EFFECT OF TEMPERATURE ON PHYSIOLOGY AND STORAGE QUALITY OF PEARS

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EFFECT OF TEMPERATURE ON PHYSIOLOGY AND STORAGE QUALITY OF PEARS

INTRODUCTION

Profitable disposal of the pear crop requires that high quality fruit be available for marketing over an extended period. This in turn demands refinement of techniques in handling and storage of the fruit. Investigators have insistently emphasized the advisability of adopting methods which ensure cooling of fruit in the least possible time and maintenance of finely controlled, uniform storage temperature. Although these recommendations are obviously sound they have lacked the compulsion of adequate experimental evidence, particularly in regard to cooling rate. It is not surprising, therefore, that in construction of cold storages, rapid cooling is sometimes sacrificed in the compromise between cost of installation and efficiency.

Cooling performance of some storages recently constructed to keep pace with expanding production shows little if any improvement over older plants. Poor design and/or inadequate refrigeration capacity have rendered these storages incapable of meeting the demands of critical periods during loading of warm fruit. The result is that cooling time may be much extended and the stabilized temperature of the fruit in some locations within the storage may be too high for long storage. This situation would be aggravated further by attempts to extend the storage period, the use of cardboard cartons for packed fruit and adoption of bulk bins for handling loose fruit.

Neither refrigeration equipment nor knowledge of its application limits achievement of desired cooling rates. The onus is on the storage owner to specify the exact requirements in the agreement with the refrigeration contractor. However, more information is required so that the value of rapid cooling can be assessed and practical limits suggested.

The purpose of this investigation was to determine the effects of cooling rate and different storage temperatures on the physiology and ultimate storage quality of Bartlett and Anjou pears.

REVIEW OF LITERATURE

In assessing effects of temperature on post-harvest physiology of fruit, it is important to be aware of some of the pecularities of the species and variety. Unlike apples, most pear varieties do not ripen normally in cold storage, but require a temperature of 60° to 70° F. to ripen with good quality. Hartman (19, p. 59) described temperatures of 35° to 45° F. as being lethal to pears. In this temperature range Bartlett, Flemish Beauty, Howell and Bosc varieties respire rapidly and assume a yellow skin color, but fail to soften. If removed to a higher temperature, pears in this condition turn brownish black with a disorder known as scald. Some varieties such as Anjou and Winter Nelis ripen slowly at 35° to 45° F. and are capable of completing the ripening process satisfactorily after removal to higher temperature.

Tindale, et al. (34, p. 20) give the following satisfactory minimum ripening temperatures: Bartlett 60°, Howell 55°, Bosc 55°, Comice 45°, Anjou 45° and Winter Nelis 37° F.

Some varieties of pears ripen slowly or incompletely at high temperature immediately after picking, but will ripen satisfactorily after cold treatment or treatment with ethylene. Hansen (15, p. 545-549) found that the effectiveness of ethylene in ripening Comice and Anjou pears decreased with increasing length of storage. Ulrich and Paulin (36, p. 603-604) reported that Passe-Crassane pears were in good condition for ripening at 18° C. after storage for 11 to 15 weeks at 0° C.

It is apparent, however, that loss of ripening ability is not related to disruption of the climacteric cycle. When pears were ripened at 65° F. immediately following harvest, Hansen (15, p. 545) found that ripening began with the onset of the respiratory climacteric and the parallel increase in ethylene production. Tindale, Trout and Huelin (34, p. 14-17) observed that at temperatures unfavorable to ripening the climacteric rise may be completed with respiration rate eventually dropping sharply to zero upon the death of the fruit. In all varieties which failed to ripen at low temperature, the ability to ripen terminated considerably in advance of the climacteric peak.

The varieties Comice and Anjou which ripen at low temperature, Hansen and Hartman (17, p. 448-451) found that the climacteric occurred during a long period in cold storage, but ripening was delayed until the post-climacteric period or until fruit was removed to temperatures more favorable to ripening.

The actual cooling rate of fruit generally is most significant when the fruit is stored promptly after harvest. With good organization and cooperation between grower and storage operator, fruit can be placed under refrigeration well within 24 hours of harvest.

INFLUENCE OF COOLING RATE ON STORAGE LIFE

Hall and Sykes in Australia (14, p. 2) observed "That rate of cooling of the fruit once it is in the cool store is more important than had been realized." They found that maximum storage life of Williams (Bartlett) pears was obtained when the flesh temperature of the fruit was reduced to 45° F. within 24 hours of picking and to 35° F. within 3 days. This cooling rate is attained in practice by pre-cooling loose fruit in picking boxes before packing.

In Oregon, Hartman (18, p. 292-294) asserted that rapid cooling of pears was imperative. He recommended that pre-cooling should be used if necessary to reduce the core temperature of Bartlett pears to 32° to 33° F. within 2 to 4 days of harvest. The Refrigeration Research Foundation (38, p. 26) advised that Bartlett pears should be cooled to 29° to 31° F. within 48 hours from picking. Delaying harvest a few days was considered to be less harmful than extending the cooling period.

In British Columbia (10, p. 12) it was found that when long storage life is required, Bartlett pears should be in cold storage within one day after picking and should be cooled to a core temperature of 33° F. or lower in not more than 5 days.

Types of containers and methods of stacking in the storage affect the cooling rate of packed fruit. In studying this problem, Sainsbury and Schomer (30, p. 8-9) found that more time was required to remove the field heat from fruit in cartons than in wooden boxes. They concluded that on the basis of firmness and color, Anjou pears were slightly riper in fiberboard cartons than in wooden boxes.

Recommended cooling rates appear to be based on empirical observations. In none of the work reviewed was experimental data given which showed actual effects of different cooling rates on physiology and storage quality of fruit.

EFFECTS OF DELAYED STORAGE

Research on pear storage has shown repeatedly that the critical period in handling pears is that between picking and cold storage. The harmful effect of withholding pears from cold storage after picking, i.e. delayed storage, is supported by ample data.

Some of the earliest work on cold storage of pears stressed the advantages of prompt cooling. In 1903 Powell and Fulton (28, p. 14) reported that storage of Bartlett pears at 32° F. within 48 hours of picking was an important factor in maintaining good quality and preventing losses which were serious if storage was delayed as long as 3 days.

In reports on pear storage experiments in Oregon, Hartman and co-workers (20, p. 10), (21, p. 10), (18, p. 292-294), (19, p. 5-9) showed that potential cold storage life of pears under certain conditions may be reduced about 10 days for each day delay at 65° F. prior to cooling.

Experimental work in Australia (34, p. 8-10) revealed the serious consequences resulting from failure to cool Williams pears promptly following picking. Fruit held 3 days at 65° F. prior to storage at 32° F. had a storage life of 6 weeks compared to that of 13 weeks for fruit placed in 32° F. storage within 24 hours.

Moderate periods of delayed storage may not always cause this spectacular reduction in storage life. Sometimes the effects are apparent only after extended storage. During the course of three years work on Washington and California grown Bartlett pears, Magness, Diehl and Allen (26, p. 16-17) found that in some instances as much as six days elapsed after picking before fruit commenced softening at 65° F. They considered, however, that ripening changes were occurring during that time because delayed storage resulted in reduced storage life.

The fact that maturity of the fruit when harvested has considerable bearing on the effects of subsequent treatment may be responsible for some conflicting results of delayed storage experiments. Thus, Hartman, et al. (20, p. 10) observed that the storage life of early harvested Bosc pears was not materially affected by a seven day exposure to orchard temperatures, but fruit harvested in midseason and later had to be cooled promptly to avoid adverse effects.

In searching for a post-harvest conditioning treatment which would permit Bartlett pears to ripen satisfactorily at 45° F., Van Der Plank (39, p. 28-50) in South Africa found that onset of softening was sometimes delayed as long as six days at 53° to 75° F. The interval during which softening was delayed was related inversely to maturity. Fruit which was cooled immediately remained firmer in storage than that exposed to the conditioning treatment.

Experiments carried out over a period of five years in Australia (33, p. 1-4) produced some interesting results regarding the effects of delayed storage on respiration, softening and color change in Bartlett pears. These studies revealed a post-harvest period of low metabolic activity lasting as long as three days at 20° C. During this period respiration rate, flesh firmness and skin color gave no indication of changes indicative of ripening. Nevertheless storage life of fruit withheld from storage for periods in excess of three days was reduced significantly.

In another report from Australia (14, p. 2) the recommendation was given that Bartlett pears be placed in cold storage as soon as possible after harvest, at least within 24 hours.

Experiments in British Columbia (11, p. 217-223) demonstrated that effects of post-harvest treatment may be considerably modified by the maturity of the fruit. Keeping quality of Bartlett pears picked at the beginning of the harvest season was not adversely affected by 3 days delay at 70° F. prior to storage for 8 weeks at 32° F. Storage life of fruit picked one week later, i.e. towards the close of the recommended harvest period, was reduced by delays exceeding one day. Samples of fruit from the first picking exhibited no changes in firmness or respiration rate indicative of ripening for as long as 6 days at 70° F. This static period in fruit of the second picking was shorter and in some cases absent. In a third picking, 2 weeks after the beginning of harvest, ripening commenced within 24 hours at 70° F.

In studies on effects of ethylene on pears, Hansen and Hartman (17, p. 450-452, 16, p. 69-72) showed that the long interval between harvest and onset of ripening in early picked fruit corresponded to a period during which ethylene was produced in concentrations too low to have a stimulatory effect. Slightly immature Comice and Anjou pears under constant aeration were kept at 65° F. for thirty days without ripening. Treatment with ethylene or volatiles from ripe fruit resulted in prompt initiation of ripening.

INFLUENCE OF TEMPERATURE ON STORAGE LIFE

Fresh fruits such as pears which are not subject to cold injury have a maximum life when stored at a temperature just above their freezing point. Small differences in temperature of fruit in storage may affect metabolism to an extent not predicted by Van't Hoff's law. Metabolic activity and hence potential storage life can be revealed by measurement of respiration. In general the temperature coefficient for respiration of plant material is 2.0 to 2.5 for a temperature range of 0° to 30° C. The Q_{10} for fruit, however, is sometimes considerably greater. James (22, p. 74-75), in discussing respiratory drifts in fruits, gives the Q_{10} of initial respiration as a little over 2.0, but states that during the climacteric rise in respiration at temperatures of 2.5° to 10° C. and 10° to 22.5° C., Q_{10}'s may be in the order of 10 and 100, respectively.

Magness, Diehl and Allan (26, p. 26) considered that storage life of Bartlett pears was terminated when fruit became overripe, was affected by scald, by core breakdown, or failed to ripen satisfactorily when removed from cold storage. On this basis they showed that storage life was doubled with temperature reduction from 43° to 36° F., and at 31° F. storage life was twice that at 36° F.

Tindale and associates in Australia (34, p. 7) found that in the range of temperature from 30° to 45° F. storage life of Bartlett pears decreased one-fifth for a rise in temperature of 2°. Comparable results were obtained by Hall and Sykes (14, p. 7) who stated that the average safe commercial storage life of Bartlett pears was 12, 10 and 7 weeks at temperatures of 30°, 32° and 34° F. respectively. Fidler (9, p. 173-185) reported that English grown Bartlett pears could be kept for six weeks at 34° F., 7.5 weeks at 32° F., 9 weeks at 31° F., 10 weeks at 30° F. and 12 weeks at 29° F. The temperature quotient for storage life calculated from the values given above in the range 30° to 36° F. is 7.2 to 7.5

Since the freezing point of most pears is about 28° F., a temperature of 29° to 30° is usually recommended. Hartman (19, p. 59-60) pointed out that even in well equipped plants some fluctuation of temperature is unavoidable. In plants which are not as well equipped or not efficiently operated, attempts to maintain a minimum temperature lower than 31° or 32° F. may be inadvisable.

RELATIONSHIP OF CARBON DIOXIDE PRODUCTION TO STORAGE LIFE

Since carbon dioxide is one of the products of respiration that can be readily determined, measurement of carbon dioxide production is the most common method of determining respiration rate and has been used to follow the respiratory pattern of fruits through various stages of development. During the post-harvest period, respiration measurement is particularly useful in assessing the response of fruit to storage treatment.

There is some evidence that, although only a small part of the respirable substrate of a fruit has been utilized, the storage life may be terminated after a specific amount of carbon dioxide has been liberated. Kidd and West (23, p. 93-109) found a strikingly close inverse correlation between duration of storage life of Bramley's Seedling apples and total carbon dioxide evolved, regardless of temperature. At temperatures of 2.5°, 10° and 22.5° C. the total carbon dioxide production during storage life was 12.84, 11.35 and 11.42 litres respectively.

Magness and Ballard (25, p. 814-815), though not widely quoted, were among the first to observe a quantitative relationship between carbon dioxide production and ripening processes. In their experiments, one sample of Bartlett pears was held continuously at 60° F. after harvest and another was stored 22 days at 32° F. prior to ripening at 60° F. Both samples had respired virtually the same amount of carbon dioxide by the beginning of the respiratory climacteric and subsequently the respiration increased at about the same rate. They also found the initial production of carbon dioxide higher and the increase more rapid from pears grown in regions producing fruit with poor keeping quality than from pears with good storage characteristics.

Tindale, et al. (34, p. 19) concluded that the total amount of carbon dioxide liberated during storage life of Howell, Bosc, Packham and Winter Nelis pears was very nearly the same at 32° as at 36° F. The carbon dioxide respired by Bartlett pears, however, was progressively less with increasing temperature between 30° and 45° F. They suggested that retardation of respiration might be caused by failure of this variety to ripen at temperatures below 55° F.

Allen and Claypool (2, p. 198-203) stored Bartlett pears at four levels of oxygen between 1 and 21 per cent at both 32° and 37° F. Rate of carbon dioxide production increased and storage life decreased with higher concentrations of oxygen and higher temperature, but the total amount of carbon dioxide evolved during the entire storage period was remarkably similar for all conditions. These results led to the conjecture that cumulative carbon dioxide might be a useful index of storage life.

From studies on respiration activity of McIntosh apple, Smock (31, p. 178-184) concluded that cumulative carbon dioxide output during the marketable period was about the same for fruit in controlled atmosphere storage at 40° F. as in air at 32° F. Likewise, Biale (3, p. 363-373) found that total carbon dioxide evolved by Fuerte avocados during a post-harvest period ending with the climacteric peak was approximately constant for fruit stored in several different modified atmospheres at 15° C.

Dealing with a somewhat different type of fruit, Eaks and Morris (8, p. 308-314), who were primarily interested in chilling injury, observed that at all non-chilling temperatures cucumber fruits evolved about the same amount of carbon dioxide during their storage life.

METHODS

(1) Source and Variety of Pears

All fruit used in these experiments was grown in commercial orchards in Medford and Hood River districts of Oregon. In 1957, because cold storage research facilities were not available until September 24, only Anjou pears from the late-growing district of Parkdale, in the upper Hood River Valley, were used.

In 1958 Anjou pears were obtained from the Hood River Branch Experiment Station on August 28 and from Medford Associated Cold Storage Inc. on September 11. The Experiment Station pears were picked at approximately the mid-point of commercial harvest in that area, and the Medford fruit was obtained during the latter part of the commercial harvest. Also in 1958, Bartlett pears were obtained from Sunset Orchards, Medford, on August 19, the latter part of the harvest period for this orchard.

Fruit of U. S. No. 1 grade, size 100 to 110 was used throughout excepting the 1958 Anjou pears from Hood River which were not sized. All fruit was brought to Corvallis and treatments started within 24 hours of harvest.

(2) Storage Treatments

A sample consisting of three standard pear boxes of fruit was used in each of the storage treatments described below.

(a) Cooling Rate

The term cooling rate as used here refers to the time required to cool the fruit from a field temperature of approximately 70° to 30° F. Cooling rates of 2, 4, 6, 10 and 14 days were obtained by moving the fruit successively from warm to colder storage rooms. Fruit remained at each temperature for a period of time which corresponded to actual curves of temperature reduction obtained in commercial cold storages by Sainsbury (30, p. 1-10).

(b) Delayed Storage

Delayed storage relates to the procedure of withholding fruit from cold storage for a period of time following harvest. Anjou pears in 1957 and Bartlett pears in 1958 were subjected to a temperature of 70° F. for 2, 3 and 4 day periods prior to storage at 30° F. In 1957 Anjou pears were delayed at 70° for as long as 6 days.

(c) Storage Temperatures

In 1957 Anjou pears and in 1958 Bartlett pears were stored continuously for the duration of their storage life at temperatures of 29°, 30°, 32°, 34°, 36°, 40°, 50°, 60°, and 70° F.

(3) Ripening and Evaluation of Fruit

Periodically, samples of fruit from each treatment were placed in the ripening room at 70° F. (65° in 1958) for ripening and examination. Observations were made on skin color, number of days required for ripening, flavor, texture and the number of days fruit remained in acceptable condition after ripening. The latter is sometimes designated "shelf life".

(4) Determination of Chemical and Physiological Changes in Storage

(a) Respiration Measurement

Respiratory activity of pears at 29°, 30°, 32°, 34°, 36°, 40°, 50°, 60° and 70° F. was determined by measuring carbon dioxide output of approximately 4 kg of fruit. Each respiration sample, consisting of an equal number of fruits uniform in size and free from skin damage or abnormal color, was weighed accurately. Samples in 5 gallon screw top glass jars were aerated continuously at a rate of 6 litres per hour for temperatures of 36° F. and below and at 10 litres per hour for all temperatures above 36° F. In 1957 respiration jars were placed in storage rooms maintained at the desired temperatures. In 1958 the desired temperatures were provided by water baths located in a 29° F. room and equipped with thermostatically controlled heaters and stirring apparatus.

Respired carbon dioxide was absorbed by passing the effluent air from the respiration chambers through sintered glass bubblers in 50 ml of dilute sodium hydroxide solution. Fifteen hundredths normal sodium hydroxide was used for temperatures of 29° to 36° F. and 0.3 N NaOH for temperatures of 40° to 70° F. Absorption was continued for two to eight hours, depending on the activity of the sample. Carbon dioxide content of NaOH solution was determined by hydrochloric acid titration of a 10 ml aliquot which was diluted to 60 ml with water and from which carbonate was precipitated with barium chloride. Dilution was found necessary to obtain a well defined end point with thymolphthalein indicator.

(b) Pressure Test

Firmness of the flesh of pears is a useful indicator of harvest maturity and degree of ripening following harvest. Pressure tests were made with a Ballauf tester using a 5/16 in. tip to make two punches on the pared surface of ten fruits. In this way changes in firmness of fruit receiving different storage treatments were followed throughout the storage period.

(c) Skin Color

Yellowing of pears in storage is a sign of approaching senescence and is viewed with concern by commercial storage operators. The color of all samples of pears taken from storage for pressure tests was evaluated by comparison with the U. S. Department of Agriculture standard ground color chart for apples and pears.

(d) Pectin

Soluble pectin was determined by precipitation as calcium pectate according to the method of Carre and Haynes (4, p. 60-69). Sectors from each of the ten pears used for the pressure test were ground in a food chopper and the juice pressed out through several layers of cheese cloth. About 250 ml of this juice was centrifuged to remove suspended material. Following the addition of 200 ml of distilled water and 100 ml of 1 N sodium hydroxide to 100 ml of centrifuged juice, the mixture was left to stand overnight. Fifty ml of 1 N acetic acid was then added to neutralize the sodium hydroxide and after five minutes 50 ml of 1 M calcium chloride was added to precipitate the pectin. After one hour the mixture was heated to boiling, filtered hot and washed with distilled water. The precipitate was transferred to tared fritted glass crucibles, dried at 75° C. and weighed.

(e) Viscosity

Viscosity of the centrifuged juice was determined with an Ostwald pipette kept at a constant temperature of 22° C. in a water bath as described by Date and Hansen (7, p. 218-222).

(f) Total Soluble Solids

Soluble solids content of the centrifuged juice was determined with a hand refractometer.

(g) Expressible Juice

The ease with which juice may be expressed from the pulp of pears has been shown by Date and Hansen (7, p. 218-222) and by Reyneke and Pearse (29, p. 9-22) to vary with length of storage and ripeness of the fruit. Expressible juice was determined only on Anjou pears in 1957 by the method described by Date and Hansen (7, p. 218). Juice was pressed from 1000 gm of ground fruit using a Carver press at 5000 p.s.i. The weight of juice was found by subtracting the weight of pressed pulp from 1000.

RESULTS

Comparison of Respiration Rate at Different Temperatures

In Figures 1 to 4, showing respiration rate of Bartlett and Anjou pears at different temperatures, smooth curves have been drawn to fit the points as closely as possible. This facilitated calculation of cumulative carbon dioxide production and illustrated respiratory trends more readily than by plotting the curves in conformity with each value determined for respiration. Apparent irregularity in rate of carbon dioxide production, particularly evident at low temperature, is not likely due to error in determination. Respiration studies on apples and pears generally show similar irregularities. Although a reasonable explanation for this phenomenum is not available, it has been shown that other reactions apparently fluctuate in a corresponding manner. Turner (35, p. 146-147) found that malic, citric acid and total organic acid content of Granny Smith apples during storage at 0° C. exhibited fluctuations corresponding to those of respiration rate. Spencer (32, p. 1261-1270) described the production of carbon dioxide occurring in waves during ripening and aging of tomato fruits and found that once ripening commenced, waves in ethylene production corresponded to those of respiration.

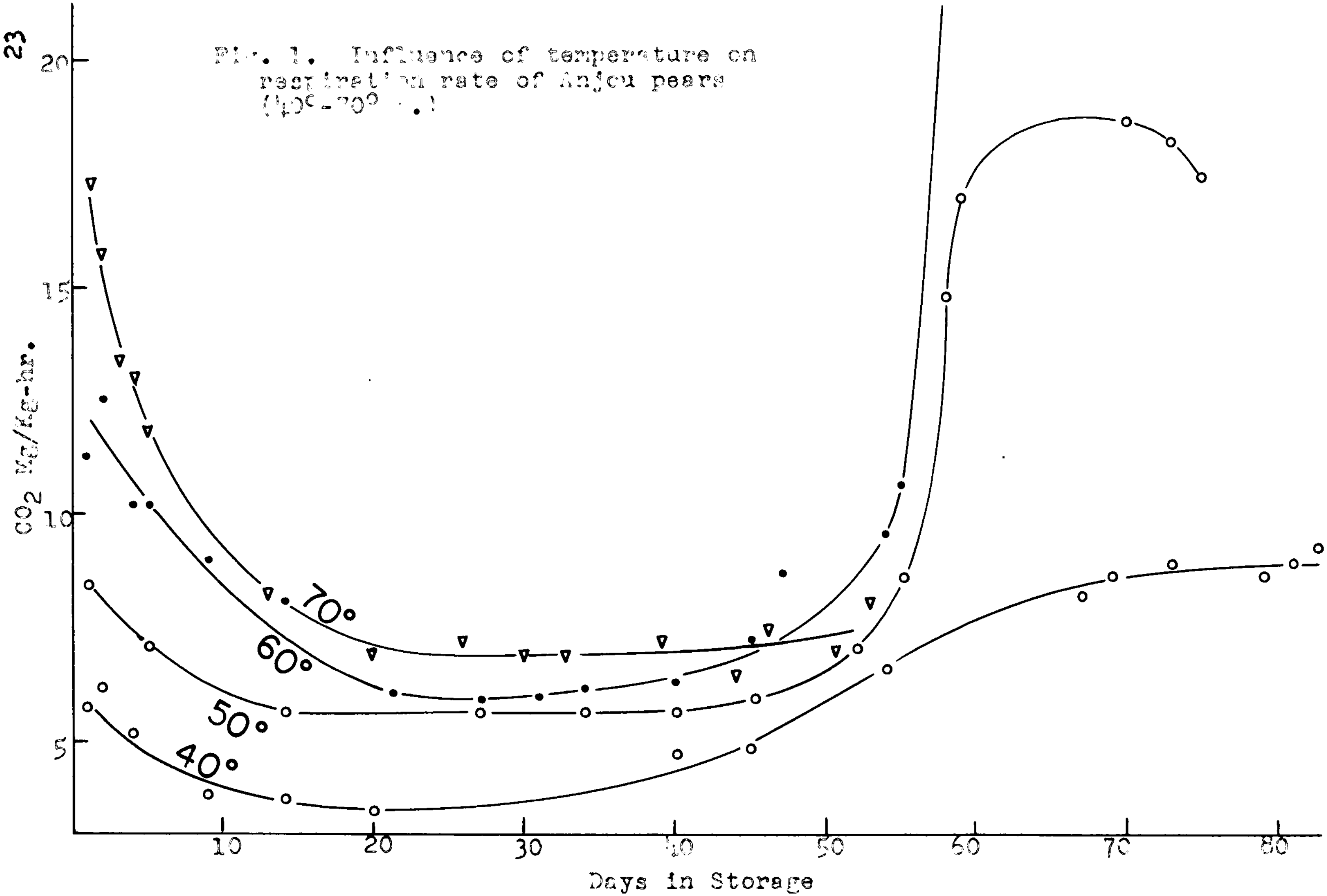


Fig. 1. Influence of temperature on respiration rate of Anjou pears (40°-70° F.)

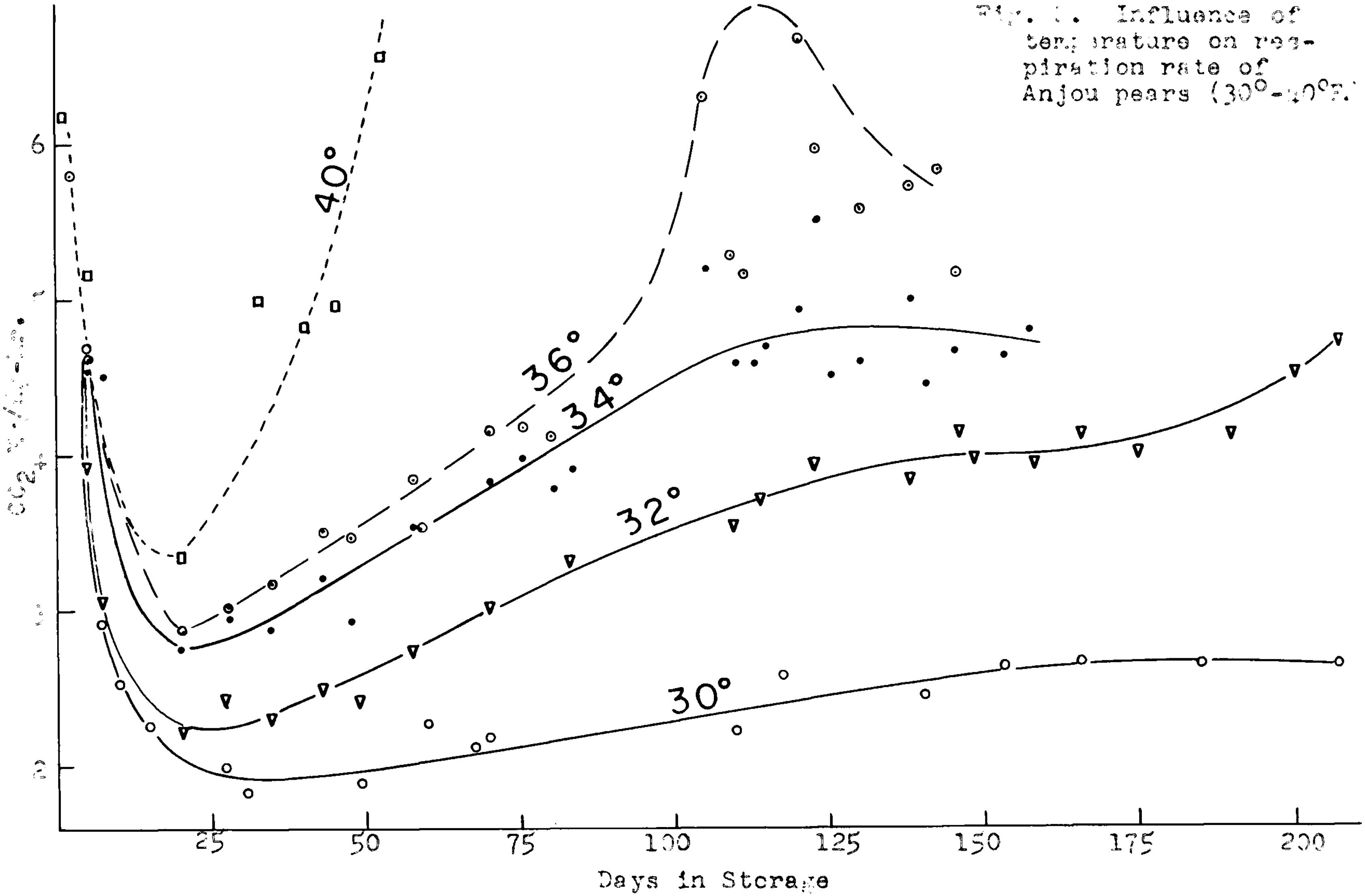


Fig. 1. Influence of temperature on respiration rate of Anjou pears (30°-40°F.)

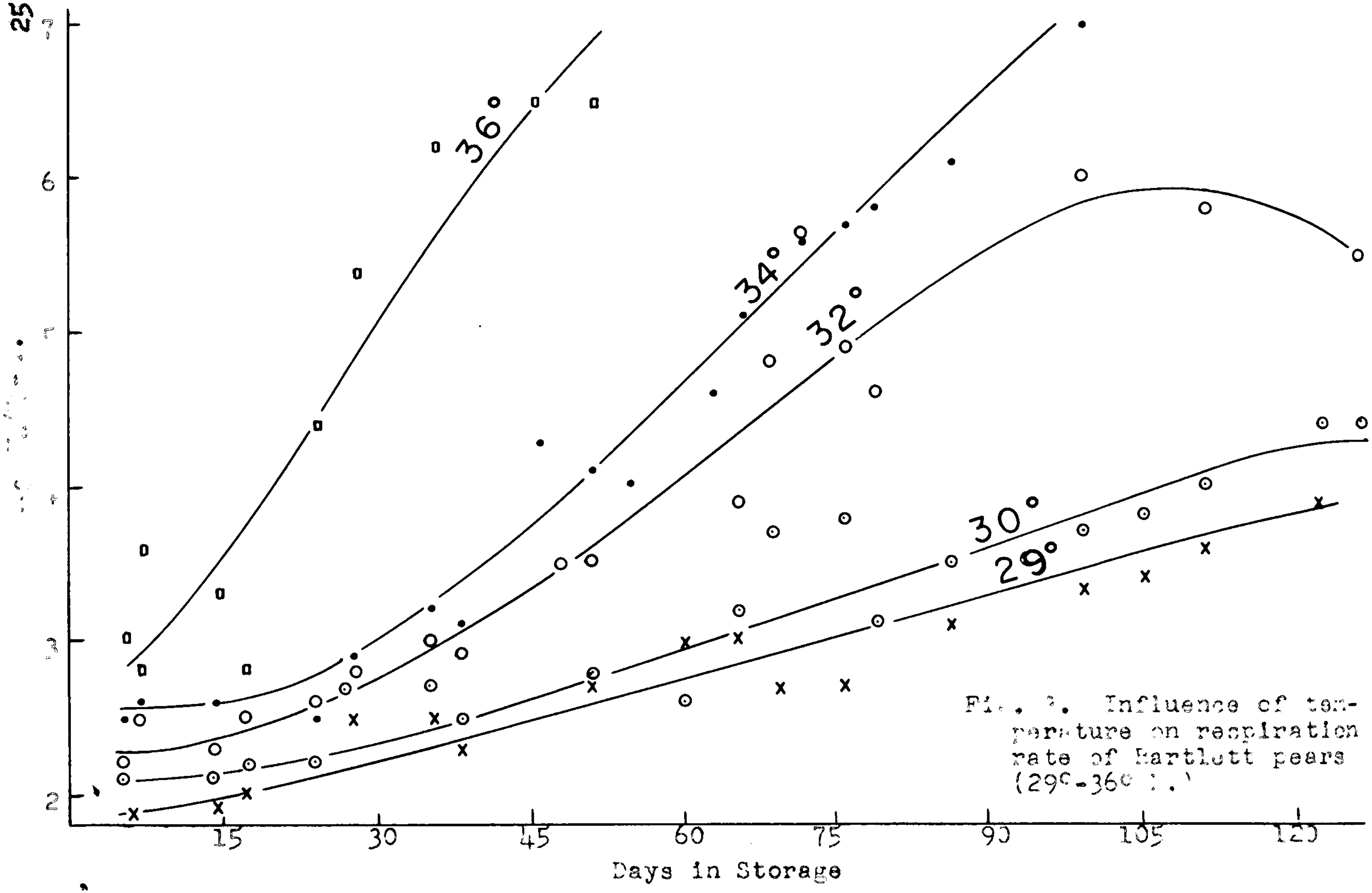


Fig. [illegible]. Influence of temperature on respiration rate of Bartlett pears (29°-36° F.)

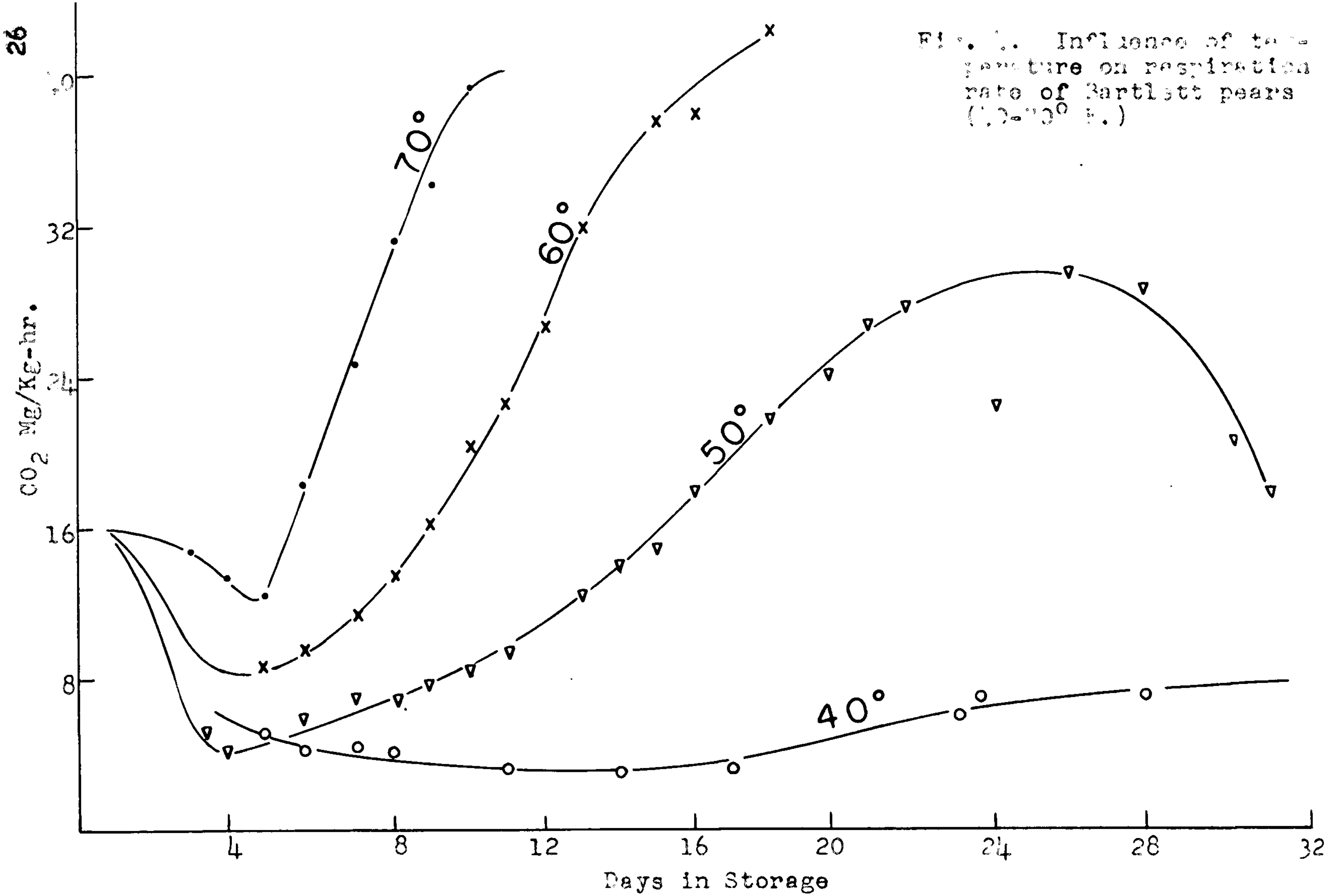


Fig. [illegible]. Influence of temperature on respiration rate of Bartlett pears (40-70° F.)

The marked influence of temperature on respiration is clearly illustrated in Figures 1 to 4. While it is convenient to depict temperature effects on respiration by Q_{10} or some other expression of rate increase per increment of temperature, values so obtained should be regarded as approximate unless restricted to a particular set of conditions. This will be apparent when one recalls the anomalous behavior of these pear varieties at different temperatures. For example, the respiratory course of Anjou pears at temperatures of 50°, 60° and 70° F. shown in Figure 1 represents a distinctly abnormal situation that sometimes may occur when Anjou pears are held continuously at high temperature following harvest. Respiration declined to a low steady state with no appearance of the climacteric rise for about fifty days. During this period there were only small differences among respiration rates at 40°, 50°, 60° and 70° F. A climacteric rise in respiration had not occurred during 53 days at 70° F. when the sample, fully yellow and firm but with some decay, was discarded. Respiration rate of Bartlett pears at 50°, 60° and 70° F. shown in Figure 4, decreased somewhat during the first four days after harvest then increased rapidly in a normal climacteric rise that commenced about the same time at all three temperatures.

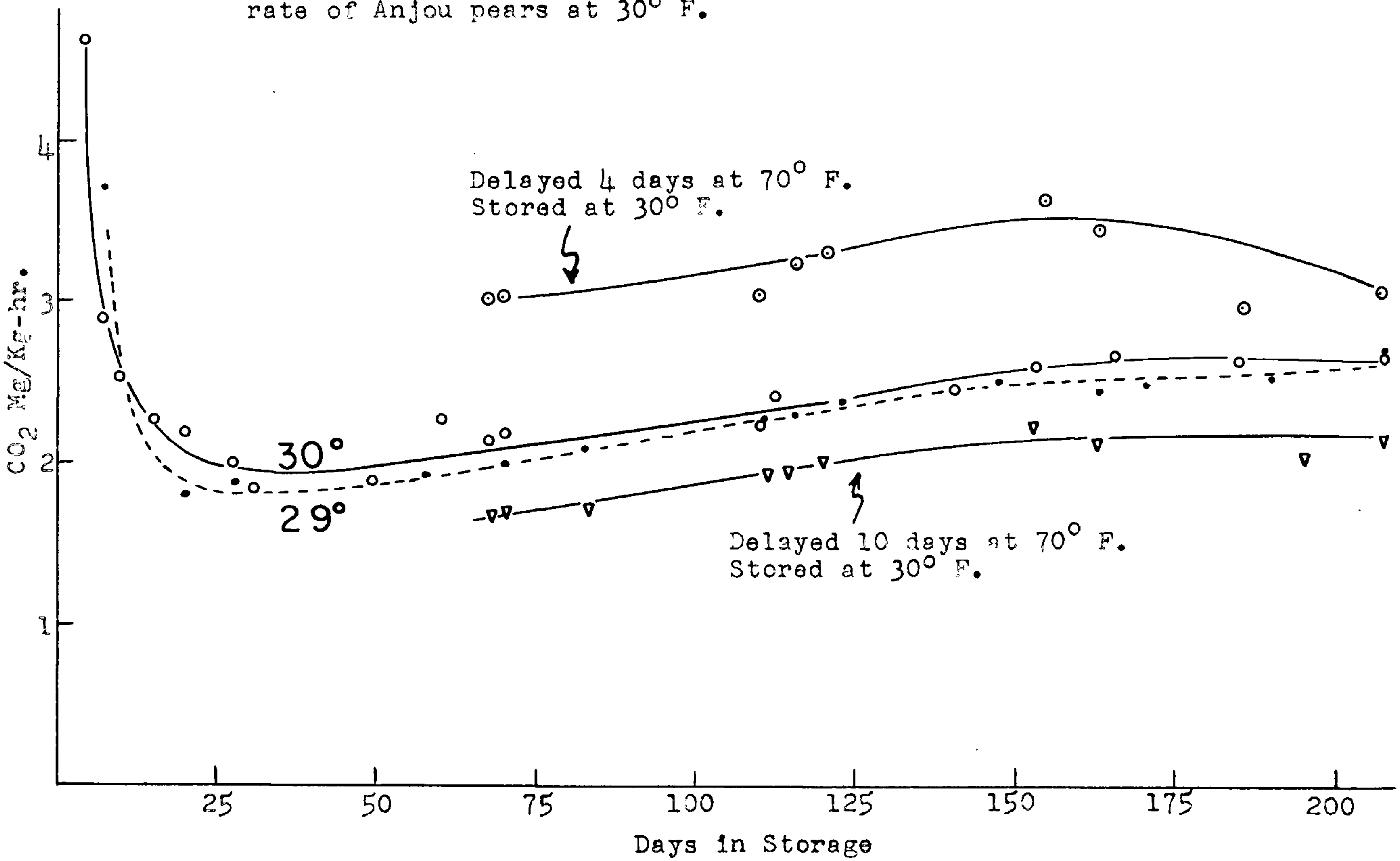
The problem of comparing respiration at different temperatures was further complicated not only by the fact that respiratory activity increased during the storage period but also because the rate of increase was greater with increasing temperature. In spite of such difficulties, it is valuable to show some numerical relationship between respiration rates at different temperatures. Thus, it was calculated that the average daily production of CO_2 per kilogram of fruit at 30° F. was 57.3 mg for Anjou and 76.0 mg for Bartlett pears. At 32° F. the values were 77.1 and 90.7 mg for Anjou and Bartlett, respectively. The respiration rate of Bartlett pears at 36° F. toward the end of storage life was about 2.25 times that of fruit stored for a comparable period at 30° F. This represents a Q_{10} of 6.7.

Respiration rate of Bartlett pears was somewhat lower at 29° than at 30°, but as shown on Figure 5 there appeared to be little difference in respiration of Anjou pears at the two temperatures.

Effect of Prestorage Treatment on Subsequent Respiration

It appears that prestorage treatment may produce a residual effect on respiration that persists throughout the storage period. It is evident from data plotted in Figure 5 that Anjou pears delayed four days at 70° F. prior to

Fig. 5. Effect of delayed storage on respiration rate of Anjou pears at 30° F.



storage respired at a considerably higher rate than comparable fruit stored at 30° F. without delay. The 10-day period at 70° during which the fruit failed to ripen apparently produced an inhibitory effect on respiration. Bartlett pears which were cooled slowly over a period of 14 days respired more actively than fruit cooled promptly. For the period shown in Figure 6, respiration rates fluctuated considerably but rate of the slowly-cooled fruit remained consistently high until about the 110th day of storage.

Gerhardt and Ezell (12, p. 13) showed in a similar study that holding Anjou pears at 65° F. for 7 days after harvest caused a reduction in respiration rate that persisted during cold storage. When Bosc pears were delayed 2 days at 65° then held at 45° for 10 days, subsequent respiration rate in cold storage was greatly accelerated. However, they did not determine if stimulatory effects could be induced by 45° temperature only.

Cumulative Carbon Dioxide Production at Different Temperatures

The difficulty in assessing total carbon dioxide production is mainly that of identifying like stages in ontogeny of the fruit undergoing different treatments. Kidd and West (23, p. 93-109) included the entire period of storage terminating in fungal rotting of the apple.

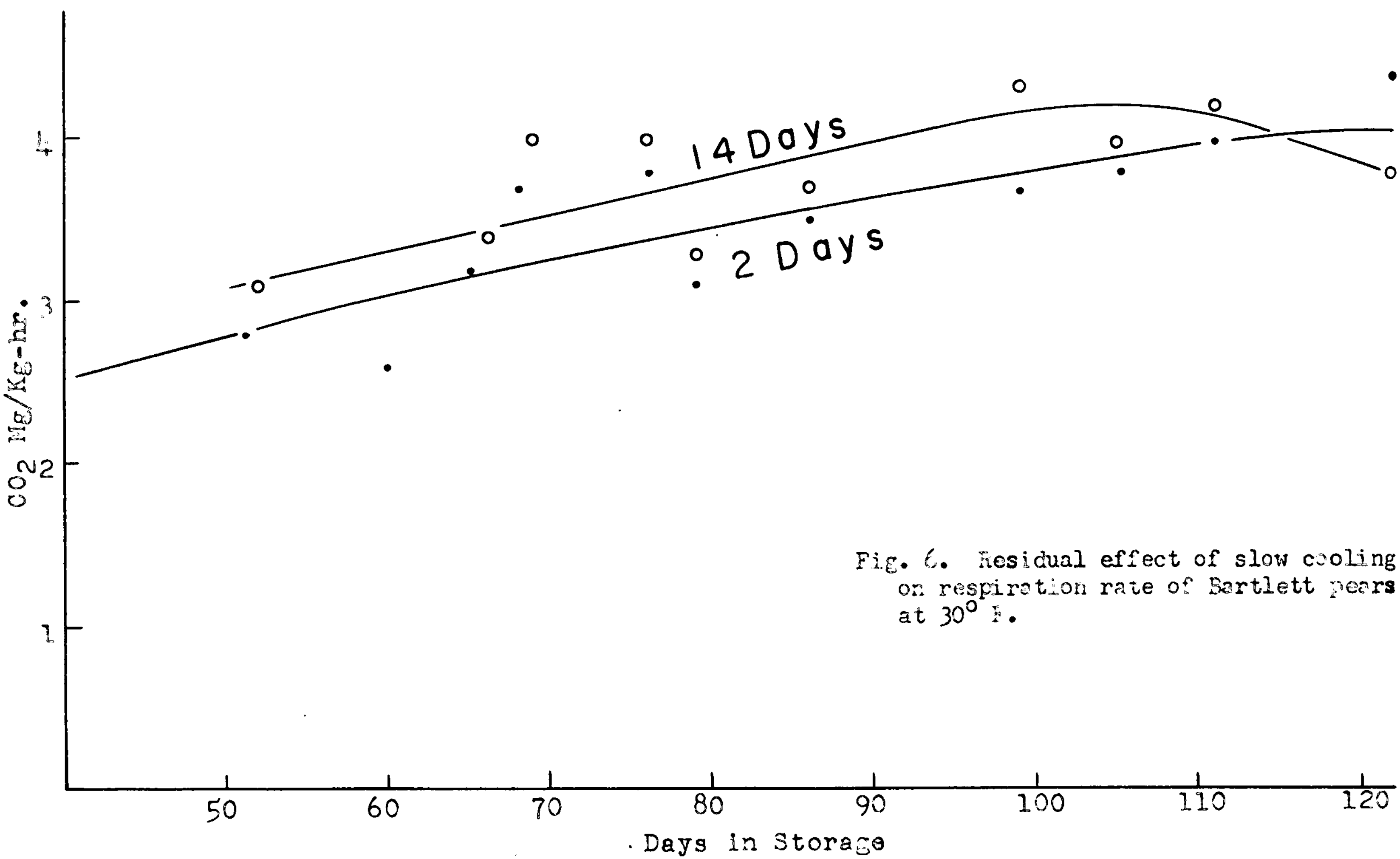


Fig. 6. Residual effect of slow cooling on respiration rate of Bartlett pears at 30° F.

Smock (31, p. 178-184) considered only the marketable period of apples, whereas Biale (3, p. 365-370) found the similarity in total carbon dioxide persisted until the climacteric peak in avocado.

An arbitrary designation of some end point is likely to be reasonably accurate for fruit at low temperature with low rate of respiration and restricted climacteric rise. At higher respiration rates and accentuated climacteric, accurate indication of the storage end point is critically important for accurate calculation of carbon dioxide output.

Tables 1 and 2 show total carbon dioxide obtained by integrating the area under respiration curves for different temperatures and storage periods. Cumulative carbon dioxide produced by Anjou pears shown in Table 1 was calculated for the period during which the fruit softened to 10 lbs. firmness. This corresponds to the upper limit of "firm ripe" condition thought to represent maximum ripening that can be tolerated safely if fruit is to be handled commercially in the usual manner. Fruit stored at 30° F. had not softened to 10 lbs. during 210 days but had reached the limit of storage during which fruit could be ripened with acceptable quality.

Normally Bartlett pears soften very little or erratically in cold storage, but yellow color develops

Table 1. Effect of temperature on cumulative carbon dioxide produced by Anjou pears during storage.

Cumulative CO_2 at Different Temperatures		
Storage Temperature	Duration of Storage	CO_2 Produced
°F	days	mg/kg.
30	210*	12,028
32	156	12,033
34	98	8,524
36	75	6,880
40	44	4,482
50	39	5,688
60	31	5,706
70	30	6,888

* Fruit had not softened to firm ripe stage but had reached the limit of marketable storage life.

Table 2. Effect of temperature on cumulative carbon dioxide produced by Bartlett pears at different periods of storage.

Storage Temperature °F	Period of Storage days	Cumulative CO_2 at Different Storage Periods: Color Change mg/kg	End of Useful Storage Life mg/kg	Ripeness or Failure to Ripen mg/kg
30	115	8,148		
	120		8,675	
	140			10,637
32	55	3,945		
	85		7,032	
	100			9,065
34	45	3,068		
	70		5,772	
	85			7,862
36	30	2,860		
	40		3,864	
	56			6,777
40	23	2,580		
	20		2,184	
	34			4,464
50	13	1,992		
	18			4,032
60	9	1,932		
	13			4,176
70	7	1,872		
	10			4,368

progressively with the loss of chlorophyll. Practical limits for commercial storage were considered to have occurred when 50 per cent of the fruit in the sample assumed a yellowish green color corresponding to stage No. 3 of the U.S.D.A. color chart. Maximum possible storage life, obviously not of practical value, was indicated by failure of the fruit to ripen properly when removed from cold storage, or by complete ripening of the fruit if stored at ripening temperatures. An intermediate storage period corresponded to the maximum length of time fruit could be stored and ripened with acceptable quality under experimental conditions. Table 2 lists cumulative carbon dioxide production for Bartlett pears according to the three storage periods described above.

It is immediately apparent from data in Tables 1 and 2 that under the conditions specified, total carbon dioxide production was considerably lower at high and intermediate temperature than at 30° and 32° F. In the temperature range 34° to 36° F., unsuitable for ripening of Bartlett pears, total carbon dioxide dropped consistently, but was fairly constant at temperatures of 40° to 70°. At 40° this fruit softened more than is generally expected, but ultimately failed to ripen normally. Anjou fruit failed to ripen under continuous storage at high temperature and exhibited abnormal respiratory patterns at 50°, 60° and 70° F.

Tindale *et al.* (34, p. 19) expressed the thought that inability of Bartlett pears to ripen at temperatures of 45 to 30° F. might be responsible for differing amounts of total carbon dioxide being liberated at each temperature. This, however, does not apply to Anjou pears.

Chemical and Physical Changes in the Fruit During Storage

Determination of firmness, soluble pectin, total soluble solids, and viscosity of juice provided objective measurement of ripening during storage. Results of analyses together with other data on ripening and quality are summarized in Tables 3 to 6.

Extractable juice was also determined on Anjou pears, but failed to show any consistent relationship to changes in firmness, soluble pectin content or ripening of the fruit. This is in contrast to results of Date and Hansen (7, p. 219) who found that extractable juice increased with ripening and was inversely correlated with fruit firmness.

Changes in total soluble solids in Anjou and Bartlett pears in all treatments were too small and inconsistent to be of value in reflecting ripening changes.

Viscosity of juice increased consistently with increase in soluble pectin until fruit was almost ripe then decreased. Dame *et al.* (6, p. 28-33) propose that decrease in viscosity may be accounted for by shortening of

Table 3. Influence of temperature on physical and chemical changes in Bartlett pears, 1958.

Storage Temp. °F	Length of Storage days	Firmness lbs.	Sol. Pectin gm/100 ml	Total Sol. Solid %	Relative Viscosity	Ripe at 65°F days	Shelf Life days	Quality
	0	16.6	.1467	12.0	1.39			
29	36	15.8	.0941	13.6	1.31	7	7	G
	64	14.4	.1417	13.4	1.39	5	3	G
	101	14.3	.1186	13.2	1.33	4	4	FG
30	45	14.5	.0684	13.7	1.29	7	7	G
	85	15.1	.1092	13.3	1.39	5	5	G
	101	14.8	.1060	14.0	1.41	4	4	G
	112	15.8	.1222	13.4	1.35	6	2	G
32	42	15.9	.1384	13.1	1.35	6	5	G
	57	14.9	.1146	13.0	1.39	6	3	G
	85	15.1	.1681	12.6	1.44	4	3	G
	101	14.4	.2434	13.2	1.35	-	0	Hard
34	28	15.3	.1049	13.1	1.35	6	6	G
	41	15.4	.1883	12.9	1.46	5	4	G
	80	12.6	.3332	13.0	1.81	4	2	G
36	28	14.9	.1078	13.1	1.36	6	5	FG, Dry
	41	15.5	.1573	13.4	1.56	4	3	F, Sharp
	52	13.4	.3936	12.9	1.90	-	-	-
	73	9.7	.5238	12.7	1.88	-	0	Scald
40	23	15.5	.2594	13.4	2.08	4	4	F, Dry
	34	9.7	.7909	13.4	3.02	-	-	-
	41	6.1	1.0966	12.8	2.98	-	0	P, Hard
50	11	15.4	.2165	13.0	1.87	-	-	-
	13	12.1	.4215	13.3	3.27	-	-	-
	15	7.7	.9139	13.0	5.00	-	-	-
	17	3.7	1.2715	12.7	5.13	-	-	-
	19	3	1.2401	12.8	3.11	18	8	P, Dry
	27		.9155	13.1	2.38	(50°F)	(50°F)	-
60	3	16.7	.1020	13.3	1.39	-	-	-
	6	15.1	.3605	13.1	2.98	-	-	-
	11	6.2	.8011	13.0	4.75	-	-	-
	13	3	.7745	12.4	3.50	13	6	G
70	3	16.4	.1489	12.5	1.39	-	-	-
	5	15.7	.2580	13.1	2.07	-	-	-
	6	10.7	.3139	12.8	2.79	-	-	-
	8	5.4	.6161	13.1	5.56	-	-	-
	10	3	1.0940	12.9	2.78	10	8	G

G = Good, F = Fair, P = Poor

Table 4. Influence of cooling rate and delayed storage on physical and chemical properties of Bartlett pears, 1958.

Treat-ment	Length of Storage	Firm-ness	Sol. Pectin	Total Sol. Solid	Rel. Vis-cosity	Ripe at 65°F	Shelf Life	Quality
	days at 30°F	lbs.	gm/100 ml	%		days	days	
Delayed Storage								
2 days	50	14.7	.1600	12.8	1.39	6	5	G
	85	15.1	.1105	13.4	1.33	4	6	G
	101	--	--	--	--	4	3-4	
	112	15.2	.1229	13.4	1.40	6	2	FG, Sharp
3 days	50	14.6	.1045	13.5	1.39	6	5	F, Sharp
	85	15.6	.1110	13.0	1.40	4	6	FG, Sharp
	101	(not all softening)				4	3	F, Sharp
	112	15.5	.1356	13.0	1.36	6	2	FP, Sharp
4 days	17	16.2	.1258	13.0	1.39	-	-	
	45	15.6	.1102	13.3	1.50	5	6	F, Sharp
	85	13.4	.2600	13.0	1.69	4	0	FP, Sharp
6 days	23	5.5	1.0888	13.9	3.46	-	-	
	38	5.4	.8700	13.7	3.59	3	3	P, Sharp
	62	3.4	.7132	13.9	2.53	3	0	P, Sharp
Cooling Rates								
2 days	Data given under 30° F. storage, see Table 3							
4 days	45	15.4	.0915	13.2	1.31	7	5	G
	85	15.5	.1186	13.7	1.42	5	5	G
	101	--	--	--	--	4	4	G
	112	15.1	.1043	13.7	1.35	6	2	G
6 days	42	15.5	.0677	13.8	1.40	6	5	G
	66	14.9	.1576	13.6	1.39	5	5	G
	101	--	--	--	--	5	2-3	G
	112	14.3	.1184	13.6	1.33	6	2	G
10 days	42	15.5	.1490	12.9	1.36	6	5	G
	66	14.5	.1576	13.6	1.39	5	5	G
	85	14.5	.0735	13.6	1.35	4	5	G
	101	--	--	--	--	5	2	FG
	112	(not all softening)				6	2	F, Sharp
14 days	42	15.0	.0879	13.1	1.31	6	5	G
	66	14.9	.1167	12.7	1.27	5	4	G
	101	15.4	.1148	12.9	1.35	5	2	FG
	112	(not all softening)				6	2	F, Sharp

G = Good
F = Fair
P = Poor

Table 5. Influence of temperature on physical and chemical changes in Anjou pears, 1957.

Storage Temp. °F	Length of Storage days	Firmness lbs.	Sol. Pectin gm/100 ml	Total Sol. Solids %	Relative Viscosity	Soft Fruit 14 days 70° %	Quality
	0	14.9	.0487	14.4	1.56	---	
29	107	15.0	--	--	--	65	F, Sharp
	196	12.5	.0763	14.3	1.62	85	F, Insipid
	220	13.6	--	--	--		P, Dry
30	54	14.5	--	--	--	0	
	107	13.8	.1068	14.5	1.54	40	F
	196	12.8	.0681	14.3	1.56	90	FP
	220	12.8					P, Dry
32	54	14.1	--	--	--	40	
	73	14.4	--	--	--	100	FG
	144	11.3	.3301	14.7	2.54	100	F
	196	8.3	.4841	14.7	2.19	100	FP, Stale
34	54	14.6	--	--	--	90	F
	108	8.7	.3551	14.9	2.35	100	F
	123	7.4	.6828	14.8	3.02	100	F
	142	5.1	.7734	15.4	2.73	100	FP, Stale
36	54	14.7	--	--	--	50	
	71	11.0	.6352	15.1	3.23	100	F
	108	5.8	.8595	15.3	2.61	100	FP
40	24	14.6	.1416	14.3	2.15	50	
	38	12.8	.1221	14.1	3.07	---	
	59	6.8	1.0941	14.3	4.03	100	FG
	104	4.6	1.2385	15.1	3.65	100	F
50	21	13.1	.3178	15.1	3.65	---	
	38	9.5	.6803	15.0	5.86	---	
	45	6.2	2.6144	14.9	11.25	---	
	59	3.7	1.6628	14.9	9.70	70	P, Dry
60	20	14.2	.3914	14.7	3.65	---	
	30	10.7	.3484	15.3	4.61	---	
	36	7.2	.8138	15.0	5.78	---	
	43	7.1	2.3195	15.4	8.50	---	
	57	3.2	1.8228	16.0	7.98	---	P, Sharp
70	10	14.8	.1548	15.2	2.21	---	
	30	10.3	.4657	15.0	4.67		
	43	7.5	1.6195	15.4	7.07	---	
	57	--	--	--	--	0	P, Sharp

G = Good, F = Fair, P = Poor

Table 6. Influence of rate of cooling and delayed storage on physical and chemical properties of Anjou pears, 1957.

Treatment	Length of Storage	Firmness	Sol. Pectin	Total Sol. Solids	Relative Viscosity	Soft Fruit 14 days 70°	Quality
	days at 30° F	lbs.	gm / 100 ml	%		%	
Delayed Storage							
2 days	107	14.2	--	--	--	90	F,Sharp
	156	--	--	--	--	--	F
	198	12.2	.1177	13.7	1.69	95	P,Dry
4 days	107	13.7	--	--	--	80	P,Sharp
	198	12.6	.1722	14.2	1.73	100	P,Stale
6 days	107	13.9	--	--	--	70	P,Sharp
	194	11.3	.1318	14.4	1.79	85	P,Stale
10 days	107	14.2	--	--	--	90	P,Sharp
	194	12.4	.1373	14.7	2.11	95	P,Stale
Rate of Cooling							
3 days	107	15.1	--	--	--	50	FG
	156	--	--	--	--	--	P,Flat
	196	12.8	.1464	14.3	1.83	--	P,Dry
5 days	107	14.9	--	--	--	40	FG
	156	13.4	--	--	--	--	P,Stale
	196	12.6	.1338	14.2	1.75	90	P,Dry
7 days	107	15.5	--	--	--	40	F
	196	11.8	.0894	13.7	1.62	65	P,Dry
11 days	107	13.9	--	--	--	90	F
	156	13.6	--	--	--	--	F,Flat
	196	11.6	.1456	13.1	1.69	85	FP,Flat
15 days	107	14.3	--	--	--	60	F
	156	14.9	--	--	--		FP,Flat
	196	12.8	.1311	14.4	1.81	100	P,Dry

G = Good
F = Fair
P = Poor

polygalacturonide chains during hydrolysis of glycoside linkage and de-estrification of methyl groups on pectin during ripening. Viscosity of juice, which appears to be closely related to soluble pectin, may prove to be a useful and sensitive indicator of ripening in storage.

Effect of Storage Temperature

Bartlett pears ripened normally at 60° and 70° F. with consistent increase in soluble pectin and viscosity, beginning approximately the same time as the respiratory climacteric. Fruit also ripened at 50° but developed a dry texture and poor quality. Both soluble pectin content and viscosity were highest when fruit was first ripe and thereafter began to decrease.

The longest period Bartlett pears could be held in storage and still retain capacity to ripen normally with acceptable quality was estimated by evaluation of fruit ripened at two-weekly intervals during the storage period. These data, designated maximum useful storage life, are given in Table 7. Onset of this point was not indicated by change in firmness, but was preceded at most temperatures by a definite increase in yellow color and by a small increase in soluble pectin and viscosity of juice. Little variation, however, occurred in soluble pectin, juice

Table 7. Influence of cooling rate and temperature on storage life of Bartlett pears

Treat-ment	Time for Color Change	Maximum Useful Storage Life	Time until Ripe or Failure to Ripen Normally
	days	days	days
Continuous Storage			
70°	7		10
60	9		13
50	13		18
40	23	20	34
36	30	40	56
34	45	70	85
32	55	85	100
30	115	120	140
29	100	100	112
Delayed Storage			
2 days	100	120	140
3 "	84	100	100
4 "	66	75	85
6 "	20	0	50
Rate of Cooling			
2 days	115	120	140
4 "	100	120	140
6 "	80	120	140
10 "	66	100	112
14 "	50	100	112

viscosity, and firmness of fruit stored continuously at 29 and 30° F.

Tindale (34, p. 11) found that yellowing of pears in storage was not always a reliable index of storage life, but suggested that if change in color was accompanied by a reduction in firmness of about 4 lbs. it would be advisable to remove the fruit. In the present studies only fruit stored at 40°, 36° and 34° F. softened to the extent of 4 lbs., at which time satisfactory ripening was not possible. Although the fruit softened to about 4.5 lbs. in storage at 40°, it failed to ripen normally before scald occurred.

It is characteristic of Anjou pears that chemical and physical changes associated with normal ripening are able to proceed at low temperature. In this particular lot of fruit, however, that stored at 29° and 30° F. showed no appreciable change in pectin or viscosity of juice, and softened less than 2 lbs. during 200 days. Degree of softening, also accompanied by increases in viscosity of juice and soluble pectin, was a useful guide to the ripening progress of fruit at 40°, 36°, 34° and 32° F. Change in firmness is presented graphically in Figure 8 and duration of storage life based on firmness of 10 lbs. is given in Table 1. It is interesting to note that rate of softening once initiated was remarkably similar at each temperature. An initial decrease followed by temporary increase in firmness of fruit stored at 34° to 30°, which has been observed on other occasions (7, p. 220), (12, p. 39), appears unrelated to pectin changes during that period. During the long period fruit remained at 50°, 60° and 70° F. without ripening normally, soluble pectin and viscosity increased slowly. None of the fruit softened properly at 70° while some of that at 50° and 60° softened eventually but remained dry and exceedingly poor in quality.

It has been observed frequently that a period of cold storage prior to exposure of pears to ripening temperature makes for uniform softening and generally improved quality. Hansen and Hartman (17, p. 441-452) observed that early picked Anjou pears required a period of cold storage or treatment with ethylene before ripening was possible. Evidence in the present work suggest that intermediate temperatures may be more effective than 29° to 30° F. in promoting ability to ripen. In early ripening tests, the first Anjou pears with normal ripening capacity were those stored at 34° to 40° F. In all subsequent ripening tests, as shown in Table 5, a portion of the fruit that had been stored at 29° and 30° F. failed to soften properly during the initial two weeks at 70° F. Ulrich and Paulin (36, p. 603-604) found that Passe-Crassane pears failed to ripen at 18° C. unless treated with ethylene or stored four weeks or more at 0° C. prior to ripening attempts. Furthermore, the longer the period at 10°, 15° or 18° C. the more injurious were the effects, with subsequent ripening following cold storage being abnormal or incomplete. More recently, (37, p. 78-81) these investigators reported that Passe-Crassane pears from the Paris district required cold treatment, but fruit from the Loire could be ripened without previous cold storage. In experimental work on Kieffer pears, Lutz and Culpepper (24, p. 13 to 29) obtained satisfactory ripening at 60° and 65° F. but ripening and softening were retarded at 70° to 80° F. even in the presence of ethylene. Experiments showed that composition of the internal atmosphere was not responsible for the inhibition.

Specific physiological on chemical changes in the fruit which might explain the chilling effects have not been determined. A report of Neal and Hulmes, however, is of interest in this respect (27, p. 142-157). They found that peel tissue of post-climacteric, but not pre-climacteric apples, decarboxylated malate vigorously; when pre-climacteric apples were cooled briefly to 3° to 5° C., however, the peel behaved like that from post-climacteric fruit.

Effect of Delayed Storage

The consequence of holding fruit at 70° F. prior to cold storage depends upon the metabolic activity of the fruit after harvest. Increase in respiration rate, soluble pectin and juice viscosity of Bartlett pears began between the 3rd and the 5th day after picking. It is apparent from Tables 4 and 7 that withholding fruit from cold storage 4 days or more initiated ripening processes that continued during storage at 30° F. A slightly increased soluble pectin content in fruit delayed 3 days persisted throughout 112 days of storage but was not sufficient to affect firmness or viscosity. Fruit delayed 4 days or more continued to soften in storage and soluble pectin and juice viscosity increased. It is evident from Table 7 that yellow color development was induced more rapidly by slow cooling than by moderate periods of delayed storage.

In view of the behavior of Anjou pears held continuously at 70° after harvest, it is not surprising that several days delay prior to cold storage had little effect on ripening. In fact, as shown in Table 6, delay periods up to 10 days caused only a slight persistent increase in soluble pectin and viscosity, insufficient to result in appreciable softening during 200 days storage. After 220 days storage, all delayed stored fruit was noticeably yellower than that cold stored immediately.

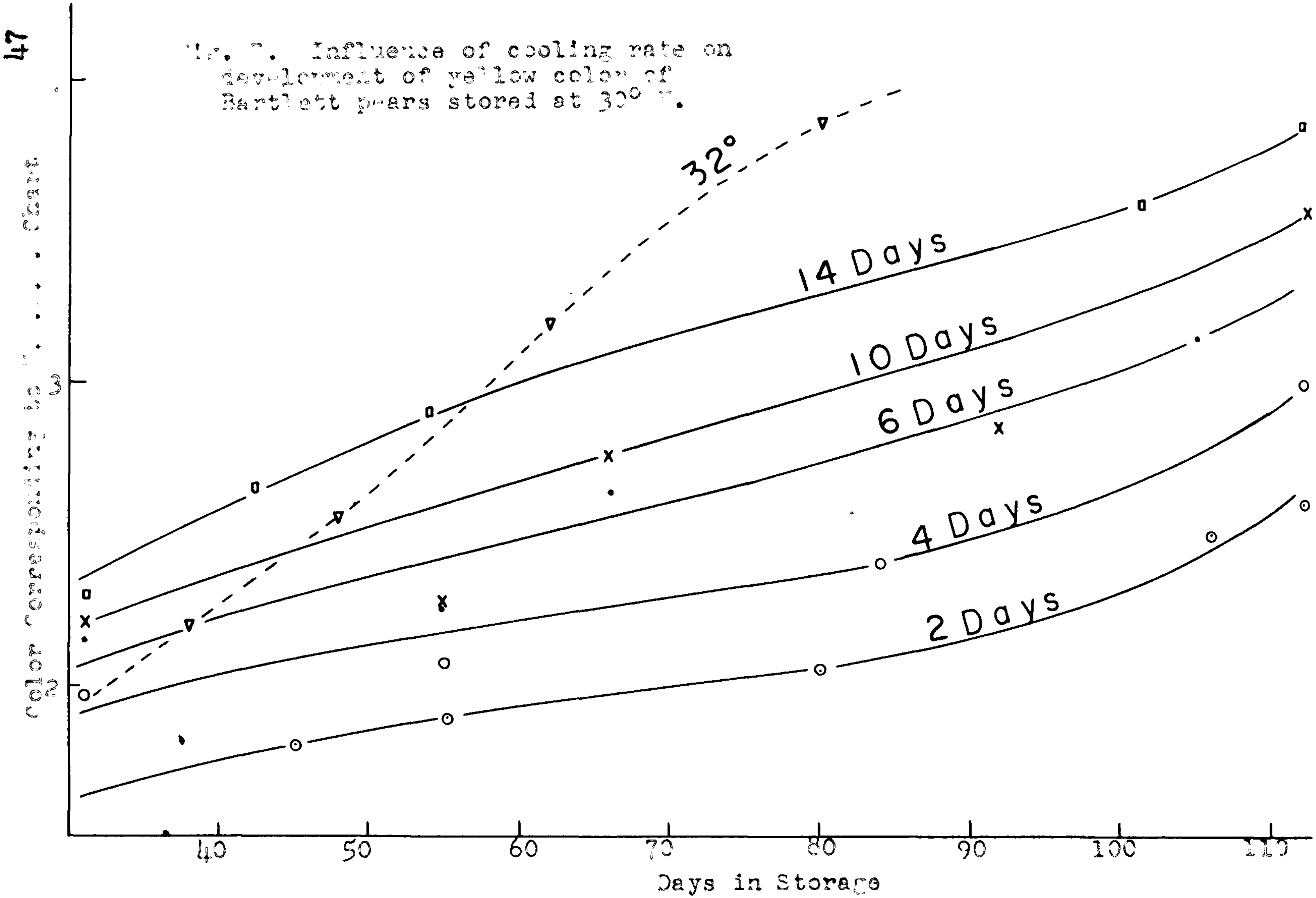


Fig. 7. Influence of cooling rate on development of yellow color of Bartlett pears stored at 30° F.

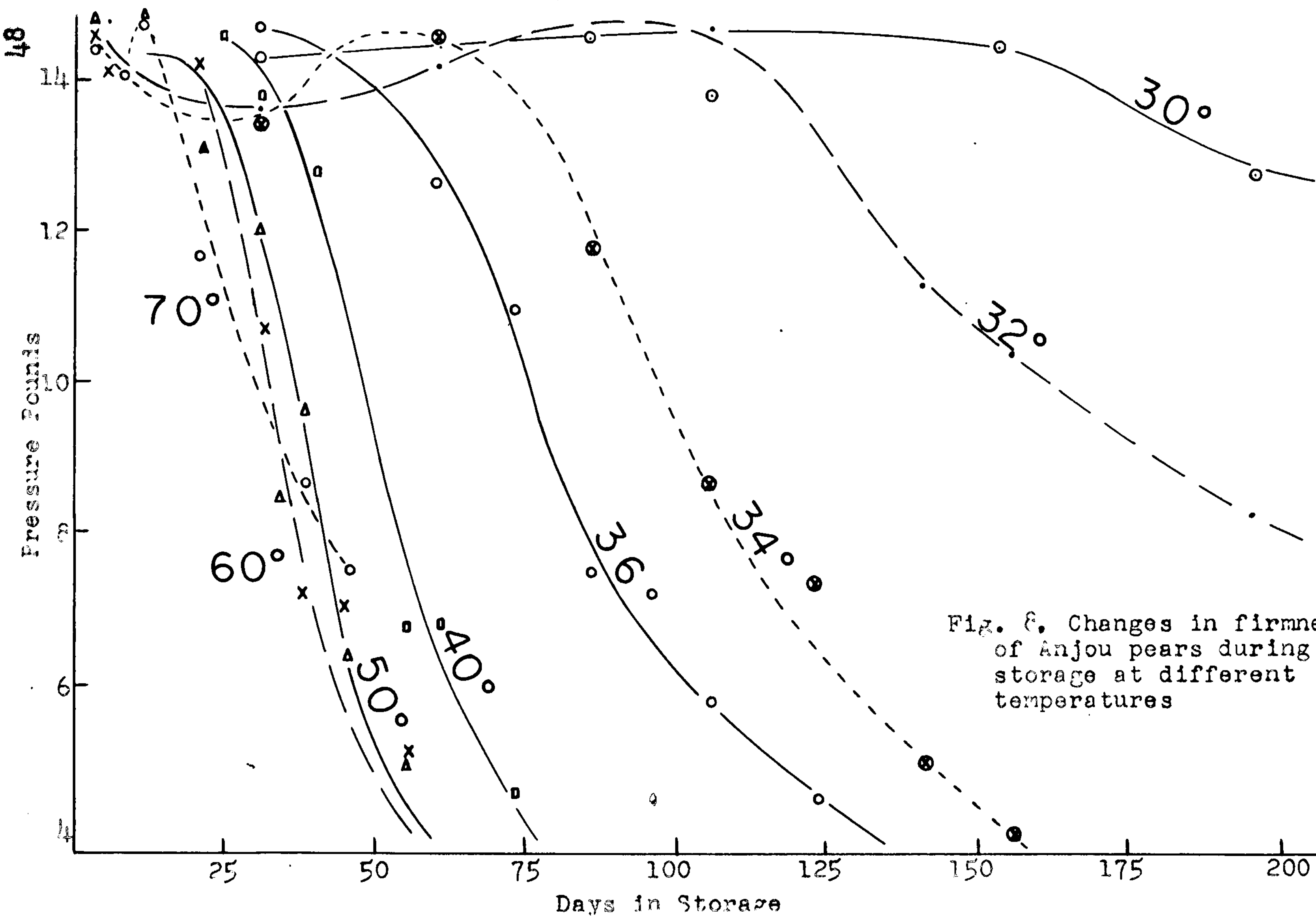
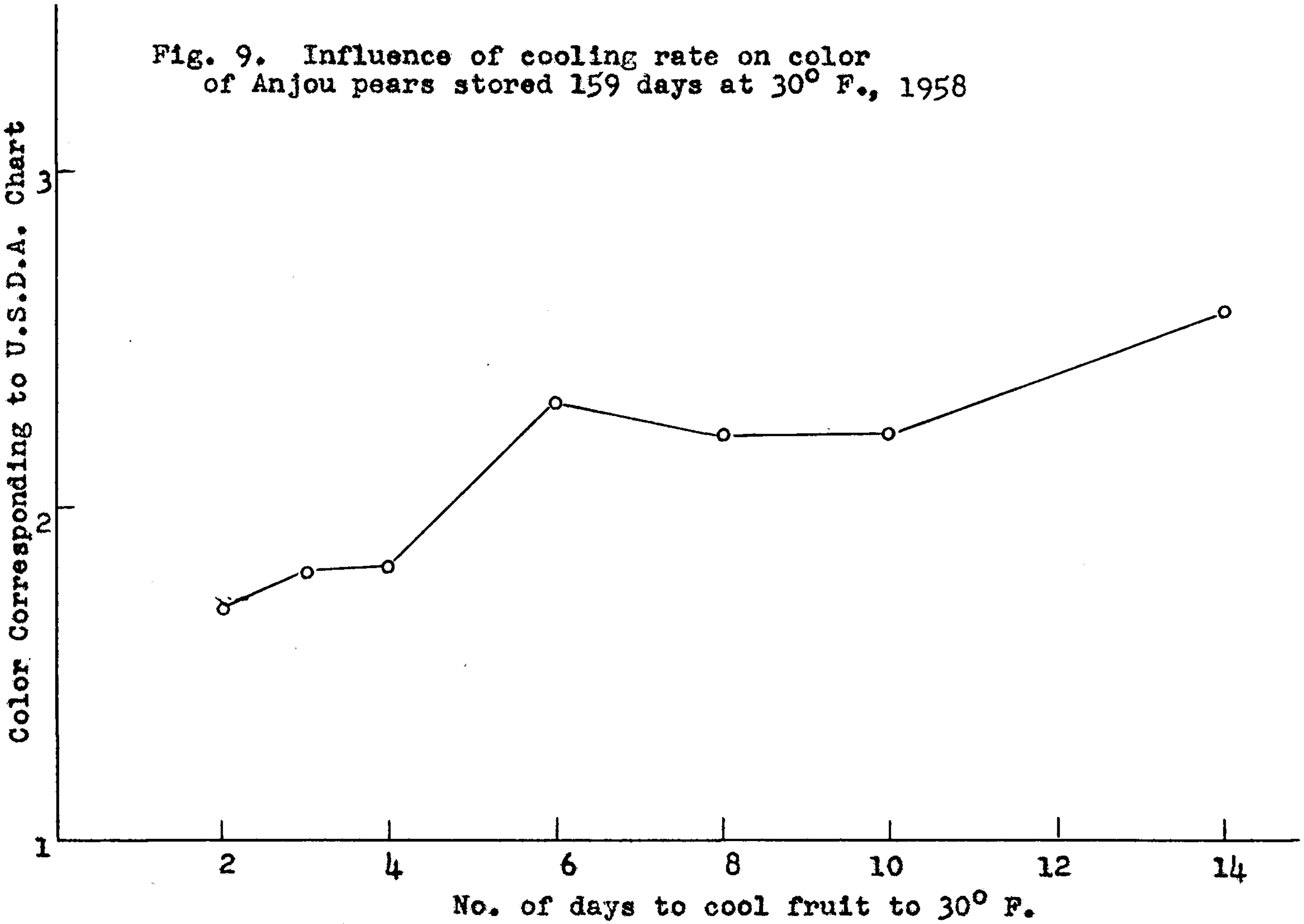


Fig. 8. Changes in firmness of Anjou pears during storage at different temperatures

Fig. 9. Influence of cooling rate on color of Anjou pears stored 159 days at 30° F., 1958



Influence of Rate of Cooling

Increase in soluble pectin and viscosity of juice which might be attributable to slow cooling was not of the magnitude associated with appreciable softening. It appears, however, that temperatures prevailing during the cooling period had a decided influence on subsequent decomposition of chlorophyll and consequent yellowing of the skin. This is strikingly revealed in Figures 7 and 9. Points on the color curves represent average color of all fruit in the sample. Each fruit was given a color score 1 to 4 by comparison with the color chart and a single value obtained for the sample by dividing the total of the color scores by the number of fruits. Yellowing of Bartlett pears in storage is frequently the forerunner of abnormal ripening and scald which may occur when the fruit is removed. Color was considered fairly advanced when the average color was 2.75, i.e., half the fruit corresponded to color plate 3 and the remainder resembled 2 to 3. A similar degree of yellowing was considered by Tindale, (34, p. 10) to prevail at about the end of storage life for fruit stored at 32° F. immediately after picking.

Data in Table 7 show considerable variation in rate of color change under different conditions. Particularly in respect to fruit cooled slowly, it appears that color indicated prematurely the approaching end of storage life. Handling fruit under commercial conditions, however, is considerably more rigorous than in this experiment. The tendency for skin marking, a brownish discoloration caused by abrasions, may be parallel to advancement of skin color, but this was not determined. In any case, fruit inspectors and others concerned in commercial handling of pears regard development of yellow color as an indication of approaching senescence.

Influence of Treatment on Storage Life and Fruit Quality

Storage life of pears is considered to have terminated when the fruit fails to ripen normally with acceptable quality at 60° to 70° F. Since this stage may not be marked by precise chemical or physical changes, it must be determined by periodic examination of fruit removed from cold storage and ripened at 60° to 70°. For the purpose of this study determination of maximum storage life was important only insofar as it provided one means of comparing effects of treatment. Some other point in the life of the fruit would be satisfactory providing progressive changes occurred in the fruit which made it possible to evaluate differences due to treatments.

Bartlett Variety. The Bartlett pears used in these experiments had exceptionally high quality and long storage life. As shown in Table 7, storage life of 120 days at 30° F. and 85 days at 32° F. was considerably in excess of the safe commercial storage life of 35 to 45 days that Hartman (19, p. 61) reported could be expected in Oregon. It is, however, comparable to experimental results with Oregon grown pears stored at 32° (21, p. 17).

The importance of temperature in pear storage is clearly emphasized by the data in Table 7. Maintaining a storage temperature of 30° F. was effective in extending storage life of Bartlett pears 40 per cent and 70 per cent over temperatures of 32° and 34° F., respectively. This is of real practical concern in plants not equipped to maintain 30° F. temperature uniformly throughout the storage.

It is sometimes stated that pears may be stored successfully at temperatures approaching the freezing point, which is considered to be 27° to 28.5° F. Furthermore, slight freezing of moderate duration is viewed with little concern. Results of this study indicate, however, that near freezing temperature may be detrimental to keeping and eating quality of pears. Ice formation was observed in some Bartlett fruit, the flesh temperature of which was not lower than 28.5° F. Although no sign of freezing injury was observed in any of the fruit examined at 65°, it was apparent that development of yellow color and deterioration of flavor proceeded more rapidly under these conditions than in 30° storage. Investigation of the physiological effects of freezing revealed that a few hours of freezing temperature after ice formation in apples (5, p. 16-20) and citrus (13, p. 132-136) resulted in an increase in respiration rate of the fruit at 0° C.

On the basis of ripening tests, it is estimated that storage life was not reduced appreciably by two days delay in placing fruit in cold storage or by extending the cooling period to 6 days. Increasing the delay period to 3 days and reduction of cooling rate to 10 or 14 days reduced maximum storage life by about one-sixth. Advancement of yellow color of the fruit cooled in 6 days, however, was sufficient to cause considerable reduction in storage life from a commercial standpoint.

In all cases, as fruit approached the end of storage life the period of time between ripening and first appearance of core breakdown (designated shelf life in Table 3) was shorter.

Flavor and texture of fruit stored at 30° to 34° F. and that cooled in 4 and 6 days remained consistently good throughout the storage period. Storage at 36° to 50° F. resulted in dry textured fruit with inferior flavor. Accompanying symptoms of abnormal ripening was an increased sharpness in flavor. This was apparent toward the end of the storage life of fruit cooled in 10 and 14 days. Fruit withheld from storage in excess of 2 days had a characteristically astringent flavor.

Anjou Variety. Complete failure of 1957 Anjou pears to ripen prior to cold storage, the weak flavor, retention of green color and slow softening in storage are characteristics of immature fruit. On the other hand, scald was not excessive even after 220 days cold storage. In any case the prevailing low quality and unresponsive nature of the fruit made evaluation of results difficult.

As shown in Figure 8, firmness changed at a fairly uniform rate at temperatures of 32° to 40°, and therefore was a useful means of evaluating the condition of the fruit. When the fruit had softened to 10 lbs., its condition was considered similar to that at the end of commercial storage life. At 30°, however, deterioration of texture and flavor indicated the end of useful storage life before much softening had occurred.

Using these criteria, Table 1 was prepared which shows the storage life of Anjou pears at the different storage temperatures. It was calculated that storage at 30° increased the life of Anjou pears 35 and 125 per cent over that at 32° and 34°, respectively.

Lack of any distinct change in condition and large variation of quality within the samples of fruit cooled at different rates made close estimate of storage life impossible. Slow and uneven ripening persisted in all lots of fruit stored at 30° or 29° regardless of prestorage treatment. After 200 days storage it was difficult to say with assurance, which fruit was in the best condition. Fruit cooled slowly, with one exception, appeared to be somewhat drier in texture than that stored immediately at 29° or 30°. After 220 days storage the condition and appearance of fruit stored immediately at 29° F., 30°, and that cooled in 2, 4, 6, and 10 days was practically identical. That cooled in 14 days was noticeably yellower than the other.

Delaying storage of Anjou pears accelerated development of yellow color and, with the exception of fruit delayed only 2 days, produced a sharply astringent, unpleasant flavor.

Full characteristic varietal flavor did not develop in any of the fruit. Up to 150 days, however, fruit stored at 32° had the best flavor, but with longer storage became stale. Fruit stored at 30° and 29° ripened with a mild almost insipid flavor.

Storage Disorders

Scald occurred in some lots of Bartlett pears, but since it commonly develops in fruit which has already lost normal ripening capacity, it was not important to this study. Anjou scald on the other hand may occur while the fruit is in otherwise good condition. Like apple scald it can be controlled by oiled wraps, at least until late in the storage season.

In 1958 Anjou pears, an unusual disorder appeared in fruit from both Medford and Hood River after relatively brief storage, preventing satisfactory evaluation of the 2nd year's work on Anjou cooling studies. Fruit with this disorder appeared entirely normal in storage but during ripening developed a dry juiceless texture and water soaked condition in the region of the vascular bundles and stone cells. This disorder, which was described by Aldrich, et al. (1, p. 93-97) who showed its relationship to high temperature and water stress, was not named at the time and has received little attention since.

The incidence of disorders in Anjou pears in 1957 and 1958 are summarized in Table 8. As might be expected, scald became more severe with a longer storage period. In the 1957 fruit, the highest incidence of scald occurred in fruit delayed 2 or 3 days before cold storage and in fruit cooled at intermediate rates. In the 1958 fruit, there was a pronounced inverse relationship between amount of scald and rate of cooling. The incidence of mealy breakdown on the other hand was directly associated with slow cooling rate. In the previous encounter with this physiological disorder (1, p. 93-97), its severity was increased by delayed storage which, however, resulted in a reduction of scald.

Table 8. Effect of treatment on physiological disorders in Anjou pears.

Treatment	Incidence of Disorder After Different Periods of Storage					
	Hood River 1957		Medford 1958			
	Scald		Scald		Mealy Breakdown	
	196 days	220 days	159 days	190 days	159 days	190 days
	%	%	%	%	%	%
29°	5	4				
30	0	11				
32	5	--				
Delayed Storage						
2 days	5	23				
3 "	10	15				
4 "	10	9				
6 "	0	7				
10 "	0	5				
Cooling Rate						
2 days	0	11	44	93	20	50
3 "	0	10	15	52	69	83
4 "	30	19	25	50	52	76
6 "	25	34	23	31	79	93
8 "	--	--	14	19	64	82
10 "	30	37	0	24	92	87
14 "	0	15	4	10	86	75

DISCUSSION

From consideration of the results obtained, it seems possible that a critical temperature zone may exist for pears between 50° and 30° F., and that exposure to this temperature range during slow cooling may have marked physiological effects on the fruit. The most impressive evidence in support of this hypothesis is seen in the comparative effects of various cooling procedures on color. Rapid development of yellow color in storage was associated with slow cooling even though fruit temperatures were below 50° F. for the greater part of the cooling period. The procedure of holding the fruit at 70° F. for 3 or 4 days then cooling it rapidly to 30° F. resulted in slower development of yellow color than cooling the fruit slowly over a 14 day period. Rapid cooling in which the temperature of the fruit was reduced to 30° F. in 2 days resulted in the least yellowing. It is evident that these results cannot be explained by comparison of cumulative degree hours to which the fruit was exposed before reaching the stabilized cold storage temperature. During the 14-day cooling period, about 2800 degree hours above 30° F. were accumulated. Beginning at the same time, fruit delayed 3 days at 70° F. had accumulated 4900 degree hours by the time it had cooled to 30° F.

Intermediate temperatures were more conducive to softening and ripening of the 1957 Anjou pears than either high or low temperature. It has been demonstrated in these experiments as well as elsewhere that ripening sometimes fails at 70° F. or is initiated after some delay unless maturity is well advanced or fruit has been chilled for a period of time. In this study, fruit failed to ripen and remained firm for more than 50 days after picking when held continuously at 50°, 60° and 70° F. Fruit that had been stored for one month at 34°, 36° or 40°, however, was capable of ripening at 70°, but fruit stored for one month at 30° and 32° had not ripened after 20 days at 70°.

Ulrich (36, p. 603-604)(37, p. 78-81) proposed that some pears have a chilling requirement which must be fulfilled before normal ripening proceeds. It is interesting to consider that this may be another example of physiological effects of cold on plant material. Treatment of the fruit with ethylene is an effective substitute for chilling in inducing ripen ing of certain varieties of pears immediately after harvest. It may seem logical to assume that ethylene or a precursor is initiated in the cold, but conditions suitable for ripening must prevail before its effects become apparent. This may be an acceptable explanation in respect to chilling effects, but it seems somewhat less applicable to the effects of slow cooling.

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