of the ripening processes at ripening temperatures.

(2) The effect of the use of activated carbon for the adsorption of fruit volatiles upon certain of the physical and biochemical changes in the fruit during storage and periodical ripening.

Chapter II

REVIEW OF LITERATURE

Chemical Composition in Relation to Environmental Factors and Storage Conditions

A brief review of some of the literature dealing with some physical and chemical changes in pears in particular and other deciduous fruits in general, during maturation and after harvest, together with factors that affect the quality of pears, is given below.

Carbohydrates-Sugar

Carbohydrate material forms a major portion of the dry matter of deciduous fruits. Of this carbohydrate material, sugers form the largest fraction. Sucrose, fructose, glucose are the most commonly found sugars. The amount of these sugars also veries in different parts of the fruit (33, 57). Fructose is the principal sugar in the flesh, whereas glucose predominates in the epidermis.

Fruits vary in their sugar content from year to year and from orchard to orchard (6). Gerhardt and Ezell (23) stated that accumulation of fructose and sucrose varied with the degree of maturity of fruit at harvest.

According to them, carbohydrates in winter pears were influenced by the relative maturity of the fruit and the variety. Magness (56) reports that Bartlett pears increase in sugar content and decrease in alcohol insoluble, acid hydrolyzable material during maturation on the trees. Ezell and Diehl (16) have reported a decrease during ripening of alcohol insoluble solids and reducing sugars.

The total sugars in deciduous fruits increase gradually during storage, mostly owing to, first the hydrolysis of starch, and later owing to the hydrolysis of sorbitol (58). The rate of this change could be slowed down or retarded by lowering the storage temperature or by modifying the composition of atmosphere (59, 60). Such changes can be hastened and an accumulation of sugars corresponding to hydrolysis of starch can be brought about by the ethylene treatment of pears after harvest (55). A difference in the temperature of storage may, therefore, make a difference in the quality of the pears. Lutz and Culpepper (55), however, report that in the case of Keiffer pears quality differences as influenced by various ripening temperatures did not show very clearly in terms of total solids, sugars, and acid. Since Keiffer pears differ from other pears by not containing any starch, this difference in their behaviour may be obvious.

It is very difficult to correlate storage behaviour with sugar changes as far as total amounts are concerned. When considered in conjunction with the total nitrogen and acid content, Archbold (6) found a correlation between the chemical composition and the storage life of fruit.

Pectin

It has been shown by several workers (1,2,3,35,36,37) that pears decrease in firmness during the later stages of maturation on the tree as well as after harvest and during storage. These workers have shown that the optimum time of harvesting can be determined by following the pressure test. The optimum pressure test for Bartlett pears varies according to the district where grown. Thus Allen (1) and Magness (56) have shown that Bartlett pears grown in relatively warm areas were firmer at optimum maturity than pears grown in cooler regions. Similar differences may be caused by the type of root stocks. Allen (3) reports that trees on Japanese roots produced firmer fruit than those on French roots.

Deciduous fruits soften during ripening and this change is associated with the changes in the pectic material of the fruit. Carré (11, 12) made extensive studies of pectic material in apples during storage. She associated ripening in storage with an increase in soluble pectin and a corresponding decrease in protopectin, the total pectic material remaining constant. In the later stages of storage when the fruit became mealy and showed breakdown, she observed a change in the pectic substances of the middle lamella. According to Bonner (8) pectin in the cell wall is different from that in the middle lamella. The pectic substances in the middle lamella are believed to occur as the calcium or magnesium salts of pectic acids. Joslyn and Phaff (42) quote Dauphine and Molliard as saying that pectin in the cell wall differs from that in the middle lamella by its association with the fibres of cellulose. Carre in her studies also presented some evidence to show that the total pectin content tends to increase as apples ripen. During this period there was a temporary increase in protopectin which again decreased. Haller's studies (27) are similar to those of Carré (11, 12). He, however, found that the relative firmness of different varieties is not correlated with the differences in pectic constituents.

Echévin (13) has shown that in pears the rate of pectic changes is related to temperature. In peaches Appleman and Conrad (4) found that such changes were observed to take place more rapidly at higher temperatures. During ripening in storage the amount of protopectin decreases, with a corresponding increase in the soluble pectin. The rate of these changes increases with increase in storage temperature. Emmett (15) using Conference pears stored at 12°, 5°, 4°, and 1°C. found that the rate of softening increased with increase in temperature. Rapid ripening was associated with more rapid conversion of protopectin to soluble pectin and a further breakdown of the soluble pectin. At 1°C. the development of soluble pectin was greatly retarded. He suggests that, in pears, differences in keeping quality are in all probability due mainly to differences in the rate of breakdown of pectic compounds. Appleman and Conrad (5) found in the case of tomatoes that pectin increases and protopectin decreases with increased maturity of tomatoes while on the vine. In canned tomatoes a close relationship existed between the amount of disintegration and the ratio of pectin to protopectin. Lutz and Culpepper (55) found a direct correlation between optimum ripening and maximum soluble pectin formation in Keiffer pears at 60°F. Smock (68), Gerhardt (22), and Plagge (64) have also correlated pectic substances with the storage behaviour of Bartlett pears in artificial atmospheres containing carbon dioxide at different levels. Plagge (64) has shown that there is a residual effect of CO_2 on inhibiting solubilization of pectic materials. Air-stored samples were consistently higher in soluble pectin than fruit stored under different carbon dioxide atmospheres.

Heinze and Appleman (39) found that in sweet potatoes protopectin increased while pectin decreased during the storage period. Some of the increase in protopectin was due to an increase in the total pectic substances. This synthesis of protopectin continued in the roots as long as they remained alive and in a marketable condition.

Thus, normal ripening is associated with progressive changes in the physical texture of the fruit, which passes from firmness and crispness to a soft, smooth, and buttery consistency. This change is directly associated with the hydrolysis of the insoluble protopectin into soluble pectin and pectic acid. Gerhardt and Ezell (23) show that there is a direct correlation between the loss of ripening capacity and the inactivity of the hydrolytic system responsible for the formation of soluble pectin. Respiratory measurements and carbohydrate analyses, however, do not afford any indication of the ripening capacity in all varieties of pears susceptible to these physiological disorders.

Color Changes

During ripening the green color fades and the yellow color becomes obvious. This is especially marked with the Bartlett variety. Bosc and Anjou do not show this characteristic change, though there is a difference in the color of the fruit when it is ripe. This color change has been suggested as a criterion of maturity (1, 2, 3, 35). However, color at optimum maturity may be influenced by variety, location and other factors. In hot dry districts with no irrigation the yellowing in Bartlett is more pronounced (2). The fruit stored at 32°F. will also gradually assume its characteristic ripe stage color.

Acid

Total acidity of apples undergoes a gradual loss during storage (6, 52). The change in pH is also very small but shows a tendency to increase (9). The acids are primarily malic in apples and citric in pears. Caldwell (9) gives an account of how pH is related to plant growth especially with respect to water content.

Alteration in pH markedly affects the colloidal properties of the cell and consequently its water imbibition capacity. Haynes (38) has shown that high acid content and a slow loss of the acid are not favorable factors for stored apples, as they lead eventually to internal breakdown. She suggests that apples should not be exposed to low temperature until their acid content has been reduced. Plagge and Gerhardt (63) have shown that soggy breakdown of apples is coincident with a rather marked diminution in pH. This suggests an intimate balance between active acidity and carbohydrate reserves of apples at low temperatures. Magness (56) stated that acidity tended to decrease in fruit from California during storage, whereas there was a tendency for it to increase in fruit from Washington and Oregon. Ezell and Diehl (16) reported a decrease in acidity with ripeness. Hansen (31) reported that during the course of ripening the acid content showed considerable variation but no well defined trends were apparent.

Nitrogen

Total nitrogen in apples does not change appreciably during storage but the protein nitrogen increases in amount during the climacteric period. Archbold (6) in discussing the relation between chemical composition and storage life of apples, stated that one condition favoring keeping quality appeared to be a suitable balance between the demand for respiratory substrate, regulated by the total nitrogen content, and the supply of readily available carbohydrate, dependent on the inversion of sucrose. Wallace (75) stated that low nitrogen, high sucrose, and probably a large amount of cell wall material were conducive to good keeping of apples, especially at low temp-perature. Smock and Boynton report that differential nitrogen treatment in orchards may show no effect on the keeping quality of apples because the amounts of nitrogen in the tree or fruit may not be affected. McIntosh apples showed a tendency for greater susceptibility to brown core whenever leaf nitrogen was high. There was always an inverse correlation between leaf nitrogen and fruit firmness and ground color (70, 71).

Respiration

The results of the respiratory studies of apples have been recently summarized by Kidd and West (52). According to them the rate of respiration in apples follows a well defined trend during development, ripening and storage. It was shown that a sharp rise in respiration occurs immediately or almost immediately after gathering. This respiratory peak has been called the climacteric. Following the climacteric, the rate of respiration declines and the fruits are said to be in senescence. The respiratory rise in apples and pears depends upon a number of factors viz., specific variety, climatic conditions during the growing season, temperature during storage, and the composition of the storage atmosphere. Respiratory rise is more evident at higher temperature than at cold storage temperature. Fruits at the post climacteric stage may not show a rise in the respiratory rate at 32°F. storage. The occurrance of the respiratory rise has a practical significance from the point of storage of apples and pears. Kidd and West (52) thus, reported that certain varieties should be picked and stored before the climacteric rise begins. Smock (70) recommended that for maximum storage life of McIntosh apples, the fruit should be picked just as the respiratory rise begins. It was found that most of the apples had abscissed from the tree by the time the climacteric was passed.

A pre- or post climacteric condition has much in common with other physiological processes in fruit. Hansen (29), indicated that emanations from ripe pears increased the rate of respiration and ripening of newly picked pears. The greatest effect was obtained with fruit picked early in the season and the least effect with fruit picked at post mature stages. Smock (69) has also shown that apples in the post climacteric stage do not respond to ethylene treatment.

Kidd and West (45, 52) pioneered the work on the use of modified atmospheres for fruit storage. They have shown that carbon dioxide in moderate concentrations lowers the rate of carbon dioxide production. This depressing effect is especially noticeable in post climacteric fruit. The amount of carbon dioxide that can be used safely over a long storage period depends on species, variety, and temperature. Use of carbon dioxide has been especially helpful in the case of fruit which shows injury at low temperature. Pears seem to be more tolerant to carbon dioxide at low temperatures than apples (50).

A reduced oxygen concentration also has a depressing effect on the respiration (48, 50). An atmosphere containing two percent oxygen is often recommended for apples and pears (50, 73).

Kidd and West (47) were probably the first to show that one lot of apples stimulated the respiration of a second lot of fruit when stored together in the same room.

The climacteric rise is sharp when pre-climacteric fruit is exposed to ethylene gas. Hansen (29) has shown that ethylene is more effective in the period of ascending respiratory activity. It appears from the literature that the stimulatory effects of ethylene on respiration depend on, (1) age, (2) variety, (3) temperature of storage, (4) number of ripe fruits present, (5) ripeness of the fruit supplying ethylene (69).

Ethylene and Other Volatiles

Elmer (14) was probably the first to report that as apples ripen they emanate a gas which inhibits the growth of potato sprouts. Gane has shown this gas to be ethylene (20, 21). Various workers have shown since then that ethylene is formed by fruits during ripening (28, 30, 67).

In apples the quantity of ethylene produced follows a progressive rise and then a decline. In pears the ethylene production curve seems to follow the respiration curve very closely. The peak point of respiration and ethylene production occur at about the same time. Varieties of pears having a long storage life seemed to produce less ethylene than those having a short storage life. Low oxygen atmospheres seemed to affect markedly the production of ethylene gas by pears (32) and apples (52). It has been shown that ethylene is produced by fruit during the development on the tree. The climacteric occurs as a result of the production of ethylene by the fruit and of an autostimulation produced by this gas when present in the tissues in amounts above the critical threshold values (52).

Complete absence of such fruit emanations from storage rooms seems to be almost impossible, when, as is usually the case, the fruit of various physiological ages is stored at the same time. It was shown (52) that the climacteric rise in apples gathered and stored in a closed container was much accelerated as compared to that of the fruit left on tree. This was due to the fact that in the case of fruit on tree ethylene produced by the fruit was removed away by air. Ventilation would then be an answer to this problem of ethylene removal from the storage rooms. But cooling of large quantities of fresh air for flushing the inside of the cold storage room is impractical. Fontanel (18) was the first to suggest that activated carbon can condition the air inside cold storage rooms and thus reduce the gas responsible for stimulating the ripening of fruit. The work of Smock and Southwick (72) suggests the use of activated coconut shell carbon partially saturated with bromine for removing ethylene. In the absence of any such device, ethylene and other volatile gases produced by the fruit accumulate and concentrations as high as 600 p. p. m. may be reached in some commercial storages (19). Such high concentrations of volatile gases are possibly the cause for the important functional condition known as scald (19).

The efficiency of air purification systems by the use of activated carbon has yet to be proved to be of economic value. Gerhardt (25) has shown in his recent publication that air purification units fail to remove ethylene though they remove volatiles other than ethylene to some extent. He showed the carbon treatment to be useful only in the case of early picked Bartlett pears.

There are other constituents of the total volatiles produced by fruit. The odorous constituents of apples have been identified as amyl esters of formic, acetic, caproic, caprylic acids and as geraniol (65, 66). As the fruits ripen these odors are formed in increasing amounts, at least until the fruit reaches the fully-ripe stage.

Acetaldehyde has been identified in pear and apple flesh (17, 23, 24, 34, 40, 61, 65). Acetaldehyde has been suggested as a normal intermediate product of respiration. In apples and pears affected with scald, there may be an accumulation of acetaldehyde (24, 34). Trout (74) is of the opinion that acetaldehyde may be a by-product but not necessarily a causal agent of pear scald. Ethyl alcohol has been found in normal pear and apple flesh (17, 61). Kidd and West have shown that vapors of ethyl alcohol retard the respiration of fruit tissue (49). Off flavors in fruits may thus be associated with improper aeration of the fruit or with a flesh breakdown caused by an accumulation of ethyl alcohol or acetaldehyde or both (24).

Changes in Chemical Composition in Relation to Ontogeny

Various workers have studied the changes in the chemical compounds of deciduous fruits during , maturity, storage and other handling operations. Very few workers, however, have followed the metabolism during the ontogeny of the fruit. Archbold (6, 7), Kidd and West (44, 52), and Krothov (53, 54) have shown that during growth, maturation, and senescence, fruits pass through a series of stages. These are characterized by cell division and enlargement, respiratory intensity, and by differences in the concentrations of various carbohydrate fractions. With respect to apples, Archbold (6) has summarized the situation by saying that although the changes in absolute amount of intake rate are very marked in the final stages of ripening before gathering, changes in concentration are obviously much less. Very small differences in concentrations may, therefore, correspond to rather big differences in the physiological age. Krotkov (53, 54) has divided the ontogeny of the fruit into six stages, three of which occur on the tree and the remainder during storage. In the first stage relative growth of the fruit is highest, though as a result of its small weight the absolute amounts of various substances added are very small. In the second stage the increase in the weight of the apple is close to one half of the final weight. The bulk of hemicelluloses, glucose, alcohol insoluble residue less starch and hemicelluloses, and practically all of the starch accumulate during this stage. In the third stage the most striking feature is the hydrolysis of starch. The absolute increase in the weight of the apple is less than in the preceding stage. The alcohol insoluble residue, less starch and hemicelluloses, continues to accumulate.

By the beginning of the fourth stage, the climacteric rise in respiration sets in and the metabolic changes take place at a faster rate. There is an increase in both invert sugars and fructose. The rise in sugar content is more than can be accounted for by starch hydrolysis. There is very little increase in the alcohol insoluble residue exclusive of starch and hemicelluloses. In the fifth stage respiration reaches a peak and the stage of senescence sets in. Total sugars begin to decrease. However, more sugars disappear from an apple than could be accounted for by respiration. In the sixth stage the percentage of sugars does not change appreciably and respiration is considerably in excess of the amounts of sugars simultaneously lost.

Chapter III

METHODS AND MATERIALS

Source, Handling, Storage and Ripening of Samples

The Bartlett, Bosc and Anjou pears used in the present investigation were obtained from the Hood River, Oregon, District. The fruits were packed with oil paper wraps and transported to Corvallis within twelve hours after picking. Each variety was then divided into comparable replicate lots, each consisting of 60 pears. A sufficient number of lots were prepared to provide monthly samples during the normal storage period of the variety. One sample from each lot was placed in a storage room equipped with a Dorex cannister unit having a capacity of 35 c. f. m., providing 6 complete recirculations of air in the room per hour. The fruit samples stored under these conditions are hereafter referred to as the carbon-treated samples (C. T.). A similar set of samples was stored in a room not provided with air purification equipment and are referred to as control samples (C.).

The temperature in each room was maintained at 30-31°F. throughout the storage period.

At monthly intervals, a 60-fruit sample from each storage treatment was placed in a ripening room maintained at 68-70°F. At intervals of 0, 3, 6, 9, and 12 days, 12 pears were tested for firmness by the Oregon Pressure Tester (62) and sampled for chemical analyses.

x Tissue Analysis

A sample, consisting of longitudinal wedges cut from each fruit, was ground through a food chopper and thoroughly mixed. Aliquots of the prepared material were used for the determination of moisture content, pectin, protopectin and alcohol insoluble residue.

Moisture Content

Duplicate ten gm. aliquots were transferred to small aluminum dishes and placed in an oven adjusted to 70°C. The dry weights were determined after 48 hours of continuous drying.

Alcohol Insoluble Material

A 250 gm. aliquot of the ground material was transferred to sufficient hot 95 per cent isopropyl alcohol to give a final concentration of 80 per cent alcohol, and boiled for 15 minutes. After cooling, the alcohol insoluble material was separated by filtering, washed 3-4 times with 80 per cent alcohol, and then was transferred to a tared beaker and dried at 45°C. to constant weight. After grinding through a Wiley mill using a 40-mesh sieve, it was stored in glass bottles with air-tight lids until used for pectin and protopectin analyses.

Pectin Estimation

Duplicate 1.0 gm. samples of the alcohol insoluble residue were transferred to 50 ml. centrifuge tubes, moistened with 10-15 ml. of water and left overnight in the refrigerator. Next morning the sample was stirred with approximately 40 ml. of water for ten minutes and soluble pectin was separated by centrifuging and decanting off the clear supernatant liquid. Four extractions were found sufficient to remove all the soluble pectin. The total extracted liquid was made up to 250 ml. in a volumetric flask. After filtering, 100 ml. aliquots were taken for pectin estimation. The solutions were neutralized to phenolphthelein with a ten percent sodium hydroxide solution and then 50 ml. of 0.5 sodium hydroxide were added for de-esterification. After 4 hours 50 ml. of 1N acetic acid were added and five minutes later, 50 ml. of M/1 calcium chloride solution were added while stirring. The sample thus treated was left overnight. Next morning the solution was boiled for a few minutes and filtered through a tared 12.5 cm. Whatman #30 filter paper. The precipitate was washed with hot distilled water until the filtrate was free from chloride. It was then dried at 70°C. to constant weight.

Protopectin

The residue remaining after extraction of soluble pectin was transferred to a 500 ml. boiling flask, 100 ml. of N/30 hydrochloric acid solution added and boiled under a reflux condensor for one hour. It was then cooled under running cold water, transferred to a 250 ml. volumetric flask, made to volume with distilled water, and filtered. A 100 ml. aliquot was taken for pectin estimation according to the procedure outlined.

Juice Analysis-Extractable Juice

The remainder of the fruit sample was cut into transverse sections approximately 2mm. thick by means of a slicer prepared from a 10-inch microtome blade fitted to an adjustable holder. A sample consisting of 1000 gm. was wrapped in #14 canvas duck and placed in a stainless steel pan fitted with a juice delivery tube. The juice was then extracted on a Carver hydrolic press at a pressure of 5000 lbs. After all of the extractable juice had drained from the pan, the residue was removed from the filter cloth and weighed. The amount of extractable juice was determined as the difference in weight of the tissue before and after extraction.

Apparent Viscosity

The extracted juice contained a small amount of suspended solid material which was removed by centrifuging at 2000 r. p. m. for 15 minutes. The apparent viscosity was determined with an Ostwald pipette immersed in a water bath maintained at 25°C. ($\pm$ .03). The running time in seconds for 1.0 ml. of the juice was compared with the running time required for the same quantity of distilled water.

Alcohol Precipitable Material

To 25 ml. of the centrifuged juice, 100 ml. of acidulated (HCL) alcohol was slowly added while stirring. The sample was set aside for one day and then filtered through a tared shark skin filter paper and washed with neutral alcohol until acid free. The precipitate was dried at 70°C. to constant weight.

Total Soluble Solids

The total dissolved solids in the juice were determined directly with a Bausch and Lomb hand refractometer.

pH and Total Acidity

The initial pH was determined using a Beckman pH meter. For the acid determination, 50.0 ml. of juice was titrated against N/20 KOH to pH 7.2 and the total acidity calculated as gm. of citric acid in 100 ml. of the juice.

Chapter IV

EXPERIMENTAL RESULTS

Changes in the Tissue Characteristics During Storage and Ripening

Firmness

As shown in Table I, the firmness of the flesh as indicated by the pressure test decreased in all varieties during low temperature storage. The magnitude of this decrease was considerably greater in Bartlett and Anjou than in Bosc. Thus at the termination of the storage periods, Bartlett, Anjou and Bosc pears decreased 10.1, 12.9, and 2.2 lbs., respectively, in pressure test. No significant differences were observed in firmness of the control and carbon-treated Bartlett and Bosc pears, but Anjous from the carbon-treated storage were 8.7 lbs. firmer than the control fruit after 7 months of low temperature storage.

The rate and degree of softening at warm temperatures varied considerably between the three varieties. Bartletts ripened in October, November, and to a lesser extent in December, showed a rapid decrease in firmness of tissue, especially during the first three days. Optimum dessert quality had developed when the pressure test was approximately 4.5 - 5 lbs., which represented a decrease in pressure test of 23 - 26 lbs., during the ripening period. Bosc pears softened more slowly than Bartletts, the most rapid decrease occurring between the third and sixth days. Best dessert quality was correlated with a pressure test of approximately 9 lbs. Anjou pears transferred to the ripening room in October softened very slowly, and after 12 days still had a pressure of 12 lbs. Samples stored for longer periods ripened to an edible condition within 6 - 9 days. Fruit from the carbon-treated room tended to soften more slowly during the early stages of ripening than the untreated fruit, but on the twelfth day the pressure tests of both lots were approximately the same.

According to the data (Figs. 1, 2, 3 and Tables I, II, III), Bartlett and Bosc pears removed from storage late in the season softened at a slower rate and to a lesser extent than similar samples ripened earlier in the season. Thus Bartletts ripened in October had a pressure test of 4.3 - 4.6 lbs. on the ninth day, while the samples ripened for a similar length of time in January had a pressure test of 14.8 - 16.5 lbs. Bosc pears behaved similarly, although the differences in degree of softening were not so great. None of the Anjou samples failed to soften to an edible condition, although the fruit ripened in March had a higher pressure test at the end of 12 days than noted previously and tended to be more mealy in texture than the samples ripened after shorter periods of storage.

The alcohol insoluble residue remained approximately the same in Bartlett pears but tended to decrease in Bosc and Anjou pears during the storage period.

Pectic Substances-Changes During Storage

As shown in Tables IV, V, and VI, the amount of both protopectin and total pectin increased during the storage period. This behaviour was consistent in all varieties. In Anjous and Bartletts, the initial increase was followed by a decline towards the latter part of the storage period but Bosc showed no similar decrease. According to these data it might be assumed that an actual synthesis of protopectin continues to occur after the fruits are harvested and placed in storage. Anjou pears contained more total and protopectin than either Bartlett or Bosc at all stages of storage.

The initial soluble pectin content of all varieties was considerably higher than those reported by Gerhardt and Ezell (23), for similar varieties grown in other regions. They found values of approximately 0.04-0.06 per cent soluble pectin in Bosc and Anjou pears throughout the storage period, whereas the percentages ranged from approximately 0.15-0.30 in the Hood River pears used in these studies.

The use of activated carbon appears to have had no consistent effect on retarding the rate of the pectic changes in any of the varieties during storage. Pears from the carbon-treated room contained in October more protopectin and less pectin than the fruit from the control room. Fruit stored for longer periods, however, did not show appreciable differences. In Bosc no differences between samples from treated and untreated rooms were observed. In Anjou pears there was no significant effect early in the storage season, but in February and March the fruit from the carbon-treated room contained more protopectin and less soluble pectin, indicating that the rate of hydrolysis had been retarded by the use of activated charcoal as a means of storage air purification.

Pectic Changes During Ripening

Although considerable variations were found relative to the changes in the total pectin content during ripening, certain trends are apparent. In all varieties there was a tendency for the total pectin content to increase, generally during the early stages of ripening. This behaviour was especially apparent in Anjou pears, but was also observed in certain samples of Bartletts and Boscs. In most cases the initial increase in total pectin was followed by a decline, so that at the end of twelve days there was an actual decrease below the amount originally present. In Bosc and Bartlett pears this trend was especially apparent early in the storage season. With increase in length of the storage period, however, the decrease in total pectin during the ripening period became progressively less. Thus Bartlett pears ripened in October decreased 54 percent in total pectin, but only 17 percent when ripened in January. Bosc pears showed a similar trend, but the total pectin content tended to remain higher throughout the ripening period.

The amount of change which occurred in the protopectin fraction during ripening was different in the samples analyzed after progressive periods of storage. Anjou pears transferred to the ripening room in October showed no reduction in protopectin content at the end of 12 days. Neither did these fruits soften appreciably as shown by pressure tests, and it is apparent that the fruit was still in the preclimacteric stage at this time. Samples ripened at later dates, however, showed rapid, consistent decreases, resulting in most of the protopectin being hydrolyzed by the end of twelve days. Protopectin in Bartlett and Bosc pears decreased in all samples during ripening. The ability of the tissues to hydrolyze this material, however, became progressively less the longer the fruit remained in the storage. This trend is apparent whether the protopectin values are expressed either as absolute amounts, (Tables IV, V, VI), or as percentages of total pectin, (Figs. 8, 9, 11, 12, 14, 15). In Bartletts ripened in October, for example, 60 percent of the protopectin was hydrolyzed in twelve days, while in January there was only a ten percent decrease during a similar period of time. Owing to the increase in protopectin content which occurred during the storage period, Bartlett pears, in January, even after being kept for twelve days in the ripening room still contained more protopectin than was originally present in the unripened fruit in October. Bosc pears behaved similarly. Thus in October the unripened fruit contained 0.38 percent protopectin which decreased to 0.17 percent during the twelve-day ripening period. In January, however, the fruit contained 0.54 and 0.36 percent, respectively on the zero and twelfth day of ripening.

The changes which occurred in the soluble pectin fraction during ripening in the three varieties were different in several respects. In Bartlett pears, with the exception of the January sample, pectin accumulated for three to six days, then declined rapidly. In Bosc, the increase in pectin content occurred over a longer period of time and declined to a less extent in the post ripening period. At the peak of ripening in both varieties, the pectin content did not generally exceed 0.35 per cent. Anjou pears removed from storage in October showed no increase in soluble pectin, even after being kept for twelve days at a temperature conducive to ripening. As already indicated, the fruit was still in the pre-climacteric period at this time. Samples ripened in December and at monthly intervals thereafter until March showed consistent increases in pectin content, the maximum amounts accumulated ranging from 0.57 to 0.68 per cent. In contrast to the other varieties the pectin content did not decrease appreciably during the latter stages of ripening. The sample removed from storage in March did not show any appreciable change in the pectin content after removal from storage.

The accumulation of soluble pectin which occurred at ripening temperatures could not in all cases be accounted for by the concomitant decrease in protopectin. In November, for example, Anjou pears showed an increase of 0.32 per cent in pectin content but a decrease of only 0.12 per cent in the amount of protopectin. It would appear from these data that the soluble pectin which accumulated during ripening was not always derived exclusively from hydrolysis of protopectin.

The use of activated carbon during the storage period appears to have resulted in no appreciable effects on the pectic changes during ripening. While differences in the rate and magnitude were found in some cases, no consistent trends are apparent.

The data on per cent of protopectin and pressure test were analysed statistically. Figs. 21 to 26 represent scatter diagrams and the lines of regression. The statistical data are given in Table No. VII. It was found that all the correlations were significant except in case of Bartlett (C.). x

Changes in Color

The appearance of the fruit, especially with respect to color, was definitely affected by the use of activated carbon. The untreated Bartlett pears were yellow in color when removed from storage in November while the treated samples were definitely green (Fig. 16). Anjou pears from the carbon-treated room were also greener in color when removed from storage in March (Fig. 17). The effect on color tended to persist even after the fruit was ripened. Thus the treated sample of Anjous was still green in color after twelve days of ripening, while in untreated fruit the chlorophyll had mostly disappeared (Fig. 18). The green color of both treated and untreated samples of Bartlett pears disappeared during ripening, but less scald developed in the treated fruit (Fig. 19). No similar effect on Bosc pears was observed. This variety, however, was mostly yellow in color when harvested and placed in storage (Fig. 20).

Changes In Juice Characteristics During Ripening

Per Cent Extractable Juice

The data showing the changes in the percentage of extractable juice in the three varieties of pears when ripened after progressive periods of low temperature storage are shown in Tables I, II, and III. In Bartletts, the amount of juice which could be extracted from the tissues increased rapidly during the ripening period and was inversely correlated with fruit firmness. The samples ripened in October had the highest percentage of extractable juice, while fruit ripened after longer periods of storage had progressively smaller amounts. A similar trend was apparent in Anjou pears. The sample removed from storage in October, decreased rather than increased in percentage extractable juice.

The amount of juice in both Bartletts and Anjous was approximately 20-30 per cent higher than in Boscs when the fruit was fully ripe.

It is apparent from the data that the amount of juice which can be extracted from the fruits is a characteristic which is closely correlated with the firmness and texture of the tissues. Both Bartlett and Anjou pears decrease considerably in firmness during ripening and when fully ripe, the tissues tend to be more or less soft and juicy. At this stage approximately 80 per cent of the juice can be extracted. Bosc pears, however, soften to a less extent and tend to have a buttery, juicy texture. This condition is associated with a lower percentage of expressable juice. Less juice also could be extracted from Bartlett and Bosc pears late in the storage season when they failed to soften normally after transferring to temperatures favorable for ripening. Less juice also could be extracted from Anjou pears which developed a mealy texture when ripened after prolonged periods of storage.

It might be expected that the decrease in extractable juice is due partly at least to a decrease in moisture content of the fruit. The data show, however, that the percentage moisture did not change appreciably during either storage or ripening. The changes in the hydrophylic properties of the pectic substances during storage and ripening probably have considerable influence on the water retaining capacity of the fruit tissues.

The data on pressure test and extractable juice were analyzed statistically to determine whether there was any correlation. It was found that, except for Bosc (C. T.) all the correlations were significant. The statistical data are presented in Table No. VIII.

Relative Viscosity

The viscosity of the juice was low in the unripened fruit and increased only slightly while stored at low temperature. In all varieties the greatest changes in viscosity occurred in the samples ripened after short periods of storage. Thus in Bartletts ripened in October, relative viscosity increased from 2 to 20 during the first three days, then declined sharply to approximately the initial value. A similar trend was observed in Bosc. Samples ripened after longer storage periods, showed progressively less increase during ripening. Late in the season the viscosity changed but little when the fruits were kept at warm temperature for twelve days. In Anjou pears the viscosity was highest in the sample ripened in November; thereafter, as in Bartlett and Bosc the changes during ripening became progressively less with the increase in length of the storage period.

In Bartlett and Bosc pears viscosity is correlated fairly closely with the soluble pectin content and the alcohol precipitable material in the juice (Figs. 4, 5, 9, 12). In Anjou pears, however, the rapid decrease in viscosity is not accompanied by a concomitant decrease in either of these constituents (Figs. 6, 15). It cannot be concluded, however, that the observed changes in viscosity are not related to the pectin content of the juice. The relative viscosity of pectic solutions, in fact, is known to increase with the concentration of pectin. This relationship, however, is not a simple one, since the degree of polymerization of the pectin molecule, the number of additional combined radicles, hydrophilic effect conditioned by the presence of cations and organic materials may cause variations in viscosity independent of the concentrations. Both Bartlett and Bosc pears are more active physiologically and became overripe more rapidly than Anjou pears. If catabolism of the pectin also proceeds at a faster rate, a decrease in viscosity would result from both a greater degree of demethoxylation and a decrease in size of the molecule.

Effect of Carbon Treatment of the Storage Atmosphere

It is apparent from Figs. 4, 5, and 6 that the use of activated carbon had very little effect on viscosity of Bartlett juice in October. During the rest of the period there was practically no difference between control and treated fruit. Boscs showed a greater difference only in October. In case of Anjous the difference was apparent in November only. Whatever difference existed, was shown on the third day of ripening in Bartletts and the sixth day of ripening in Bosc and Anjous.

Gelation Characteristics

Early in the course of the investigation, it was found that the juice after titration for acid content jelled after standing for some time. In the case of Bartlett and Bosc this gelation occurred during October, November and December, wheras Anjou juice continued to gel until March. Gelation must be closely associated with the nature of the soluble pectin in the juice. In spite of the decrease in viscosity of Anjou pear juice from January on, the gelation characteristic did not change appreciably. There was little or no difference shown by pears under treatment and control with respect to this gelation property.

pH and Total Acidity

Anjou pear juice tended to be lower in pH than either Bartlett or Bosc pears and the total acid content was approximately twice as great. In Bartletts there was a consistent decrease in pH of the juice during ripening, but in the other two varieties this trend was not apparent. The total acid content of all varieties varied to some extent during ripening but no consistent trends were observed.

Total Solids

The total solids content in Bartlett and Bosc pears tended to be lower than in Anjou pears. In all varieties ripening of the fruit was accompanied by an increase in percentage total solids, especially in samples ripened after short periods of storage. Less change in the total solid content occurred in fruit ripened late in the storage season.

Table I

Physical and Biochemical Changes in Bartlett Pears During Storage and Ripening

No. of Days Ripened	Pressure Test Lbs.		Moisture Per cent		Extractable Juice Per cent		Total Sol. Solids Per cent		Acid as Citric Acid Per cent		pH		Alcohol ppt. Per cent		Relative Viscosity		Alcohol Insol. Residue Per cent	
	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.
Oct. 0	30.7	28.8	85.40	84.65	37.1	38.3	11.2	12.0	0.08	0.14	5.00	4.57	0.44	0.63	1.54	1.68	5.02	5.10
3	11.3	11.6	85.70	85.00	36.2	34.7	11.5	12.1	0.13	0.13	4.58	4.61	1.90	2.08	17.00	23.30	5.03	4.68
6	4.4	4.8	82.65	82.20	59.5	69.5	13.5	12.9	0.15	0.15	4.24	4.35	1.04	1.01	2.60	3.13	4.63	4.35
9	4.3	4.6	84.45	85.00	86.0	71.0	12.4	12.6	0.18	0.17	3.97	4.02	1.18	1.17	1.69	1.75	5.08	4.53
12	-	-	84.35	84.75	74.2	74.0	12.9	12.3	0.15	0.13	4.05	4.12	0.98	0.99	1.75	1.61	4.54	4.52
Nov. 0	27.8	27.8	84.15	85.45	32.8	20.0	12.2	12.1	0.13	0.11	4.65	4.71	0.33	0.29	2.35	2.28	4.66	4.50
3	9.8	9.8	84.70	85.70	42.5	38.3	13.4	13.2	0.12	0.13	4.52	4.50	0.95	0.96	7.79	7.94	4.83	4.43
6	4.4	4.4	85.20	85.60	64.0	69.5	13.1	13.1	0.15	0.16	4.30	4.30	0.83	0.65	2.76	3.25	4.44	4.15
9	5.8	5.8	84.80	86.00	71.2	64.7	13.0	11.6	0.16	0.16	4.03	4.16	0.68	0.59	1.90	1.73	4.98	4.38
12	-	-	85.65	85.80	70.2	70.0	12.1	11.7	0.11	0.11	4.30	4.30	0.75	0.57	1.54	1.40	4.34	4.34
Dec. 0	25.7	21.7	84.00	84.70	32.0	34.8	12.4	12.2	0.12	0.09	4.70	4.68	0.41	0.51	3.35	4.12	5.04	5.00
3	11.6	10.8	84.50	85.00	37.3	39.0	13.9	13.7	0.13	0.14	4.60	4.46	0.48	1.12	4.20	4.81	4.69	4.39
6	8.9	9.3	85.00	85.20	47.0	48.0	12.7	12.5	0.13	0.13	4.30	4.33	2.02	0.65	2.40	2.02	4.25	4.23
9	7.1	7.2	86.00	86.00	56.0	54.3	11.4	11.5	0.12	0.11	4.30	4.40	1.54	0.92	1.54	1.54	4.15	3.95
12	-	6.2	85.40	85.50	58.5	60.0	12.7	11.7	0.14	0.12	4.12	4.23	1.50	0.92	1.50	1.50	4.86	4.60
Jan. 0	23.4	18.8	85.20	84.20	25.0	34.7	11.7	12.4	0.09	0.07	4.92	4.95	0.70	0.84	2.12	3.68	5.23	5.18
3	20.1	14.0	85.20	85.00	41.7	38.7	12.0	12.4	0.08	0.09	4.90	4.80	0.61	0.80	1.92	1.83	4.47	4.54
6	14.3	15.5	85.00	85.30	42.2	40.2	12.8	12.7	0.13	0.10	4.40	4.70	0.55	0.58	1.39	1.65	4.43	4.57
9	14.8	10.5	85.10	85.00	46.1	47.7	12.0	12.8	0.13	0.11	4.43	4.33	0.53	0.48	1.35	1.46	4.94	4.88
12	15.3	16.2	85.10	84.30	61.1	59.0	12.0	12.5	0.09	0.12	4.60	4.48	0.33	0.35	1.65	1.48	4.61	4.71
Feb. 0	20.6	19.5	85.70	85.80	33.9	36.3	11.6	12.7	0.12	0.13	4.95	4.88	0.58	0.68	1.88	2.12	4.81	4.26
6	15.9	12.9	86.40	85.60	50.1	42.7	10.1	11.7	0.12	0.14	4.76	4.58	0.38	0.72	1.35	1.77	4.67	3.95

Table II

Physical and Biochemical Changes in Bosc Pears During Storage and Ripening

No. of Days Ripened	Pressure Test Lbs.		Moisture Per cent		Extractable Juice Per cent		Total Sol. Solids Per cent		Acid as Citric Acid Per cent		pH		Alcohol ppt. Per cent		Relative Viscosity		Alcohol Insol. Residue Per cent	
	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.
Oct. 0	23.5	22.2	85.05	84.10	37.0	40.0	12.1	11.3	0.12	0.11	4.58	4.65	0.46	0.41	1.48	1.48	5.22	5.32
3	25.2	24.8	83.70	84.90	32.5	44.2	11.1	10.7	0.10	0.09	4.68	4.68	0.77	0.68	3.46	3.74	4.93	5.17
6	13.8	14.4	84.00	84.40	42.5	46.0	11.9	11.7	0.07	0.07	4.95	4.93	0.86	0.91	11.20	20.40	4.90	4.96
9	9.3	10.0	83.50	85.00	46.0	48.0	12.8	11.8	0.11	0.10	4.68	4.77	1.40	1.23	4.80	3.64	4.63	4.74
12	7.1	8.3	84.50	84.15	49.7	50.2	13.7	12.8	0.12	0.12	4.65	4.62	0.77	0.62	2.60	2.30	4.12	4.50
Nov. 0	23.4	24.3	85.30	85.20	41.8	43.3	12.0	11.7	0.13	0.13	4.54	4.55	0.13	0.14	1.54	1.54	5.02	5.15
3	21.8	23.9	84.30	85.10	40.0	37.0	12.7	12.2	0.11	0.12	4.65	4.62	0.28	0.23	5.04	5.89	4.83	4.97
6	12.3	13.4	84.80	84.40	51.0	48.8	13.2	13.4	0.09	0.10	4.75	4.78	0.58	0.73	5.10	7.21	4.70	4.80
9	9.3	10.3	84.70	84.80	50.2	56.3	12.8	12.3	0.11	0.12	4.55	4.62	0.58	0.60	3.09	3.35	4.53	4.55
12	8.2	8.3	84.10	84.00	57.3	57.5	13.4	13.7	0.10	0.14	4.51	4.44	0.50	0.50	2.35	2.40	3.98	4.36
Dec. 0	24.1	25.8	84.70	84.50	43.5	45.3	12.3	12.1	0.14	0.13	4.50	4.60	0.20	0.19	1.62	1.65	4.86	5.13
3	22.5	23.0	84.30	84.50	42.0	45.0	13.5	13.1	0.13	0.11	4.75	4.82	0.42	0.36	4.23	2.88	4.88	4.61
6	12.9	12.9	84.00	84.30	45.3	45.5	13.2	13.2	0.10	0.09	4.76	4.86	0.74	0.77	4.23	4.23	4.35	4.37
9	11.8	9.6	84.20	84.50	51.5	49.3	13.5	13.3	0.11	0.11	4.75	4.69	0.81	0.83	2.12	2.31	4.50	4.18
12	9.1	9.0	84.60	85.00	47.5	55.0	13.1	12.7	0.13	0.12	4.50	4.50	1.27	1.09	1.92	1.92	3.84	4.01
Jan. 0	23.8	23.9	84.50	85.00	47.2	50.2	12.7	12.6	0.13	0.12	4.80	4.73	0.34	0.32	1.54	1.63	5.02	5.08
3	20.2	19.8	85.00	84.60	39.5	40.3	12.5	12.5	0.11	0.10	4.75	4.80	0.44	0.52	2.98	2.98	4.73	4.40
6	15.8	16.2	84.40	84.20	42.6	42.7	13.2	13.3	0.17	0.11	4.75	4.80	0.75	0.74	2.88	2.60	4.76	6.31
9	13.4	13.8	84.50	84.70	41.2	37.6	12.6	13.2	0.11	0.10	4.72	4.72	0.78	0.80	2.60	2.08	4.70	4.45
12	13.9	12.6	84.20	83.70	49.5	42.4	13.5	13.6	0.11	0.11	4.63	4.74	0.69	0.72	2.15	2.54	4.66	4.99
Feb. 0	21.3	22.9	84.10	84.00	45.1	53.7	13.1	12.6	0.21	0.19	4.65	4.63	0.40	0.23	2.17	1.54	4.71	4.51
3	16.4	21.2	83.80	83.40	41.8	43.9	13.5	13.8	0.16	0.17	4.88	4.90	0.60	0.53	2.58	2.79	5.03	4.70
6	13.8	17.0	84.20	83.70	42.1	37.1	14.1	13.9	0.17	0.17	4.82	4.92	0.75	0.63	3.17	2.88	4.63	4.71
9	12.6	14.7	83.60	83.40	45.7	39.2	14.2	14.5	0.16	0.16	4.78	4.88	0.71	0.64	2.48	2.98	4.96	5.12
12	11.7	13.5	83.90	82.70	46.8	42.2	13.4	14.2	0.16	0.16	4.72	4.65	0.83	0.73	2.44	2.46	4.52	4.58

Table III

Physical and Biochemical Changes in Anjou Pears During Storage and Ripening

No. of Days Ripened	Pressure Test Lbs.		Moisture Per cent		Extractable Juice Per cent		Total Sol. Solids Per cent		Acid as Citric Acid Per cent		pH		Alcohol ppt. Per cent		Relative Viscosity		Alcohol Insol. Residue Per cent	
	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.	C.	C.T.
Oct. 0	26.7	27.5	82.75	82.50	41.0	38.2	11.4	11.4	0.22	0.23	4.13	4.13	0.14	0.15	1.70	1.62	5.22	5.78
3	29.8	30.5	82.30	82.50	36.2	29.0	12.0	12.1	0.11	0.10	4.73	4.89	0.95	0.95	4.26	4.65	4.95	5.45
6	27.9	30.3	81.90	81.75	33.0	30.0	12.8	12.8	0.18	0.21	4.32	4.23	0.95	0.84	15.80	15.60	5.46	5.10
9	22.2	25.5	82.50	82.40	27.5	33.0	12.9	12.8	0.20	0.23	4.29	4.17	0.83	1.04	25.40	20.70	5.43	5.22
12	17.2	21.3	81.50	82.00	39.0	30.5	13.6	13.4	0.16	0.14	4.40	4.45	0.92	0.91	17.00	11.90	5.13	5.06
Nov. 0	29.3	28.1	83.40	83.90	29.5	34.5	14.1	14.0	0.31	0.28	4.05	4.14	0.14	0.11	2.92	2.15	5.10	5.55
3	24.7	30.1	83.60	83.80	33.7	33.0	-	-	0.21	0.22	4.25	4.25	0.48	0.30	18.01	5.90	4.73	5.20
6	10.3	16.0	82.20	83.70	56.5	45.3	15.3	15.3	0.24	0.21	4.25	4.38	1.22	0.89	19.02	31.15	5.03	4.75
9	7.1	9.8	83.00	83.40	75.2	43.0	14.9	14.7	0.27	0.23	4.25	4.28	1.11	1.05	7.60	13.86	5.00	4.73
12	5.3	7.3	84.30	84.60	82.2	66.0	14.4	14.5	0.28	0.23	-	-	0.94	1.07	3.48	5.17	4.73	4.65
Dec. 0	27.8	31.5	82.80	83.30	31.3	26.1	14.5	14.1	0.25	0.24	4.18	4.20	0.36	0.37	5.00	3.37	5.00	5.19
3	15.9	21.3	83.10	83.10	31.5	30.3	14.7	14.3	0.22	0.21	4.32	4.43	0.72	0.62	13.46	12.31	4.43	4.69
6	8.2	8.9	82.10	82.50	46.3	42.8	14.8	15.0	0.22	0.23	4.26	4.25	1.21	1.23	7.21	9.42	4.34	4.45
9	6.3	5.7	82.50	83.10	70.2	71.0	15.3	15.1	0.26	0.25	4.08	4.20	1.53	1.58	4.23	4.42	4.39	4.24
12	6.7	6.2	83.40	83.30	59.5	62.3	14.3	14.1	0.27	0.25	3.97	4.10	1.59	1.72	2.67	2.69	4.15	4.40
Jan. 0	25.8	27.7	83.60	83.10	33.2	25.7	13.7	14.5	0.21	0.22	4.35	4.33	0.59	0.71	4.81	5.19	4.91	4.91
3	19.3	16.5	83.30	83.00	37.0	31.8	13.6	14.5	0.19	0.21	4.38	4.30	0.82	0.78	8.34	9.31	4.73	4.73
6	10.7	9.6	83.40	83.00	43.4	40.2	14.1	15.3	0.19	0.23	4.30	4.22	1.07	1.68	8.38	7.41	4.61	4.61
9	8.3	8.6	83.20	83.00	52.5	51.2	14.5	14.9	0.22	0.23	4.25	4.25	1.19	1.20	4.94	5.23	4.80	4.80
12	7.7	7.3	83.50	82.60	55.5	56.0	14.3	14.6	0.23	0.22	4.12	4.18	0.98	0.99	3.17	3.48	4.88	4.88
Feb. 0	20.3	29.5	83.60	83.40	34.9	31.1	14.0	13.8	0.30	0.31	4.35	4.42	0.61	0.40	5.33	3.89	4.60	5.12
3	13.5	19.5	83.60	83.20	39.8	31.0	14.8	14.7	0.27	0.26	4.48	4.50	0.91	0.64	5.90	7.08	4.24	5.06
6	9.2	10.4	83.20	82.80	45.6	35.7	14.7	15.5	0.27	0.31	4.52	4.42	1.35	1.45	4.23	6.40	4.58	4.86
9	7.8	8.6	82.80	83.00	58.5	53.5	15.1	14.8	0.32	0.31	4.28	4.28	1.25	1.29	3.64	4.23	4.75	4.95
12	8.0	7.8	82.90	82.50	61.3	60.6	15.0	15.3	0.35	0.34	4.20	4.25	1.13	1.32	2.67	3.48	4.72	4.98
Mar. 0	13.8	22.5	83.40	83.00	41.9	30.2	14.0	13.7	0.30	0.28	4.45	4.35	0.92	0.57	5.44	7.85	4.33	4.82
3	11.0	15.0	82.00	82.60	40.7	36.1	16.6	15.7	0.29	0.28	4.35	4.42	1.13	0.86	5.87	8.90	4.63	4.75
6	9.4	10.1	82.30	82.80	54.4	46.5	15.3	15.0	0.29	0.28	4.30	4.36	1.13	1.09	4.85	5.72	4.28	4.34
9	8.5	8.8	82.60	82.60	53.6	55.1	15.0	15.1	0.29	0.29	4.20	4.22	0.96	1.09	3.14	2.98	4.07	4.26
12	8.2	8.3	82.60	82.10	62.5	61.2	14.9	15.3	0.32	0.33	4.08	4.10	1.04	1.15	2.25	2.44	4.10	4.16

Table IV

Pectic Changes in Bartlett Pears
During Storage and Ripening

(Pectic material weighed as calcium-pectate and expressed as percent of fresh weight.)

Months	No. of days Ripened	Control Pectin	Control Proto-pectin	Control Total Pectin	Carbon Treated Pectin	Carbon Treated Proto-pectin	Carbon Treated Total Pectin
Oct.	0	0.3070	0.3765	0.6835	0.2158	0.5294	0.7452
	3	.3028	.3554	.6582	.3200	.3914	.7114
	6	.3683	.3739	.7422	.3323	.2751	.7074
	9	.2813	.3683	.6496	.2458	.2741	.5199
	12	.1498	.1583	.3081	.1571	.1124	.2695
Nov.	0	0.2018	0.5091	0.7109	0.2098	0.4897	0.6990
	3	.3819	.4483	.8301	.4260	.4400	.8660
	6	.2997	.4666	.7664	.3475	.4051	.7527
	9	.2132	.3586	.5719	.2287	.3588	.5876
	12	.1198	.2650	.3848	.1368	.2695	.4063
Dec.	0	0.2374	0.6513	0.8887	0.2816	0.6204	0.9019
	3	.3522	.5020	.8543	.3545	.4377	.7922
	6	.2349	.5149	.7498	.2401	.4686	.7088
	9	.1185	.3634	.4813	.1274	.4141	.5510
	12	.1527	.3044	.4572	.1334	.3240	.4574
Jan.	0	0.2574	0.4945	0.7518	0.3102	0.4844	0.7946
	3	.1691	.6579	.8270	.2963	.6214	.9177
	6	.1624	.5307	.6932	.1964	.5182	.7146
	9	.1632	.4289	.5921	.1698	.4105	.5803
	12	.1630	.4587	.6217	.1905	.4456	.6361
Feb.	0	0.2157	0.4808	0.6965	0.1588	0.4442	0.6030
	6	.1487	.4223	.5710	.1698	.3678	.5376

Table V

Pectic Changes in Bosc Pears
During Storage and Ripening

(Pectic material weighed as calcium-pectate and expressed as percent of fresh weight.)

Months	No. of days Ripened	Control			Carbon Treated		
		Pectin	Proto-pectin	Total Pectin	Pectin	Proto-pectin	Total Pectin
Oct.	0	0.2072	0.3805	0.5877	0.2093	0.3729	0.5822
	3	.1875	.4870	.6745	.1577	.4371	.5948
	6	.3124	.2879	.6003	.3323	.2560	.5883
	9	.3553	.2500	.6053	.3644	.2738	.6382
	12	.2477	.1689	.4166	.2456	.1873	.4329
Nov.	0	0.2912	0.3990	0.6902	0.2483	0.4047	0.6530
	3	.1899	.3387	.5287	.2192	.3539	.5732
	6	.2715	.3359	.6074	.2811	.3135	.5947
	9	.2485	.2397	.4882	.2565	.2488	.5055
	12	.2715	.3463	.6178	.3281	.3155	.6435
Dec.	0	0.2208	0.4796	0.7005	0.2254	0.4320	0.6574
	3	.1911	.4982	.6894	.2124	.4952	.7076
	6	.3614	.4197	.7811	.3759	.3836	.7595
	9	.3341	.3870	.7211	.3409	.3752	.7160
	12	.1880	.2539	.4419	.2203	.3112	.5315
Jan.	0	0.1567	0.5593	0.7160	0.1931	0.5545	0.7476
	3	.2562	.5178	.7739	.2217	.5059	.7276
	6	.2522	.3997	.6519	.2927	.4583	.7510
	9	.2944	.3156	.6099	.3201	.3197	.6398
	12	.2324	.2506	.4830	.2601	.3224	.5825
Feb.	0	0.2224	0.5434	0.7658	0.2187	0.5189	0.7376
	3	.1961	.4154	.6115	.1992	.3864	.5855
	6	.3450	.4113	.7562	.3439	.4767	.8206
	9	.2765	.3795	.6559	.2365	.4254	.6619
	12	.2709	.3576	.6285	.2197	.3054	.5251

Table VI

Pectic Changes in Anjou Pears
During Storage and Ripening

(Pectic material weighed as calcium-pectate and expressed as percent of fresh weight.)

Month	No. of days Ripened	Control Pectin	Control Proto-pectin	Control Total Pectin	Carbon Treated Pectin	Carbon Treated Proto-pectin	Carbon Treated Total Pectin
Oct.	0	0.2955	0.4732	0.7687	0.1687	0.5280	0.6967
	3	.1782	.4733	.6515	.1764	.5266	.7030
	6	.1590	.6286	.7876	.1479	.5017	.6496
	9	.1887	.4513	.6400	.1520	.4880	.6400
	12	.2610	.5245	.7855	.3118	.3895	.7013
Nov.	0	0.2016	0.4307	0.6323	0.2540	0.4688	0.7228
	3	.2148	.5697	.7844	.1736	.5417	.7153
	6	.3488	.4241	.7729	.1792	.5094	.6886
	9	.5739	.3799	.9538	.4232	.4637	.8867
	12	.5219	.3106	.8325	.4992	.3674	.8666
Dec.	0	0.1715	0.6897	0.8613	0.1835	0.6460	0.8295
	3	.2715	.6250	.8967	.2265	.6739	.9004
	6	.4615	.4448	.9063	.4348	.4612	.8960
	9	.5863	.3896	.9759	.5820	.3334	.9154
	12	.4208	.3034	.7242	.4252	.2973	.7225
Jan.	0	0.1905	0.7423	0.9328	0.1807	0.6774	0.8581
	3	.2278	.6292	.8570	.2289	.5775	.8073
	6	.4688	.4660	.9348	.4907	.4637	.9544
	9	.5868	.3314	.9182	.5631	.3211	.8842
	12	.6836	.3823	1.0659	.6825	.3932	1.0757
Feb.	0	0.2320	0.4730	0.7050	0.1177	0.6298	0.7475
	3	.4268	.5169	.9437	.2996	.6992	.9888
	6	.5600	.4057	.9657	.5822	.4069	.9891
	9	.5694	.3517	.9211	.5539	.3519	.9058
	12	.3694	.3289	.6983	.5003	.3040	.8043
Mar.	0	0.3607	0.4484	0.8091	0.2076	0.5687	0.7763
	3	.3894	.4280	.8174	.4030	.6349	1.0379
	6	.4034	.3795	.7829	.5560	.3834	.9394
	9	.3181	.3018	.6198	.4180	.3455	.7635
	12	.3386	.4182	.7568	.3625	.3246	.6870

Table VII

Statistical Data on Correlation Between
Pressure Test and Percent Protopectin in Pears

Variety and Treatment		Coefficient of Correlation "r"	"t" Value	d.f.	Remarks (at 5% level)
Bartlett	C.	0.457	2.12	17	Not Significant
Bartlett	C.T.	0.686	4.88	18	Significant
Bosc	C.	0.760	5.61	23	"
Bosc	C.T.	0.706	5.18	23	"
Anjou	C.	0.714	5.36	28	"
Anjou	C.T.	0.708	5.30	28	"

Table VIII

Statistical Data on Correlation Between
Pressure Test and Percent Expressable Juice in Pears

Variety and Treatment		Coefficient of Correlation "r"	"t" Value	d.f.	Remarks (at 5% level)
Bartlett	C.	0.740	4.52	17	Significant
Bartlett	C.T.	0.777	5.23	18	"
Bosc	C.	0.699	4.70	23	"
Bosc	C.T.	0.406	2.13	23	Not Significant
Anjou	C.	0.801	7.09	28	Significant
Anjou	C.T.	0.823	7.66	28	"

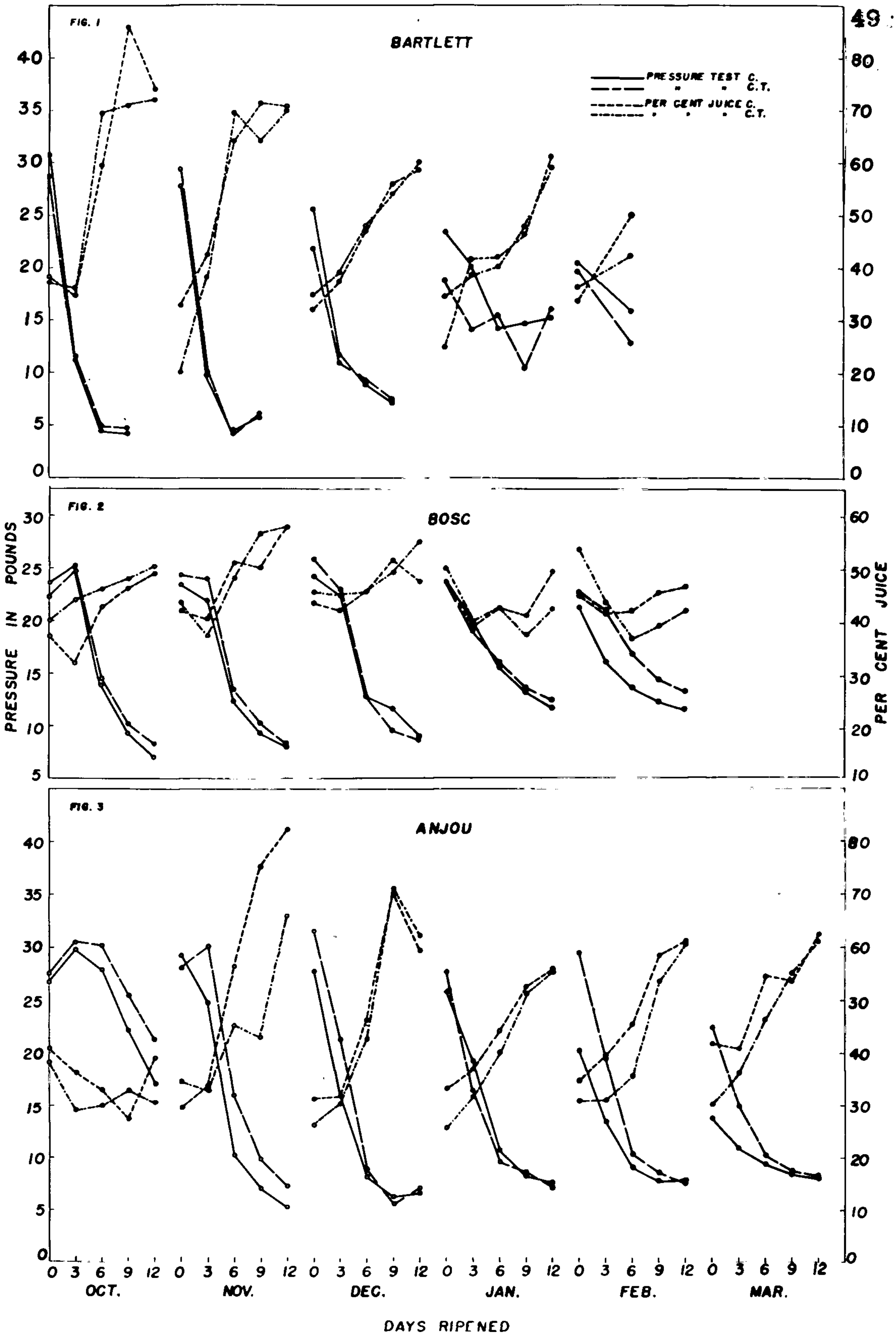


FIG. 1
BARTLETT
PRESSURE TEST C.
" " C.T.
PER CENT JUICE C.
" " " C.T.
FIG. 2
BOSC
PRESSURE IN POUNDS
PER CENT JUICE
FIG. 3
ANJOU
0 3 6 9 12 0 3 6 9 12 0 3 6 9 12 0 3 6 9 12 0 3 6 9 12 0 3 6 9 12
OCT. NOV. DEC. JAN. FEB. MAR.
DAYS RIPENED

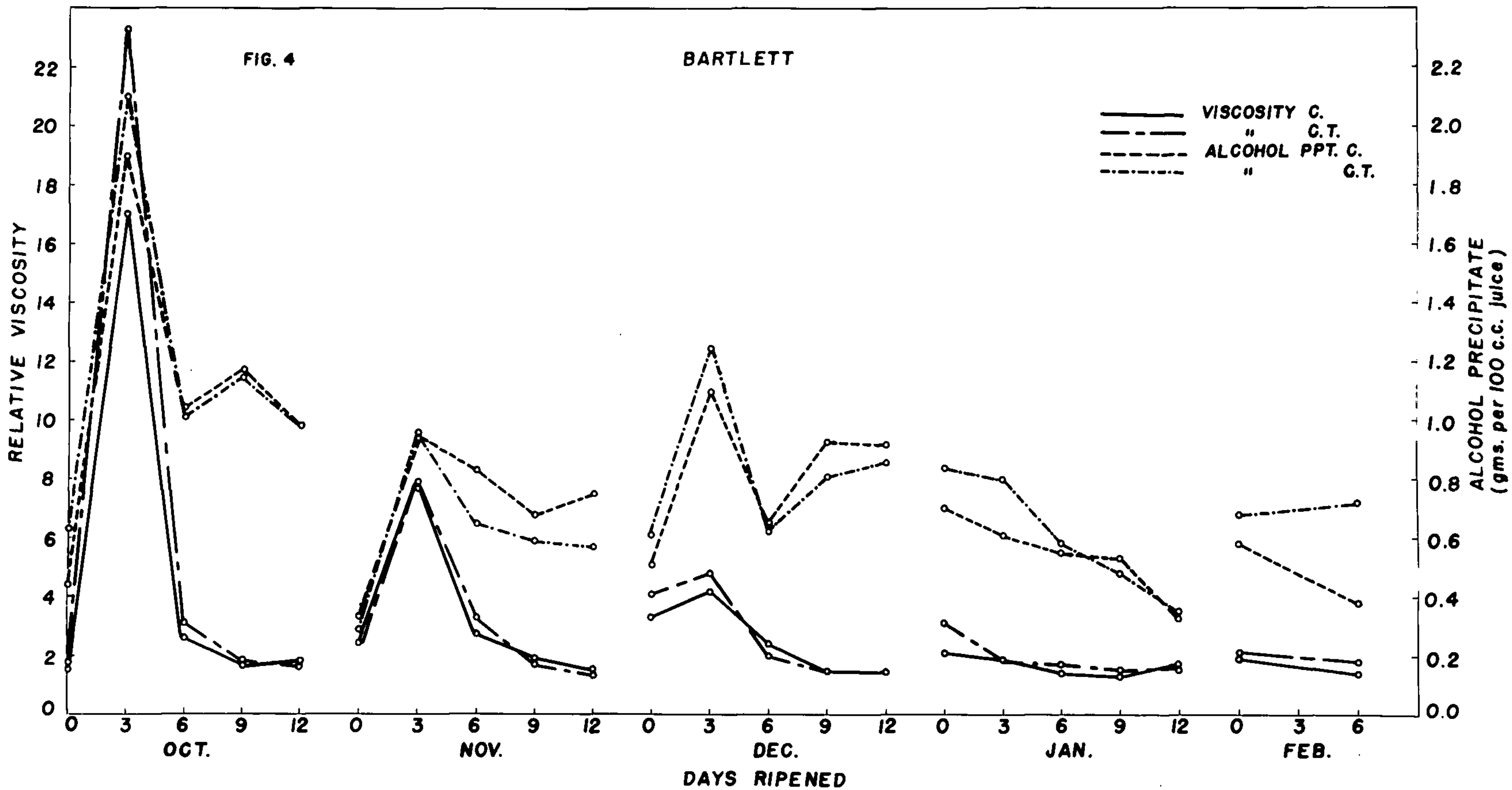


FIG. 4
BARTLETT
VISCOSITY C.
" C.T.
ALCOHOL PPT. C.
" C.T.
RELATIVE VISCOSITY
ALCOHOL PRECIPITATE (gms. per 100 c.c. juice)
0
2
4
6
8
10
12
14
16
18
20
22
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
0 3 6 9 12
OCT.
0 3 6 9 12
NOV.
0 3 6 9 12
DEC.
0 3 6 9 12
JAN.
0 3 6
FEB.
DAYS RIPENED

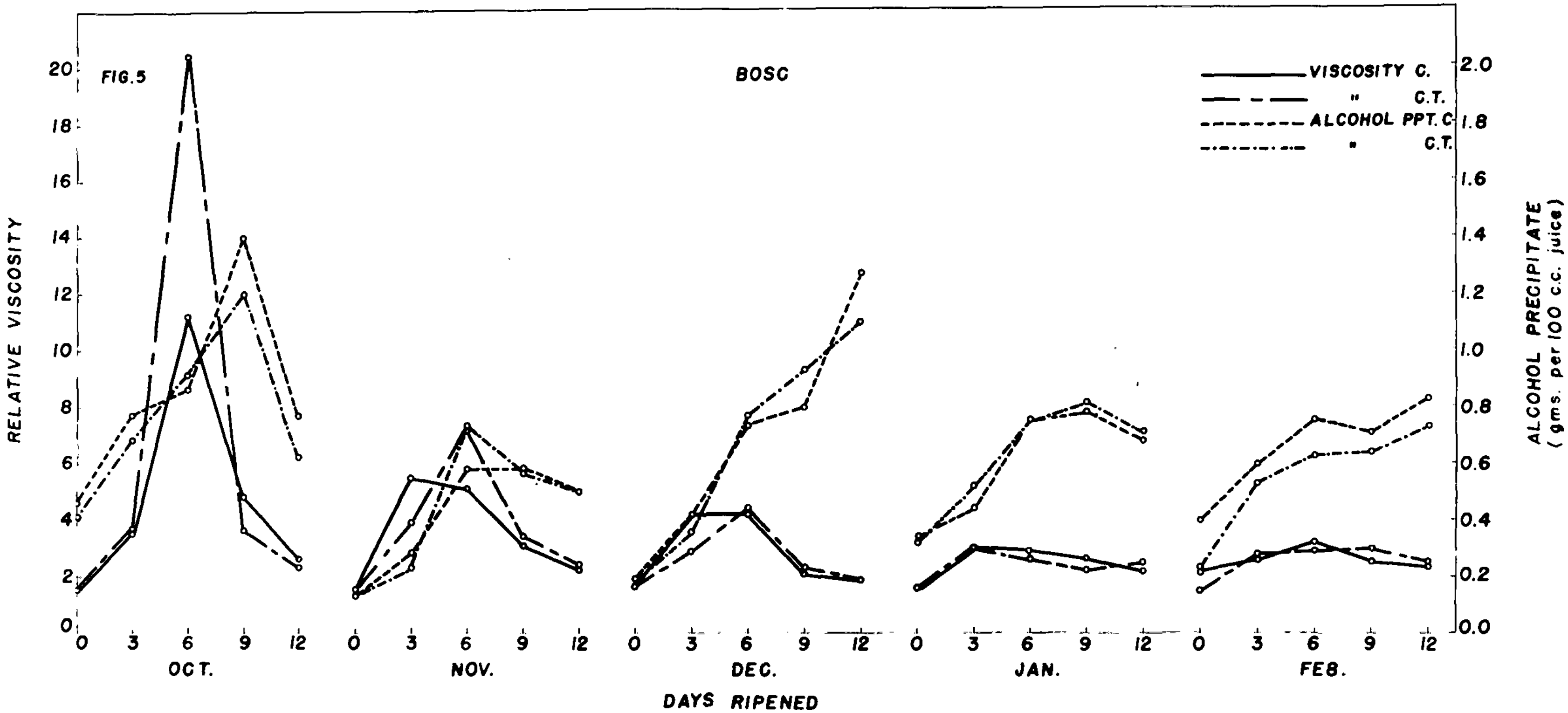


FIG.5
BOSC
VISCOSITY C.
" C.T.
ALCOHOL PPT. C
" C.T.
RELATIVE VISCOSITY
ALCOHOL PRECIPITATE (gms. per 100 c.c. juice)
OCT.
NOV.
DEC.
JAN.
FEB.
DAYS RIPENED

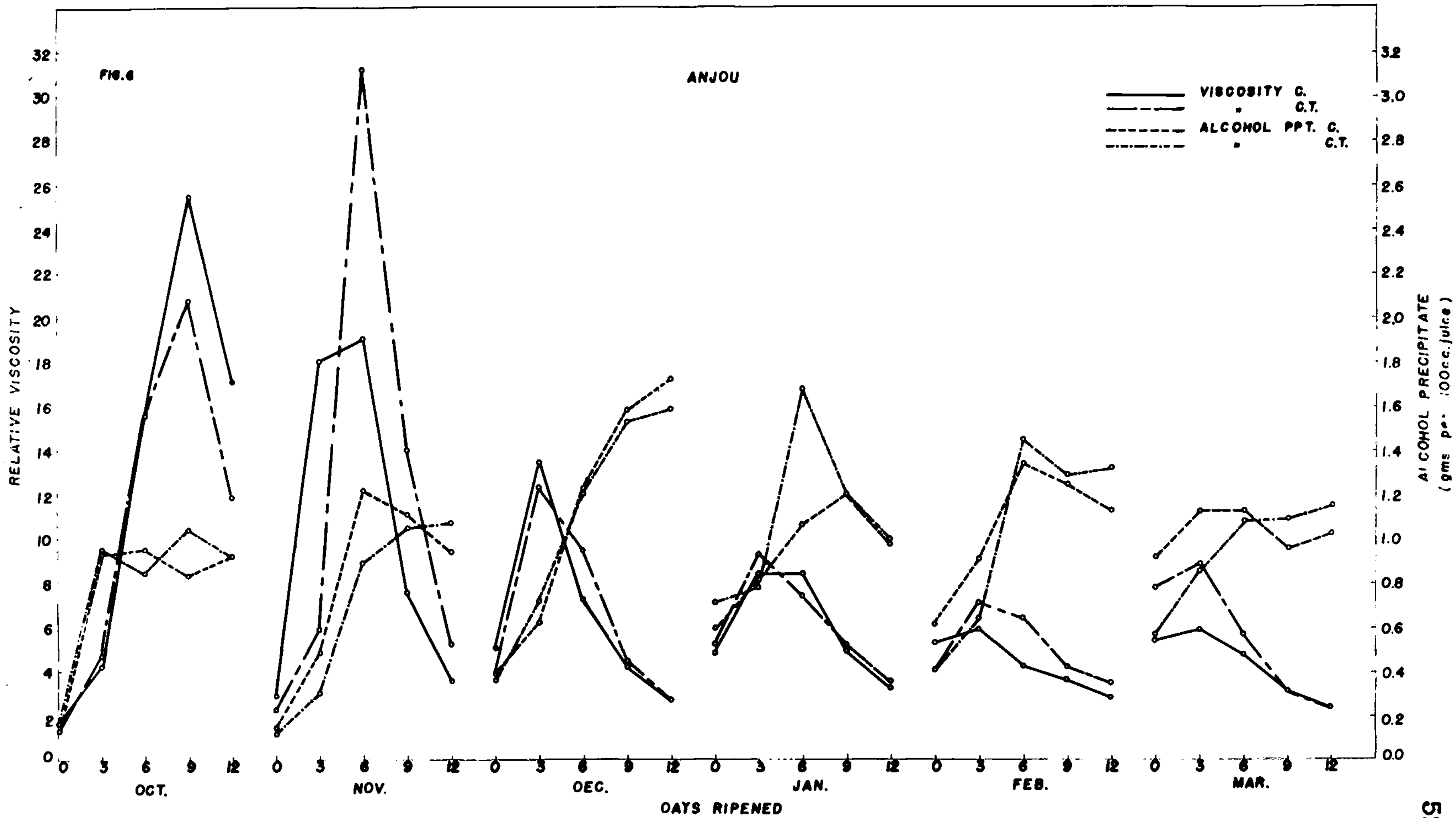


FIG.6
ANJOU
VISCOSITY C.
" C.T.
ALCOHOL PPT. C.
" C.T.
RELATIVE VISCOSITY
ALCOHOL PRECIPITATE
(gms per 100cc. juice)
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
DAYS RIPENED

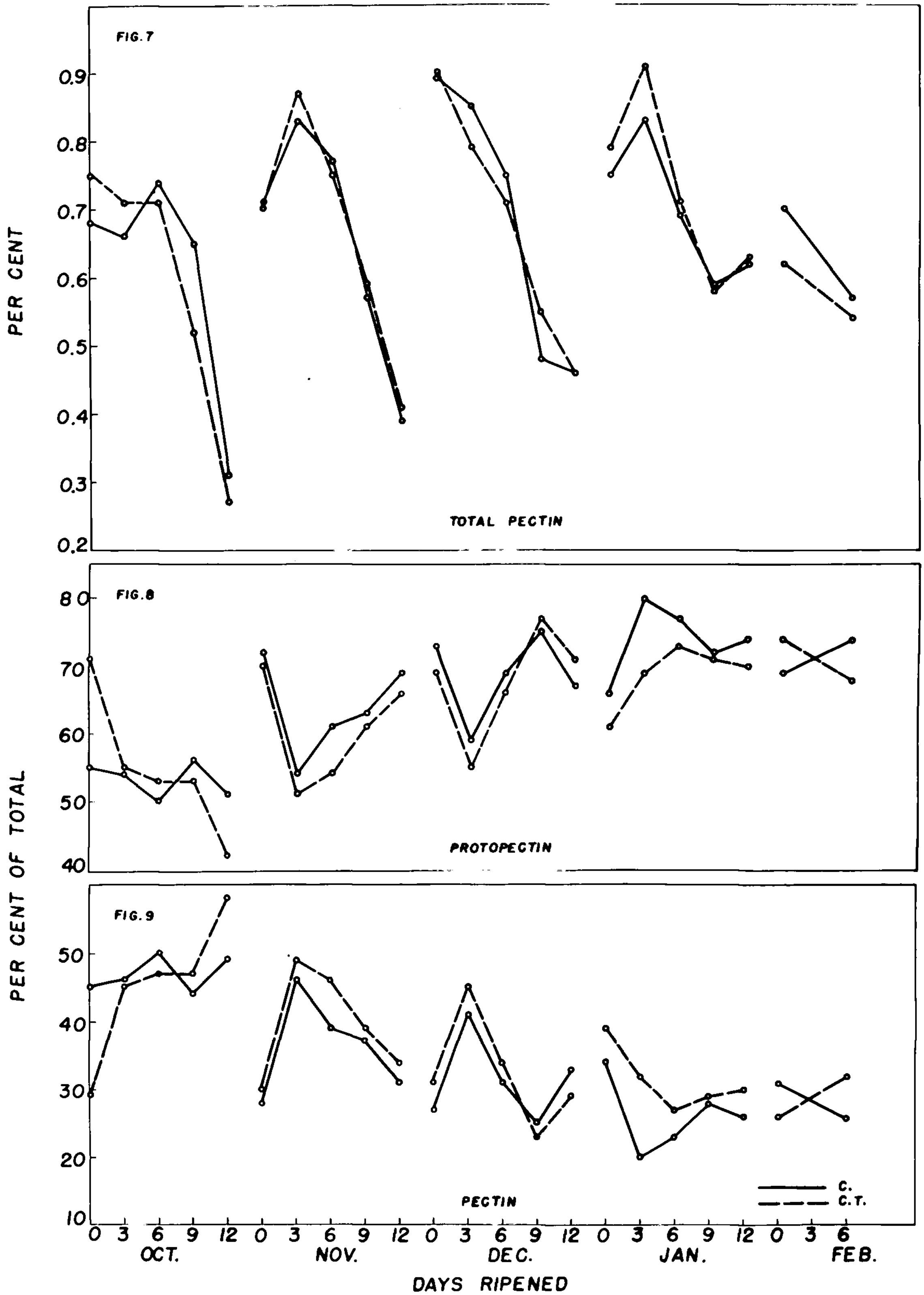
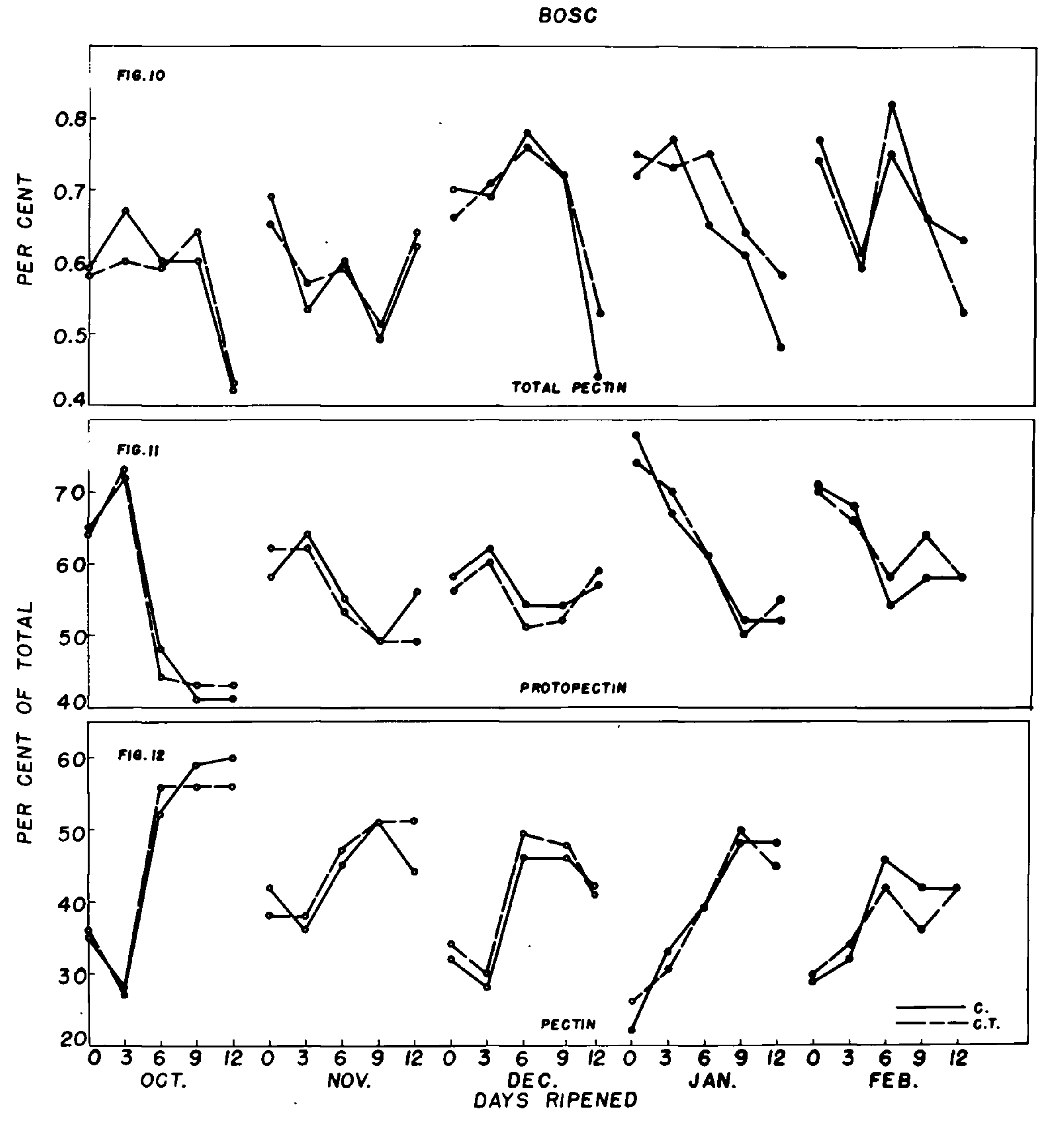


FIG. 7
TOTAL PECTIN
PER CENT
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
FIG. 8
PROTOPECTIN
80
70
60
50
40
FIG. 9
PECTIN
PER CENT OF TOTAL
50
40
30
20
10
C.
C.T.
0 3 6 9 12 0 3 6 9 12 0 3 6 9 12 0 3 6 9 12 0 3 6
OCT.
NOV.
DEC.
JAN.
FEB.
DAYS RIPENED



BOSC
FIG. 10
PER CENT
0.8
0.7
0.6
0.5
0.4
TOTAL PECTIN
FIG. 11
70
60
50
40
PROTOPECTIN
PER CENT OF TOTAL
FIG. 12
60
50
40
30
20
PECTIN
C.
C.T.
0 3 6 9 12 0 3 6 9 12 0 3 6 9 12 0 3 6 9 12 0 3 6 9 12
OCT. NOV. DEC. JAN. FEB.
DAYS RIPENED

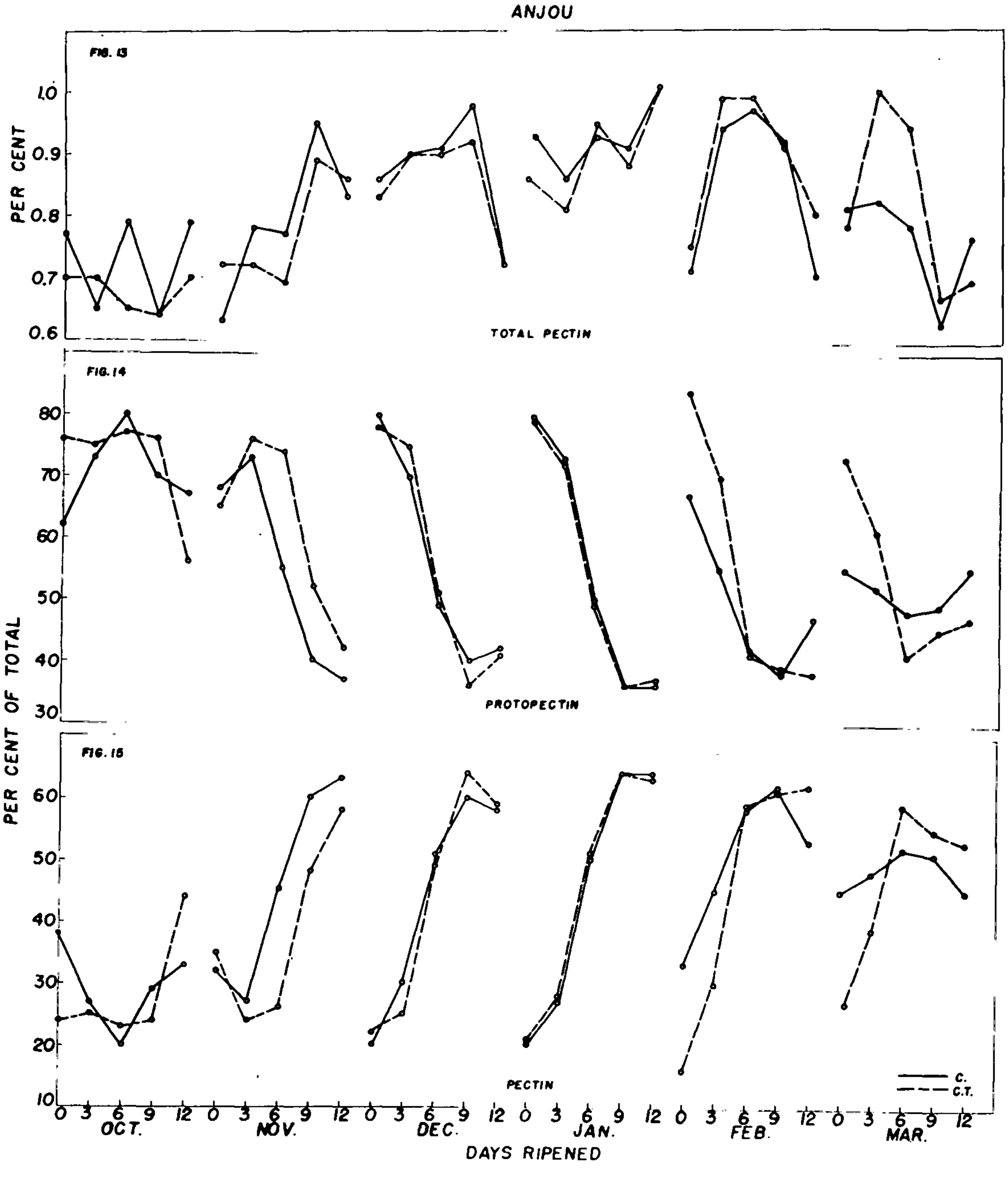

ANJOU
FIG. 13
PER CENT
1.0
0.9
0.8
0.7
0.6
TOTAL PECTIN
FIG. 14
PER CENT OF TOTAL
80
70
60
50
40
30
PROTOPECTIN
FIG. 15
60
50
40
30
20
10
PECTIN
C.
C.T.
0 3 6 9 12
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
DAYS RIPENED

Figure 16. Effect of Storage Treatment on the Yellowing of Bartlett Pears. (November 1948).

Figure 17. Effect of Storage Treatment on the Yellowing of Anjou Pears During Ripening. (March 1949).

Figure 18. Effect of Storage Treatment on the Yellowing of Anjou Pears During Storage. (November 1948).

Figure 19. Effect of Storage Treatment on the Development of Scald in Bartlett Pears During Ripening. (October 1948).

Figure 20. Effect of Storage Treatment on the Color Change in Bosc Pears. (January 1949).

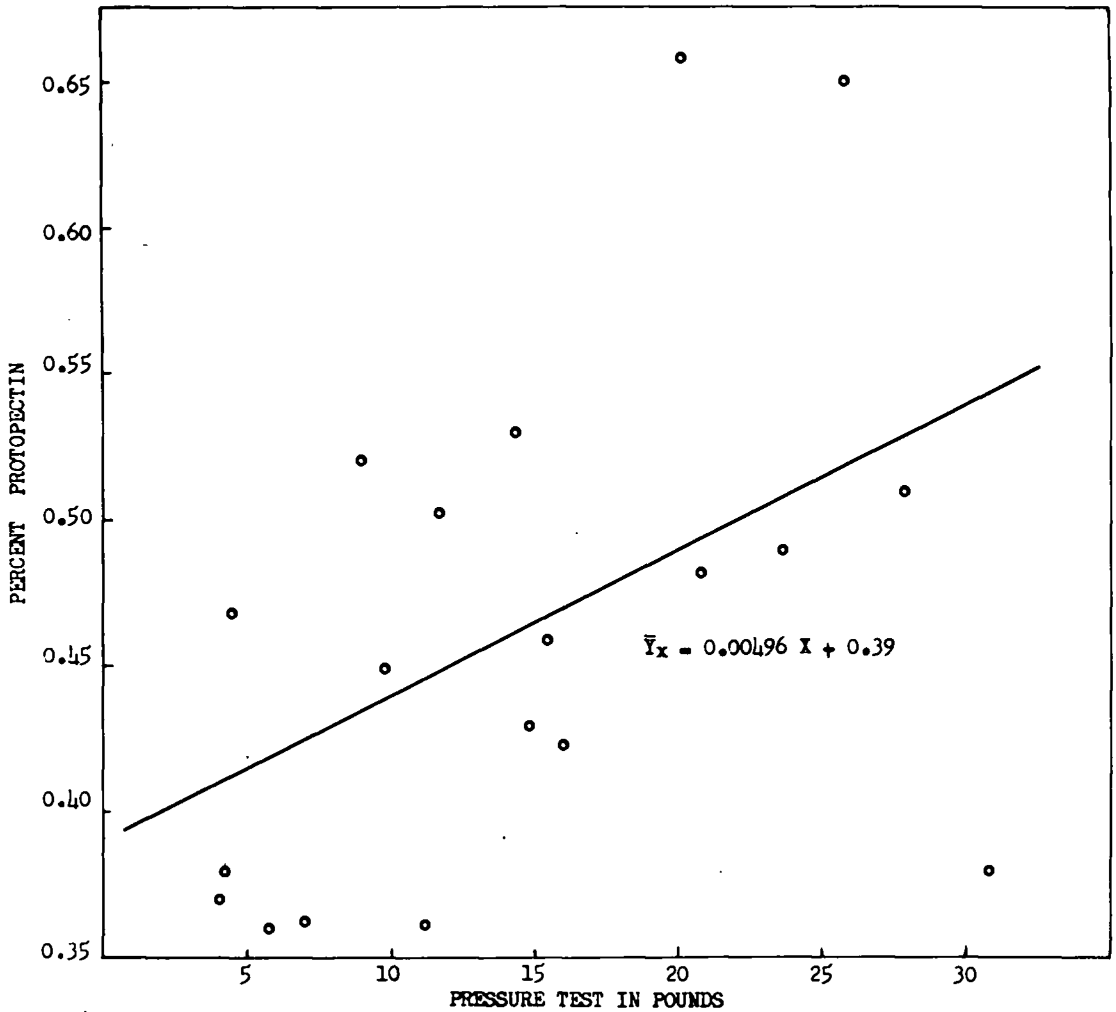


FIGURE 21. RELATIONSHIP BETWEEN PRESSURE TEST AND PERCENT OF PROTOPECTIN IN BARTLETT PEARS (CONTROL).

The coefficient of correlation is 0.457. The line of regression can be expressed as $\bar{Y}_x = 0.00496\ X + 0.39$ where Y = percent of protopectin and X = pressure in pounds.

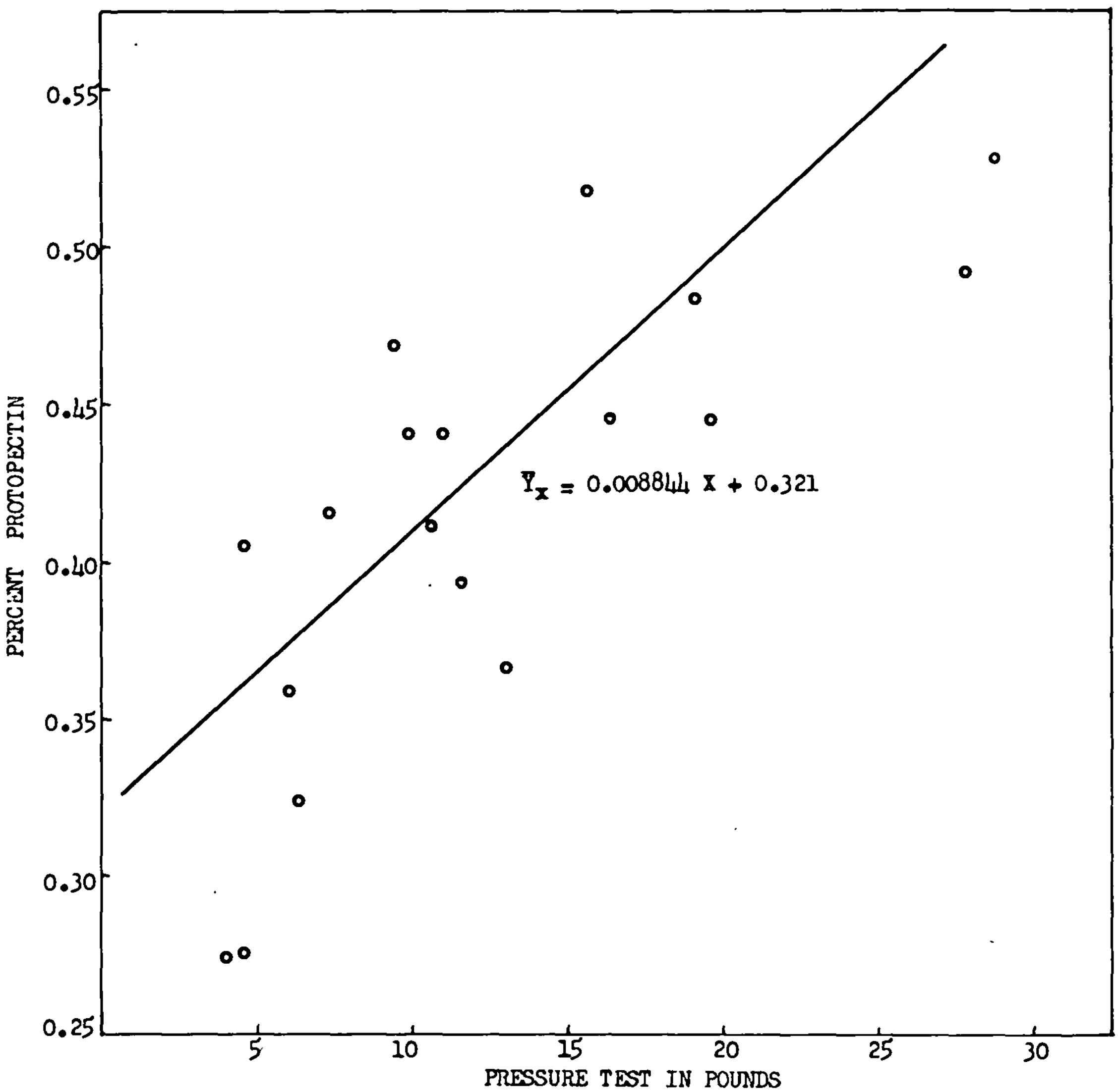


FIGURE 22. RELATIONSHIP BETWEEN PRESSURE TEST AND PERCENT PROTOPECTIN IN BARTLETT PEARS (CARBON TREATED)

The coefficient of correlation is 0.686. The line of regression can be expressed as $\bar{Y}_x = 0.008844\ X + 0.321$ where Y = percent of protopectin and X = pressure in pounds.

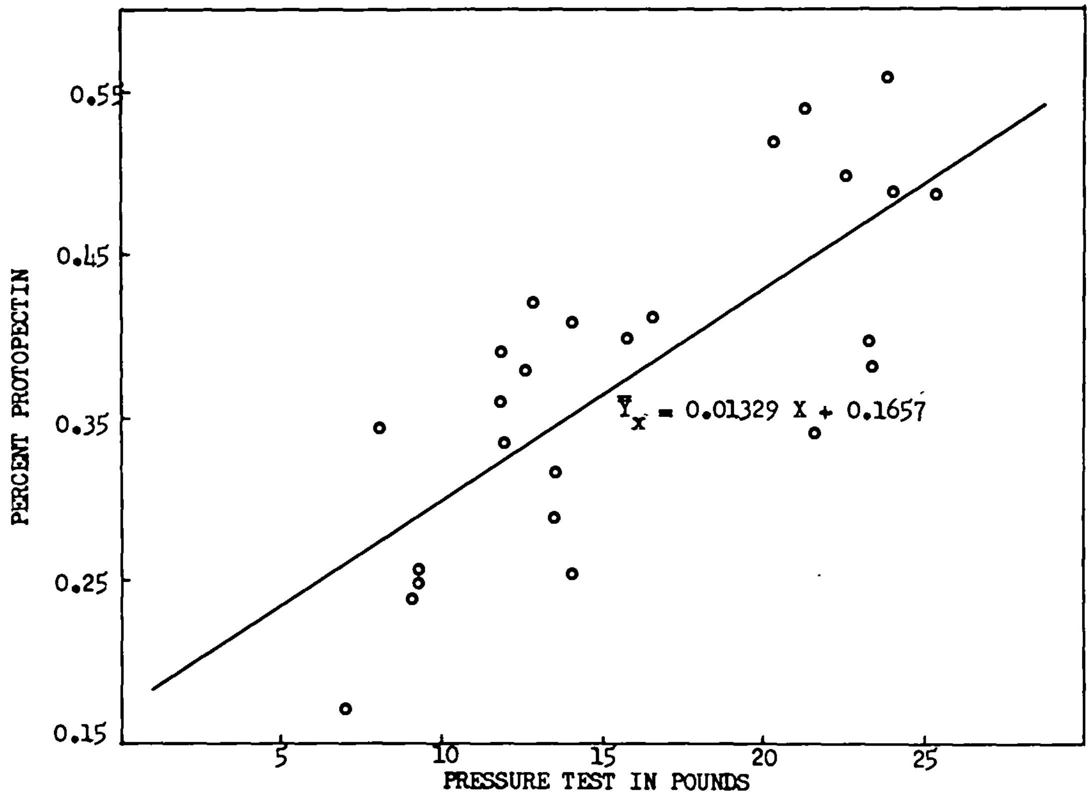


FIGURE 23. RELATIONSHIP BETWEEN PRESSURE TEST AND PERCENT PROTOPECTIN IN BOSC PEARS (CONTROL)

The coefficient of correlation is 0.7602. The line of regression can be expressed as $\bar{Y}_x = 0.01329\ X + 0.1657$ where Y = percent of protopectin and X = pressure in pounds.

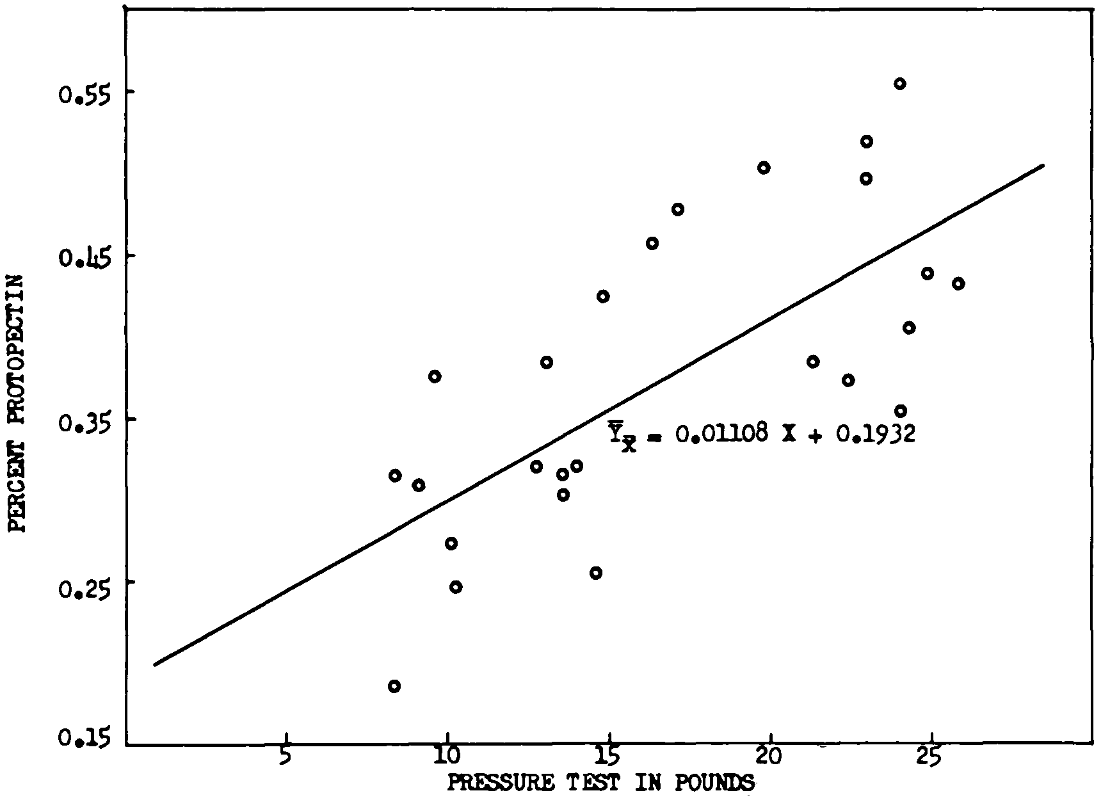


FIGURE 24. RELATIONSHIP BETWEEN PRESSURE TEST AND PERCENT PROTOPECTIN IN BOSC PEARS (CARBON TREATED)

The coefficient of correlation is 0.7059. The line of regression can be expressed as $\bar{Y}_x = 0.01108\ X + 0.1932$ where Y = percent of protopectin and X = pressure in pounds.

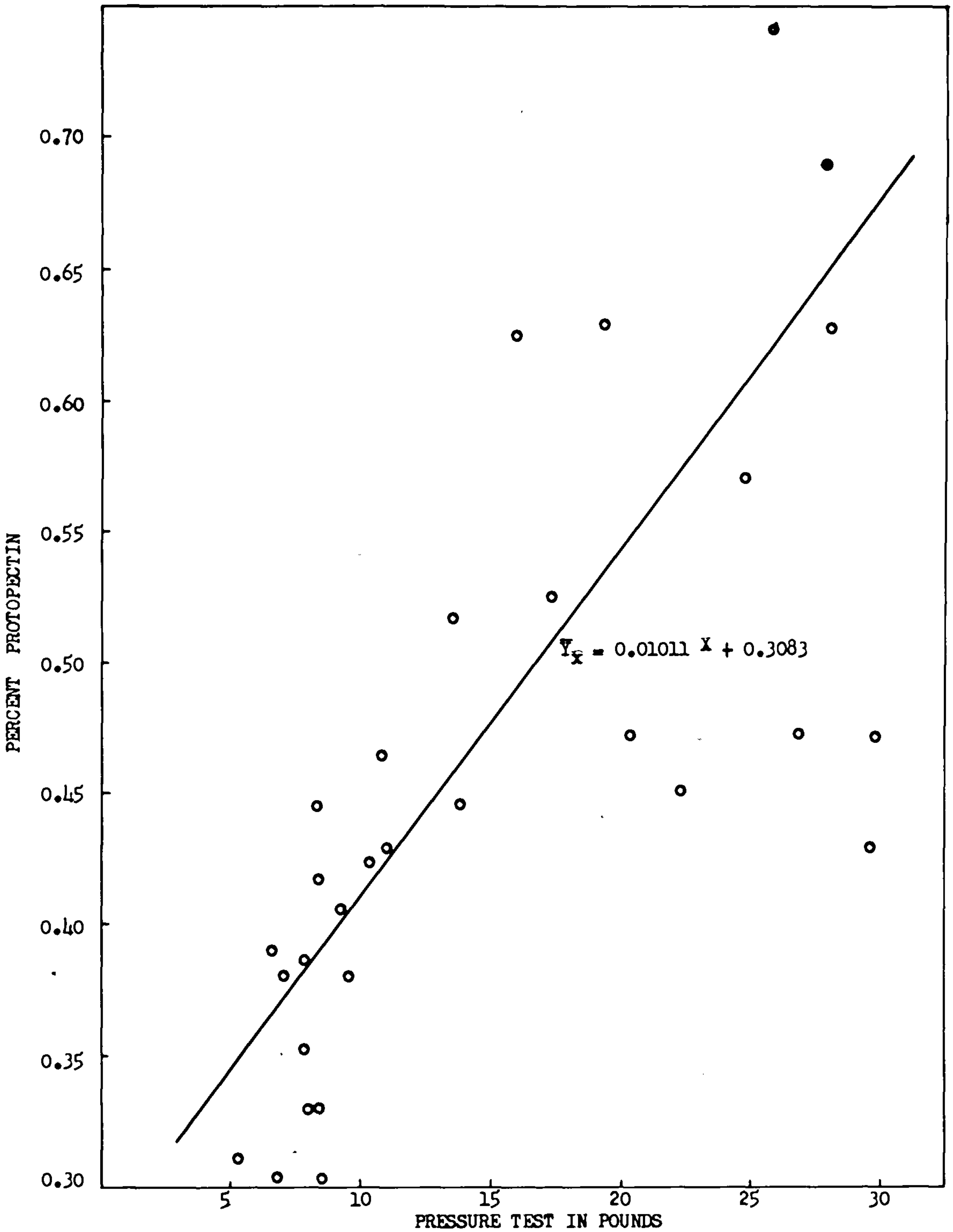


FIGURE 25. RELATIONSHIP BETWEEN PRESSURE TEST AND PERCENT PROTOPECTIN IN ANJOU PEARS (CONTROL)

The coefficient of correlation is 0.7144. The line of regression can be expressed as $\bar{Y}_{\bar{X}} = 0.01011\ X + 0.3083$ where Y = percent of protopectin and X = pressure in pounds.

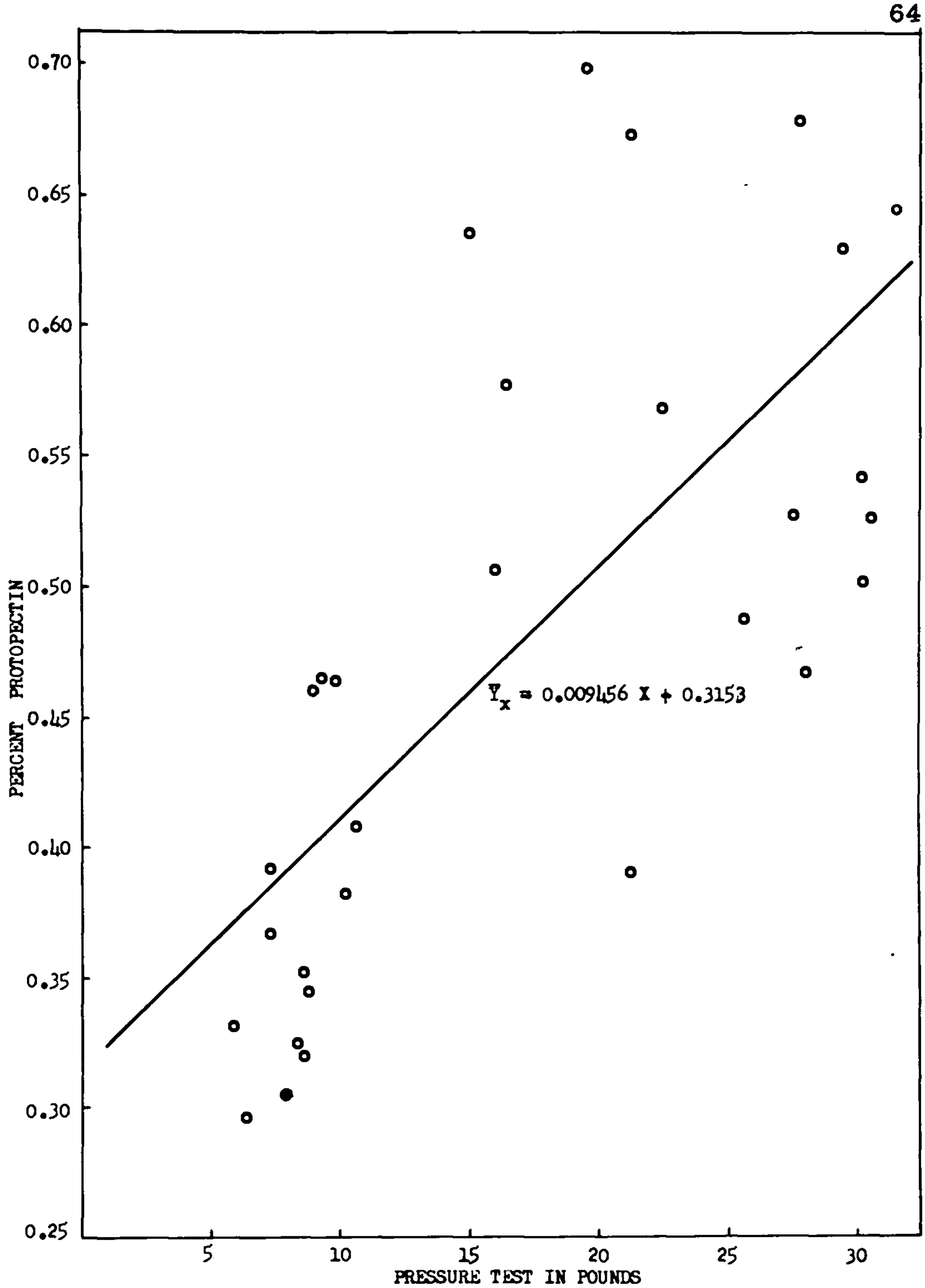


FIGURE 26. RELATIONSHIP BETWEEN PRESSURE TEST AND PERCENT PROTOPECTIN IN ANJOU PEARS (CARBON TREATED)

The coefficient of correlation is 0.7078. The line of regression can be expressed as $\bar{Y}_x = 0.009456\ X + 0.3153$ where Y = percent of protopectin and X = pressure in pounds.

Chapter V

DISCUSSION

The data obtained in this investigation show clearly that the biochemical changes which occur in pear tissue during cold storage have a definite influence upon the nature of the ripening processes when the fruit is transferred to a temperature 68-70°F.

In each of the three varieties studied, the most apparent and significant change which occurred during ripening was a rapid and consistent decrease in firmness from a hard and crisp to a soft or butterlike condition. The data show that as the fruit softens, there is also a corresponding decline in the protopectin content of the tissues. This behaviour was characteristic of all samples which ripened normally and developed a texture consistent with a desirable dessert quality. Fruit which failed to soften when removed to temperatures favorable for ripening showed anamolous behaviour with respect to the pectic substances. Thus the Anjou pears removed from storage in October while still in the pre-climacteric stage, did not soften and showed no appreciable change in the protopectin content during the twelve day ripening period. Bartlett and Bosc pears which failed to soften after long periods of storage retained large amounts of protopectin in the tissues. According to these data, it is the changes which occur at low temperature storage in the pectic substances which largely determine the ability of the fruit to soften during the ripening processes.

The quantity of juice which could be extracted from the tissues also appears to be correlated with the metabolism of the pectic substances. In unripened Bartlett and Anjou pears, the amount of juice which could be extracted from the tissues was approximately 20 per cent but increased rapidly as the tissues softened. The highest amounts of extractable juice were observed in samples ripened early in the storage season. Thus Bartlett and Anjou pears ripened in October, and November, respectively, contained approximately 85 per cent juice when fully ripe. Samples ripened at monthly intervals thereafter contained progressively smaller amounts, and late in the season only 50-60 per cent of the juice could be extracted from the tissues. Bosc pears developed less extractable juice than either Anjou or Bartlett varieties, and this condition is probably associated with the characteristic buttery texture of this variety. The relation of length of the storage period and the degree of ripeness to the extractable juice content should be of value to commercial processors interested in obtaining the maximum yields of juice from pear tissues.

The question arises as to what changes occur in the metabolism of the pectic substances during prolonged low temperature storage which result in a decline or loss in the ability of the fruit to soften during the ripening process. Gerhardt and Ezell (23) found no evidence to indicate that the apparent inactivation resulted directly from low-temperature injury, as suggested by Kidd and West (46). In fact they found that its inception was earlier and more severe at 36°F. than at 30°F. Neither could they find any apparent correlation between the loss in ripening capacity and the accumulation of possible toxic metabolic products, including acetaldehyde, alcohol and astringent substances. The rate of respiration in cold storage, catalase and oxidase activity, or changes in carbohydrates also did not appear to be associated with the development of this condition. They concluded that the loss of ripening capacity in pears can be explained by the inactivation of the protopectinase system during the cold storage period. This conclusion presupposes that the dissimilation of protopectin is due to enzymatic action. Kertesz (43), Griffin and Kertesz (26), however, were unable to demonstrate the presence in fruits of an enzyme which hydrolyzed protopectin. They suggested that in some fruits, at least, the breakdown of protopectin is non-enzymatic but is catalyzed by organic acids. Because of the comparatively low acid content, together with the minor changes which occur in total acidity and pH during storage and ripening, it does not seem plausible that this explanation can account for the pectic changes in pears.

The theories which have been advanced for the transformation of the protopectin to pectin, while differing as indicated as to the nature of the catalytic agent, are in agreement that the process is a hydrolytic reaction involving the addition of water, a process similar to the hydrolysis of starch and sucrose. This viewpoint is consistent with the concept that with the maturation of fruits there is a cessation of synthetic reactions, and the metabolism becomes predominantly catabolic in nature. The data obtained in this investigation show, however, that during the storage period the protopectin content actually increased, and it would appear, therefore, that the synthesis of this substance continues after the fruit has become mature and removed from the tree. Heinze and Appleman (39) have indicated that there is a similar increase in the protopectin content of sweet potatoes during storage. Data from other sources also show that the concentration of sucrose and of protein increases during storage and the initial stages of fruit ripening (41, 51). On the basis of these observations the capacity of the fruit to synthesize appears to be retained after maturation, at least until the beginning of the climacteric.

Since there can be no further increase in the total amount of food materials in the fruit after abscission, any increase in sucrose or of the more complex substances such as protopectin and pectin would involve their formation from the simple sugars and other compounds already present, the required energy for the processes presumably being furnished by respiration. The only known mechanism for the utilization of energy liberated by respiration is through the formation of labile high-energy phosphate bonds, a process involving the formation of phosphorylated intermediates and a transfer of energy from compound to compound by the transfer of phosphate. Since the majority of these reactions are reversible, the possibility is suggested that the breakdown of the complex substances in fruits may be brought about by the uptake of phosphorus rather than by that of water.

Reactions of this nature are known to occur with starch and sucrose, and the specific phosphorylases have been identified. The recent identification (10) of uridine-diphosphate glucose as the coenzyme associated with the enzymatic conversion of glucose-1-phosphate to galactose-1-phosphate suggests the possibility that phosphorylation reactions may be associated with at least certain of the steps in the metabolism of the pectic substances.

If the dissimilation of protopectin involves phosphorylation, then it would not be necessary to assume that the protopectinase system has an active role in this reaction as suggested by Gerhardt and Ezell (23). The loss in ripening capacity, instead of being due to the inactivation of this enzyme or enzyme system, could be explained on the basis of a disruption in the sequence of reactions involving the uptake of inorganic phosphate and its utilization in phosphorylation reactions. If the uptake of inorganic phosphorus is coupled with respiration, it is conceivable that the supply of inorganic phosphate could become a limiting factor after long periods of storage. This supposition is consistent with the observation that it is the short-keeping varieties of pears such as the Bartlett and Bosc, which have comparatively high rate of respiration, that develop this condition, and that its inception is augmented by an increase in the storage temperature. It is consistent also with the observations that the loss in ripening capacity does not occur when pears are stored in low concentrations of oxygen, such as are used in modified atmosphere storage (45).

According to the data obtained, certain of the reactions associated with the ripening processes were influenced by the use of activated charcoal as a means of storage air purification. The most pronounced influence was on the retention of the green color of the fruit. No effect on the metabolism of the pectic substances was apparent in Bartlett and Bosc pears, and the data for Anjous are not consistent, although there is an indication that the rate of protopectin breakdown was retarded during the storage period. These results indicate that the various biochemical reactions associated with ripening respond differently to the presence of ethylene in the atmosphere, the decomposition of chlorophyll apparently being the most sensitive. With lemons it has been found that yellowing of the peel is stimulated by treatment with 4 p. p. m. of ethylene, at which concentration respiration does not appear to be affected. Apparently the differences in ethylene content between the untreated and treated rooms were not sufficiently great to be reflected in the major physiological processes associated with ripening.

Chapter VI

SUMMARY

1. A study has been made of the interrelations between certain of the physical and biochemical changes in three varieties of pears during storage and ripening. The metabolic changes which occurred in the fruit during cold temperature storage were found to influence the development of certain characteristics associated with dessert quality of the ripened fruit. The nature of these changes varied according to variety.

2. The rate and degree of softening at a temperature favorable for ripening (68-70°F.) varied considerably according to variety and according to length of the storage period. Bartlett pears decreased rapidly in pressure test when ripened in October and November. Bosc pears softened slower and to a lesser degree. Both varieties failed to soften and ripen normally after prolonged periods of storage. This condition was not observed in Anjou pears, but this variety ripened in April tended to have a mealy texture.

3. The amounts of both protopectin and total pectin increased during storage in all the three varieties. Anjou pears contained more total and protopectin than the

other two varieties. The data on pectin changes indicate a possibility of synthesis of protopectin during storage. A possible explanation for such phenomenon is discussed. There is a fairly significant correlation between per cent protopectin and pressure test.

4. The percentage of extractable juice was inversely correlated with fruit firmness, and increased rapidly during ripening. Highest yields of extractable juice were obtained from Anjou and Bartlett pears, and the percentages decreased in all varieties with increase in length of the storage period. Low extractable juice content was correlated with the loss of ripening capacity in Bartlett and Bosc pears and the occurrence of mealy texture in Anjou pears. The relative viscosity of the juice increased during the ripening process and was highest in all varieties ripened after short periods of storage.

5. Total acid content of all varieties varied to some extent but no consistent trends were observed.

6. In all varieties total solids increased with ripening, and were lower in Bartlett and Bosc than in Anjou pears.

7. The use of activated carbon treatment of the storage atmosphere retarded the rate of loss of green

color. No effect on the metabolism of pectic substances was apparent in Bartlett and Bosc pears, while the data for Anjou pears were not consistent.

BIBLIOGRAPHY

1. Allen, F. W. Maturity standards for harvesting Bartlett pears for eastern shipments. California Agricultural Experiment Station Bulletin No. 470, pp.27, 1929.

2. Allen, F. W. Physical and chemical changes in the ripening of deciduous fruits. Hilgardia 6, 381-441, 1932.

3. Allen, F. W. The harvesting and handling of fall and winter pears. California Agricultural Experiment Station Bulletin No. 553, pp. 46, 1932.

4. Appleman, C. O. and Conrad, C. M. Pectic constituents of peaches and their relation to the softening of the fruit. Maryland Agricultural Experiment Station Bulletin 283, pp. 8, 1926.

5. Appleman, C. O. and Conrad, C. M. The pectic constituents of tomatoes and their relation to the canned product. Maryland Agricultural Experiment Station Bulletin 291, pp. 17, 1927.

6. Archbold, H. K. Chemical changes in stored apples. The relation of the time of picking to the chemical composition and storage life of the apple. Proceedings of the First Imperial Horticultural Conference, London, Part III, 91-97, 1931.

7. Archbold, H. K. Chemical studies in the physiology of apples. XII: Ripening processes in the apple and the relation of time of gathering to the chemical changes in cold storage. Annals of Botany 46, 407-459, 1932

8. Bonner, J. The chemistry and physiology of pectins. The Botanical Review 2, 475-497, 1936.

9. Caldwell, J. S. Hydrion concentration changes in relation to growth and ripening of fruits. United States Department of Agriculture, Technical Bulletin No. 403, pp. 54, 1934.

10. Cardini, C. E., Paladini, A. C., Caputo, R. and Leloir, L. E. Uridine diphosphate glucose: the coenzyme of the galactose-glucose phosphate isomerization. Nature 165, 191-192, 1950.

11. Carré, M. H. The pectic constituents of stored fruits. The Biochemical Journal 16, 704-712, 1922.

12. Carré, M. H. and Haynes, D. The estimation of pectin as calcium pectate and the application of this method to the determination of soluble pectin in apples. The Biochemical Journal 16, 60-69, 1922.

13. E'chévin, R. L'evolution du complexe pecto-cellulosique dans les fruits conserves per le froid. Comptes Rendus. 213 (14), 458-460, 1941.

14. Elmer, O. H. Growth inhibition in potato sprouts by volatile products of apples. Science 75, 193, 1932.

15. Emmett, A. M. An investigation of the changes which take place in the chemical composition of pears stored at different temperatures with special reference to pectic changes. Annals of Botany 43, 269-308, 1929.

16. Ezell, B. D. and Diehl, H. C. Relation of maturity and handling of Bartlett pears in the Pacific Northwest to the quality of canned product. United States Department of Agriculture, Technical Bulletin 450, pp. 24, 1934.

17. Fidler, J. C. Studies in zymasis. The estimation of the ethyl alcohol and acetaldehyde content of apples. The Biochemical Journal 28, 1107-1120, 1934.

18. Fontanel, L. Stimulating action of ripe fruit on adjacent fruit. Proceedings, 7th International Congress on refrigeration. The Hague, Amsterdam, 4, 79-80, 1937. (In French). Chemical Abstracts 32, 8487, 1938.

19. Food Investigation. 1940 to 1946. (Great Britain) Department of Scientific and Industrial Research, pp. 42, 1948.

20. Gane, R. Production of ethylene by ripening fruits. Nature 134, 1008, 1934.

21. Gane, R. The formation of ethylene by plant tissues, and its significance in the ripening of fruits. Journal of Pomology and Horticultural Science 13, 351-358, 1935.

22. Gerhardt, F. and Ezell, B. D. Effect of carbon dioxide storage on Bartlett pears under stimulated transit conditions. Journal of Agricultural Research 56, 121-136, 1938.

23. Gerhardt, F. and Ezell, B. D. Physiological investigations on fall and winter pears in the Pacific Northwest. United State Department of Agriculture, Technical Bulletin No. 759, pp. 66, 1941.

24. Gerhardt, F. Simultaneous measurement of carbon dioxide and organic volatiles in the internal atmosphere of fruits and vegetables. Journal of Agricultural Research 64, 207-219, 1942.

25. Gerhardt, F. Air purification in apple and pear storages. Refrigerating Engineering 58, 145-148, 192-194, 1950.

26. Griffin, J. H. and Kertesz, Z. I. Changes which occur in apple tissue upon treatment with various agents and their relation to the natural mechanism of softening during maturation. The Botanical Gazette 108, 279-285, 1946-47.

27. Haller, M. H. Changes in pectic constituents of apples in relation to softening. Journal of Agricultural Research 39, 739-746, 1929.

28. Hansen, Elmer and Hartman, H. The occurrence in pears of metabolic gases other than carbon dioxide. Oregon Agricultural Experiment Station Bulletin No. 342, pp. 10, 1935.

29. Hansen, Elmer, and Hartman, H. Effect of ethylene and certain metabolic gases upon respiration and ripening of pears before and after cold storage. Plant Physiology 12, 441-454, 1937.

30. Hansen, Elmer, and Hartman, H. Chemical determination of ethylene in the emanations from apples and pears. The Botanical Gazette 101, 403-409, 1939.

31. Hansen, Elmer. Effect of ethylene on certain chemical changes associated with the ripening of pears. Plant Physiology 14, 145-161, 1939.

32. Hansen, Elmer. Quantitative study of ethylene production in relation to respiration of pears. The Botanical Gazette 103, 543-559, 1942.

33. Harding, P. L. Distribution of total soluble solids and catalase in different parts of Jonathan apples. Journal of Agricultural Research 53, 43-48, 1936.

34. Hartley, C. D., and Fisher, D. B. The occurrence of acetaldehyde in Bartlett pears and its relation to pear scald and breakdown. Journal of Agricultural Research 35, 983-993, 1927.

35. Hartman, Henry. Studies relating to the harvesting and storage of apples and pears. Oregon Agricultural Experiment Station Bulletin 206, pp.32, 1924.

36. Hartman, H., Magness, J. R., Reimer, F. C., and Haller, M. H. Investigations on harvesting and handling of Bosc pears from Rogue River Valley. Oregon Agricultural Experiment Station Bulletin No. 228, pp. 30, 1927.

37. Hartman, H., Reimer, F. C., and Norris, R. K. Further investigations on harvesting, storing and ripening of pears from Rogue River Valley. Oregon Agricultural Experiment Station Bulletin No. 254, pp. 23, 1929.

38. Haynes, P. Chemical studies in the physiology of apples: I. Changes in the acid content of stored apples and its physiological significance. Annals of Botany 39, 77-96, 1925.

39. Heinze, P. H., and Appleman, C. O. A biochemical study of curing processes in sweet potatoes. Plant Physiology 18, 548-555, 1943.

40. Hulme, A. C. The acetaldehyde and ethyl alcohol contents of apples during storage. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1933, 70-71, 1934.

41. Hulme, A. C. Metabolism of nitrogen in apple fruits. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1937, 117-123, 1938.

42. Joslyn, M. A. and Phaff, H. J. Recent advances in the chemistry of pectic substances. Wallerstein Laboratories Communications 10, 39-56, 1947.

43. Kertesz, Z. I. A possible non-enzymatic mechanism of changes occurring in the pectic substances and other polysaccharides in living plants. Plant Physiology 18, 308-309, 1943.

44. Kidd, F. and West, C. The course of respiratory activity throughout the life of an apple. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1924, 27-33, 1925.

45. Kidd, F. and West, C. The gas storage of pears. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1931, 92-99, 1932.

46. Kidd F. and West, C. Low temperature injury in the cool storage of fruits and vegetables. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1931, 122-127, 1932.

47. Kidd, F. and West, C. Effects of ethylene and apple vapors on the ripening of fruits. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1932, 55-58, 1933.

48. Kidd, F. and West, C. The influence of the composition of the atmosphere upon the incidence of climacteric. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1933, 51-57, 1934.

49. Kidd, F. and West, C. The effects of ethyl alcohol upon the respiratory metabolism of apples. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1933, 60-67, 1934.

50. Kidd, F. and West, C. Gas storage of English grown Conference Pears. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1935, 102-110, 1936.

51. Kidd, F., West, C. and Hulme, A. C. Rise in insoluble (protein) fraction of the total nitrogen during the climacteric in apples and pears, and the effect on this phenomenon of retarding the climacteric by carbon dioxide or stimulating the climacteric by ethylene. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1938, 119-125, 1939.

52. Kidd, F. and West, C. Respiratory activity of life of apples gathered at different stages of development and subsequently maintained at a constant temperature. Plant Physiology 20, 467-504, 1945.

53. Krotkov, G. The respiratory mechanism of McIntosh apples during ontogeny, as determined at 22°C. Plant Physiology 16, 799-812, 1941.

54. Krotkov, G. and Helson, V. Carbohydrate metabolism of McIntosh apples during the development on tree and in cold storage. Part 1. General trends. Canadian Journal of Research, C, 24, 126-144, 1946.

55. Lutz, J. M. and Culpepper, C. W. Certain chemical and physical changes produced in Keifter pears during ripening and storage. United states Department of Agriculture, Technical Bulletin No. 590, pp. 37, 1937.

56. Magness, J. R. Handling, shipping and cold storage of Bartlett pears in the Pacific Coast States. United States Department of Agriculture, Bulletin No. 1072, pp. 16, 1922.

57. Martin, W. E. The distribution of certain sugars in Bosc pears. Plant Physiology 11, 139-147, 1936.

58. Martin, W. E. Chemical study of the ripening process of Bosc pears. The Botanical Gazette 99, 42-68, 1937.

59. Miller, E. V. and Brooks, C. Effect of carbon dioxide content of storage atmosphere on carbohydrate transformation in certain fruits and vegetables. Journal of Agricultural Research 45, 449-459, 1932.

60. Miller, E. V. and Dowd, O. J. Effect of carbon dioxide on carbohydrates and acidity of fruits and vegetables in storage. Journal of Agricultural Research 53, 1-17, 1936.

61. Miller, E. V. Distribution of acetaldehyde and alcohol in the apple fruit. Journal of Agricultural Research 53, 49-55, 1936.

62. Murneck, A. E. A new test for maturity of the pear. Oregon Agricultural Experiment Station Bulletin No. 186, pp. 28, 1921.

63. Plagge, H. H. and Gerhardt, F. Acidity changes associated with keeping quality of apples under various storage conditions. Iowa Agricultural Experiment Station, Research Bulletin No. 131, 341-358, 1930.

64. Plagge, H. H. and Fisher, D. V. Pectic changes in Jonathan apples as a measure of ripening under differential carbon dioxide treatments. American Society of Horticultural Science, Proceedings 40, 169-171, 1942.

65. Powers, F. B. and Chestnut, V. K. The odorous constituents of apples. Emanations of acetaldehyde from ripe fruit. American Chemical Society Journal 42, 1509-1526, 1920.

66. Powers, F. B. and Chestnut, V. K. The odorous constituents of apples II. Evidence of the presence of geraniol. American Chemical Society Journal 44, 2938-2942, 1922.

67. Pratt, H. K., Young, R. E. and Biale, J. B. The identification of ethylene as a volatile product of ripening avocados. Plant Physiology 23, 526-531, 1948.

68. Smock, R. M. and Allen, F. W. Soluble pectin changes in gas stored fruit. American Society of Horticultural Science Proceedings 35, 184-187, 1937.

69. Smock, R. M. Influence of stored apples on the ripening of other apples stored with them. Cornell Agricultural Experiment Station Bulletin 799, pp. 36, 1943.

70. Smock, R. M. The physiology of deciduous fruits in storage. The Botanical Review 10 (9), 560-598, 1944.

71. Smock, R. M. and Boynton, D. The effects of differential nitrogen treatments in the orchard on keeping quality of McIntosh apples. Proceedings American Society of Horticultural Science 45, 77-86, 1944.

72. Smock, R. M. and Southwick, F. W. Air purification in the apple storage. Cornell Agricultural Experiment Station Bulletin 843, pp. 52, 1948.

73. Smock, R. M. Controlled atmosphere storage of apples. Cornell Agricultural Experiment Station. Bulletin 759, pp. 39, 1949.

74. Trout, S. A. Effect of volatile products on the storage life of fruit. (Great Britain) Department of Scientific and Industrial Research. Food Investigation Board Report for 1929, 60, 1930.

75. Wallace, T. Factors influencing the storage qualities of fruits. Proceedings of the First Imperial Horticultural Conference, London, 1930. Part III. 9-25, 1931.