UNITED STATES DEPARTMENT OF AGRICULTURE

In Cooperation with the
Agricultural Experiment Stations of Massachusetts, New York (Cornell University), Ohio, Michigan, and Iowa

DEPARTMENT BULLETIN No. 1406

Washington, D. C. ▼ August, 1926

THE RIPENING, STORAGE, AND HANDLING OF APPLES

By

J. R. MAGNESS, Physiologist, H. C. DIEHL, Assistant Physiologist, M. H. HALLER, Junior Pomologist, and W. S. GRAHAM, Junior Physiologist, Office of Horticulture, Bureau of Plant Industry, with the cooperation of D. B. CARRICK, New York Agricultural Experiment Station at Cornell University, F. S. HOWLETT, Ohio Agricultural Experiment Station, R. E. MARSHALL, Michigan Agricultural Experiment Station, H. H. PLAGGE, Iowa Agricultural Experiment Station, and G. J. RALEIGH Massachusetts Agricultural Experiment Station

CONTENTS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1926

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
20 CENTS PER COPY

UNITED STATES DEPARTMENT OF AGRICULTURE

In Cooperation with the
Agricultural Experiment Stations of Massachusetts, New York (Cornell University), Ohio, Michigan, and Iowa

DEPARTMENT BULLETIN No. 1406

Washington, D. C. ▼ August, 1926

THE RIPENING, STORAGE, AND HANDLING OF APPLES

By J. R. MAGNESS, *Physiologist*, H. C. DIEHL, *Assistant Physiologist*, M. H. HALLER, *Junior Pomologist*, and W. S. GRAHAM, *Junior Physiologist, Office of Horticulture, Bureau of Plant Industry*, with the cooperation of D. B. CARRICK, *New York Agricultural Experiment Station at Cornell University*, F. S. HOWLETT, *Ohio Agricultural Experiment Station*, R. E. MARSHALL, *Michigan Agricultural Experiment Station*, H. H. PLAGGE, *Iowa Agricultural Experiment Station*, and G. J. RALEIGH, *Massachusetts Agricultural Experiment Station*.

CONTENTS

I. STUDIES OF THE RIPENING OF APPLES[1]

INTRODUCTION

The determination of the best time to remove apples from the tree is one of the most important problems which the fruit grower must

[1] Part I of this bulletin is based on contributions of data supplied jointly by the nine persons mentioned under the general title.

solve. If too immature when picked apples will wilt in storage and be poorly colored and unattractive in appearance; they will be of poor quality and lacking in aroma and flavor when they reach prime eating condition; and many varieties will be very likely to develop bad storage scald. On the other hand, it is very important that certain varieties be picked before becoming overripe. Internal breakdown—the softening and discoloration of the flesh of such varieties as Jonathan and, more rarely, Grimes Golden, Stayman Winesap, Delicious, Esopus Spitzenburg, and others—appears to be associated with allowing the fruit to remain too long on the trees. The development of water-core also appears to be associated with overmaturity on the tree.

Various tests are used by growers to determine the proper time of picking apples. The color of the seeds, the ground color or color of the unblushed portion of the fruit, the extent and intensity of the blushed surface, the ease of separation of the fruit from the tree, and the apparent firmness of the flesh are used to determine the time when the fruit is in proper condition to be removed from the tree. Extended critical studies have not heretofore been made to determine the exact dependability of these various tests, particularly for fruit growing under the various climatic conditions prevailing in different parts of the country or in the same section from year to year. Consequently, a series of investigations was inaugurated by the United States Department of Agriculture in cooperation with several State agricultural experiment stations to study carefully the changes which take place in apples as they approach maturity on the tree.

The most prominent of these changes are (1) increase in size, (2) change in color of seeds, (3) change in the color of the unblushed portion of the fruit, (4) development of blush or red color on colored varieties, (5) progressive softening of the fruit, and (6) change in the tenacity with which the fruit adheres to the tree.

It was proposed to study all these changes in order to determine if possible (1) which of them constitute the most reliable criteria for judging when the fruit is ready to be picked, (2) how these ripening changes differ in the same variety when grown in different sections of the country under widely varying climatic conditions, (3) the effect of a long or short growing season on the time of ripening of the variety, and (4) whether an early bloom necessarily indicates early ripening and a late bloom late ripening.

EXPERIMENTAL METHODS

In order to obtain standard observations on the fruit, an attempt was made to eliminate so far as possible the variations in observations due to the personal factor. The general outline of the observations and tests was carried on simultaneously in the experimental orchards at Amherst, Mass.; Ithaca, N. Y.; East Lansing, Mich.; Wooster, Ohio; Council Bluffs, Iowa; Rosslyn, Va.; and in commercial orchards at Wenatchee, Wash.

Observations and tests were made at 10-day intervals, starting several weeks prior to picking dates in the different sections, as follows:

Increase in the size of the fruit.—In each orchard 100 apples of each variety were selected, tagged, numbered, and the largest radial circumference measured in centimeters at the beginning of the test. These apples were remeasured at 10-day intervals to determine the growth increment. Thus, the rate of growth and the length of time growth continues have been determined. Individual apples that dropped prior to the last measurement were eliminated from all averages.

Hardness of the fruit.—A mechanical tester similar in essential details to that described by Murneek (*15*)[2] for determining the hardness of the fruit was used. The number of pounds pressure required to force a smoothly rounded plunger seven-sixteenths inch in diameter into the fruit to a depth of five-sixteenths inch was determined. The tests were made with the peel intact and with the peel removed, but since the latter tests are considered the more reliable all the data presented on hardness of the fruit are based on tests directly on the flesh of the apple (with the peel removed). In most cases 30 representative apples of each variety were used for each test, and three individual tests were made about the radial circumference of each apple. These 90 tests have been averaged to represent the pressure tests, i. e., hardness of the fruit on the different dates.

Changes in the ground color or color of the unblushed portion of the fruit.—In order to determine the changes in the ground color of the fruit from week to week, a chart was made up, representing as nearly as possible the color changes through which the unblushed portion of most apple varieties pass as they approach maturity on the tree. A reproduction of the chart used is shown as Plate I. The exact colors in different varieties of apples vary greatly, but by comparison with the chart the ground color of the fruit at any particular time could be fairly accurately placed. Instead of attempting to describe the color, the fruit was designated by its chart number according to the shade most nearly represented. Thus, No. 1 represents a very green shade and Nos. 2, 3, and 4 represent successive stages of yellowing; fruit falling between Nos. 2 and 3, for example, is called 2½. Similar charts were used in all districts, so that the color comparisons are believed to be accurate and directly comparable.

Increase in the blushed surface of the fruit.—Careful estimates of the area of the blushed surface of the 30 apples used for testing were made at each testing date. The averages presented give a fairly good indication of the change in blushed surface from time to time in the different sections.

Change in the color of the seed.—The color of the seeds was noted when the different tests were made. The time of turning brown and when full light brown are the really definite points in seed-color change and have been particularly noted.

Ease of separation from the spur and extent of dropping.—General notes were made on the ease of separation of the fruit from the spur and on the extent of natural dropping from the tree at the time of the different tests.

---

[2] Numbers (*italic*) in parentheses refer to "Literature cited," p. 64.

SOIL AND CULTURAL CONDITIONS

The soil and cultural conditions prevailing in the different orchards in which the test trees were selected may be summarized as follows:

Rosslyn, Va.—The orchard at the Arlington Experiment Farm, located across the Potomac River from Washington, D. C., is in grass sod on loam soil. During 1923 no fertilizer was applied. In the spring of 1924, 5 pounds of nitrate of soda and 5 pounds of superphosphate were applied to each tree prior to blossoming.

Amherst, Mass.—The soil is a stony loam. In 1923 the Baldwin and Delicious trees were in sod, with nitrate fertilizer added. Ben Davis, Winesap, and Jonathan were given stripped cultivation, with 5 pounds of nitrate to each tree, while the Grimes Golden was under cultivation, receiving no nitrate. In 1924 Baldwin and Grimes Golden were in sod, with nitrate, while Ben Davis, Delicious, Winesap, and Jonathan received stripped cultivation, with nitrate.

Council Bluffs, Iowa.—The trees are on silt-loam soil in clover sod, which is reseeded every three years, so the orchard is cultivated every third year. No fertilizer was applied.

Wooster, Ohio.—This soil is a silt loam. The orchard is in sod mulch and receives nitrate applications in the spring.

East Lansing, Mich.—Delicious, Jonathan, Winesap, and Baldwin received cultivation annually until 1920, when clover was sown, and since then have been in clover sod. No fertilizers have been added. Ben Davis has been in sod for many years.

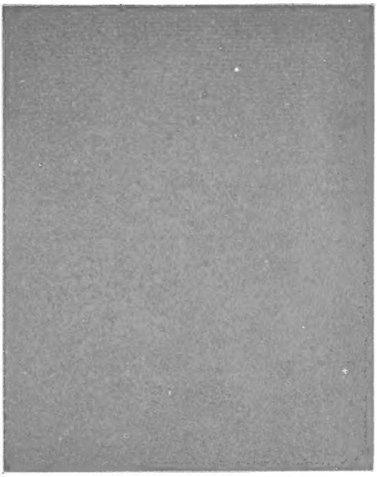
Ithaca, N. Y.—The soil is a heavy loam. The trees are 12 to 14 years old and receive cultivation annually, with a weed cover crop. No fertilizers are added. The Baldwin crop was light; the other varieties had an average yield.

Wenatchee, Wash.—The soil for the Jonathan and Grimes Golden is a fine sandy loam; the Ben Davis and Winesap trees are growing in loam soil, and Delicious trees in sandy soil. Ben Davis, Winesap, and Delicious trees received abundant water, but the irrigation of the Jonathan and Grimes Golden trees was somewhat irregular and scanty. All trees were in alfalfa sod. Ben Davis and Winesap received in addition 3 pounds nitrate of soda per tree.

WEATHER CONDITIONS

Table 1 shows detailed mean temperatures and precipitation by months at the different stations, as reported by the United States Weather Bureau. It is apparent from this summary that there was a very fair distribution of moisture through both years in those regions which depend on natural rainfall. At nearly all stations the mean temperatures for 1923 were somewhat above those for 1924 during May, June, July, and September; the mean temperatures in August, 1924, were somewhat above those for 1923. On the whole, the season of 1924 would be characterized as cool throughout all the eastern section of the United States. In the Wenatchee district of Washington the mean May temperature was about 6° F. above normal for the month; the remainder of the season averaged very close to the mean for that section.

PLATE I



1

2

3

4

Table 1.—*Mean temperatures and precipitation of seven stations, compiled from United States Weather Bureau data*

Station and month	1923		1924	
	Mean temperature	Precipitation	Mean temperature	Precipitation
Amherst, Mass.:	°F.	*Inches*	°F.	*Inches*
May	56.4	3.26	53.2	2.21
June	67.9	2.24	64.3	1.28
July	68.5	1.77	71.4	1.75
August	67.6	2.55	70.3	3.11
September	63.9	1.89	59.2	5.87
October	51.1	5.50	51.3	.01
Rosslyn, Va.:				
May	63.0	1.50	60.0	6.73
June	76.0	2.80	71.3	3.89
July	76.0	4.92	75.0	2.76
August	74.0	2.19	74.8	5.07
September	70.0	3.15	64.2	7.86
October	56.0	1.36	57.4	.44
Council Bluffs, Iowa:				
May	60.9	2.50	55.7	2.01
June	72.4	6.00	69.0	9.08
July	79.5	.86	73.2	2.79
August	72.9	4.24	76.0	1.67
September	67.4	9.32	62.2	4.56
October	51.8	.71	61.4	.51
East Lansing, Mich.:				
May	54.6	3.45	50.6	4.20
June	70.0	2.90	64.2	4.94
July	70.6	4.76	67.4	2.68
East Lansing, Mich.—Contd.	°F.	*Inches*	°F.	*Inches*
August	66.7	1.27	66.8	2.01
September	62.1	5.61	56.8	2.58
October	48.5	1.39	54.6	.30
Ithaca, N. Y.:				
May			51.6	3.19
June			62.4	2.71
July			67.5	4.37
August			66.8	3.30
September			57.2	6.83
October			48.6	.23
Wenatchee, Wash.:				
May			64.2	0
June			65.6	.08
July			71.6	0
August			70.4	.94
September			61.3	.55
October			50.0	.47
Wooster, Ohio:				
May	56.9	4.11	54.2	4.13
June	69.6	1.99	66.6	6.40
July	71.7	2.08	68.7	4.32
August	69.4	4.70	70.5	2.34
September	64.6	3.08	60.3	5.38
October	50.0	1.38	53.7	.30

From the temperatures presented in Table 1 and from the average temperatures for the growing season shown in Table 3, it is apparent that the average temperature at the Arlington Experiment Farm at Rosslyn, Va., was about 6° F. above that at Amherst, Mass., and East Lansing, Mich., during 1923. Wooster, Ohio, and Council Bluffs, Iowa, were intermediate in temperatures, the latter being almost as warm as Rosslyn.

The 1924 growing-season temperatures averaged somewhat cooler throughout the Eastern States, with less variation in the different districts then in 1923. Mean temperatures for the full growing season at Wenatchee during 1924 averaged slightly warmer than at Amherst, Wooster, and Ithaca, and somewhat cooler than Rosslyn and Council Bluffs. The daily fluctuation at Wenatchee is greater than at any other station studied; the mean temperature was intermediate, but the daily maximum averaged higher and the daily minimum lower than at the other stations.

INCREASE IN SIZE OF FRUIT

The exact increase in the size of apples during the latter part of the growing season, and particularly through and following the normal picking season, has not heretofore been extensively studied. Whitehouse (*19*) determined the rate of growth of Grimes Golden apples in western Oregon from June until September 20 and found that the increase in diameter proceeded at a fairly constant rate. Magness and Diehl (*11*) showed that Winesap apples at Rosslyn, Va., were still growing rapidly on October 10 during the season of 1919. The rates of increase in size of the fruit of the different varieties at the various stations where observations were made are shown graphically in Figures 1 to 9. The size of the apples, given in cubic centimeters, is based on calculations from circumference measurements, assuming the fruit to be a sphere. The volume of the fruit is slightly less than this, but the data for each variety are comparable and give a more accurate indication of the actual increase in size than would be obtained by circumference measurements. For purposes of comparison, a 2-inch apple on this basis would have a volume of about 65 cubic centimeters, a 2½-inch apple 125 cubic centimeters, and a 3-inch apple about 220 cubic centimeters. These data are based on measurements of the same apples taken from time to time in the different sections and are representative of the actual increase in size occurring at the different dates. The data are averages of 50 to 100 apples.

From the data shown in Figures 1 to 9 it is apparent that the increase in size of the fruit continues as long as the apples remain

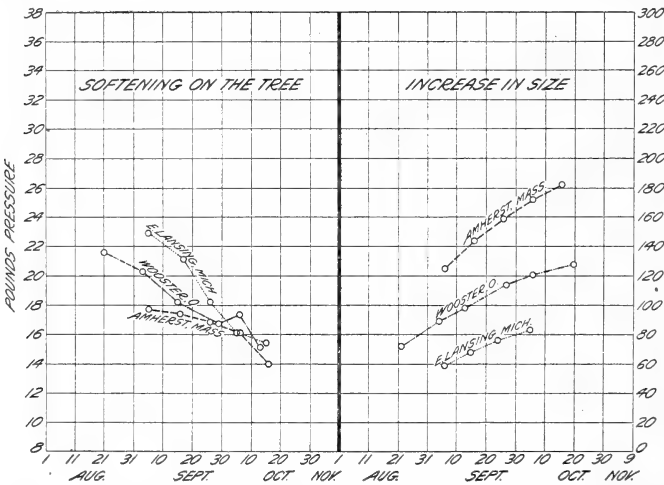


FIG. 1.—Change in firmness of flesh and size of Jonathan apples, 1923

attached to the tree. Many of the measurements on which these data are based were made after the commercial picking season had passed and when the crop as a whole was dropping very badly; yet it is apparent that growth in size continued at a very nearly uniform rate. For example, in 1923 the Baldwin apples at Amherst were dropping considerably by October 6, yet measurements made October 8 showed growth to be continuing in those apples which still adhered to the tree. At Rosslyn so many Baldwin apples had dropped by September 17 that it was impossible to get further measurements, yet up to that date growth was continuing at a practically uniform rate. The data for 1924 show a similar condition. Delicious apples at Wooster, Ohio, were showing a medium drop and were apparently ready to pick on October 12, yet growth continued at a uniform rate throughout the remainder of the month. Jonathan at Wenatchee appeared ready to pick on September 10, but showed a marked increase in size between that date and

September 26. Practically all the Grimes Golden fruits at Rosslyn dropped about September 30, although up to that time they were showing a uniform growth rate. These specific examples might be extended. It is apparent from the charts, however, that as long as the fruit remained on the tree in the different sections, a marked and more or less uniform increase in its size occurred.

It has not been possible from the data at hand to make a critical analysis of the factors involved in determining the rate of growth in apples. With most varieties the fruit grown under fairly constant moisture supply and high fertility in the Wenatchee district increased in size somewhat more rapidly and became larger than that in most of the eastern districts. Grimes Golden, with a heavy crop, however, did not become larger than in the eastern districts, while Delicious, with a light crop, became very large. It would appear that the water supply and the quantity of fruit on the tree are the two main factors in determining the size attained. Under

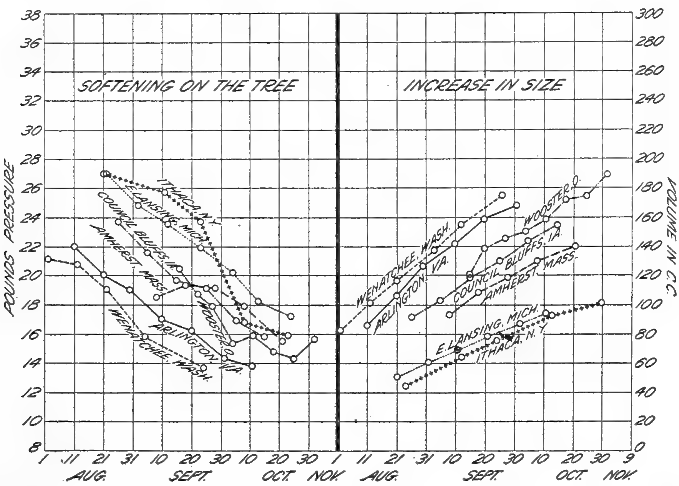


FIG. 2.—Change in firmness of flesh and size of Jonathan apples, 1924

certain conditions a third factor, namely, length of growing season, is very important. The data show conclusively that within the seasonal limits here studied, which in most cases extended as long as the fruit was adhering to the tree, regardless of the exact climatic conditions prevailing, there is a rather distinct increase in size from week to week. Thus, delaying picking operations as long as the condition of the fruit permits will result in a distinctly larger size than will be obtained by early picking.

SOFTENING OF APPLES ON THE TREE

It has long been recognized that as fruit matures on the tree there is a gradual softening of the tissue. The mechanical measurement of the rate of softening of certain fruits has been suggested and used as a test of the proper time for removing them from the tree (*15*). The exact rate of softening of apples before and during the picking season has been determined to a limited extent. Burroughs (*4*) reported that Wagener apples at Canton, Pa., softened only very slightly between September 23 and October 13, 1922, and then showed a marked softening before October 24. Hartman (*9*) reports that in Grimes Golden, Jonathan, and Ortley apples grown in western Oregon the rate of softening just prior to picking time as measured by mechanical tests was not sufficiently rapid to be a satisfactory index of picking maturity. Magness and Diehl (*11*) in 1922 found a rather rapid softening in Winesap, Ben Davis, and Rome Beauty apples at Rosslyn during the last month of the ripening season on the trees, whereas Delicious showed much less rapid softening. One of the authors (*12*) in a preliminary report showed the softening rates of several varieties in different sections of the country during the fall of 1923.

Figures 1 to 9 show graphically the rates of softening of some of the different varieties under observation at the various stations

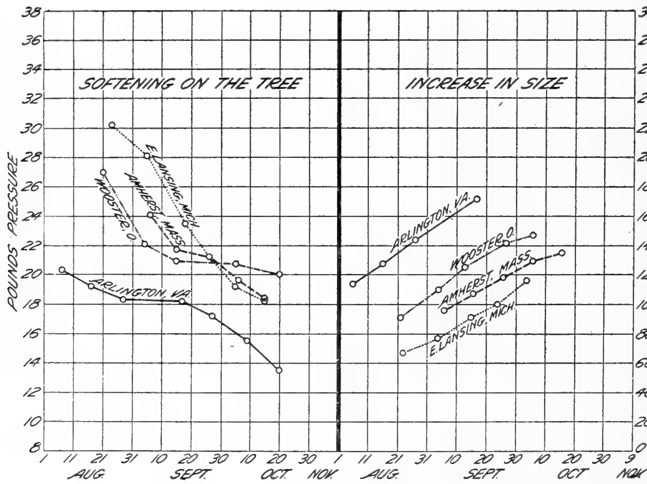


FIG. 3.—Change in firmness of flesh and size of Baldwin apples, 1923

during the years 1923 and 1924. It is at once apparent that there is a marked variation in the softening rate of different varieties and also for the same variety under different growing conditions.

Fruit at Rosslyn during 1923 appeared to be distinctly softer throughout the growing season than the same varieties grown in the more northern latitudes. The blooming season at Rosslyn in 1923 occurred the last week in April, while at Amherst and East Lansing full bloom was reported on May 23. Considering that the different varieties were one month more advanced at Rosslyn than in the northern sections, it is still apparent that the fruit at Rosslyn was much softer. For example, on August 7 Winesap at Rosslyn registered on pressure testing under 24 pounds, whereas on September 7 at East Lansing the Winesap tested almost 29 pounds. The Michigan fruit on September 7 was considerably larger than that in Virginia on August 7. Similarly, Baldwins at Rosslyn on August 7 were markedly softer than Baldwins from Michigan, Ohio, or

Massachusetts on September 7. Delicious, detailed data for which are not shown, was distinctly softer at Rosslyn on August 7 than in the northern regions on September 7. The same general condition held with Ben Davis. With Grimes Golden, on the other hand, there was little difference between the Rosslyn fruit on August 7 and the more northern grown fruit on September 7.

During August, 1924, most varieties at Rosslyn were harder than during the corresponding month in 1923. In 1924 the trees were later in blooming and the weather was cooler than in 1923. The fruit in Virginia was softer than that from the more northern regions at any given date but only approximately in proportion to the difference in season between the two sections. Fruit from Wenatchee, blooming two weeks earlier than that in Virginia, closely paralleled the Virginia fruit, although remaining constantly about two weeks in advance of it in softness.

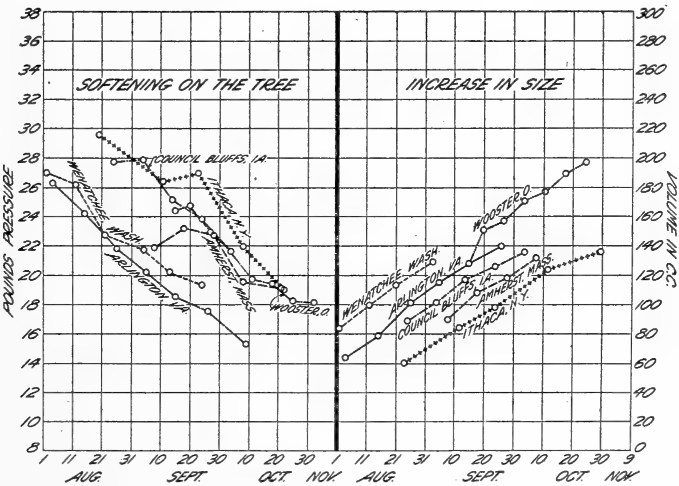


Fig. 4.—Change in firmness of flesh and size of Grimes Golden apples, 1924

It is somewhat surprising to find that the Iowa fruit was distinctly harder, particularly in 1924, than the same varieties grown in Virginia. The blooming season in the two sections was almost identical, while the mean temperatures at Council Bluffs were only slightly below those which prevailed at Rosslyn. There is no outstanding variation either in temperature, moisture supply, or size of fruit to account for this variation.

Of particular importance from the point of view of the use of the pressure-test apparatus as a means of determining picking time in apples is the rate of softening just prior to the picking season, as well as the exact condition of firmness of the different varieties from the various sections at the time the fruit is in prime picking condition.

From all the data which were available, including notes on color, adherence of the fruit to the tree and extent of dropping, size of the fruit, pressure test, etc., the optimum picking season for the various varieties in the different sections has been determined as accurately as possible. Particular emphasis in determining this date was placed on the factors of the ground color of the fruit and the adherence of the fruit to the tree. The optimum picking dates for the different varieties are shown in Table 3.

In Table 2 is summarized the pressure test at the optimum picking date for the various varieties in the different sections. The pressure test one month earlier is also recorded with the difference between the two tests, which represents the amount of softening during the month prior to the picking date.

From a study of the data presented in Table 2 it is apparent that a wide variation may occur in the rate of softening prior to picking time. Thus, Delicious at Rosslyn in 1923 showed no apparent softening during this period, but in 1924 there was a softening of 3.5 pounds. At East Lansing the softening was 2.7 pounds in 1923 and 2 pounds in 1924; at Wooster it was 3.1 pounds in 1923 and 4.6 pounds in 1924. In all the observations on this variety there

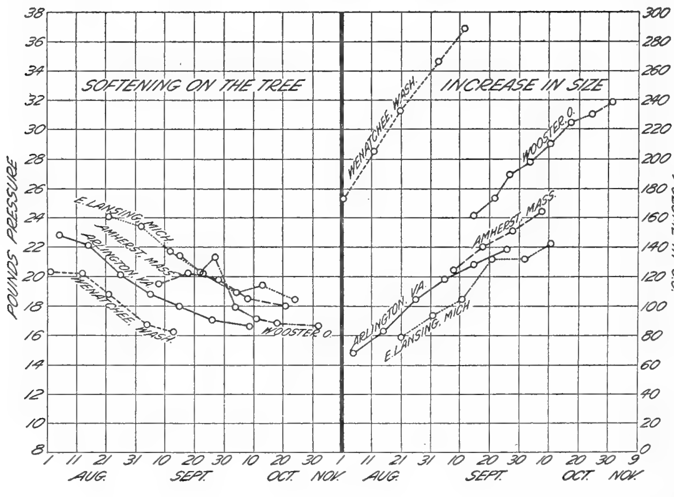


FIG. 5.—Change in firmness of flesh and size of Delicious apples, 1924

is a range from no softening to 4.6 pounds. Jonathan in 1924 ranged from 1.3 pounds at Amherst to 5 pounds at East Lansing, 5.1 pounds at Wenatchee, and 8.4 pounds at Ithaca. Grimes Golden showed a range in 1924 from 0.9 pound at Amherst to 5.1 pounds at Wenatchee and Ithaca. Baldwin ranged from 1.5 pounds at Rosslyn in 1923 to 8.5 pounds at East Lansing. Winesap showed a variation in 1924 from 2.1 pounds in Michigan to 5.7 pounds at Amherst and 7.2 pounds at Ithaca. Ben Davis ranged from 1.4 pounds in Virginia in 1924 to 6.5 pounds in Michigan in 1923.

It has not been possible to determine by a study of the climatic conditions why these wide variations occur. The rate of softening in all varieties at any one station has not been consistent during any year. For example, at Amherst during 1924 the softening was very slight in Delicious, Jonathan, Grimes Golden, Baldwin, and Ben Davis during the month prior to picking time, while that in Winesap was very rapid. At Rosslyn in 1924 the softening was slight in Winesap and Ben Davis and moderately rapid in Grimes Golden, Jonathan, and Delicious. From the available data it has not been possible to predict, either by a study of the climatic conditions, including temperature and moisture, or from the size and quantity of fruit on the tree, whether the softening will be slow or rapid. From the data so far obtained it appears that the factors which control the actual rate of softening of the fruit as it approaches maturity on the tree are largely internal rather than external. Conditions within the tree, probably the nutrient materials available for the fruit rather than external conditions, would seem to determine the softening rate.

TABLE 2.—*Pressure test at picking time and extent of softening prior to picking time in apples*

Variety and station	Pressure test, 1923			Pressure test, 1924		
	Optimum picking date	One month prior to optimum picking date	Difference	Optimum picking date	One month prior to optimum picking date	Difference
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Delicious:						
Rosslyn, Va	17.6	17.3	−0.3	17.3	20.8	3.5
Amherst, Mass				18.7	19.5	.8
East Lansing, Mich	18.3	21.0	2.7	19.4	21.4	2.0
Wooster, Ohio	18.6	21.7	3.1	17.1	21.7	4.6
Wenatchee, Wash				16.3	20.2	3.9
Jonathan:						
Rosslyn, Va				16.2	20.2	4.0
Amherst, Mass	15.7	17.6	1.9	17.5	18.8	1.3
East Lansing, Mich	15.4	21.1	5.7	17.7	22.7	5.0
Wooster, Ohio	16.3	19.5	3.2	15.2	20.1	4.9
Council Bluffs, Iowa	17.0	23.8	6.8	18.0	22.8	4.8
Ithaca, N. Y				16.4	24.8	8.4
Wenatchee, Wash				15.2	20.3	5.1
Grimes Golden:						
Rosslyn, Va	19.7	21.4	1.7	17.9	22.7	4.8
Amherst, Mass	19.0	21.5	2.5	21.1	22.0	.9
Wooster, Ohio				20.5	24.5	4.0
Council Bluffs, Iowa	23.3	30.7	7.4	23.2	27.8	4.6
Ithaca, N. Y				21.9	27.0	5.1
Wenatchee, Wash				20.0	25.1	5.1
Baldwin:						
Rosslyn, Va	18.2	19.7	1.5			
Amherst, Mass	19.7	24.0	4.3	20.9	22.4	1.5
East Lansing, Mich	19.2	27.7	8.5			
Wooster, Ohio	20.7	22.8	2.1	20.0	26.5	6.5
Ithaca, N. Y				21.2	24.4	3.2
Wenatchee, Wash				18.6	22.7	4.1
Winesap:						
Rosslyn, Va	20.9	24.0	3.1	20.1	22.5	2.4
Amherst, Mass	22.2	26.2	4.0	22.0	27.7	5.7
East Lansing, Mich	22.5	26.1	3.6	22.3	24.4	2.1
Wooster, Ohio	22.2	25.3	3.1	20.3	24.9	4.6
Ithaca, N. Y				21.1	28.3	7.2
Council Bluffs, Iowa	23.0	28.7	5.7	23.4	28.8	5.4
Wenatchee, Wash				[1] 19.5	23.0	3.5
Ben Davis:						
Rosslyn, Va	19.5	21.9	2.4	18.0	19.4	1.4
Amherst, Mass	20.0	21.5	1.5	20.3	23.1	2.8
East Lansing, Mich	[1] 20.5	27.0	6.5	[1] 22.0	25.8	3.8
Wooster, Ohio	23.1	25.3	2.2	20.2	22.9	2.7
Ithaca, N. Y				[1] 22.0	26.9	4.9

[1] Estimated from latest data available.

A study of the firmness of the different varieties at the optimum picking time reveals a somewhat greater uniformity of condition. For example, the pressure test of all the Baldwins for the two years specified ranged between 18.2 and 21.2 pounds at picking time. Winesap ranged between 19.5 and 23.4 pounds; Ben Davis, between 18 and 23.1 pounds; Delicious, between 16.3 and 19.4 pounds; Jonathan, between 15.4 and 18 pounds; and Grimes Golden, between 19 and 23.3 pounds. It is at once apparent that the districts having the longer growing season, particularly Wenatchee, Wash., and Rosslyn, Va., have on the average distinctly softer fruit at picking time than those with shorter growing seasons. With the later ripening varieties, such as Winesap and Ben Davis, this may be associated with the fact that the fruit is really not fully matured when cold weather comes on in the northern sections.

PRESSURE TEST AS A MEASURE OF FRUIT MATURITY

From the data presented in Table 2 it is apparent that the pressure test taken alone is not a satisfactory index of picking maturity in apples. Under certain conditions, which have not been deter-

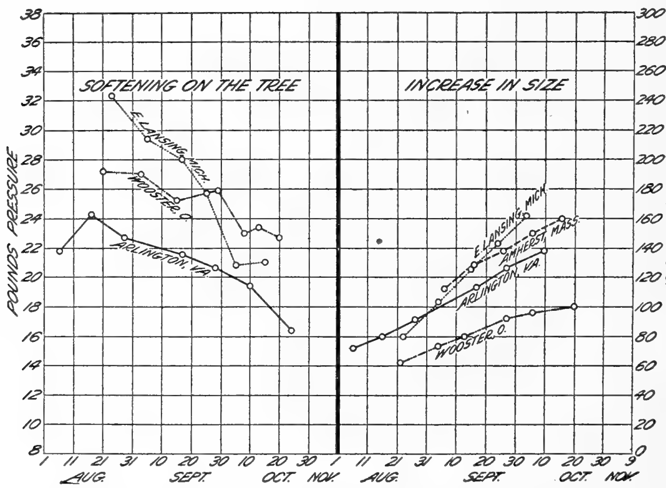


FIG. 6.—Change in firmness of flesh and size of Ben Davis apples, 1923

mined, there appears to be little softening during the month preceding the optimum picking date for the fruit. The condition of firmness of the fruit at picking time, however, is to a limited extent an indication of the length of the period that the fruit will remain firm in storage. The rate of softening following picking is discussed in detail in the second part of this report. The pressure test at picking time gives a measure of the actual condition of firmness of the fruit at the time of its removal from the tree and is an indication of the length of time the fruit will remain firm under different storage conditions.

With many varieties, particularly in the sections having a long growing season, it is important to pick the fruit before it becomes too mature on the tree, in order to avoid excessive softening and internal breakdown in storage. This is particularly true of Jonathan in the Pacific Northwest and to a lesser extent of Grimes Golden, Stayman Winesap, Delicious, etc., in the Pacific Northwest and the southern portions of the eastern apple-growing regions. Such varieties are sometimes left on the trees until late, to obtain size and color. By measuring the firmness of the apples the pressure test indicates when the fruit on the tree is becoming so soft that loss is likely to occur. As will be mentioned later, other tests for time of picking are not always satisfactory in determining whether or not the fruit is becoming too ripe to hold up satisfactorily in storage. The average rate of softening in apples appears to be about a pound a week during the last month of the growing season. So long as Jonathan apples are testing 15 pounds or above, Delicious 16 pounds or above, and Grimes Golden 18 pounds or above, there is little probability that they are becoming too mature for good storage holding. Thus, it appears that, in addition to the tests now in use to determine optimum picking dates, the mechanical-pressure test will prove valuable for these varieties. For firmer varieties, such as Winesap, York Im-

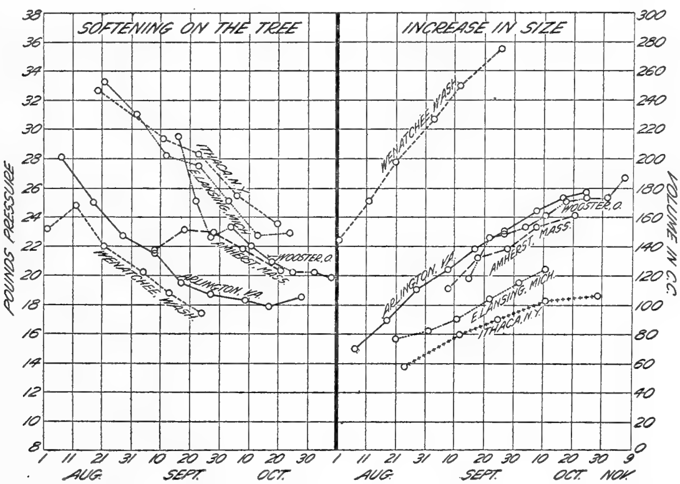


FIG. 7.—Change in firmness of flesh and size of Ben Davis apples, 1924

perial, and Yellow Newtown, which usually begin to drop before becoming so soft as to endanger their storage quality, its use is less essential.

GROUND COLOR OF APPLES

The change in the color of the unblushed portion of apples from green to yellow or yellow-green has been extensively recommended as a satisfactory test to determine when the fruit is ready to remove from the tree. Corbett (*6*) has made this color change a basis for picking recommendations. Ramsey et al. (*17*) state "perhaps the most reliable single indication [of maturity] is the 'ground' color of the fruit; that is, the color which underlies the red color or blush. The 'ground' color, which is green when the fruit is immature, begins to whiten or yellow slightly as it approaches full maturity. . . . As a rule, in a mature apple the green color should be largely replaced by a white or light-yellow color."

In order to determine as accurately as possible the changes in the ground color of the fruit, the color chart shown as Plate I has been used, the ground color of the fruit in the different growing regions being compared with the colors on this chart. In order to obtain the best comparison, holes were cut in the centers of the color charts and the apples placed behind them, so that the same light was available on the fruit surface as on the chart.

Table 3 gives in summarized form the exact conditions of the different varieties at the time each year when they were in optimum picking condition in the various sections. The column headed "Ground color" refers to the chart color.

It is apparent that there is a marked variation in the ground color of different varieties at the optimum picking date for each variety. Jonathan, Ben Davis, and Winesap in all sections were either color 3 or color 4 at the time they were ready to pick. Delicious ranged from 2½ to 4 at the different stations. Grimes

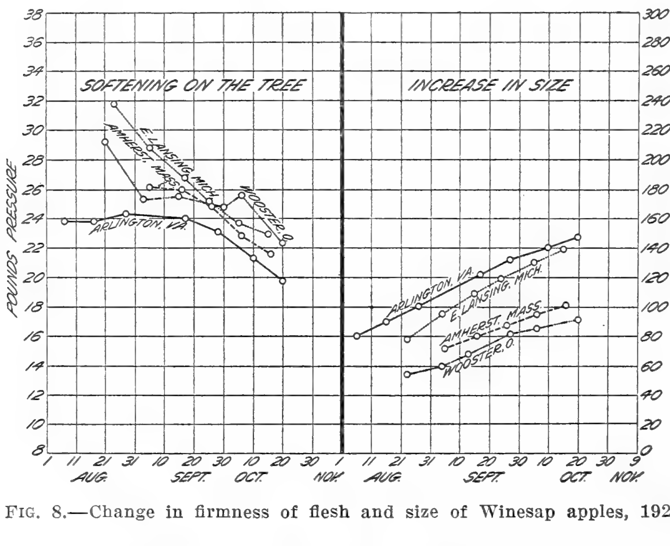


FIG. 8.—Change in firmness of flesh and size of Winesap apples, 1923

Golden at the optimum picking date ranged from 2 at Rosslyn in 1924 to 3 as the general color at picking time in most sections. Baldwin ranged from a color between 1 and 2 at Wenatchee in 1924 and Rosslyn in 1923 to between 3 and 4 at Amherst in 1923. Thus it is evident that the same changes in ground color can not be applied for all varieties under all conditions. Of the varieties under test, Ben Davis and Winesap became very yellow. Jonathan and Delicious became full yellow in certain sections but remained with a decidedly greenish tinge in other sections. Grimes Golden was rather green in some sections, whereas Baldwin showed only a slight yellowing in all sections except Amherst in 1923. The Baldwin apple in most stations dropped very badly before there was an appreciable yellowing in the ground color.

A careful study of the data in Table 3 indicates that on the whole the ground color becomes more yellow before picking time in the regions where ripening is late and where the prevailing temperatures at ripening time are relatively low. The ground colors at Amherst, East Lansing, and Ithaca were generally more yellow at picking time than at Rosslyn or Wenatchee, particularly in the Baldwin, Jonathan, and Delicious, which ripened when the weather was very warm at the two latter stations. Although the Virginia and Washington State apples had a greener ground color on the optimum picking date than the same varieties in the districts having shorter growing seasons, the fruit from the districts first mentioned was softer and was dropping more than that from New York or Michigan.

The picking season at Wenatchee in 1924 was fully two weeks earlier than normal. Under these conditions the early varieties did not attain the yellow ground color generally characteristic in that section. It appears that when apples ripen under very warm climatic conditions the green color does not disappear to the same extent by the time the fruit is beginning to drop from the tree as

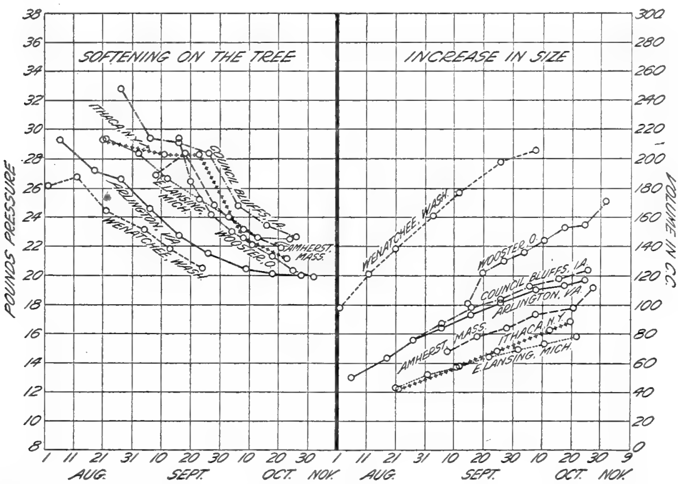


FIG. 9.—Change in firmness of flesh and size of Winesap apples, 1924

when ripening occurs under cooler conditions. If this is true, in any season when ripening occurs abnormally early the ground color would seem to be a less accurate test for determining maturity than during normal ripening seasons. Though the change in ground color is an exceedingly valuable test for determining the time of picking, the interpretation of the test will of necessity vary with the different varieties and with the particular seasonal conditions. Considered in conjunction with the firmness of the flesh and the way the fruit is holding on the tree, however, it offers an exceedingly valuable index to the real condition of the fruit.

EASE OF SEPARATION FROM THE TREE

In Table 3 are general notes on the extent of dropping at the time the fruit was rated as in optimum picking condition. In practically all cases there was slight dropping, indicating that the fruit would separate fairly readily from the tree. In certain instances, particularly with the Baldwin, there was medium to bad dropping at the time the fruit was rated in optimum picking condition.

From the data available it has been impossible to determine the exact causes leading to the loosening of the fruit and dropping from the tree. It is apparent from the data presented in Table 3 that under certain conditions the fruit will drop when still hard, whereas under others it will continue to adhere to the tree until fairly soft. Jonathan, for example, showed only slight dropping at Wenatchee in 1924, when it was testing only 15.4 pounds, but showed medium dropping at Council Bluffs the same year when testing 18 pounds. In many instances fruit of a greener ground color in one section would show more dropping than fruit with a more yellow ground color in another district. It has not been possible to correlate dropping in any very satisfactory manner either with the prevailing temperatures or with rainfall or irrigation. In the varieties here studied it does not appear to be very definitely correlated either with the firmness of the flesh, the ground color of the fruit, or the length of time the seeds have been brown.

In the Baldwin, Delicious, Grimes Golden, and Jonathan the loosening and dropping of the fruit seems to be associated to a certain extent with the number of days that have elapsed following blooming. Baldwin generally showed some dropping in from 135 to 145 days following blooming. Delicious showed dropping in 135 to 140 days following the date of full bloom. Grimes Golden generally ran 140 to 150 days, with Jonathan 135 to 150 days.

On the other hand, Winesap and Ben Davis showed slight dropping after about 150 days in Massachusetts and 160 to 170 days in districts having long growing seasons. It should be pointed out that even 150 days in the former district carried the fruit into late October, when cold weather and heavy frosts are likely to occur. It would appear that Winesap and Ben Davis really require from 160 to 170 days to reach natural maturity on the tree, but if the season is shorter than this, loosening and some dropping may occur as cold weather comes on.

Particular conditions in the trees and in the orchard also undoubtedly exert a great influence on the way the fruit adheres to the tree. At Wooster, in 1924, for example, the fruit of all varieties grew very rapidly, attained large size, and adhered remarkably well. A medium-sized crop on vigorous nitrated trees with ample soil moisture in this case resulted in the fruit holding on the tree until late in the season.

It has been shown that so long as it adheres to the tree growth of the fruit is generally occurring, indicating that the fruit is actively receiving food materials. It seems probable that when the movement of food materials from the tree to the fruit stops for any reason the abscission layer forms and the fruit loosens or drops from the tree. It is apparent from the data here presented, however, that any explanation of the real factors involved in the dropping of fruit will have to be based on studies of conditions within the individual tree rather than the external or climatic conditions prevailing.

Since it is absolutely essential that the crop be picked before dropping becomes excessive, the way the fruit adheres to the tree is of fundamental importance in determining the time of picking. Under certain conditions the fruit begins to drop very badly before it is sufficiently matured to be of the best quality or to be the most satisfactory for storage. For example, some varieties, such as York Imperial and Baldwin, in many instances will have to be picked because of excessive dropping when the apples are still so immature that storage scald will develop excessively. On the other hand, apples of other varieties, particularly Jonathan, will often adhere to the tree until they have gone well by the optimum picking condition, thus developing internal breakdown and other storage troubles. On the whole, however, the tenacity with which apples adhere to the tree is a most important index to their maturity condition, and with most varieties constitutes a safe guide to time of picking.

COLOR OF SEEDS

The column of Table 3 headed "Number of days after seeds became brown" refers to the days which have elapsed between the time when the seeds were full brown and that in which the fruit was in optimum picking condition.

As the seeds color they first become brown at the tip, then pass through a half-brown condition, and finally are uniformly colored light brown. Following this, they gradually darken until usually they attain a dark-brown color in the well-matured apple. The number of days elapsing between the time when the seeds were completely light brown in color and the time the fruit is in picking condition is recorded in column 10.

Apparently there is a wide variation between the different varieties in the length of time following full color of the seeds before the fruit is in optimum picking condition. With Grimes Golden 3 to 25 days elapsed, generally about 15 days; Delicious ranged from 14 to 44 days, averaging about 20 days; Baldwin ranged from 6 to 25 days, averaging about 15 days. Winesap showed a minimum of 34 days and a maximum of 56 days, generally requiring 40 days or more after the seeds were brown to attain maturity. In many instances Winesap seeds were actually more completely colored and darker by the middle of September than were Delicious, Grimes Golden, or Jonathan seeds on the same date. The wide variation existing in the different varieties and in the same variety under different growing conditions indicates that little dependence can be placed on this factor as a picking test for winter apples.

LENGTH OF GROWING SEASON

The length of the growing season was briefly discussed in connection with the dropping of the fruit. In columns 2, 3, 4, and 5 of Table 3 are reported the blooming dates, the optimum picking dates, the number of days intervening, and the average mean daily temperature for the growing season at the different stations. It is evident from these data that there is a marked variation in the length of the growing season for the different varieties and in certain cases a considerable variation in the same variety, depending upon where it is grown.

82956—26——3

TABLE 3.—*Notes on the condition of apples at optimum picking dates*

Variety and station	Year	Date of—		Number of days	Mean temperature° F.	Pressure test (pounds)	Ground Color	Percentage of blush		Number of days after seeds became brown	Extent of dropping	Size (c. c.)
		Blooming	Optimum picking					At optimum date	10 days previous			
Baldwin:												
Amherst, Mass.	1923	May 23	Oct. 6	136	66.0	19.7	3½	50	40	18	Medium to bad	129
Do.	1924	May 22	Oct. 15	146	65.0	20.9	2½	60	45	6	Medium	157
East Lansing, Mich.	1923	May 23	Oct. 6	136	66.0	19.2	2½			18	Medium to bad	118
Wooster, Ohio	1923	May 13	Oct. 2	142	68.5	20.7	2	50	35	18	Bad	145
Do.	1924	do.	Oct. 20	160	65.0	20.0	2½			23	Slight	244
Rosslyn, Va.	1923	Apr. 27	Sept. 12	138	72.0	18.2	1½			14	Medium to bad	165
Ithaca, N. Y.	1924	June 2	Oct. 25	145	61.0	21.2	2	60	43	25	Slight	[1] 180
Wenatchee, Wash.	1924	Apr. 23	Sept. 15	145	66.5	18.6	1½	10	5	15	Medium	178
Delicious:												
Amherst, Mass.	1923	May 23	Oct. 10	140	66.0		4	85	75	34	Slight to medium	146
Do.	1924	May 22	Oct. 6	137	65.5	18.7	3½	80		18	Slight	161
East Lansing, Mich.	1923	May 24	Oct. 5	134	66.0	18.3	3½			20	do.	180
Do.	1924	June 1	Oct. 14	135	63.0	19.4	4	75	65	21		[1] 145
Wooster, Ohio	1923	May 14	Oct. 4	143	68.5	18.6	3	75	65	44	Medium	165
Do.	1924	May 12	Oct. 12	153	65.5	17.1	3			15	Slight	212
Rosslyn, Va.	1923	Apr. 27	Sept. 12	138	72.0	17.6	2½			14	Medium to bad	156
Do.	1924	May 6	Sept. 22	139	68.0	17.3	2½	45	30	27	Slight	134
Wenatchee, Wash.	1924	Apr. 23	Sept. 12	142	66.5	16.3	3	80	70	21	Medium	290
Grimes Golden:												
Amherst, Mass.	1923	May 23	Oct. 1	131	65.5	19.0	3			15	Medium	146
Do.	1924	May 22	Oct. 3	134	65.5	21.1	3			5	Slight	125
Council Bluffs, Iowa	1923	May 4	Sept. 25	144	70.5	23.3	2½			25	do.	
Do.	1924	do.	Sept. 27	146	68.0	23.2	2½			3	do.	129
Wooster, Ohio	1923	May 15	Oct. 4	142	68.5		3			24	do.	96
Do.	1924	May 13	Oct. 8	148	65.5	20.5	3			11	do.	174
Rosslyn, Va.	1923	Apr. 27	Sept. 18	144	72.0	19.7	3+			20	Slight to medium	140
Do.	1924	May 6	Sept. 22	139	68.0	17.9	2			17	do.	136
Ithaca, N. Y.	1924	June 1	Oct. 8	130	63.0	21.9	2½			15	Slight	118
Wenatchee, Wash.	1924	Apr. 23	Sept. 15	145	66.5	20.0	3			11	do.	[1] 145
Jonathan:												
Amherst, Mass.	1923	May 23	Oct. 8	138	66.0	15.7	4	80	75	32	Slight	175
Do.	1924	May 22	Oct. 10	141	65.0	17.5	3½	95	90	30	Slight to medium	132
East Lansing, Mich.	1923	do.	Oct. 15	146	65.5	15.4	4	86	85	40		87
Do.	1924	June 1	Oct. 18	139	63.0	17.7	4			25		[1] 98
Wooster, Ohio	1923	May 14	Oct. 8	147	68.0	16.3	3½	75	65	35	Slight	122
Do.	1924	May 12	Oct. 16	157	65.5	15.2	3			19	do.	170
Rosslyn, Va.	1924	May 6	Sept. 20	137	68.0	16.2	3	70	55	24	do.	159
Council Bluffs, Iowa	1923	May 4	Sept. 30	149	70.0	17.0	3½	85	60	27	Slight to medium	
Do.	1924	do.	do.	149	68.0	18.0	3½	70	50	25	Medium	136

Wenatchee, Wash	1924	Apr. 23	Sept. 15	145	66.5	15.4	3	80	60	11	Slight	152
Ithaca, N. Y	1924	May 28	Oct. 15	140	62.0	16.4	3½	75	55	45	None	94
Winesap:												
Amherst, Mass	1923	May 23	Oct. 10	140	66.0	22.2	4	90	75	34	Slight	97
Do	1924	May 22	Oct. 20	151	64.5	22.0	4	95	95	42	do	97
East Lansing, Mich	1923	May 23	do	150	65.5	[1] 22.5	4			45		[1] 140
Do	1924	June 1	Oct. 30	151	62.0	[1] 22.3	3½	65	60	37		[1] 80
Wooster, Ohio	1923	May 15	Oct. 20	157	67.5	22.2	4	90	85	47	Slight	92
Do	1924	May 13	Oct. 25	164	64.0	20.3	3			35	do	155
Council Bluffs, Iowa	1923	May 4	Oct. 20	168	68.5	23.0	4	90	75	44	do	
Do	1924	do	do	168	66.5	23.4	3	70	55	56	Slight to medium	120
Rosslyn, Va	1923	Apr. 27	Oct. 12	167	71.0	20.9	3½			56	Slight	141
Do	1924	May 6	Oct. 18	164	67.5	20.1	3	95	90	52	do	113
Wenatchee, Wash	1924	Apr. 23	Oct. 5	164	65.0	[1] 19.5	3½		77	53	do	207
Ithaca, N. Y	1924	June 1	Oct. 23	144	61.0	21.1	4			53	None	86
Ben Davis:												
Amherst, Mass	1923	May 23	Oct. 16	146	65.5	20.0	4	65	50	0	Slight	160
Do	1924	May 23	Oct. 20	151	64.5	20.3	3			0	do	160
East Lansing, Mich	1923	do	do	151	65.5	[1] 20.5	4			5		[1] 180
Do	1924	June 1	Oct. 30	151	62.0	[1] 22.0	4	60	57	18		[1] 135
Wooster, Ohio	1923	May 14	Oct. 16	155	67.5	23.1	4	90	85	18	Slight to medium	98
Do	1924	May 10	Oct. 30	173	63.5	20.2	3			18	None	173
Rosslyn, Va	1923	Apr. 27	Oct. 10	167	71.0	19.5	3½			42	Medium	137
Do	1924	May 5	Oct. 18	166	67.5	18.0	3	65	55	30	Slight	174
Wenatchee, Wash	1924	Apr. 23	Sept. 25	155	66.0	17.3	3	55	35	0	Medium	272
Ithaca, N. Y	1924	June 1	Oct. 30	151	60.5	[1] 22.0	4	90	80	30	None	106

[1] Estimated from last data available.

Baldwin, Delicious, Grimes Golden, and Jonathan may be grouped as more or less short-season varieties. Baldwin generally ranged from 135 to 145 days; Delicious had approximately the same length of growing season; Grimes Golden, except at Amherst, was generally 140 to 150 days, and Jonathan about the same. The length of the growing season of these four varieties varied only slightly, depending upon the geographic location or climatic conditions prevailing. With Winesap and Ben Davis very different conditions prevailed. Winesap in the northeastern districts had a total growing season of 140 to 150 days. In the earlier blooming districts, however, the fruit did not reach optimum picking condition until 160 to 170 days following blooming.

The growing season for Ben Davis similarly ranged from 145 to 150 days in the northeastern districts and from about 160 to 170 days in the districts having a longer growing season. Phillips (*16*) pointed out that under certain conditions varieties in the Northern States seemed to be ready for picking following a shorter growing season than the same variety grown in the warmer southern districts and suggested that the result might be due to the longer days in the northern districts. That theory does not hold in the present case, however, for the season for these varieties was about as long at Wenatchee as at Rosslyn. Wenatchee, being farther north, has longer days during the growing season than any of the eastern apple-growing districts here studied. It appears rather that varieties like Winesap and Ben Davis require a long growing season to develop proper maturity. In the northeastern districts cold weather usually comes on before this condition is reached. With the advent of cold weather color development goes on rapidly and the fruit softens to a considerable extent, but apples of such varieties in sections with a short growing season do not generally have the quality that they attain in regions having growing seasons of greater length.

Varieties like Baldwin, Delicious, and Jonathan, which ripen in September, and are really fall or early-winter varieties in districts with a long growing season, do not ripen until well into October in districts having shorter growing seasons, and consequently become good midwinter or later winter storage varieties there.

It is particularly interesting in this connection to point out the apparent outstanding influence of the length of growing season on variety distribution. The different sections of the United States which have approximately the same length of growing season are peculiarly adapted to the same varieties. Varieties of apples which are well adapted to Virginia, southern Ohio and Missouri, and the country to the southward are equally well adapted to the Pacific Northwest, although soil, moisture, humidity, and temperature conditions are very different. On the other hand, an entirely different group of varieties is well adapted to conditions where the total available growing season is shorter. Thus varieties adapted to the Northeast differ from those adapted to Virginia and the Pacific Northwest. Varieties such as York Imperial, Winesap, Arkansas (*Mammoth Black Twig*), Yellow Newtown, Stayman Winesap, Arkansas Black, and Rome Beauty require a fairly long growing season to reach good condition and high quality, and nearly all appear to require more days to reach proper maturity than are usually available in districts with short growing seasons. Other varieties, such as

Grimes Golden, seem to develop the best quality and appearance if the end of the normal growing period comes while the weather is still fairly warm.

Jonathan and Delicious are satisfactory varieties both in districts having long and moderately short growing seasons, but in the latter districts usually are of small size. On the other hand, varieties like Baldwin, Northern Spy, Rhode Island Greening, McIntosh, Tompkins King, and Hubbardston, which reach prime condition during a relatively short growing season, are peculiarly adapted to the northern and eastern districts, and when grown under long-season conditions become rather inferior later summer or fall varieties. From the data presented in Table 3 as well as from general observations it appears that the length of growing season is probably the most fundamental factor in determining the adaptability of a variety to any particular condition. An extra-long growing season in districts normally having a short season apparently will result in very early ripening of the varieties usually grown there. Thus an early bloom in the northeastern apple sections will usually result in the early ripening of varieties such as Baldwin, Rhode Island Greening, McIntosh, and Northern Spy. On the other hand, varieties such as Winesap or Yellow Newtown will probably not need to be picked earlier than normal in such seasons in the northeastern districts, and will usually attain higher quality than during a normal season in these sections.

Extra-early blossoming in districts having a long growing season usually results in the earlier maturity of all varieties. This happened in the Pacific Northwest in 1924 and 1925. A late bloom in such a district will retard the picking date somewhat and usually will result in lower quality in the fruit of varieties best adapted to a long season.

TESTS FOR TIME OF PICKING

The outstanding reason for undertaking this series of studies was to determine, if possible, the most dependable tests for the time of removing the fruit from the tree. From the results obtained it is possible to suggest the relative dependability of certain factors for the determination of the condition of the fruit while on the tree.

The persistence with which the fruit adheres to the tree or the ease with which the stem separates from the spur is a fundamentally important consideration in determining when apples are ready to pick. In some cases fruit begins to drop while in a somewhat immature condition; in others it will adhere firmly until past prime picking condition. In general, however, the ease of separation of the fruit from the spur will be closely correlated with the actual condition of maturity of the fruit.

The ground color of the fruit, or the degree of yellow in the unblushed portion, is apparently a very valuable guide to picking maturity. It varies greatly, however, with different varieties and to a certain extent under different climatic conditions. The results here reported indicate that if the fruit is approaching maturity while the weather is still warm and the prevailing temperatures are high, the ground color will not become yellow to the same degree as when the fruit is ripening under cooler conditions. In the tests so far carried on, the ground color of the fruits has been less yellow in apples from the southern and northwestern districts than in fruit from the northern and eastern sections. Different varieties will also differ markedly in their tendency to take on a yellow ground color. It is also undoubtedly true, although not apparent from these investigations, that cultural conditions, and particularly nitrogen supply, are important factors in the ground-color change. Excessive nitrogen is very likely to retard the yellowing of the fruit even though softening and other maturity factors are well advanced.

The pressure test, or the test of the actual condition of firmness of the flesh, is apparently a very valuable index of condition, particularly for certain varieties and under certain growing conditions. Varieties having a growing season of medium or short length when grown in districts having a long growing season may become so mature on the trees that they will develop internal breakdown or flesh collapse while in storage. Daly (*7*) has shown this breakdown in Jonathan to be associated with allowing the fruit to remain on the tree too long. This breakdown while particularly severe in Jonathan may also occur to a certain extent in Grimes Golden, Delicious, Stayman Winesap, etc., grown in the southern or northwestern districts, but apparently is not likely to occur unless the fruit becomes too soft prior to harvest. The pressure test gives a means of determining the exact flesh condition while the fruit is still on the tree.

The limit of softness to which different varieties may be allowed to go before danger of internal breakdown in storage is pronounced has not been studied sufficiently in connection with the extent of breakdown in storage to make accurate recommendations. From the results obtained, however, it may be suggested that when such a variety as Jonathan shows a flesh test of 15 pounds or less it is getting close to the danger point. A pressure test of about 18 pounds on an average sample represents approximately the maximum softening on the tree which should be allowed in Grimes Golden, whereas Delicious should not go under 16 pounds if good storage fruit is desired.

In the districts having shorter growing seasons and for varieties requiring a long growing season in the early-blooming districts it would appear that the fruit is usually sufficiently firm at picking time. Color and the way the fruit adheres to the tree are sufficiently dependable characters for determining the best time to remove the apples from the tree. For the varieties heretofore mentioned, however, it is believed that the pressure test to determine the actual flesh condition will be of great aid in preventing overmaturity and the resultant breakdown in storage which so often occurs.

In conclusion it should be emphasized that the ripening process in apples is a combination of many factors, some of which appear to be controlled by conditions within the tree, while others are greatly influenced by external conditions. The different changes taking place in the fruit as it approaches maturity on the tree may continue at varying rates in different seasons and under varying climatic and nutritional conditions. The seeds may become brown relatively early or relatively late. In one case the ground color may become yellow prior to the fruit dropping appreciably; under other conditions the apples may drop badly while the ground color is still quite green. The accumulation of sugars within the fruit apparently is not intimately associated with any of the external factors. From the data obtained so far in these investigations, however, it appears that a consideration of the factors of the ground color of the fruit, the tenacity with which it adheres to the tree, and under certain conditions at least the firmness of the flesh forms the best basis for determining when apples are ready to remove from the tree.

SUMMARY OF PART I

A study has been made of the gross changes in apples as they approach maturity on the tree in order to determine the most dependable tests for time of picking and how seasonal conditions influence the ripening changes in the fruit.

Under a wide range of growing conditions the fruit of a number of varieties of apples has been found to increase greatly in size during the late growing season. Apparently increase in size continues as long as the fruit and leaves are adhering to the tree.

The rate of softening of apples as they approach picking maturity varied greatly under different growing conditions. In some instances practically no softening occurred during the month prior to picking time; whereas in others, even in the same varieties, softening prior to picking proceeded rapidly.

Apples from regions having a long growing season were, on the whole, softer at picking time than those from the districts having a shorter growing season. Fruit from Virginia and Washington State was softer when in optimum picking condition than similar varieties from Michigan or New York.

It has not been possible to associate rate of softening prior to picking with climatic conditions prevailing in the different districts.

The mechanical pressure tester apparently will be of value as a measure of picking maturity for apples mainly to determine when certain varieties are becoming too soft on the trees.

As apples ripen on the tree, the unblushed portions change from green to yellow or yellowish green. The color attained when the fruit is in prime picking condition varies greatly in different varieties, and to a limited extent in the same variety grown under varying climatic conditions.

Evidence obtained indicates that when apples ripen under warm conditions, such as prevail during an early-ripening season, the unblushed portion of the fruit is greener when the fruit is in prime picking condition than during normal seasons.

The ease of separation of the fruit from the tree is perhaps the most consistent of the changes as the fruit approaches picking maturity. This loosening under certain conditions may occur while the fruit is still very firm and poorly colored. However, it generally affords a very satisfactory index of picking maturity.

Because there is a wide variation in the time of the browning of the seeds in relation to picking time, their color is not a satisfactory index of maturity in winter apples.

The length of growing season is closely associated with maturity in many varieties and does not appear to vary widely with different climatic conditions. There appears to be a fairly definite length of time required to bring the different varieties to prime picking condition. Baldwin and Delicious required 135 to 145 days, Jonathan and Grimes Golden 140 to 150 days, and Winesap and Ben Davis 160 to 170 days to attain their best condition.

Length of the growing season is a potent factor in variety distribution. With many varieties, the time of blooming will largely determine the time the fruit will reach picking maturity.

The adherence of the fruit to the tree, the ground color of the fruit, and the firmness of the flesh are all important considerations in determining when to pick the fruit.

II. THE RIPENING OF APPLES IN STORAGE AS INFLUENCED BY TEMPERATURE

By J. R. MAGNESS, *Physiologist*, M. H. HALLER, *Junior Pomologist*, and H. C. DIEHL, *Assistant Physiologist, Office of Horticulture, Bureau of Plant Industry*

Following the removal of apples from the tree, the ripening processes which go on are to a considerable extent a continuation of those in progress while the fruit was still attached to the tree. The most outstanding change which occurs in apples between the time of picking and that of ultimate consumption is in the structure of the cell walls which results in the softening of the flesh. At the time of picking most varieties of apples are too firm and hard to be in prime eating condition. As softening proceeds, however, the apples pass through a prime eating condition and ultimately become mealy or overripe. This softening process in storage is, of course, accompanied by other changes in the fruit. The unblushed portion usually becomes more yellow in storage. There is also a change in the chemical composition of the fruit. The starch disappears, changing to sugar; consequently the sugar content usually increases slightly between the time of picking and the time when the fruit is soft ripe. The acid content of the fruit decreases during the storage period.

Magness and Burroughs (*10*) and Magness and Diehl (*11*) have reported that under normal storage conditions the rate of softening of apples while in storage is apparently almost entirely controlled by the temperature at which the fruit is held. Other factors, such as humidity, ventilation, and type of package, have little influence on the actual rate of softening or ripening of the apples. In the investigation here reported a comprehensive and detailed study has been made of the exact influence of different temperatures on the rate of softening and other changes which occur during ripening in a large number of important commercial apple varieties. This information is fundamental to a proper understanding of the factors involved in handling apples in storage, regardless of whether the fruit is being handled in cold storage or in air-cooled or common storage.

INFLUENCE OF TEMPERATURE ON RATE OF SOFTENING

Since softening in apples is the most obvious change during the period between picking time and ultimate consumption, it has been studied in greater detail than any other. The apples used in the tests were picked at approximately the commercial picking season for the varieties. The fruit of the different varieties was taken as quickly as possible to the storage plant and in most cases placed in storage the day following that of picking. The Yellow Newtown, York Imperial, and Arkansas (*Mammoth Black Twig*) apples had to be transported a considerable distance, and three days elapsed between the picking and the placing of these varieties in storage.

As soon as the fruit reached the storage plant all packages in which it had been picked were placed in a row and a certain number of apples from each individual package were placed in another package for storage. In this way as thorough a mixture of fruit and as uniform a sample as it is possible to obtain were procured. If the lot of fruit for testing had come from several different trees, the same number of apples from individual trees was placed in each package used for holding the fruit.

During the season of 1923–24 it was not possible to move the fruit directly from the orchard into the different temperatures at which it was planned to hold the fruit. Consequently, the apples were all held at 32° F. for a period of from one to two and one-half months. The firmness of the fruit was tested with a mechanical pressure tester, as described in Part I of this bulletin, at the time of placing the apples in storage and again when it became possible to move the fruit to the different temperatures for holding.

The storage rooms in which the fruit was held were maintained at temperatures of 32°, 36°, 40°, 50°, 60°, 70°, and 85° F., respectively. The temperatures in all of the warmer rooms were thermostatically controlled and usually were maintained to within less than a degree of the desired point. Rooms held at 32°, 36°, and 40° were regulated by controlling the brine flow through pipes, since the fruit was being held in regular cold-storage rooms. Although there were slight fluctuations in temperatures in these rooms, the controls on the whole were very satisfactory.

Samples from the different lots of fruit were tested at intervals to determine the exact rate of softening at the different temperatures. Apples held at 70° and 85° F. were tested at intervals of three or four days; those held at 60° at five or six day intervals; those at 50° at about weekly intervals; those at the lower temperatures were tested at intervals which were correspondingly increased. At 32° most varieties were tested about once a month.

The data for the storage season 1923–24 gave a very satisfactory measure of the relative rate of softening at different temperatures. Since all fruit had been previously held for a certain length of time at 32° F., however, it was not possible to determine whether or not this holding at a low temperature influenced the subsequent rate of softening at higher temperatures. During the storage season of 1924–25 it was possible to take the apples directly from the orchards and place them in rooms held at the different temperatures. Prior to storage the fruit was handled in the same way as during the preceding year, being moved to the storage plant as quickly as possible and repacked into uniform sample lots for storing at the different temperatures. Holding fruit at 85° F. was omitted during the second season's work, and storage at 30° was added to the temperatures used. The fruit was tested for hardness at the time of placing it in the different storage temperatures, and pressure tests to determine the rate of softening of the different varieties were made at approximately the same intervals as during the preceding year.

Most of the results here reported were obtained with fruit grown on the Arlington Experiment Farm, Rosslyn, Va., just across the Potomac River from Washington, D. C., or in the commercial apple districts of Virginia. During 1923 attempts were made to ship fruit from the Pacific Northwest and also from New York State, but the apples ripened so much in transit that the data obtained were not considered entirely reliable. During the season of 1924–25, however, certain varieties of apples grown in New York State and at Wenatchee, Wash., were held in storage at 32° F. in these two districts and the softening rate determined at this temperature. Thus it was possible to compare to a certain extent the rate of softening of the leading commercial varieties as grown in the different districts while in storage at 32°. At Wenatchee, tests were also made of the rate of softening of a number of varieties when held at 70°.

Pressure tests were made throughout the season both with the peel intact and with the peel removed, or directly on the exposed flesh of the apple. Magness and Taylor (*13*) have recently shown, however, that testing apples with the peel intact tends to mask the actual softening of the flesh, since the presence of the skin makes a far greater difference in the testing of soft fruit than in the testing of similar varieties while in a firm condition. Consequently, only tests on the exposed flesh of the fruit are here reported.

RATES OF SOFTENING AT DIFFERENT TEMPERATURES

The rates of softening of a large number of commercial varieties of apples when held continuously at 32° F. are shown in Figure 10. The data show that in general the apples which are hardest at picking time remain firmest throughout the storage season. Certain varieties, including Winesap, Arkansas (*Mammoth Black Twig*), York Imperial, and Yellow Newtown as grown in Virginia, were fairly firm at the time of picking and softened slowly, so that even by March 1 if held continuously at 32° F. they were hardly soft enough to be considered in prime eating condition. Other varieties, including Rome Beauty, Stayman Winesap, Ben Davis, and King David as grown in Virginia, were somewhat softer at the time of picking and softened at about the same rate as the first group. Consequently, these varieties were in prime eating condition by the last of January, even when held continuously at a temperature of 32°. At this temperature, however, they remained in fairly firm condition without becoming mealy until well into March. Although fairly firm at time of picking, Grimes Golden apples grown in Virginia softened rather rapidly and were full eating ripe early in December, whereas McIntosh apples as grown in Virginia were very soft when picked the middle of September and were full eating ripe by the latter part of November.

As was brought out in Part I of this bulletin, the apples grown in the more northern districts are considerably firmer at time of picking, even though the picking season is considerably later. Figure 11 shows Stark, Tompkins King, Rome Beauty, and Baldwin apples picked and stored at Hall, N. Y., and held continuously at 32° F. Stark and Tompkins King were harder at time of picking than most of the Virginia varieties, whereas Baldwin from New York was approximately the same as Yellow Newtown and Winesap from

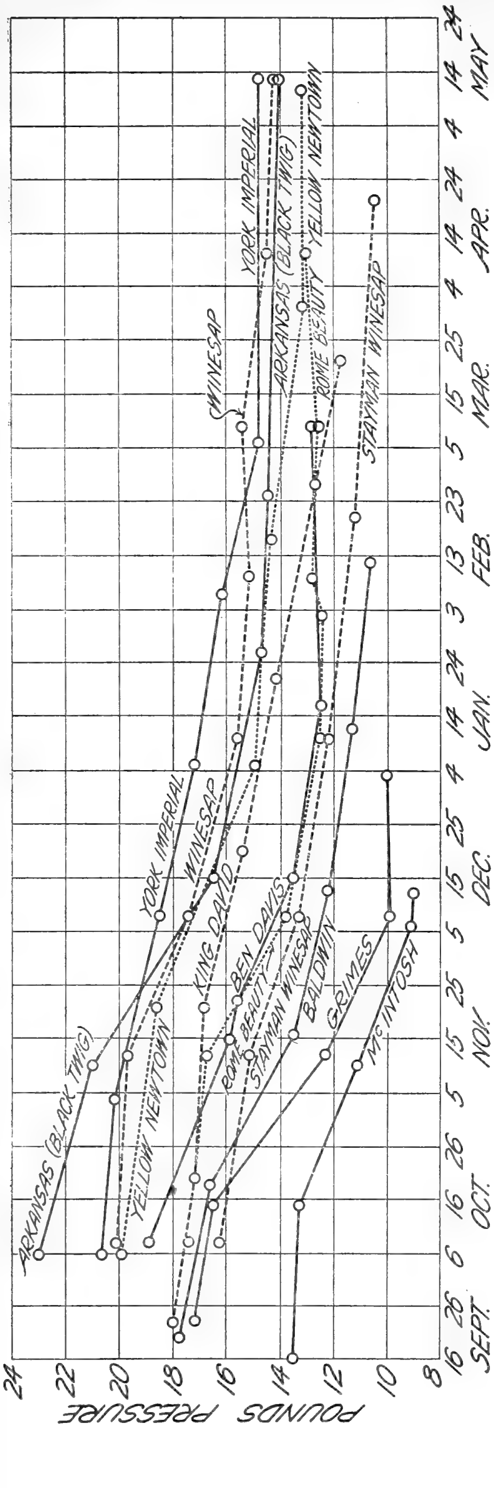


FIG. 10.—Softening of Virginia-grown apples while in storage at 32° F., 1924–25

Virginia. It is apparent, however, that these varieties soften somewhat more rapidly at 32° than the slowest softening group of Virginia varieties. Consequently, by the middle of January the Stark, Tompkins King, and Baldwin from New York were slightly softer than the Arkansas, Winesap, York Imperial, and Yellow Newtown group from Virginia. Apparently the slower softening group of varieties, which are particularly adapted to a long growing season, inherently soften somewhat less rapidly than the northern-grown apples, even though the latter are harder at the time of picking.

Figure 11 shows also the rate of softening of the different varieties of apples grown at Wenatchee when held continuously at temperatures of 32° F. These apples were also stored locally and consequently were not under exactly the same conditions as the Virginia-grown fruit shown in Figure 10, but it is believed that the storage conditions were sufficiently similar to make the results comparable.

A careful analysis of the data for the same varieties shown in Figures 10 and 11 indicates that, although the Washington-grown apples were of about the same hardness at the time of picking as those grown in Virginia, the rate of softening when the fruit was held continuously at 32° F. was slightly less rapid than in the same varieties grown in Virginia. For example, Yellow Newtown when picked in Washington showed a pressure test of slightly less than 21 pounds, and a test of 20 pounds when picked at Linden, Va. By the middle of January the Yellow Newtowns from Washington State still tested about 17½ pounds, whereas those from Virginia tested slightly under 15 pounds on the same date. Stayman Winesaps from both districts were between 16 and 17 pounds at the time of picking. By the middle of January Washington-grown Stayman Winesaps showed a firmness corresponding to 14 pounds pressure, whereas the Virginia-grown fruit gave a test only slightly over 12 pounds. Rome Beauty in Washington showed a pres-

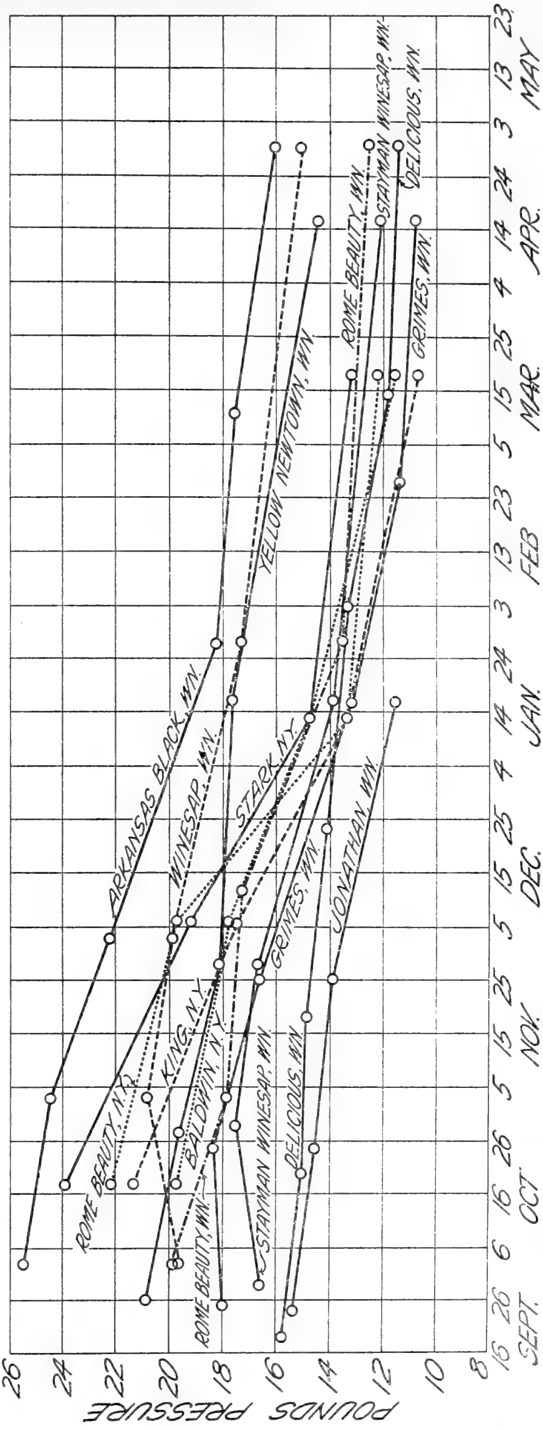


FIG. 11.—Softening of New York and Washington grown apples while in storage at 32° F., 1924–25

sure test slightly under 20 pounds when picked and only about 14½ pounds the middle of January. Rome Beauty grown in Virginia showed a test of about 17½ pounds when picked and tested 12½ pounds the middle of January. Winesap tested approximately 20 pounds in each district at the time of picking. By the end of January the Washington-grown fruit still tested 17 pounds, whereas that from Virginia tested only slightly over 15 pounds. Thus it is apparent that at least for the season 1924–25 the fruit grown in the dry, arid districts of the Pacific Northwest was somewhat slower in softening when held continuously at 32° than apples of similar varieties grown under the more humid conditions which prevailed in Virginia.

It is rather difficult to compare the rate of softening of apples grown in New York with those in Virginia or the Pacific Northwest, since the varieties which are well adapted to the latter sections are entirely different from those adapted to the Northeastern States. As was pointed out in Part I, the varieties grown under the short growing season prevailing in the northeastern section of the country tend to be somewhat harder at picking time than the same varieties grown under conditions of a long growing season. Rome Beauty, for example, when picked on October 18 in New York State showed a pressure test of over 22 pounds; the same variety picked on October 3 at Wenatchee, Wash., tested under 20 pounds and when picked October 8 at Rosslyn, Va., tested considerably under 18 pounds. The Baldwin when picked in Virginia on September 20 showed a pressure test under 18 pounds; in New York, on October 18, it was only slightly under 20 pounds. Thus, it would appear that, on the average, apples grown in the northeastern sections are much firmer at picking time than the same varieties in the southern or northwestern districts, where a much longer growing season prevails. Apparently, it is also true that the average firmness of all the varieties grown in the sections having a short growing season is greater at picking time than is the average firmness of the varieties in regions with a long growing season.

It is apparent from Figure 11, however, that the New York-grown apples studied softened more rapidly when held continuously at 32° F. than did the average of the varieties grown in the Pacific Northwest or even in Virginia. Thus the Baldwin, Tompkins King, Stark, and Rome Beauty grown in New York were all harder at the time of picking than the Delicious, Stayman Winesap, or Rome Beauty grown at Wenatchee; yet, by the middle of January, the varieties grown in New York were in approximately the same condition of firmness as those grown at Wenatchee, whereas the Winesap and Yellow Newtown from Washington were much firmer than any of the varieties studied from New York. It therefore appears that the firmer condition at time of picking of apples having a short growing season is not particularly associated with better storage holding. Although the varieties adapted to these regions were firmer at picking time on the average than were varieties adapted to a long growing season, they also softened somewhat more rapidly when held at 32° F.

SOFTENING OF APPLES HELD AT 40° F.

The comparative rate of softening of different varieties of apples when held at a temperature of 40° F. gives a very satisfactory index to their behavior when held under common, or air-cooled, storage conditions. The temperatures which prevail during the early storage season in air-cooled storages will be considerably above 40° in most of the apple-growing sections of the United States. Temperatures will drop off, however, until in most of the apple-growing regions a temperature of 40° can be maintained by the middle of November with lower temperatures through December and the winter months. Consequently, the behavior of different varieties when held continuously at 40° gives a very satisfactory index of the behavior of these same varieties under good common-storage conditions. The rates of softening of Virginia-grown apple varieties held continuously at 40° are shown graphically in Figure 12. It has not been possible to obtain satisfactory data on the behavior of varieties grown in other sections when held continuously at 40°, because the fruit ripened so much while in transit to the experimental storage plant at Rosslyn, Va., that the results obtained from it are of little significance, and storage space at this temperature was not available where other work was being done.

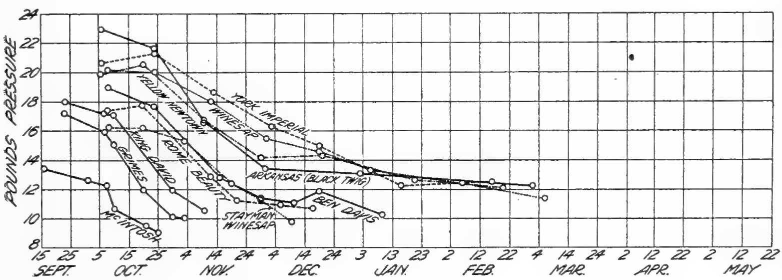


FIG. 12.—Softening of Virginia-grown apples while in storage at 40° F., 1924–25

It is apparent that the order of softening in fruit held at 40° F. is approximately the same as in similar fruit held at 32°. Thus, the four varieties, York Imperial, Winesap, Yellow Newtown, and Arkansas (*Mammoth Black Twig*), softened approximately at the same rate, and a considerably longer period was required before the fruit reached prime eating condition than in the other varieties studied. These varieties did not reach prime eating condition until about the end of December when held continuously at this temperature, and they remained in very good condition until the end of February. The Ben Davis, Stayman Winesap, and Rome Beauty varieties, which were somewhat softer when picked and softened somewhat more rapidly in storage, reached prime eating condition by the middle of November and by the middle to the latter part of December were becoming very soft. King David and Grimes Golden softened much more rapidly, reaching prime eating condition within about a month and becoming full ripe to overripe before the middle of November. McIntosh grown in Virginia reached prime eating condition in less than a month from time of picking. Thus, it is evident that for satisfactory holding at the best temperatures which can be obtained in air-cooled storage, such varieties as York Imperial, Winesap, Yellow Newtown, and Arkansas (*Mammoth Black Twig*) will give the best results. Stayman Winesap, Ben Davis, and Rome Beauty held moderately well, but varieties which ripen still more rapidly, such as King David and Grimes Golden, should be held for only a very short period in common storage.

It is unfortunate that it has not been possible to obtain for comparison similar records on the rate of softening of the varieties grown extensively in the Northeastern States. However, from the available data relative to rate of softening of such varieties as Baldwin, Stark, Northern Spy, and Rhode Island Greening, it appears that most of them soften much faster in storage at the same temperatures than do the best storage varieties grown in the southern and northwestern growing districts. Ben Davis and Gano grown in New York are usually hard at time of picking and ripen relatively slowly. These varieties, however, do not attain their best quality under short-season conditions such as usually prevail in the Northeastern States.

SOFTENING OF APPLES HELD AT 70° F.

Figure 13 shows graphically the rate of softening of a number of Virginia and Washington-grown apple varieties when held in storage at 70° F. It is apparent that all varieties which were studied, softened with great rapidity when held continuously at this temperature. Of all the varieties studied, Yellow Newtown, both Virginia and Washington grown, softened the most slowly.

It it rather surprising that even such varieties as Winesap and York Imperial soften almost as rapidly as Grimes Golden, Delicious, and Jonathan when held at 70° F. Since these varieties were harder at time of picking, a somewhat longer period was required before they reached prime eating condition, but the decrease in hardness each 24 hours in storage was practically as great in these varieties as in the fruit having the shorter storage season.

These results are particularly significant in connection with the effect of delaying storage on fruit intended for cold-storage holding. Temperatures of 60° to 70° F. are not unusual during the picking season in many apple-growing sections. A comparison of Figure 13, showing the softening rate at 70° with Figures 10 and 11, showing the softening rate of the same varieties at 32°, reveals some interesting comparisons. Virginia-grown Grimes Golden, for example, softened as much in 11 days at 70° as in 60 days at 32°. At the end of 10 days at 70° Washington-grown Stayman Winesaps were softer than at the end of 100 days at 32°. Washington-grown Winesaps at the end of 10 days at 70° were as soft as at the end of 115 days at 32°; Virginia-grown Winesaps were as soft at the end of 20 days at 70° as at the end of a 6 months' storage period at 32°. McIntosh softened as much in 7 days at 70° as in 70 days at 32°. A detailed study of the comparative softening rates at 70° and at 32° indicates that the extent of softening in 1 day at 70° is approximately the same in most varieties as in 10 days at 32°.

It is interesting to note that in practically all varieties of fruit held at 70° F. there was very little softening and in many instances an apparent slight increase in hardness during the first 3 or 4 days, following picking. At 32° the first test following picking was generally made at the end of about a month in storage. During this time there was usually a slight softening, although during the first month in almost all varieties it was less rapid than in the month following. In Figures 14 to 20 the softening rates of certain varieties over a wide range of temperature show that this condition of an initial storage period in which practically no softening occurs holds generally and is particularly apparent at the higher temperatures. Following the initial period of a very few days in which practically no softening occurs, all varieties soften with great

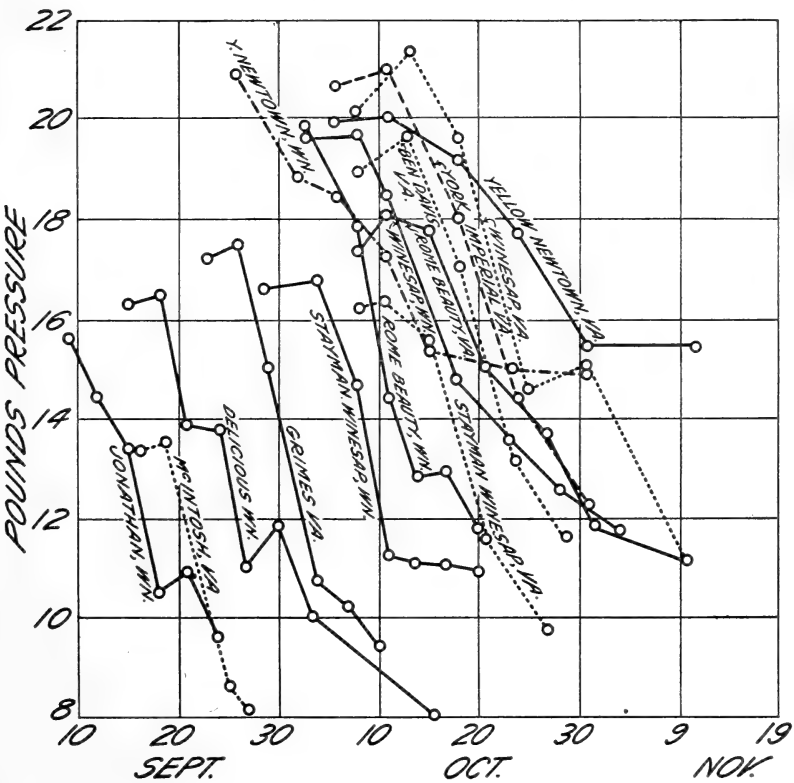


FIG. 13.—Softening of Washington and Virginia grown apples while in storage at 70° F., 1924

rapidity at the high temperatures. Since 1 day at 70° softens the fruit approximately as much as 10 days at 32°, it would appear that the beginning of softening at 32° should be delayed for a period of at least a month if the fruit responds at 32° in a way corresponding to its response at 70°. Since there is a rather pronounced softening during the first month in storage at 32°, however, it is apparent that softening begins relatively earlier in fruit held at low temperatures than in fruit held at the higher temperatures.

SOFTENING OF APPLES HELD AT VARIOUS TEMPERATURES

During the season of 1924–25 a number of apple varieties were placed in storage at temperatures of 30°, 32°, 36°, 40°, 50°, 60°, and 70° F., respectively. The softening rates of some of these varieties at this wide range of temperature are shown in Figures 14 to 20.

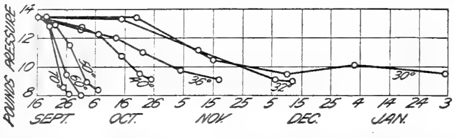


FIG. 14.—Softening of Virginia-grown McIntosh apples in storage at various temperatures, 1924–25

Aside from the comparison of softening rates of different varieties, which has been discussed under the rate of softening at 32°, 40°, and 70° F., it is of primary interest to compare the rate of softening in the same variety at the different storage temperatures. A comparison of all the charts will show that softening at 60° is only slightly slower than at 70°. On the average, about one-third longer was required for fruit to reach prime eating condition when held at 60° than was required for similar fruit when held at 70°.

The softening rate of practically all varieties held at 50° F. was approximately one-half as fast as when held at 70°. It is thus apparent that there is a distinctly greater difference in softening rate between 50° and 60° than there is between 60° and 70°. At 40° the softening rate averages slightly over one-half the rate at 50°, or approximately one-fourth the rate at 70°.

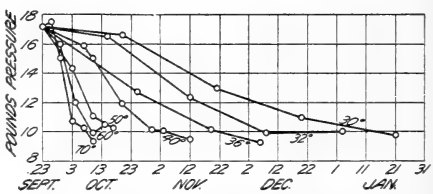


FIG. 15.—Softening of Virginia-grown Grimes Golden apples in storage at various temperatures, 1924–25

At 32° F. softening in most varieties was slightly less than half as rapid as at 40°; at a temperature of 36° the softening rate is intermediate between 32° and 40°.

The comparative rates of softening at 30° and at 32° F. are very interesting. Most varieties required 20 to 30 days longer to reach prime eating condition when held at 30° than similar fruit held continuously at 32°. The temperatures in these two rooms were very

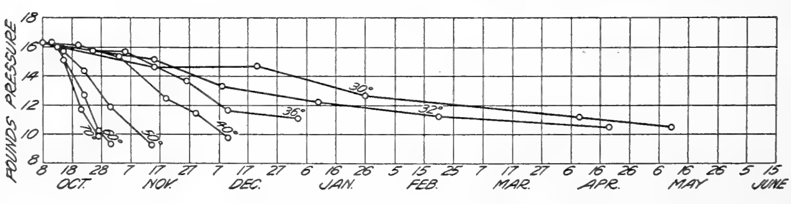


FIG. 16.—Softening of Virginia-grown Stayman Winesap apples in storage at various temperatures, 1924–25

accurately controlled, so that the slower softening rate at 30° is a real index of the effect of small differences in temperature when the storage-room temperature is close to the minimum. At 32° the fruit softened approximately 25 per cent faster than at 30°.

To summarize the softening data, then, it may be stated that at 32° F. the apple varieties on the whole softened about 25 per cent more rapidly than at 30°; at 40° the average softening rate was slightly more than double the rate at 32°; at 50° the softening rate was a little less than double the rate at 40°; and at 70° the fruit softened approximately twice as rapidly as at 50°. In other words, 1 day at 70° will soften the fruit approximately as much as 2 days at 50°, 4 days at 40°, 8 to 10 days at 32°, or 12 days at 30°. The comparative softening rates vary somewhat in different varieties, but the data mentioned represent the approximate average of a considerable number of varieties.

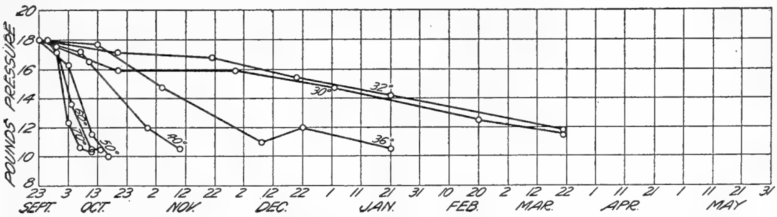


FIG. 17.—Softening of Virginia-grown King David apples in storage at various temperatures, 1924–25

It is apparent from the data presented in Figures 14 to 20 that immediately following picking there is an initial period when relatively little softening occurs at any temperature. Following this initial period softening proceeds at a more or less uniform rate until the fruit reaches a soft stage which is approximately that found suitable for eating. After the fruit attains this condition, softening occurs at a very much reduced rate until it reaches the mealy or overripe stage. The apples from which the data in Figures 14 to 20 were obtained were held from picking time until they were full

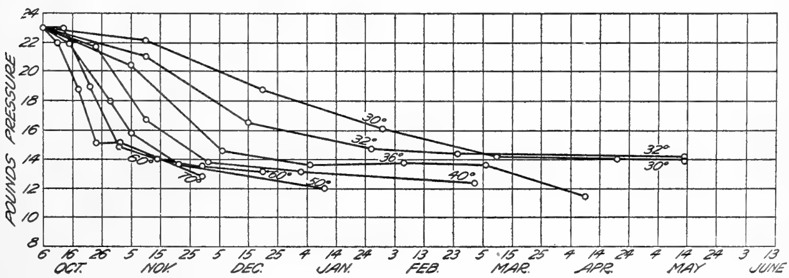


FIG. 18.—Softening of Virginia-grown Arkansas (*Mammoth Black Twig*) apples in storage at various temperatures, 1924–25

eating soft, or in the condition in which it should be in the hands of the consumer.

INFLUENCE OF STORING AT LOW TEMPERATURES ON SOFTENING RATE WHEN REMOVED TO HIGH TEMPERATURES

The opinion is rather general that fruit held at low temperatures, such as 30° to 32° F., breaks down very quickly following its removal to higher temperatures. In order to determine whether or not holding the fruit at a low temperature affects the rate of softening following its removal to a higher temperature, a series of tests was conducted in which the fruit was held at 32° and then removed to higher temperatures. Figures 21 and 22 show the softening rates of two varieties held for a short period at 32° and then removed to various temperatures from 32° to 85°. It is apparent that the softening rate at the different temperatures following an initial period of holding at 32° is approximately the same as for similar varieties held continuously from the time of picking at corresponding temperatures. Softening at 70° proceeded at approximately 10 times

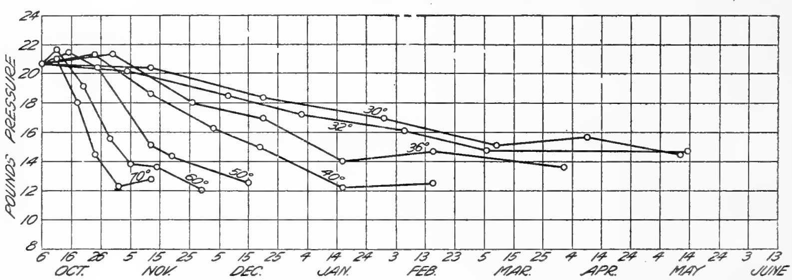


FIG. 19.—Softening of Virginia-grown York Imperial apples in storage at various temperatures, 1924–25

the rate of the softening at 32° with intermediate temperatures ranging about in the same order.

In order to still further determine whether or not there was an appreciable difference in softening rate, depending on whether or not the fruit had been held at low temperatures, the data reported in Figure 23 were obtained. Certain lots of Winesap and Ben Davis apples were placed in storage at 32° F., and similar lots were stored immediately after picking at temperatures of 70°, 50°, and 40° and the softening rates at these various temperatures determined. After a period of three months in storage at 32°, the firmness of the

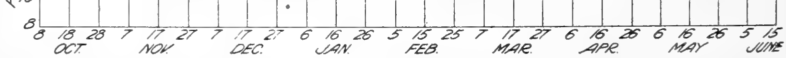


FIG. 20.—Softening of Virginia-grown Winesap apples in storage at various temperatures, 1924–25

fruit held at this temperature was tested and portions of it removed to 40°, 50°, and 70° respectively. The softening rates at these temperatures, following three months at 32°, were then determined. The solid lines in Figure 23 represent the softening of the fruit held from time of picking at 40°, 50°, and 70°. The broken lines represent fruit held three months at 32°, then removed to 40°, 50°, and 70°. To facilitate comparison, the broken lines for all temperatures are started on the chart adjacent to the solid lines for the same temperatures and at points determined by the hardness of the fruit when removed from storage at 32°.

Section A of Figure 23, giving data for the Ben Davis apple, shows that at 70° and 50° F. softening following removal from 32° was slightly faster than in fruit held continuously at the higher temperatures when in a correspondingly firm condition. At 40°, however, softening of the fruit previously held at 32° progressed more slowly than in fruit continuously held at the higher temperature. Section B, showing data on Winesap apples, indicates a very slightly faster softening at 70° and a very slightly slower softening at 50° and 40° in fruit previously held at 32°. The data presented both for Ben Davis and Winesap, however, show differences too small to be significant. Apparently the average rate of softening in fruit held for a time at 32° and then removed to higher temperatures is approximately the same as in fruit in the same condition of ripeness which has been held continuously at the higher temperature. Holding apples for three months at 32° did not result in more rapid ripening of these apples when subsequently removed to 40°, 50°, or 70°, respectively. Similar results were obtained with other varieties.

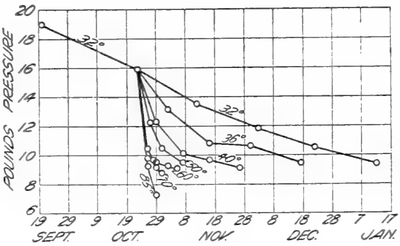


FIG. 21.—Softening of Virginia-grown Grimes Golden apples held for five weeks at 32° F., then stored at various temperatures, 1923–24

INFLUENCE OF TIME OF PICKING ON SOFTENING OF APPLES STORED AT VARIOUS TEMPERATURES

In Part I of this bulletin it was pointed out that there is generally a considerable softening in apples as they approach maturity on the tree. As will be shown later, the rate of softening which occurs while the fruit remains on the tree is considerably less than that following picking if the fruit is held at prevailing orchard temperatures. In order to determine whether or not late-picked fruit softened faster when held in storage at various temperatures than fruit removed from the tree in a more immature condition, two pickings of several varieties of apples were made and the rate of softening at different temperatures compared. The first picking in most cases was made at approximately the time of the commercial harvest for the variety, and the second was made two to four weeks later. With the varieties used in this investigation there was not a marked softening of the fruit on the tree between the time of the first and second pickings.

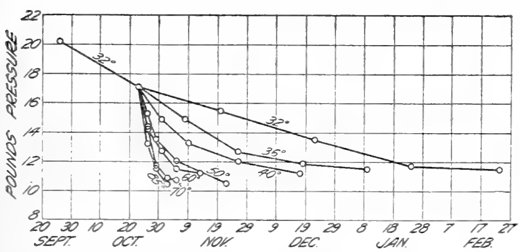


FIG. 22.—Softening of Virginia-grown Rome Beauty apples held one month at 32° F., then stored at various temperatures, 1923–24

The data on the softening of the fruit of several varieties while in storage at 32° F. are shown in Figure 24. It is apparent from the data presented that the softening of these particular varieties while on the tree was not appreciably more rapid than that which occurred in storage at 32°. Also, there was no appreciable difference in the rate of softening between early and late picked fruit held from the time of picking at 32° F. Thus, at any particular time during the storage season there was no appreciable difference between the firmness of the commercially picked and the late-picked fruit in storage at 32°. In nearly all cases the late-picked fruit was slightly firmer at any particular time than that picked during the commercial season.

In Figure 25 is shown the rate of softening of medium and late-picked Winesap apples when held in storage from time of picking at 40°, 50°, and 70° F. In Figure 26 is shown the rate of softening of Washington-grown Stayman Winesap apples picked at four different intervals and held in storage at 70° until soft. It is apparent from the data presented in Figures 25 and 26 that at the higher temperatures late-picked fruit softens somewhat more rapidly than the earlier picked fruit. In Figure 25, for example, the first-picked Winesaps required 30 days to reach a 12-pound test, which represents prime eating condition in this variety, when held at 70°. Fruit picked 20 days later was equally soft after less than 20 days' holding at 70°. At 50° the late-picked fruit was in prime eating condition as soon as the earlier picked fruit, though there was 20 days' difference in time of picking and practically no difference in the firmness of the fruit at the two picking dates. At 40°, also, the late-picked fruit reached prime eating condition slightly ahead of that picked 20 days earlier. The data for Stayman Winesap shown in Figure 26 give a similar result. There was not a great variation in the firmness of the fruit at the date of the different pickings, although they were obtained from the same trees. The first picking held at 70° required 16 days to reach a pressure test of 12 pounds; the second required 12 days to reach this same degree of softness; the third 12 days; and the fourth, which tested practically the same as the first when removed from the trees, showed a test of 12 pounds at the end of 9 days. Apparently the later picked fruit softened more rapidly at 70° than the early-picked fruit from the same trees. Similar data for other varieties have been obtained. It is evident that while late picking did

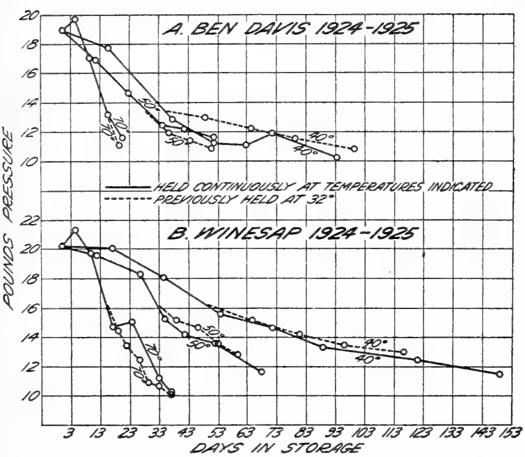


FIG. 23.—Rate of softening of Ben Davis and Winesap apples held continuously from time of picking at temperatures of 40°, 50°, and 70° F., compared with rate of softening in similar fruit held for a period at 32°, then stored at 40°, 50°, and 70° F.

not result in appreciably faster softening in fruit held continuously from time of picking at 32°, it did result in more rapid softening when the fruit was held at higher temperatures.

The more rapid softening of late-picked fruit when held at the higher temperatures is apparently due to two factors. Softening following picking in late-picked fruit begins at once, whereas in varieties picked in the ordinary commercial season there is usually a period of three or four days before appreciable softening occurs. Also, the rate of softening appears to be slightly more rapid in late-picked fruit.

YELLOWING OF FRUIT IN STORAGE AS AFFECTED BY TEMPERATURE

When apples are picked the unblushed portions are sometimes distinctly green tinged. In some cases, particularly with varieties such as Baldwin, Grimes Golden, Stayman Winesap, and numerous others, the green color is sufficient to render the fruit distinctly less attractive than it would be if it were entirely replaced with yellow.

During the time the fruit ripens and softens in storage, the green color of the unblushed portions tends to become yellow. Although exact records were not made of this color change in the fruit held at the different storage temperatures, the general observations may be summarized as follows:

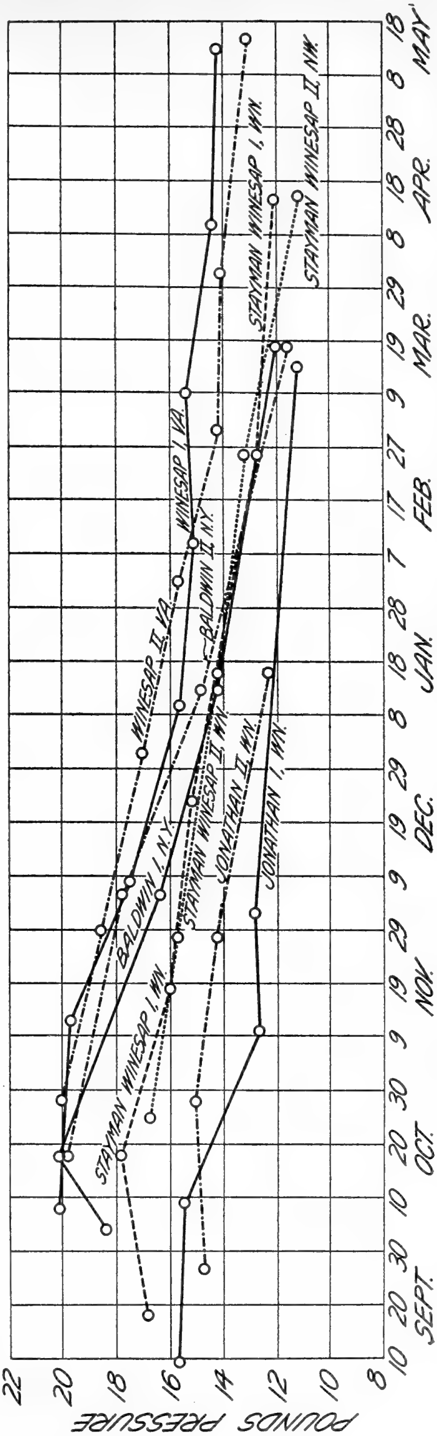


FIG. 24.—Relation of time of picking to rate of softening of Washington, New York, and Virginia grown apples at 32° F., 1924–25

A certain amount of yellowing occurred between the time the fruit was picked and the time it was in prime eating condition, regardless of the temperature at which it was held. This yellowing occurred to only a slight extent at temperatures of 30° or 32° F. Fruit going into storage with a color corresponding to No. 2 in Plate I usually came out of storage when in prime eating condition if held continuously at 30° to 32°, with a ground color not more yellow than No. 3 and usually between Nos. 2 and 3.

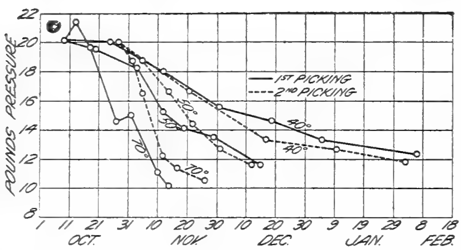


FIG. 25.—Relation of time of picking to rate of softening of Virginia-grown Winesap apples while in storage at 40°, 50°, and 70° F., 1924–25

At 36° to 40° F. fruit usually became considerably more yellow during the time required for it to soften than if held at 30° or 32°, but even at this higher temperature it was generally distinctly tinged with green when soft enough for eating. In apples held at 50° or higher the green color almost entirely disappeared by the time the fruit was full soft unless it was very green when placed in storage. Although the time required for the fruit to soften at the higher temperatures is much shorter than at the lower ones, the green color seems to disappear at even a faster rate proportionately than at the lower temperatures.

The fullest yellowing will therefore usually occur in fruit held at moderately high temperatures. Fruit held in common or air-cooled storages where the temperatures are generally high during the first few weeks usually comes out of storage much yellower than that held for even a much longer period at temperatures of 30° to 32°.

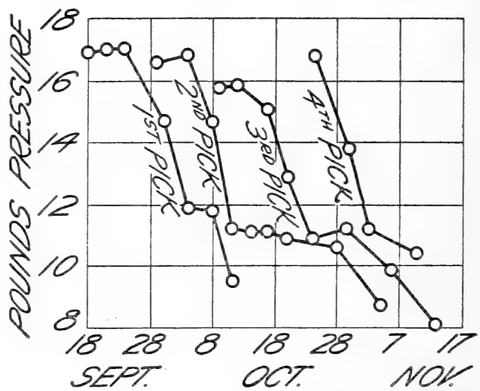


FIG. 26.—Relation of time of picking to rate of softening of Washington-grown Stayman Winesap apples while in storage at 70° F., 1924

CHANGES IN CHEMICAL COMPOSITION OF APPLES STORED AT DIFFERENT TEMPERATURES

In order to determine whether or not there is any appreciable effect of the temperature at which apples are held during the ripening process on the chemical composition of the ripened fruit, samples of a number of varieties were analyzed for sugars and titratable acidity at the close of the storage period for each temperature. Instead of holding the fruit for a definite length of time at the different temperatures studied, it was left at these temperatures until in full-ripe condition regardless of the time required. Since firmness is the outstanding change associated with ripening, the condition of full ripeness was primarily determined by the pressure test. The fruit was placed in the different storage temperatures at the same time and left until the pressure test indicated that it was full ripe for the variety. A slight variation necessarily occurred in the firmness of the fruit at the time of sampling, but an attempt was made to have the apples as nearly as possible in a uniform condition.

From 25 to 30 apples were generally used as a sample for the making of the chemical analyses. After the apples had been tested to determine their firmness, a plug of tissue was removed from each by means of a cork borer and passed through a sampling press of the type described by Clark (*5*), which pulverized it thoroughly. Fifty-gram samples of this tissue were boiled and made up to 500 c. c. with water for acidity determinations. The samples were allowed to stand for three days, about 2 c. c. of toluol being added as a preservative. After three days' standing extraction, the pulp was filtered off through cotton and the acidity determined by titration with N/10 NaOH. Phenolphthalein was used as indicator.

The 50-gram samples for sugar determinations were boiled in alcohol, $CaCO_3$ being added prior to boiling to neutralize the acidity. These samples were made up to 500 c. c. with 50 per cent alcohol and allowed to stand several weeks for extraction. The pulp was then filtered off and aliquot portions of the filtrate taken for the sugar determinations. The alcohol was evaporated from these portions, the solution cleared with neutral lead acetate, and the sugars determined by Mathews' modification of the Bertrand and Munson and Walker methods (*14, p. 994*).

The number of days in storage, the pressure test at the end of the storage period, the percentage of sugars both free reducing and total, and the percentage of acidity calculated as malic acid are given in Table 4. Part of the data are for the storage season of 1923–24 and part for 1924–25. As heretofore mentioned, the fruit for the season of 1923–24 was picked and held for a certain length of time at 32° F. before being placed in various storage temperatures. In addition to this holding, fruit listed from Yakima, Wash., was shipped by express from that place to the experimental storage plant at the Arlington Experiment Farm, Rosslyn, Va., requiring approximately a week in transit at relatively high temperatures. The fruit used in the 1924–25 experiments was placed in storage at the different temperatures the day following picking. As previously stated, an effort was made to take the apples from the different temperatures in similar conditions of hardness, but as will be noted in the column headed "Pressure test (pounds)" some variation existed within the different varieties at the time they were removed from storage.

It is apparent from the data in Table 4 that in all varieties there was an increase in the quantity of total sugar between the time the fruit was picked and the time it reached prime eating condition at the various temperatures. The 1924–25 fruit placed in storage immediately following picking shows a rather sharp increase in the quantity of sugar present between picking time and when the fruit was full ripe; this increase is apparently due primarily to the change of starch to sugar.

There does not appear to be any direct association between the temperature at which the fruit was held and the total quantity of sugar present in ripened fruit. There was some variation in the quantity of sugar present in the different samples, owing to variations in the fruit from which they were taken, but no consistent variations appear to be due to storage conditions. Thus, by the time the fruit reached prime eating condition, regardless of the storage temperature at which it was held, it appears that about the maximum quantity of carbohydrates present in the fruit was in the form of sugars and there was little variation, depending upon the particular temperature at which the fruit had been held during the ripening process.

Similarly, there appears to be little influence of the temperature at which the fruit is held upon the quantity of reducing sugar present. There was no marked variation in the reducing-sugar content of the samples of fruit from different storage temperatures.

There is a considerable variation in different varieties in regard to the percentage of the total sugar which is in the form of free-reducing sugar. In Grimes Golden, for example, only slightly more than half the total sugar present is in the free-reducing form. Baldwin also is relatively low in free-reducing sugars. Winesap, on the other hand, has more than 80 per cent of its sugar in the free-reducing form, and Delicious is relatively high in reducing sugars. Other varieties are intermediate in reducing-sugar content.

It is interesting to note the wide variation in sugar content in apples of the same variety and from the same trees grown in Virginia during the two seasons, 1923 and 1924. Grimes Golden grown at the Arlington Experiment Farm, Rosslyn, Va., showed a sugar content in the ripe fruit of about 15 per cent in 1923, whereas the fruit grown during 1924 was between 11.5 and 12 per cent. Winesap at Linden, Va., in 1923 had a sugar content averaging about 13 per cent; at Rosslyn in 1924 Winesap averaged only about 11½ per cent. A few analyses have been run on other varieties not reported in Table 4 which indicate that apple varieties in general grown in Virginia in 1924 were distinctly under the 1923 crop in sugar content. It will be recalled from the data in Part I that the growing season at Rosslyn in 1924 was unusually late and cool for that section, with a rather high rainfall during August and September.

In the last column of Table 4 are recorded the percentages of acid calculated as malic in the fruit ripened at the different temperatures. It is apparent that at all temperatures there is a reduction in acidity in apples between the time of picking and the time when the fruit is in a soft-ripe condition. In certain varieties stored during 1924–25 which were removed to the various temperatures immediately after picking, it appears that the fruit held at a high temperature, 70° F., and that held at low temperatures, 30° and 32°, was lower in acidity when fully ripe than that held at intermediate temperatures. This is particularly apparent in the data for McIntosh, King David, and Grimes Golden.

In other varieties and in most of the data for 1923–24 there does not appear to be a marked variation in the quantity of titratable acidity, depending upon the temperature at which the fruit has been held. In nearly all varieties during both seasons' work, fruit held at 70° or 85° F. was lower in acidity when fully ripe than that held at lower temperatures. There is, however, not a sufficiently consistent variation in the titratable acidity to be certain of the general effect of temperature upon the amount of this reduction. A summary of all of the data presented indicates that, in general, apples held until soft ripe at temperatures of 70° or 85° will be somewhat lower in acidity than those held at 40° to 50° and that fruit held at 30° or 32° may also be somewhat lower in acidity than that held at intermediate temperatures. It seems probable that the acidity changes are associated with the respiration rate and the quantity of oxygen available in the tissues, and consequently they will vary with different varieties and with the same variety grown under widely varying conditions. As a result, it is impossible to make any generalizations except that at all the temperatures there is a distinct reduction in titratable acidity between the time the fruit is picked and the time it is soft ripe. In general, it appears that the least reduction in acidity occurs when the fruit is ripened at temperatures of 40° to 60°.

TABLE 4.—*Length of time in storage, pressure test at end of storage period, and chemical composition of apples held at various storage temperatures*

Variety, station, and season	Storage temperature (°F.)	Time in storage (days)	Pressure test (pounds)	Percentage of sugar		Titratable acidity as malic acid (per cent)
				Total	Reducing	
McIntosh, Rosslyn, Va., 1924–25	[1]	0	13.45	10.47	7.62	0.73
	70	11	8.10	10.77	7.88	.58
	60	15	8.05	11.20	7.90	.63
	50	21	8.40	10.91	7.69	.68
	40	39	9.10	11.34	8.14	.68
	36	62	9.10	10.84	8.30	.62
	32	87	9.00	11.34	9.24	.50
	30	108	9.50	11.26	9.22	.40
King David, Rosslyn, Va., 1924–25	[1]	0	18.00	----------	----------	1.01
	70	18	10.35	12.26	9.30	.88
	60	21	10.45	12.74	9.42	.88
	50	24	10.05	----------	----------	.95
	40	48	10.50	----------	----------	.93
	36	120	10.55	----------	----------	.78
	32	180	11.80	----------	----------	.71
	30	180	11.60	----------	----------	.71
Jonathan, Yakima, Wash., 1923–24	[2]	----------	11.00	----------	----------	.69
	85	4	8.00	12.88	9.64	.47
	70	6	8.10	12.59	8.96	.54
	60	8	7.90	12.38	8.59	.52
	50	11	8.25	12.38	8.61	.56
	40	17	8.55	12.67	9.16	.55
	36	43	8.35	12.13	8.86	.56
	32	48	8.65	12.67	8.96	.58
Grimes Golden, Rosslyn, Va., 1923–24	[2]	33	15.90	13.83	7.22	.55
	85	6	7.25	15.05	7.69	.45
	70	8	8.75	15.05	7.66	.47
	60	13	9.15	14.96	7.68	.45
	50	25	9.55	15.00	7.87	.53
	40	33	9.10	----------	----------	.46
	36	55	9.15	15.05	8.10	.49
	32	81	9.40	15.14	8.06	.55
Grimes Golden, Rosslyn, Va., 1924–25	[1]	0	17.20	9.38	6.56	.55
	70	17	9.35	11.34	6.98	.38
	60	21	10.5	11.80	7.12	.42
	50	24	10.25	11.70	7.36	.49
	40	50	9.5	11.62	8.10	.46
	36	74	9.25	11.62	8.22	.40
	32	102	10.00	11.92	8.30	.39
	30	130	9.75	11.72	8.74	.39

[1] At picking. [2] Removal from 32° F.

TABLE 4.—*Length of time in storage, pressure test at end of storage period, etc.*—Continued

Variety, station, and season	Storage temperature (°F.)	Time in storage (days)	Pressure test (pounds)	Percentage of sugar		Titratable acidity as malic acid (per cent)
				Total	Reducing	
Delicious, Yakima, Wash., 1923–24	[2]	----------	12.15	12.40	9.70	0.23
	85	8	9.60	12.84	11.04	.20
	70	8	9.25	13.20	10.82	.21
	60	8	9.25	13.24	10.56	.20
	50	13	9.60	13.28	10.72	.21
	40	20	9.50	13.04	10.56	.29
	36	49	9.40	13.40	11.42	.23
	32	77	9.60	13.12	11.46	.20
Baldwin, Rosslyn, Va., 1923–24	[2]	30	16.60	11.46	7.32	.75
	85	8	9.75	12.30	9.20	.59
	70	8	9.80	11.76	7.66	.65
	60	10	10.20	12.34	7.69	.67
	50	19	9.90	12.44	7.46	.74
	40	43	10.80	12.40	7.96	.65
	36	85	9.80	12.68	8.22	.65
	32	145	10.70	12.36	8.14	----------
Rome Beauty, Rosslyn, Va., 1923–24	[2]	----------	17.10	11.57	8.10	.55
	85	10	10.45	11.50	9.25	.41
	70	13	10.75	11.50	8.60	.37
	60	21	11.20	12.35	8.28	.43
	50	30	10.50	11.35	8.03	.40
	40	55	11.20	11.45	8.27	.45
	36	78	11.50	11.75	8.90	.37
	32	123	11.55	12.10	9.35	.43
Rome Beauty, Hall, N. Y., 1923–24	[2]	----------	13.90	11.25	7.45	.38
	85	8	9.75	11.55	9.03	.25
	70	8	10.35	11.45	8.35	.33
	60	9	10.25	11.35	8.03	.34
	50	12	10.25	10.45	8.20	.34
	40	20	10.80	10.25	7.85	.34
	36	28	10.15	10.55	8.00	.32
	32	62	10.25	10.45	8.18	.28
Winesap, Linden, Va., 1923–24	[2]	88	14.90	12.80	10.28	.59
	85	11	11.20	14.40	13.23	.49
	70	12	11.45	13.30	11.10	.57
	60	32	9.85	13.70	12.45	.44
	50	50	10.60	12.70	11.08	.44
	40	90	10.95	13.35	11.35	.52
	36	142	12.30	12.65	11.38	.44
	32	146	12.55	12.85	11.30	.56
Winesap, Yakima, Wash., 1923–24	[2]	----------	16.55	12.60	10.23	.63
	85	18	10.90	13.60	13.20	.41
	70	17	10.85	13.35	12.13	.46
	60	25	11.95	13.20	11.40	.58
	50	41	11.45	13.15	11.18	.58
	40	67	11.70	13.25	11.05	.58
	36	111	11.85	12.60	11.28	.64
	32	139	12.45	12.60	11.53	.57
Winesap, Rosslyn, Va., 1924–25	[1]	0	20.10	9.76	8.04	.60
	70	37	10.15	11.82	10.90	.40
	60	52	10.45	11.08	9.70	.47
	50	68	11.60	11.20	9.60	.41
	40	184	11.30	11.18	10.46	.42
	36	217	12.30	11.70	11.40	.42
	32	217	14.25	12.12	11.04	.47
	30	217	12.80	11.80	11.04	.48
York Imperial, Linden, Va., 1923–24	[2]	59	16.45	10.80	8.18	.64
	85	16	13.00	13.70	10.73	.36
	70	20	12.60	13.70	9.63	.45
	60	46	11.65	13.60	10.45	.45
	50	77	12.35	12.95	9.63	.48
	40	117	12.20	12.55	10.03	.37
	36	123	12.40	12.60	9.18	.42
	32	130	14.95	12.00	8.58	----------
Arkansas, Linden, Va., 1923–24	[2]	88	16.00	12.85	9.28	.60
	85	11	12.55	14.40	12.25	.56
	70	12	11.65	13.50	10.15	.75
	60	34	10.75	14.75	10.95	.61
	50	54	11.80	14.05	10.73	.50
	40	81	11.95	12.80	9.93	.51
	36	127	12.50	13.25	10.18	.48
	32	149	13.45	13.25	11.13	.49

[1] At picking. [2] Removal from 32° F.

TABLE 4.—*Length of time in storage, pressure test at end of storage period, etc.*—Continued

Variety, station, and season	Storage temperature (°F.)	Time in storage (days)	Pressure test (pounds)	Percentage of sugar		Titratable acidity as malic acid (per cent)
				Total	Reducing	
Yellow Newtown, Linden, Va., 1923–24	(2)	----------	13.30	12.60	7.85	0.63
	85	14	10.70	13.25	9.28	.49
	70	16	10.95	13.10	8.73	.57
	60	25	10.55	13.35	8.73	.58
	50	38	10.35	13.15	8.40	.52
	40	82	10.70	13.50	8.98	.60
	36	103	11.05	13.20	8.78	.53
	32	131	11.55	13.05	8.93	----------
Ben Davis, Rosslyn, Va., 1924–25	(1)	0	18.95	9.48	7.24	.60
	70	21	11.65	10.52	8.04	.48
	60	21	10.50	10.46	7.60	.50
	50	52	11.60	9.92	7.44	.49
	40	94	10.25	10.38	8.12	.46
	36	135	11.50	10.18	8.54	.52
	32	153	12.75	10.10	8.42	.36
	30	184	12.60	10.54	9.02	.33

[1] At picking. [2] Removal from 32° F.

The data in Table 4 indicate that so far as chemical analysis is concerned there is not an outstanding difference in the composition of apples depending upon the temperature at which they have been ripened, provided the apples are in a comparable condition of maturity when tested. In other words, there is not a marked difference in composition of apples held at 70° or at 32° F. provided they are held at each temperature until in a similar condition of maturity.

The data in Table 4 relative to the pressure test when the fruit was sampled are important. With certain varieties, such as Arkansas (*Mammoth Black Twig*) and York Imperial, the fruit was not left in storage at 30° and 32° F. until really comparable in softness with fruit held at higher temperatures, because of the excessive development of storage scald prior to this time. Certain other varieties, such as Yellow Newtown and Winesap, did not attain as soft a condition at 30° and 32° as at higher temperatures.

RESPIRATION RATE OF APPLES AT DIFFERENT TEMPERATURES

It has long been known that as fruits ripen following their removal from the tree they take up oxygen from the air and give off carbon dioxide. Associated with the ripening process is the oxidation of the sugars and the other carbohydrate materials primarily to carbon dioxide and water. The work of Gore (*8*) and many others has shown that the rate of carbon-dioxide evolution from fruit is closely associated with temperature. It was planned to determine how closely the respiration rate in apples is really associated with the rate of softening at the different temperatures.

The rate of carbon-dioxide output of the fruit and of oxygen absorption was determined by the method previously described by two of the writers (*11*). The determination of the respiration rate of the apples was made during the winter of 1923–24, and all determinations were on fruit which had previously been held at 32° F. The fruit was removed to the different temperatures immediately preceding the start of the respiration tests. At 32° and 40° three runs were made on each variety, using the same lot of fruit for all three. From 20 to 25 apples, weighing from 2,500 to 3,000 grams, were used in each experiment. At 60° and 85° duplicate lots of each variety were run and two or three determinations made on each lot. The data, as recorded in Table 5, are calculated in milligrams and cubic centimeters of carbon dioxide evolved per kilogram of fruit per hour and cubic centimeters of oxygen consumed per kilogram of fruit per hour.

From the data on the weights of carbon dioxide evolved, it is at once apparent that there is a rather close relationship between the respiration rate and the rate of softening of the different varieties. Grimes Golden, for example, evolved carbon dioxide at a rate between 4 and 5 milligrams per kilogram of fruit per hour at 32° F.; between 8 and 9 milligrams at 40°; between 29 and 30 milligrams at 60°; and from 60 to 70 milligrams at 85°. Thus at 40° the rate was slightly less than double that at 32°, and that at 60° was about six times that at 32° and more than three times that at 40°. At 85° the respiration was more than double the rate at 60°. Referring to the data for the Arlington Experiment Farm Grimes Golden in 1923–24 in Table 4, it is apparent that 6 days were required for full ripening at 85°, 13 days at 60°, 33 days at 40°, and 81 days at 32°. Thus at 60° the softening was six times as fast as at 32°, and the respiration rate was about six times the rate at 32°. At 85° both the softening and respiration rates were slightly more than double the rates at 60°. The ripening rate at 60° was two and one-half times the rate at 40°, while there is an even greater difference in respiration rate. In general, however, there is a very close agreement between the rates of respiration and softening for Grimes Golden.

TABLE 5.—*Respiration of apples in relation to temperature*

Variety, station, and temperature	Run No.	Length of run (hours)	Per kilogram of fruit per hour			Respiration ratio $CO_2 \div O_2$
			CO_2 evolved (mgr.)	CO_2 evolved (c. c.)	O_2 consumed (c. c.)	
Grimes Golden, Rosslyn, Va.:						
32° F. (0° C.)	1	288	4.84	2.46	2.03	1.21
	2	263½	4.73	2.41	2.16	1.11
	3	310½	4.71	2.40	2.02	1.19
40° F. (4.5° C.)	1	143⅙	8.55	4.35	4.06	1.07
	2	187	8.32	4.23	3.89	1.09
	3	190½	8.16	4.15	3.85	1.08
60° F. (15.5° C.)	1A	47½	29.2	14.85	14.16	1.05
	2A	43¾	29.2	14.85	14.50	1.02
	1B	47½	29.6	15.06	14.17	1.06
	2B	43¾	29.0	14.75	14.34	1.03
85° F. (29.5° C.)	1A	23½	70.4	35.82	32.96	1.09
	2A	22¾	68.3	34.75	33.34	1.04
	3A	23¾	62.2	31.66	27.69	1.19
	1B	23½	73.3	37.30	33.69	1.11
	2B	22¾	69.2	35.21	33.73	1.04
	3B	23¾	63.5	32.31	28.05	1.15
Jonathan, Yakima, Wash.:						
32° F. (0° C.)	1	432½	3.25	1.66	1.50	1.11
	2	405	3.50	1.78	1.70	1.05
	3	331	3.61	1.84	------	------
40° F. (4.5° C.)	1	235	6.79	3.46	3.22	1.07
	2	191¾	7.35	3.75	3.19	1.17
	3	237	7.45	3.80	3.41	1.11
60° F. (15.5° C.)	1A	46¾	29.1	14.84	12.48	1.19
	2A	68¾	24.7	12.60	11.99	1.05
	3A	47½	23.3	11.88	11.41	1.04
	1B	46¾	30.9	15.76	13.24	1.19
	2B	68¾	25.9	13.21	11.41	1.16
	3B	47½	25.0	12.75	11.94	1.07

TABLE 5.—*Respiration of apples in relation to temperature*—Continued

Variety, station, and temperature	Run No.	Length of run (hours)	Per kilogram of fruit per hour			Respiration ratio $CO_2 \div O_2$
			CO_2 evolved (mgr.)	CO_2 evolved (c. c.)	O_2 consumed (c. c.)	
Baldwin, Rosslyn, Va.:						
32° F. (0° C.)	1	288	2.94	1.49	----------	----------
	2	263½	2.92	1.48	1.23	1.20
	3	310½	2.84	1.44	1.31	1.10
40° F. (4.5° C.)	1	143⅓	5.88	2.99	2.70	1.11
	2	187	5.34	2.72	2.37	1.15
	3	190½	4.88	2.48	----------	----------
60° F. (15.5° C.)	1A	49½	18.51	9.43	8.73	1.08
	2A	72¼	20.10	10.24	9.44	1.09
	3A	66¼	20.40	10.38	9.61	1.08
	1B	49½	18.95	9.65	8.77	1.10
	2B	72¼	19.82	10.08	9.23	1.09
	3B	66¼	20.1	10.23	9.30	1.10
85° F. (29.5° C.)	1A	48¾	41.5	21.12	18.75	1.13
	2A	22¾	38.8	19.75	15.89	1.24
	3A	47¼	34.2	17.40	14.23	1.22
	1B	48¾	42.7	21.73	18.90	1.15
	2B	22¾	38.9	19.80	16.56	1.19
	3B	47¼	34.85	17.74	14.68	1.19
Winesap, Linden, Va.:						
32° F. (0° C.)	1	432½	2.68	1.36	----------	----------
	2	405	2.82	1.43	1.21	1.18
40° F. (4.5° C.)	1A	335½	5.21	2.67	2.27	1.17
	1B	335½	5.38	2.74	2.55	1.08
60° F. (15.5° C.)	1A	67	20.82	10.60	11.18	.95
	2A	67	20.25	10.30	9.33	1.10
	3A	50	20.28	10.32	11.23	.92
	1B	67	20.11	10.24	11.02	.93
	2B	67	20.95	10.66	9.48	1.12
	3B	50	20.29	10.32	11.13	.93
85° F. (29.5° C.)	1A	44¾	38.57	19.62	17.89	1.10
	2A	44¾	30.73	15.64	13.67	1.14
	3A	47¼	28.46	14.48	12.06	1.20
	1B	44¾	38.21	19.45	18.10	1.07
	2B	44¾	35.27	17.95	13.91	1.29
	3B	47¼	32.47	16.52	11.86	1.39

Jonathan from Yakima, Wash., shows a fairly close relationship between respiration and softening rate. At 60° F. the respiration rate was between three and four times the rate at 40°, while at 40° it was approximately double that at 32°. The softening rate of 40° was almost three times that at 32°, and that at 60° was double that at 40°. Thus, the difference in respiration rate between 40° and 60° was greater than the difference in softening rate. The respiration rate at 60° was about seven times the rate at 32°, which is in rather close agreement with the softening at the different temperatures.

With the Baldwin the agreement between the rate of respiration and softening is also fairly close. The respiration rate at 40° F. was slightly less than double that at 32°, whereas the softening rate was more than three times that at 32°. The respiration rate at 60° was between three and four times the rate at 40°, with a similar difference in softening rate. Between 60° and 85° the respiration rate almost doubles, whereas the softening rate does not show a marked increase at the higher temperature.

The respiration data for Winesap indicate fairly close agreement with softening data. At 32° F. the respiration rate is a little more than half that at 40°. The softening rate was about in the same proportion, although at 32° the fruit did not become sufficiently soft in the time it was held to determine it with accuracy. At 60°

the respiration was 7 to 8 times the respiration rate at 32°, whereas at 85° it was more than 10 times the rate at 32°. Comparative softening rates were similar.

It is apparent that in general there is an approximate agreement between the respiration rate and the rate of softening of the fruit. Between 40° and 60° F. there appears to be a somewhat greater difference in the rate of respiration than in that of softening, but on the whole, within the range of temperatures here studied, there is a sufficiently close agreement between the softening rate and that of respiration to indicate that the softening processes in apples which are apparently associated with changes in the cell-wall materials may be directly associated with the oxidation processes which are measured in respiration studies.

The respiratory ratio, determined by dividing the volume of carbon dioxide given off by the volume of oxygen taken up, is indicative of the type of material being oxidized in the fruit. If reducing sugars are being oxidized to carbon dioxide and water, the respiratory ratio should be 1, and if malic acid is being oxidized the ratio would rise to 1.33. It is apparent that practically all the ratios fall between these two points, indicating that there is an oxidation of both acids and carbohydrates. A ratio of 1.165 indicates equal oxidation of acids and sugars. In the case of Grimes Golden this is about the average at 32° F., but is distinctly above the average at both 40° and 60°, and is somewhat above the average at 85°, thus indicating that there is approximately equal oxidation of acids and sugars at 32°, while at 40° and 60° sugars are mainly oxidized. At 85° there is a somewhat greater oxidation of acids. The results with the other varieties are similar. At practically all temperatures both acids and sugars are being oxidized, but on the average it would appear that the greatest oxidation of acids occurs at the highest and lowest temperatures here studied. This is in line with the fact that on the average acids seem to drop off least during ripening at the intermediate temperatures.

Because of the wide variations which exist, particularly in the acid content of different individual apples, it is difficult to determine accurately the decrease in acidity under different storage conditions. The data in Table 4 together with respiratory data indicate that at all temperatures there is a distinct falling off in acidity owing to oxidation in the normal respiration of the fruit. Under certain conditions not yet determined the carbon dioxide given off in respiration appears to come largely from the oxidation of acids. Under other conditions there is relatively little decrease in acidity, and the products of respiration appear to come largely from sugars. In general, there is a fairly close correlation between the rate of respiration as measured by carbon dioxide given off and the rate of softening of the fruit. Apparently both the rate of softening and the rate of respiration are controlled almost entirely by the temperature at which the fruit is held.

SUMMARY OF PART II

The ripening processes following picking are largely a continuation of those going on before the fruit is removed from the tree.

The rate of ripening following picking is determined almost entirely by the temperature at which the fruit is held.

The exact rates of softening of a large number of varieties of apples when held at temperatures ranging from 30° to 85° F. have been determined.

There is a wide variation in the softening rates of different varieties of apples when held at 32° F. Winesap, Arkansas (*Mammoth Black Twig*), Yellow Newtown, York Imperial, and Arkansas Black were hard when picked, and softened slowly. Rome Beauty, Stayman Winesap, Ben Davis, and King David grown in Virginia were softer when picked and reached prime eating condition earlier. Grimes Golden and McIntosh reached a full soft condition still earlier.

Apples grown in New York State were harder when picked than the same varieties in Virginia. The former softened slightly faster in storage at 32° F.

Apples in Washington State were in about the same condition of hardness when picked as Virginia apples. They softened somewhat slower when held at 32° F. than the same varieties from Virginia.

The softening of different varieties at 40° F. was in about the same order as at 32°. All varieties softened with great rapidity at 70°. Even varieties such as Winesap and York Imperial, though hard when picked, were in prime eating condition within a few days.

Most varieties when held at higher temperatures have an initial short period after picking when little softening occurs. Following this initial period softening proceeds rapidly.

At 70° F. softening proceeds approximately twice as fast as at 50°. At 50° it is almost double the rate at 40°, while at the latter temperature softening proceeds fully twice as rapidly as at 32°. About 25 per cent longer time was required for fruit to ripen at 30° than was required at 32°.

Holding apples at low temperatures for a period and then removing them to higher temperatures does not result in more rapid softening than the holding of similar fruit continuously at the higher temperature.

Late picking has not resulted in the fruit softening faster than earlier picked apples while held continuously in storage at 32° F. At temperatures of 40°, 50°, and 70° F., respectively, late-picked apples softened somewhat more rapidly than did early-picked fruit from the same tree.

Fruit held at temperatures of 50° F. or above from time of picking until full eating ripe was usually somewhat more yellow than fruit held until equally soft at 30° or 32°. At 36° and 40° the degree of yellowing was intermediate.

Apples held at the different storage temperatures were analyzed at the time they reached full soft condition, to determine the effect of the storage temperature upon the sugar and acid content.

There was a slight increase in the total quantity of sugar in all varieties between the time of picking and when the fruit was full soft.

There was no consistent variation in the quantity either of total or reducing sugar depending upon the temperature at which the fruit was held while ripening.

Acidity decreased between the time of picking and that of full ripeness in all varieties and at all temperatures. On the average, the decrease was greatest in fruit held at the highest temperatures. At 40° to 60° F. there was only a slight decrease in acidity. At 32° and 30° the decrease was variable, in some varieties being large and in others slight.

On the whole, there was a close agreement between the respiration and the softening rates in apples. The respiration rate at 40° F. was almost double that at 32°, while the rate at 60° was about three times that at 40°. The softening rates in most cases were in about the same order.

The respiratory ratio was practically always slightly more than 1, the ratio for the complete oxidation of dextrose, and less than 1.33, the ratio for the complete oxidation of malic acid, indicating that at all temperatures both acid and sugars were being oxidized. At 85° and 32° F. the ratio averaged slightly higher than at 40° and 60°, indicating that a somewhat larger proportion of acid was being oxidized at these extreme temperatures than at intermediate temperatures.

III. THE HANDLING OF APPLES FOR STORAGE

By J. R. Magness, *Physiologist*, H. C. Diehl, *Assistant Physiologist, and* M. H. Haller, *Junior Pomologist, Office of Horticulture, Bureau of Plant Industry*

There are two general methods of storing the commercial apple crop in the United States. The first of these is the holding of the fruit in common, or air-cooled, storage, where the temperatures maintained are obtained primarily through ventilation with cool outdoor air. The second method is to put the fruit in cold storage, where artificial cooling, usually by refrigerating machines, makes it possible to hold the temperatures at approximately the point most satisfactory for preserving the product. It is impossible to get exact information on the quantity of the commercial apple crop of the United States handled through air-cooled, or common, storage, but apparently it is equal to considerably more than half of the total commercial apple crop of the country. Available statistics relative to the holding of apples in cold storage indicate that somewhat less than half of the commercial apple crop of the United States is handled in this way, the remainder being either marketed directly or held for varying lengths of time in air-cooled storages.

In Part II the discussion dealt primarily with the influence of different temperatures on the ripening of apples following their removal from the tree. It was pointed out that temperature is apparently almost the sole determining factor in the rate of ripening of any variety following picking. The difference in results obtained in holding apples in an air-cooled storage as compared with holding them in cold storage will largely depend upon the difference in the temperatures maintained in the two types of storage.

TEMPERATURES PREVAILING IN AIR-COOLED STORAGES

During the past 10 years the United States Department of Agriculture has obtained thermographic records of the temperatures prevailing in common, or air-cooled, apple-storage houses in many sections of the United States, including basement, hillside, and aboveground storages of various types. From these records it is possible to make some general statements regarding the temperatures which may be expected in air-cooled storage houses.

It is rarely found that the mean temperature existing in an apple storage house or basement which depends upon outside air temperatures for cooling will, over a period as long as 10 days, be appreciably below the mean of the outdoor temperatures during that time. By outdoor temperatures are meant shade temperatures as reported by the United States Weather Bureau. In a great many cases existing outdoor temperatures, particularly during the fall months, will average considerably below the mean of those inside the storage. Storage temperatures are usually above the mean of those prevailing outside when inadequate ventilation openings are used or where the storage is not properly handled.

If ventilation openings are sufficiently large and the storage rooms are opened as much as possible whenever outdoor temperatures are below those existing in the storage room and closed when outdoor temperatures rise above those prevailing inside, it is possible to obtain approximately the mean of the outdoor temperatures in the storage room. Basement-type storages, partially underground types (such as hillside storages), or entirely aboveground types of storage have been found to hold about the same temperature if properly handled.

It is not the purpose in this report to discuss common-storage construction and handling but rather to deal with the handling of fruit intended for common-storage holding. The investigations reported in Parts I and II, dealing with the ripening of apples on the tree and in the storage rooms at various temperatures, give a background for recommendations in regard to the actual handling of fruit in common storage.

The mean prevailing outdoor temperatures, available from the United States Weather Bureau in many sections of every State, give an accurate index of the temperatures which may be expected in an air-cooled storage house and are of great value in determining the adaptability of common storage to any locality. With this fact in mind a map has been prepared (fig. 27) showing the average mean prevailing temperatures for November for various sections of the United States. November was chosen as the first full month in which apples are generally held in common storage. It is also a particularly critical month for common-storage holdings, as it is during this period that the fruit should be cooled from temperatures prevailing at picking time to near the optimum temperature for holding the fruit. The mean October temperatures prevailing over the country are, according to isotherm maps prepared by Ward (*18*), approximately 10° above the temperatures given for November. In the northern sections October temperatures are somewhat more than 10° above those prevailing in November, while in the warmer sections there is a difference of slightly less than 10°. December temperatures, on the other hand, will average fully 10° below those prevailing in November in most of the apple-growing sections of the United States. The prevailing temperatures for late October, November, and early December largely determine the adaptability of any district for holding apples in common, or air-cooled, storage. By the latter part of December common-storage temperatures in most apple-growing districts will approximate those for cold storage if the storages are carefully managed. Consequently, the prevailing temperatures during the cooling period from the time of picking to December largely determine the efficiency of common storage for apples.

Figure 27 requires little comment. It is apparent that in nearly all of the northern apple districts, including most of New England, New York, northern Pennsylvania, northern Ohio, Illinois, and westward, the mean November temperatures average under 40° F. The southern parts of Missouri, Illinois, Indiana, and Ohio, on the other hand, have a mean November temperature above 44°. Thus there is a difference of about 6 degrees even between northern and southern Ohio or northern and southern Indiana. From Part II it will be recalled that apples at 50° soften fully twice as fast as apples at 40°, so this

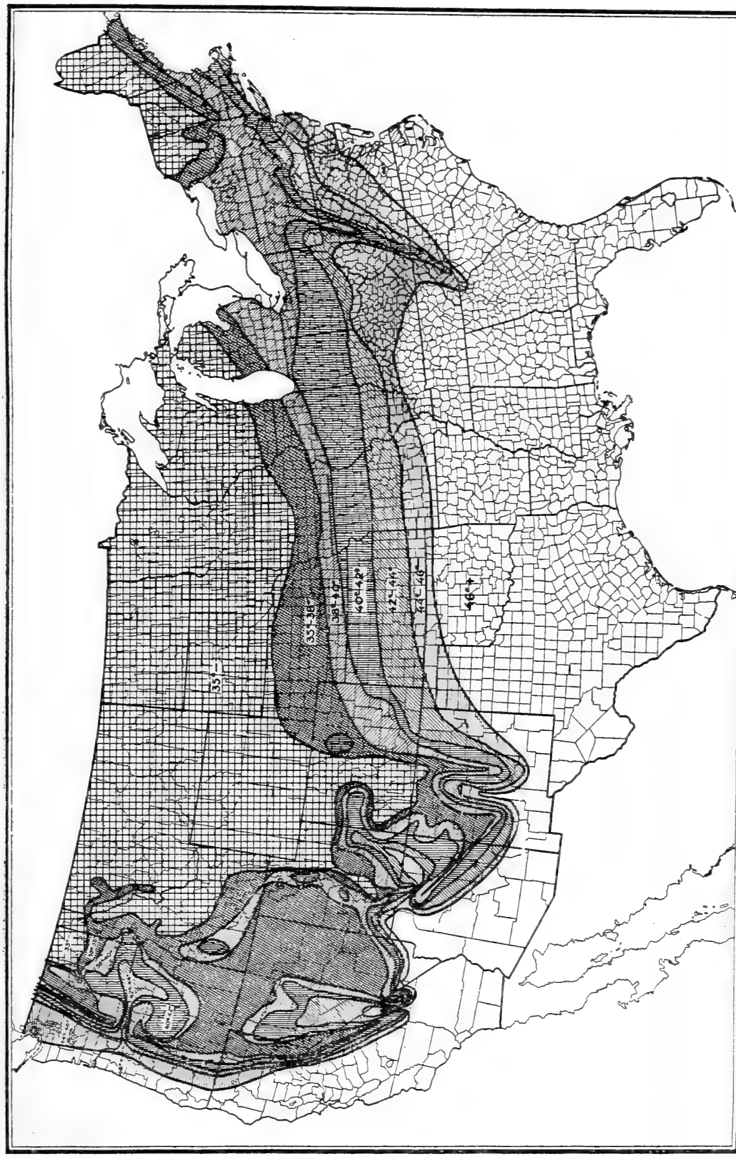


FIG. 27.—Map of the United States, showing mean temperatures for November

difference in temperature will make a marked difference in the keeping quality of apples in common storage.

In the Pacific Northwest wide variations in temperature exist within relatively narrow limits because of abrupt changes in the topography of the country and of the marked influence of coast winds. In Figure 28 is shown a somewhat enlarged map of this territory. It should be emphasized, however, that in regions such as the Pacific Northwest or the Appalachian Plateau in the Eastern States it is important for the individual grower to know the temperatures prevailing in his own district in order to determine the efficiency of common storage. Figures 27 and 28 give a basis of comparison, but it is not possible in such a map to give the detailed effects of varying conditions of elevation.

A territory having a mean prevailing temperature of about 40° F. during November will probably average above 50° in October and will be close to 30° for the December mean. The data presented in Figure 27 are based on the United States Weather Bureau records for

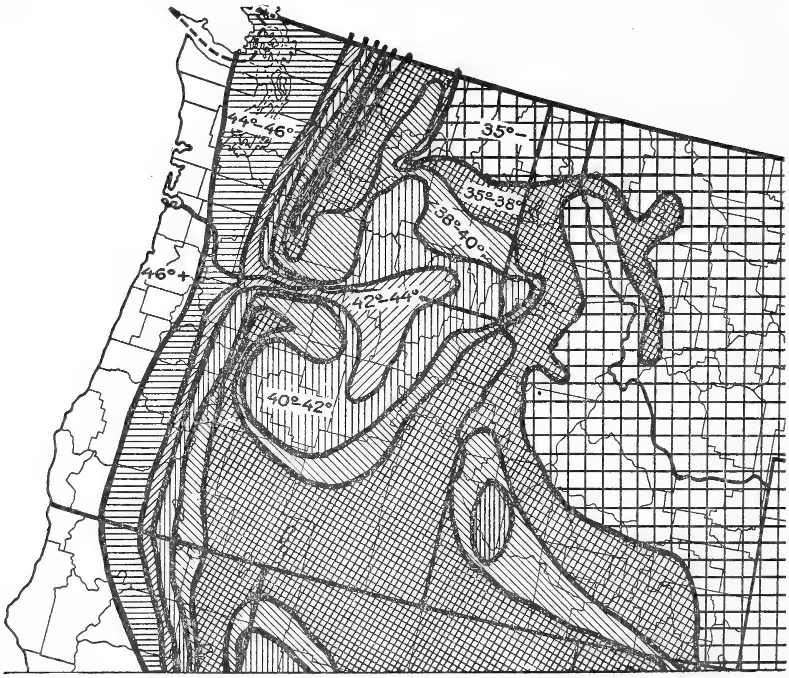


FIG. 28.—Map of the Pacific Northwest, showing mean November temperatures

many years and represent about the average condition to be expected. It should be emphasized that particular seasons will vary considerably from this mean, some ranging above and some below the averages here given. The data give an indication, however, of what the apple grower in different sections of the United States can expect in November temperatures, thus affording a basis of comparison between the different apple-growing sections.

TESTING COMMON-STORAGE HOUSES

The fact that the average temperatures prevailing in common-storage houses, particularly during the fall months, are often somewhat above the mean of the prevailing outdoor temperatures, when, with good management, it is possible to obtain temperatures equal to or slightly below the mean of those prevailing outdoors, affords an excellent means of testing the performance of common-storage houses. The operator of a common-storage house should provide himself with two maximum-minimum thermometers. One of these should be placed outside the storage house at a point where the sunshine never strikes and where it is not influenced by heated buildings, etc. The other should be placed in the storage room, preferably about the height of the top of the fruit. The maximum and minimum temperatures both inside and outside the storage house should be recorded daily. If at the end of a 10-day period the average of the maximum-minimum temperatures inside the house is above that prevailing outside, the storage is not performing in a satisfactory manner, in which case the trouble is due either to inadequate or poorly arranged ventilation openings or lack of care in opening and closing the ventilators to take advantage of the cool outdoor conditions. Inadequate insulation in aboveground storages may also be a factor. If temperatures equal to the mean of those prevailing outdoors are obtained, it may be considered that the storage is giving satisfactory service in view of the climatic conditions under which it is being operated. Such a test of the operation of the house should be made during the fall months, when the temperatures both inside and outside are gradually falling.

VARIETIES OF APPLES FOR COMMON-STORAGE HOLDING

The varieties of apples which may be held successfully in common storage will vary widely in different sections of the United States. As was pointed out in Part I, the same varieties ripened relatively much earlier in the growing districts having a long season, such as the Pacific Northwest, Virginia, or southern Ohio, than in the shorter growing-season sections, such as Michigan, New York, or New England. Baldwin apples, for example, which normally reach picking condition from the middle to the end of October in New York State, will reach that condition from the middle to the 20th of September in Virginia. Holding this variety in common storage in Virginia, therefore, would be impracticable, since the fruit would have to be in storage through late September and October with temperatures in Virginia ranging from 55° to 60° F. In New York, however, by picking and storing around the last of October, this variety during a normal season can be handled in common storage at temperatures averaging for the month of November somewhat under 40°. A similar condition exists with other varieties. Jonathan, for example, which ripens early in the Pacific Northwest and in Missouri and Virginia, becomes a late-ripening variety in Michigan or New England. Picking in the latter sections can be delayed until cool weather, and the variety can be handled very satisfactorily in common storage while entirely unsuited for common-storage holding in the Southern and Pacific Northwest States.

In general, it may be said that only varieties which mature late in the section in which they are grown will give satisfactory results if handled for a relatively long period in common storage. In the Michigan, New York, and New England districts such varieties would include Baldwin, Stark, Ben Davis, Northern Spy, etc. In most seasons Jonathan will also give fairly satisfactory results. In the districts with longer growing seasons, however, these same varieties ripen early while temperatures are still high and consequently are unsatisfactory for common-storage holding. The best holding varieties in these latter districts include Yellow Newtown, Winesap, York Imperial, Arkansas Black, and Arkansas (*Mammoth Black Twig*). Rome Beauty, Stayman Winesap, and Ben Davis will give results much less satisfactory than the first list. Other varieties, including Grimes Golden, Jonathan, and Delicious in the long growing season districts and Rhode Island Greening, Tompkins King, Wealthy, and McIntosh in the districts of shorter growing seasons, will become full soft in a relatively short time when exposed to temperatures prevailing in common storages at the picking season.

The data in Part II indicate that the group of varieties best adapted to common-storage holding in the districts with long growing seasons are inherently somewhat slower ripening in storage than the varieties generally grown in the northern districts. Thus Winesap, York Imperial, Arkansas Black, and Yellow Newtown ripen somewhat less rapidly at any given temperature than most varieties grown in the northern sections when held at the same temperature. Since these varieties are particularly adapted to sections having a long growing season they tend to overcome in part the advantage of cooler weather at picking time in the northern districts. Varieties like Ben Davis and Gano, however, when grown in the northern districts are generally very hard at picking time and soften slowly even in common storage. Although varieties which normally require a long growing season will not develop high quality and good size in the northern sections, they do produce fruit which will usually hold in remarkably good condition in common storage.

TIME OF PICKING APPLES FOR COMMON STORAGE

In Part I it was pointed out that the rate of softening of apples while they remain on the tree is relatively slow. Consequently, it was planned to determine whether apples ripen faster following removal from the tree than while remaining attached to the tree if held under similar temperature conditions. Tests of this kind have been conducted at Wenatchee, Wash., Hall, N. Y., and Rosslyn, Va. At the time of picking, the fruit was tested in the usual manner to determine its firmness. One lot was then picked and left in baskets or boxes in the crotch of the tree from which it had been removed. At intervals, the firmness of the fruit remaining on the tree and of that held in the boxes was determined. Some of these data are shown graphically in Figure 29.

It is apparent that all varieties studied softened much faster following removal from the tree and while held in the orchard at prevailing temperatures than while remaining attached to the tree. There was an initial period following picking when practically no softening occurred in fruit held in the orchard, just as was noted in the fruit held in different controlled temperatures of storage. Following this initial period, however, the fruit softened rather rapidly, and at the end of an interval of three weeks it was always much softer than the fruit remaining on the tree from which it was picked. Apparently, so long as the fruit remains attached to the tree it is deriving material from it which tends to check the ripening processes which set in following picking.

The fact that apples ripen faster if picked and held in the orchard than if remaining on the tree is of much importance in relation to the time of picking apples for common-storage holding. Since the temperatures in common storages generally approximate the mean of those prevailing outdoors, it follows that fruit so held softens much more rapidly than similar fruit remaining on the tree. As was pointed out in Part II, however, late-picked apples soften somewhat faster when held at high temperatures than early-picked fruit from the same trees. Consequently, it was necessary to run actual common-storage holding tests to determine whether late-picked fruit, which would be stored under cooler conditions and would have a shorter exposure to high temperatures, would be in firmer condition throughout the storage season than would early-picked fruit from the same orchard. These tests were carried on at Hall, N. Y., during the season of 1924–25. Early, medium, and late season pickings were made on several varieties, and the firmness of the fruit was tested both at picking time and at intervals during the storage season. In Figure 30 are shown data for two varieties of apples picked at different times and held in basement common storage in western New York.

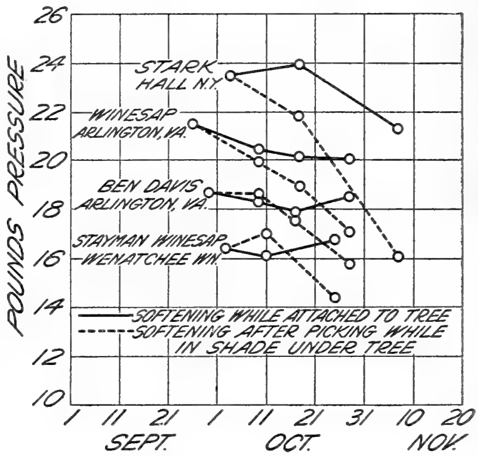


Fig. 29.—Rate of softening of apples in New York, Virginia, and Washington while attached to the tree compared with rate of softening of fruit picked and held under the tree

It is apparent that the late-picked Baldwin and Stark apples here tested gave much more satisfactory results in common storage than did early-picked fruit. The early-picked fruit was softer throughout the storage season than that picked late in the season. This result apparently was due to the fact that the late-picked fruit had a much shorter exposure to high temperatures than the early-picked lots. The average temperatures prevailing in the storage room during each 10-day period of the fall season are recorded in Figure 30.

Similar results have been obtained with other good common-storage varieties in New York. Tompkins King, a poorer keeping variety, did not give appreciably better results from late picking than from early picking. Apparently, for the better common-storage varieties, the later it is possible to pick them the better the results that may be expected. The somewhat faster softening of the late-picked fruit when held at high temperatures is more than offset by the lower temperatures prevailing in the common-storage

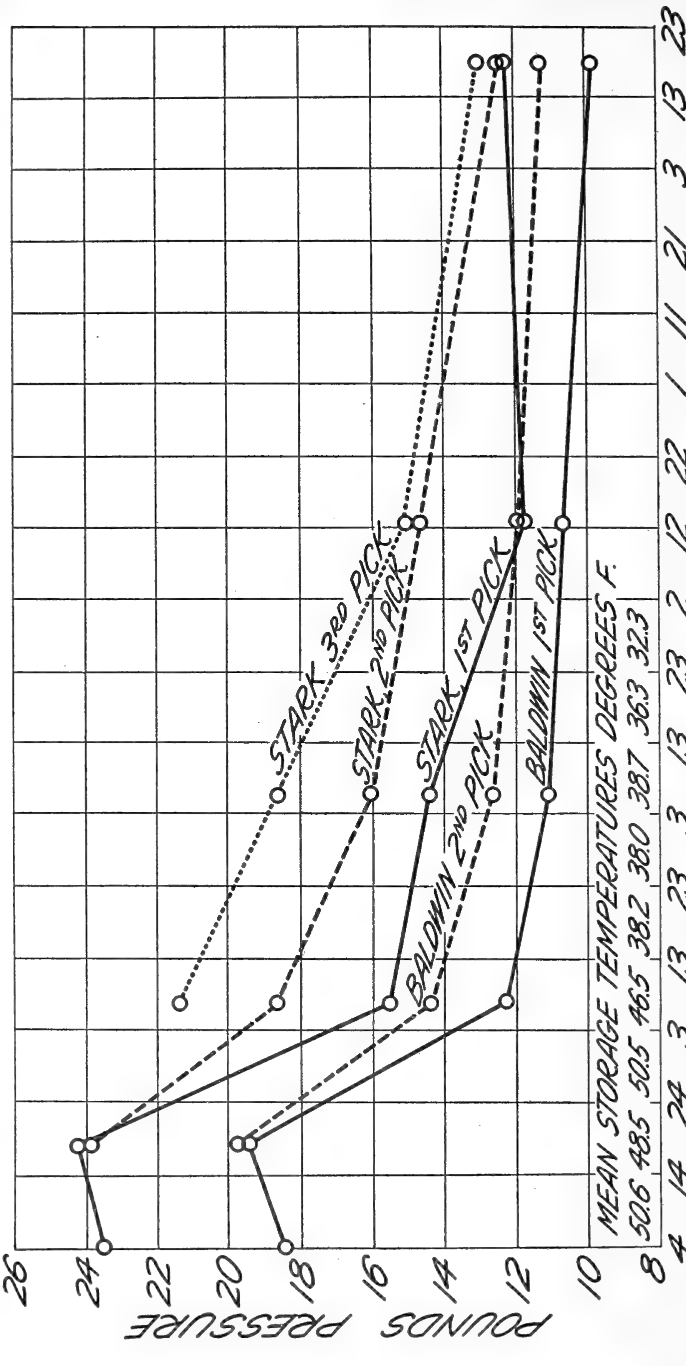


FIG. 30.—Rate of softening of Stark and Baldwin apples in an air-cooled basement storage at Hall, N. Y., in relation to the time of picking, 1924–25

rooms. For best results in common-storage holding of the better-keeping varieties, picking should be delayed as long as the fruit is holding well on the tree or until danger of freezing is serious.

As mentioned in Parts I and II of this bulletin, certain varieties of apples under certain conditions tend to develop physiological breakdown in storage. This occurs so frequently in Jonathans that it has been termed "Jonathan breakdown," although many other varieties are also somewhat susceptible to the trouble. It has been shown that this breakdown is closely associated with leaving the fruit on the trees too long and usually is particularly serious when the apples ripen early following a long growing season.

Obviously, for varieties susceptible to this trouble late picking is not feasible. Fortunately, those varieties well adapted to common-storage holding seldom are affected in this way. Breakdown of this type rarely occurs in Winesap, York Imperial, Yellow Newtown, Ben Davis, Arkansas Black, and other good common-storage varieties of the Southern or Pacific coast growing regions, or in Baldwin, Stark, Northern Spy, or Ben Davis in the Northeastern States. For varieties well adapted to common-storage holding it appears that delaying picking as long as possible will give best results.

The time of ripening of apples, which varies from season to season, is also of great importance in the handling of fruit in common storage. A season when the fruit ripens late will prove especially satisfactory. On the other hand, if the fruit matures particularly early very unsatisfactory results may be expected even from varieties which normally do well in common storage. During the season of 1921, for example, apples in New York State matured very early, and varieties such as Baldwin, which normally hold satisfactorily in common storage, softened very quickly and soon became unmarketable. In 1924 a similar condition prevailed in the Pacific Northwest, with unsatisfactory results from common storage. It is at once apparent that if apples normally picked the latter part of October are picked the first of October they are exposed to from three to four weeks of high temperatures in storage to which late-picked apples are not subjected. Consequently, poor results will necessarily be obtained in common storage when the picking season is abnormally early.

REMOVING THE FRUIT TO THE COMMON-STORAGE HOUSE

The data in Figures 29 and 30 are of particular interest in connection with the necessity of removing fruit to the storage house following picking. Fruit held in the orchard did not soften more rapidly than fruit held in common storage. That held in the orchard in shade averaged an even slightly firmer condition than fruit held for this same period of time under common-storage conditions. Since the temperatures prevailing in common-storage houses as now constructed usually are not below the mean of the outdoor temperatures and often are somewhat above the mean of those prevailing outside, it is apparent that fruit protected from rain and sunshine, even though remaining outside, is in about as satisfactory a storage condition as fruit placed in the average air-cooled storage.

On the other hand, when cool weather is prevailing outdoors, fruit in the open will cool more readily than in storage. If apples can be protected from rain and sunshine, it is well to leave them exposed to the outdoor temperatures until thoroughly cooled before placing in common storage. Unless such an outdoor storage is available, however, it is preferable to remove the fruit rather promptly to the storage rooms, leaving it standing outside overnight to cool as much as possible.

When the fruit has been placed in storage, careful attention should be paid to the ventilation of the building in order to obtain the lowest temperatures possible. A difference of even 3 or 4 degrees in the temperature at which the fruit is held makes a marked difference in the rate of softening of the fruit. The best results from handling apples in air-cooled storage will be obtained by having a well-ventilated storage room, by storing only varieties well adapted to holding at relatively high temperatures, and by delaying the picking of these varieties as long as possible. Varieties with a shorter storage season can be held successfully for a relatively short time, but the limitations of the different varieties should be clearly recognized. When particularly early-ripening seasons occur, as they do at intervals in practically all apple-growing sections, it should be recognized that common storage will prove less satisfactory than usual for the fruit, and relatively more of it should be handled through cold storages if they are available. When late-ripening seasons occur, common storage will prove even more satisfactory than normal in any particular section.

HANDLING APPLES FOR COLD STORAGE

In artificial cold storage temperature control is independent of outside conditions, and if adequate refrigeration is available the fruit can be cooled promptly to the temperature most desirable for holding. Consequently, somewhat different considerations will prevail relative to the handling of the fruit.

TIME OF PICKING

Apples for cold storage should be fairly well matured when they are picked, both to obtain highest quality and appearance and to reduce the occurrence of storage scald. The latter development can be greatly reduced by the use of oiled paper (*2*, *3*), but the control will be more effective, particularly in barreled apples, if the fruit is well matured when picked. The data in Figure 24 show that fairly late picking does not result in more rapid softening in fruit held at 32° F. In general, apples for cold storage should not be picked before they show a decided yellow cast in the ground color or until they are beginning to loosen on the tree.

From the results that have been obtained, it seems fairly certain that a great many apples grown in the eastern section of the United States are picked too early, either for common or cold storage, to obtain best results. In cold storage, an equally firm fruit of better color and flavor and with less tendency to scald will be obtained from later picking than from that now generally practiced. In common storage late picking will give not only better flavored fruit but also fruit in a firmer condition throughout the storage period.

MOVING THE FRUIT TO STORAGE

It is of fundamental importance that apples intended for cold-storage holding be moved to the storage rooms as soon as possible after picking. As was pointed out in Part II, 1 day at 70° F. will result in as much softening in most varieties as will 10 days at 32°. Temperatures of 60° to 70° often prevail at picking time, so a delay of a week or 10 days in getting the fruit into storage will often decrease the holding period two to three months. The delay between time of picking and the placing of the fruit in cold storage should be reduced as much as possible.

HOLDING CONDITIONS IN COLD STORAGE

After the fruit reaches the storage rooms, it should be cooled as promptly as possible. Sufficient refrigeration should be available to reduce the temperature of the fruit to from 30° to 32° F. within two or three days of the time it is placed in storage. There is no possibility of cooling the fruit too rapidly, and the ripening processes are not delayed until the temperature of the fruit is actually reduced.

After being cooled, apples from most sections of the United States should be held at 30° to 32° F. An exception should be made to apples grown in the Pajaro Valley of California (*1*), since storage of this fruit at 35° to 38° is necessary to prevent one type of internal browning or breakdown. Apples from all other sections of the United States, however, generally give best results if held at 30° to 32°.

A humidity of about 85 to 88 per cent saturated is ideal for the apple-storage rooms. This is sufficiently high to prevent shriveling in the apples. At humidities higher than 85 per cent mold growth may develop, although a slight mold on the boxes and barrels is not harmful.

The length of time apples can be held successfully in cold storage will vary with the variety. Figures 10 and 11 show about how much time different varieties require to reach full eating soft condition at 32° F. It is apparent that the better keeping varieties, such as Winesap and Yellow Newtown, can be held in firm condition until June, making it possible to have apples available every month in the year.

To hold apples in cold storage successfully, it is essential that the fruit be well matured when picked, be moved promptly to cold storage, be cooled quickly and held at a low temperature, and be removed from storage when the variety has reached full eating soft condition. After they reach this condition, apples rapidly deteriorate in flavor and appearance.

SUMMARY OF PART III

The commercial apple crop of the United States is handled largely in air-cooled storage houses which depend on ventilation with cold outdoor air for cooling and in cold storage where cooling is by mechanical means.

The difference in results between the two methods is due almost entirely to the variations in temperature prevailing in the two types of storage.

Actual temperature records obtained in many types of air-cooled storage rooms in various sections of the United States show that mean temperatures in common-storage rooms during the cooling fall months rarely average below the mean outdoor temperature for the same period.

Mean November temperatures for the United States are shown on an isotherm map. October temperatures will average about 10 to 12 degrees above and those for December about 10 degrees below those given for November.

It is easily possible to determine whether or not any air-cooled apple-storage house is performing satisfactorily considering the prevailing outdoor temperature. Mean temperatures inside should equal those outdoors.

Late-ripening varieties in any district are usually suitable for common-storage holding. Varieties fairly hard at picking time and softening slowly at temperatures around 40° F. will prove most satisfactory. Varieties giving good results in Michigan, New York, or New England may be entirely unsuited for common storage in the southern or Pacific-coast apple sections.

Apples soften much faster in common storage or if picked and held in the orchard than while remaining on the trees. For best results in common storage, the picking of most varieties should be delayed as long as the fruit is holding on the tree fairly well or until there is danger of freezing. Exception should be made of the Jonathan when grown under long growing-season conditions. Late picking of good common-storage varieties results in a firmer and higher quality of fruit in storage.

Seasons when the fruit ripens early will prove very much less satisfactory for holding apples in common storage than will normal seasons, and seasons when apples are late ripening will prove particularly satisfactory for common-storage holding.

Fruit intended for common storage does not soften faster standing in a shady spot protected from rain than in the ordinary common storage. Consequently, the fruit should stand outside the storage until well cooled, if a sheltered place is available.

Careful attention to the ventilation of the storage rooms is essential to the maintenance of low temperatures. A difference of even 2 to 4 degrees in temperatures obtained will markedly influence the way the fruit holds in storage.

Fruit intended for cold storage should be well ripened on the tree, which results not only in better flavored fruit with better color but also in fruit much more resistant to storage scald.

Following picking, the fruit should be removed to the cold-storage rooms as soon as possible. If the weather is warm every day's delay in cooling the fruit will reduce the possible storage life 8 to 10 days. Even with relatively cool weather each day's delay will result in a four or five day reduction in possible storage life.

When the fruit reaches the storage room it should be cooled as quickly as possible to from 30° to 32° F. and maintained at that temperature. The softening of the apples is retarded only in proportion as the fruit itself is cooled down.

A humidity of at least 85 per cent saturated should be maintained to prevent shriveling of the more thin-skinned varieties.

The fruit should not be held in cold storage beyond the time required for it to reach a condition soft enough for prime eating, which varies widely with different varieties.

LITERATURE CITED

(1) BALLARD, W. S., J. R. MAGNESS, and L. A. HAWKINS.
1922. Internal browning of the Yellow Newtown apple. U. S. Dept. Agr. Bul. 1104, 24 pp., illus.

(2) BROOKS, C., J. S. COOLEY, and D. F. FISHER.
1923. Oiled wrappers, oils and waxes in the control of apple scald. *In* Jour. Agr. Research, vol. 26, pp. 513–536, illus.

(3) ——— and J. S. COOLEY.
1924. Oiled paper and other oiled materials in the control of scald on barrel apples. *In* Jour. Agr. Research, vol. 29, pp. 129–135.

(4) BURROUGHS, A. M.
1922. Changes in the respiration rate of ripening apples. *In* Proc. Amer. Soc. Hort. Sci., 1922, pp. 225–235.

(5) CLARK, W. B.
1917. A sampling press. *In* Jour. Indus. and Engin. Chem., vol. 9, pp. 788–790, illus.

(6) CORBETT, L. C.
1917. Color as an indication of the picking maturity of fruits and vegetables. *In* U. S. Dept. Agr. Yearbook 1916, pp. 99–106, illus.

(7) DALY, P. M.
1925. A preliminary report on Jonathan breakdown. *In* Sci. Agr., vol. 5, pp. 155–165, illus.

(8) GORE, H. C.
1911. Studies on fruit respiration. U. S. Dept. Agr., Bur. Chem. Bul. 142, 40 pp., illus.

(9) HARTMAN, H.
1924. Studies relating to the harvesting and storage of apples and pears. Oreg. Agr. Exp. Sta. Bul. 206, 32 pp., illus.

(10) MAGNESS, J. R., and A. M. BURROUGHS.
[1923]. Studies in apple storage. *In* Storage Investigations, 1921–1922. The Marble Laboratory Inc., pp. 17–98, illus. Canton, Pa.

(11) ——— and H. C. DIEHL.
1924. Physiological studies on apples in storage. *In* Jour. Agr. Research, vol. 27, pp. 1–38, illus.

(12) ———
[1924]. Preliminary report upon the influence of climatic conditions on the ripening processes in apples. *In* Proc. Soc. Hort. Sci., 20 (1923), pp. 108–113, illus.

(13) ——— and G. F. TAYLOR.
1925. An improved type of pressure tester for the determination of fruit maturity. U. S. Dept. Agr. Circ. 350, 8 pp., illus.

(14) MATHEWS, A. P.
1916. Physiological chemistry. Ed. 2, 1,040 pp., illus. New York.

(15) MURNEEK, A. E.
1921. A new test for maturity of the pear. Oreg. Agr. Exp. Sta. Bul. 186, 28 pp., illus.

(16) PHILLIPS, H. A.
1922. Effect of climatic conditions on the blooming and ripening dates of fruit trees. N. Y. Cornell Agr. Exp. Sta. Mem. 59, pp. 1379–1416, illus.

(17) RAMSEY, H. J., A. W. MCKAY, E. L. MARKELL, and H. S. BIRD.
1917. The handling and storage of apples in the Pacific Northwest. U. S. Dept. Agr. Bul. 587, 32 pp., illus.

(18) WARD, R. D.
1922. Some characteristics of United States temperatures. *In* Mo. Weather Rev., vol. 49 (1921), pp. 595–606, illus.

(19) WHITEHOUSE, W. E.
1916. A study of variation in apples during the growing season. Oreg. Agr. Exp. Sta. Bul. 134, 13 pp.

O