

EFFECT OF DORMANT SEASON TEMPERATURE VARIABILITY ON PEACH FLOWER BUD HARDINESS

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ABSTRACT.—Temperature variability during the dormant period of peach trees was investigated by analysis of daily temperature data for 16 years at five locations representing the continental climate of Illinois. The standard deviation was used as the criterion of temperature variability, and the daily minimum and daily maximum temperatures were the most meaningful temperature measures investigated. The magnitude of temperature fluctuations about the mean was progressively greater at more northern locations in Illinois. Southern Illinois differs from the remainder of Illinois in having relatively similar temperature characteristics affecting peach flower bud hardness during the dormant period. Fluctuations of the daily maximum temperature during the dormant period more frequently exceed the basal temperature (45° F.) for growth of peach trees at southern locations in Illinois than at northern locations. Temperature fluctuations exceeding the basal temperature are presumed to be responsible for observations of reduced dormant flower bud hardness of specific peach varieties when grown in warmer climatic regions.

Many factors (Anonymous, 1959) influence the hardness of peach flower buds to damage from low temperatures during the dormant season. In addition to the age, vigor and state of development of the plant, the following climatic factors are closely associated with the degree of hardness expressed by the plant in a specific instance: the lowest temperature attained; the rate of cooling; the duration of the low temperature period; the date when low temperatures occur and the relative stability of the temperature, which includes the magnitude, frequency

and duration of short-term temperature fluctuations.

Chaplain (1948) reported the killing point of peach flower buds fluctuated directly with temperature changes during the winter months. The greatest hardness reached by flower buds coincided approximately with the date when the rest period was broken in mid-winter. Bradford (1922) used 43° F. as the basal temperature effective for the growth of many parts of temperate deciduous tree fruit plants. However, 45° F. has been extensively used as the basal temperature in more recent phenological studies with the chilling requirement of peach buds (Lammerts, 1949).

Blake (1933) and Mowry (1962) noted that flower buds of the Sunapee, Veteran, and Triogen peach varieties were classed as hardy during severe winters and in northern localities where low temperatures were extreme. The same varieties were regarded as less hardy to cold in mild winters and in southern localities characterized by the common occurrence of temperatures above 45° F. during the dormant season. Certain other varieties were classed as hardy during mild winters and classed as tender only during severe winters. Prairie Dawn, Halehaven, and Elberta varieties were rather uniformly resistant or tender to cold in both situations.

Two possible explanations for the fact that flower buds of different peach varieties seemingly differ in their ability to withstand winter temperature fluctuations are: (1) an explanation which directly associates the temperature variability data with the biological response of the fruit trees, and (2) that solely the magnitude of temperature fluctuations, *per se*, may be responsible for the contradictory observations on dormant peach flower bud hardiness. Because no specific information on the variability of temperatures or the magnitude of temperature fluctuations was found in the literature, it became necessary to test methods and determine the variability of winter temperatures at representative locations in the continental climatic regions of Illinois.

Although Illinois presents a wide range in climatic conditions because of the length of about 385 miles, Page (1949) found that seven stations with long-term weather records were apparently representative of the temperatures in Illinois: Dubuque, Iowa; Chicago; Peoria; Springfield; Urbana; St. Louis, Missouri; and Cairo. Jeos (1960) noted that spring seemed to arrive about a month later at Freeport in northern Illinois than at Anna in southern Illinois. Baker (1936) also showed that the date when the average daily temperature rises above 45°F. occurs about four weeks later in the spring at Dubuque (April 15) than at Cairo (March 16).

Powell et al. (1960) divided Illinois into four fruit growing regions based upon the average date that a specific phenological event (such as the date of full bloom on apple varie-

ties) occurred during the growing season. Each area was about one week later in development than the preceding area from south to north. These fruit growing areas are represented by specific weather stations: Cairo for Area A, St. Louis for Area B, Springfield for Area C, and Peoria and Moline for Area D. Dubuque is included in the preliminary analyses for information at the extreme northern limit of Illinois.

METHODS OF DETERMINING TEMPERATURE VARIABILITY

For the preliminary analyses the dormant season was defined as the months with an average monthly temperature less than 45°F. The average monthly temperature is the average of the average daily temperatures during the month. The average daily temperature is the average of the maximum and the minimum temperatures recorded for the day. The dormant season of Cairo and St. Louis included the winter months of December, January and February. The dormant season for Springfield, Peoria and Dubuque included November and March in addition to the winter months. Baker (1936) presented maps showing long-term average dates when the average daily temperature fell below and rose above 45°F. and the duration of the dormant periods at the locations was obtained from these maps (Table 1). For the IBM computer analyses the dormant season for peach trees was defined as the period when the average daily temperature was continuously less than 45°F.

In the absence of literature describing suitable techniques for determining temperature variability, a

TABLE 1.—Length of Dormant Period and Variability of Lowest Temperatures Recorded at Selected Locations Representing Illinois for the Dormant Periods of 65 Years, 1881 Through 1945.

Location	Dormant period ¹			Lowest temp. °F.	Mean annual lowest temp. °F.	Sig. ref. ²	Std. dev.	Coef. var. %
	Start	End	Days					
Cairo,	Nov. 21	Mar. 15	115	-16	3	d	4.4	.95
St. Louis,	Nov. 13	Mar. 24	132	-22	-3	d	5.8	1.28
Springfield,	Nov. 8	Apr. 1	144	-21	-8	e	6.9	1.53
Peoria,	Nov. 5	Apr. 6	153	-27	-12	b	7.4	1.66
Moline,	Nov. 1	Apr. 9	169					
Dubuque,	Oct. 30	Apr. 13	166	-32	-17	a	6.6	1.49

¹ Dormant periods in the preliminary analyses are the months of November through March for Dubuque, Peoria and Springfield; and December through February for St. Louis and Cairo.

² From Baker (1936) and used for IBM computation.

³ Locations followed by the same letter are not significantly different at the 5 per cent. level of probability.

preliminary measure of temperature variability used was data on annual lowest temperatures recorded during the dormant periods of 65 years, 1881 through 1945, at five locations as reported by Page (1949). The lowest temperature is defined as the single lowest temperature recorded in the period. Average temperatures are considered unsuited to studies of temperature variability because extreme temperatures are deliberately sacrificed in the calculation of averages.

In preliminary analyses the variance, standard deviation and coefficient of variation was calculated for each of the following locations independently: Cairo, St. Louis, Springfield, Peoria and Dubuque. The standard deviation characterized the variability of temperatures about the mean at each location. The relative variability between locations was determined from the coefficient of variation.

In order to determine temperature variability more precisely, four tem-

perature measures were investigated by IBM computer calculations: the daily minimum temperature (A), the daily maximum temperature (B), the product of the daily maximum and daily minimum temperatures (AB) and the difference between the daily maximum and daily minimum temperatures (B-A). Data on these temperature measures were available on IBM cards for Cairo, St. Louis, Springfield, Peoria and Moline.

Two types of analysis were calculated with the IBM Model 14C1 computer. First, an analysis of variance was calculated with each temperature measure for five locations and 46 years, 1909 through 1955. The standard deviation of each location indicated the variability of temperatures around the mean for each temperature measure.

For the second analysis the raw data for the four temperature measures over 46 years at each location individually was summarized in 10-day segments spanning the total dor-

TABLE 2.—Mean Temperatures and Temperature Variabilities of three Temperature Measures for the 115-day Dormant Period and the Full Dormant Period at Five Locations Representing Illinois Over 46 Years, 1909 Through 1955.

Temperature measure and location	115-day dormant pd.			Full dormant pd.			Difference between means	Diff./S. E. Diff.	Difference between Std. dev.
	Mean °F.	Std. Dev.	Days	Mean °F.	Std. Dev.	Days			
Daily minimum temp. (A)	(F=1005, 62**) ²								
Cairo.....	32.22 ± .15	10.57 ± .08	110	31.80 ± .15	10.54		.33	1.57	.03
St. Louis.....	28.43 ± .15	11.09 ± .08	130	29.51 ± .14	10.83		1.08	4.91**	.26
Springfield.....	23.61 ± .16	11.31 ± .08	130	26.61 ± .11	11.02		1.13	5.14**	.32
Peoria.....	21.18 ± .16	11.97 ± .08	160	24.00 ± .14	11.97		2.82	12.26**	.70
Moline.....	19.73 ± .17	12.41 ± .08	160	23.68 ± .13	11.35		3.95	16.46**	1.06
Daily maximum temp. (B)	(F=532, 72**)								
Cairo.....	47.99 ± .17	12.17 ± .06	110	47.38 ± .17	11.94		.61	2.34*	.23
St. Louis.....	44.29 ± .18	12.96 ± .06	130	46.55 ± .15	12.69		.26	1.04	.27
Springfield.....	39.78 ± .17	12.45 ± .06	130	41.15 ± .15	12.13		1.37	5.48**	.32
Peoria.....	37.34 ± .17	12.26 ± .06	150	40.83 ± .14	11.08		3.40	14.34**	.28
Moline.....	35.46 ± .17	12.45 ± .06	160	40.06 ± .14	12.16		4.60	18.40**	.29
Product (AB)	(F=1094, 98**)								
Cairo.....	113.49 ± .14	10.38 ± .07	110	104.53 ± .14	10.23		9.10	43.90**	.15
St. Louis.....	126.18 ± .15	10.91 ± .08	130	112.85 ± .14	10.63		13.33	60.59**	.31
Springfield.....	124.79 ± .15	10.85 ± .08	130	109.59 ± .14	10.47		15.40	73.33**	.39
Peoria.....	128.05 ± .15	10.98 ± .08	150	107.08 ± .12	10.36		20.97	95.32**	.62
Moline.....	136.85 ± .16	11.31 ± .08	160	109.67 ± .12	10.52		27.15	123.35**	.81

* Means followed by the same letter are not significantly different at the 1 per cent level of probability.
 ** Single and double asterisks indicate values significant at .05 and .01 levels of probability, respectively.

mant period. The calendar dates delimiting the 10-day segments were identical for all five locations. An analysis of variance for each location individually was calculated to determine differences between the means and the standard deviations of the 10-day segments.

Finally, the mean temperatures and standard deviations at each location obtained by the two types of analysis were compared by using the *t* test and standard error of the difference between means.

RESULTS OF TEMPERATURE VARIABILITY ANALYSIS

A minimum of the temperature variability results are included here to assess the biological effects on dormant peach flower bud hardiness. A more complete presentation of the methods and results of determining temperature variability will be published in another paper. In the preliminary analyses the mean annual lowest temperature (Table 1) was significantly different for all locations excepting Cairo and St. Louis, and the respective standard deviations indicated that the annual lowest temperatures were more variable at northern locations than at southern locations. The similarity of the Cairo and St. Louis means indicated that southern Illinois differs from the remainder of Illinois in having relatively similar temperature characteristics during the dormant period. In unpublished preliminary analysis of other temperature measurements comparisons of the temperature variability of the locations using the standard deviation versus the coefficient of variation led to op-

posite conclusions. Thus, the preliminary results were inconclusive with regard to interpreting the biological significance of the data.

Presumably, the greatest precision would be obtained by using daily data rather than monthly or annual data. The first type of analysis with the IBM Model 1401 computer was an analysis of variance using data for a standardized 115 day dormant period from all locations combined as the basis for determining the error variance (Table 2). Highly significant *F* values and differences between means of all locations were found for three temperature measures: the daily minimum temperature (*A*), the daily maximum temperature (*B*), and the product of the daily minimum and maximum temperatures (*AB*). The latter temperature measure did not contribute additional information to that provided by the first two temperature measures, and the biological significance was less evident. Therefore, the product will not be considered further as a measure of temperature variability. The fourth temperature measure, the difference between the daily maximum and daily minimum temperatures (*B - A*), showed no significant differences in any of the analyses and was of little use in analyzing differences in temperature variability. The mean daily minimum and daily maximum temperatures were progressively higher at more southern locations. The variability of the daily minimum temperature, according to the respective standard deviations, was progressively greater at more northern locations and was correlated with the latitude of the locations and negatively cor-

TABLE 3.—Comparison of Percentile Group Ranks for Temperature Variability During 10-day Segments of the Dormant Periods Over 46 Years, 1909 Through 1957, at Five Locations Representing Illinois.

No.	Segments		Daily maximum temp. (A)					Daily maximum temp. (B)					Product (AB)							
	Dates		Carro	St. Louis	Springfield	Peoria	Moline	Avg. Rank	Carro	St. Louis	Springfield	Peoria	Moline	Avg. Rank	Carro	St. Louis	Springfield	Peoria	Moline	Avg. Rank
1	Nov. 1—Nov. 10	.....						9	5	9	10	10	7	10	5	9	10	7	10	10.0
2	Nov. 11—Nov. 20	.....						6	10	10	9	9	8	8	10	10	10	7	10	6.0
3	Nov. 21—Nov. 30	.....						10	10	10	9	9	8	8	10	10	10	7	10	9.4
4	Dec. 1—Dec. 10	.....						1	1	2	3	4	2	2	3	2	3	2	2	2.8
5	Dec. 11—Dec. 20	.....						1	4	4	4	4	3	3	6	6	6	10	5	5.6
6	Dec. 21—Dec. 30	.....						1	5	4	3	4	4	10	10	10	10	10	10	8.0
7	Dec. 31—Jan. 9	.....						3	2	1	1	1	5	4	4	4	4	2	1	3.8
8	Jan. 10—Jan. 19	.....						3	2	1	1	1	4	4	5	5	5	6	6	5.6
9	Jan. 20—Jan. 29	.....						3	1	2	1	1	4	4	5	5	5	6	6	5.6
10	Jan. 30—Feb. 8	.....						2	2	1	1	1	3	3	2	2	1	1	1	4.0
11	Feb. 9—Feb. 18	.....						3	1	1	1	1	1	1	1	1	1	1	1	1.4
12	Feb. 19—Feb. 28	.....						8	7	1	0	5	6	4	5	5	5	7	8	6.4
13	Mar. 1—Mar. 10	.....						6	6	8	7	7	7	5	5	5	6	7	8	6.4
14	Mar. 11—Mar. 20	.....						4	4	9	9	9	8	5	5	5	9	10	10	9.0
15	Mar. 21—Mar. 30	.....						4	4	10	10	10	10	1	1	1	1	1	1	4.0
16	Mar. 31—Apr. 9	.....						10	10	10	10	10	4	4	4	4	4	4	4	4.0

* Percentile group rank for the variances; rank 1 is most variable, rank 10 is least variable.

related with the location means. With the daily maximum temperature, the trend of the standard deviations of the locations was inconclusive and showed little correlation with the respective latitudes or location means.

In the second type of analysis each location was investigated independently by analysis of variance of the entire dormant period divided into 10-day segments (Table 2). At each location the segments factor also had a highly significant *F* value with the A, B and AB temperature measures, and the *F* values for the B-A temperature measure again were uniformly not significant. The conclusions regarding the mean temperatures and the magnitude of temperature variability at the locations were identical with those obtained in the first type of analysis.

The percentile ranks for temperature variability are assembled in Table 3 and grouped by dormant period segment and by location to facilitate comparisons. The general temperature pattern during the dormant period was not the same for the two temperature measures. For the daily minimum temperature, the lowest mean temperature occurred in segment 9, January 23 through 29, and the highest mean temperature occurred in the extreme end segments of the dormant period at all locations. The magnitude of variability was generally greatest in segments 7 through 11, the middle of the dormant period, and the extreme ends of the dormant period showed the least variability. At Cairo and St. Louis the most variable temperatures occurred in segment 4, December 1 through 10, or one month earlier than segment 7, the most variable

segment at Springfield, Peoria and Moline. This observation lends support for the observation that southern Illinois differs from the remainder of Illinois in having relatively similar temperature characteristics during the dormant period.

For the daily maximum temperature, the lowest mean temperature occurred in segment 7, December 31 through January 3, and the highest mean temperature occurred in the extreme end segments of the dormant period at all locations. The greatest temperature variability was restricted to segment 11, from February 9 through 18, and the least variability was restricted to segment 6, from December 21 through 30, at all locations.

The location means for the significant temperature measures, as determined from the two types of IBM computer analysis, are compared in Table 2. With the daily minimum temperature the means were significantly different at all locations except Cairo, where the dormant period used in both types of analyses was very similar, and the means of the daily maximum temperature were significantly different at all locations except St. Louis. Little difference was noted between the standard deviations obtained by the two types of analysis. This observation emphasizes the fact that the greatest variability of temperatures occurs within the 110-day portion of the dormant period, November 21 through March 15 at all locations.

DISCUSSION

In considering the two explanations for the fact that flower buds

of different peach varieties seemingly differ in their ability to withstand winter temperature fluctuations, the first explanation, wherein temperature fluctuations may exceed the basal temperature (45°F.) required for growth of deciduous tree fruit plants, directly associates the climatic data with the biological response of the fruit trees. An examination of Table 2 reveals that the mean daily maximum temperature at Cairo is 48°F., and the standard deviation indicates that two thirds of the daily maximum temperatures during the dormant periods will be within the range of 36° to 60°F. The mean daily maximum temperatures are progressively lower at more northern locations. Thus, at Moline the mean daily maximum temperature is about 35°F., and two thirds of the daily maximum temperatures will be within the range of 25° to 48°F. In comparing these extreme locations in Illinois it is apparent that daily maximum temperatures will exceed the basal temperature for peach tree growth (45°F.) during the dormant period much more frequently at Cairo than at Moline. The same tendency is revealed in a study of the daily minimum temperatures. Chaplin (1948) reported the killing point of peach flower buds fluctuated directly with temperature changes during the winter months. Therefore, the greater frequency of temperature fluctuations exceeding 45°F. in southern locations than in northern locations is likely to be responsible for the contradictory observations of reduced flower bud hardness on peach trees of the same variety grown in a warmer continental climatic region. A more precise

estimate of the temperature fluctuation frequencies must await a different type of temperature analysis—perhaps an enumeration of the days when temperatures exceed the basal temperature, or possibly a degree-days summation at each location.

The second explanation, concerned solely with the magnitude of temperature fluctuations, has not been substantiated. The variability of temperatures about the mean is smaller at southern locations than at northern locations within the continental climate of Illinois. This conclusion holds true with a variety of temperature measures: the daily minimum temperature, daily maximum temperature, the product of the first two measures, and the annual lowest temperature. Therefore, temperature variability, *per se*, cannot be responsible for the observation that peach varieties with hardy flower buds in northern locations may be considerably less hardy when the variety is grown in southern locations with considerably warmer dormant period temperatures.

Chaplin (1948) noted that the greatest hardness of peach varieties at Olney, Illinois, occurred between December 15 and January 10 during a three year period. This period of greatest hardness of peach varieties should occur in January because the lowest mean daily minimum and maximum temperatures occur in the month of January throughout the state. During the dormant periods of the past six years, 1957 through 1963, at Carbondale, a total of 1200 hours of temperatures below 45°F. have accumulated by January 1 through 10 (Mowry, unpublished data). At Olney the 1200 hour total

should accumulate by December 24 through January 1. Since 1200 hours of temperatures below 45°F. will break the rest period of flower buds of practically all peach varieties, Chaplin's statement that the period of greatest bud hardiness of peach varieties coincided with the breaking of the rest period is generally confirmed.

SUMMARY

Temperature variability during the dormant period of peach trees was investigated by analysis of daily temperature data for 46 years at five locations representing the continental climate of Illinois. The standard deviation was used as the criterion of temperature variability, and the daily minimum and daily maximum temperatures were the most meaningful temperature measures investigated.

The magnitude of temperature fluctuations about the mean was progressively greater at more northern locations in Illinois. The two major parameters exhibited a different pattern of variability during the dormant period at each location. The variability of the daily minimum temperature was generally greater in the middle of the dormant period, and the extreme ends of the dormant period showed the least variability. At Cairo and St. Louis the most variable segment occurred about one month earlier than at Springfield, Peoria and Moline. For the daily maximum temperature the most variable segment of the dormant period was February 9 through 18, and the least variable segment was December 21 through 30 at all locations.

When considering the average of both parameters, the February 9 through 18 segment had the greatest variability, and the November 21 through 30 segment had the least variability at all locations.

Southern Illinois differs from the remainder of Illinois in having relatively similar temperature characteristics affecting peach flower bud hardiness during the dormant period.

Fluctuations of the daily maximum temperature during the dormant period more frequently exceed the basal temperature (45°F.) for growth of peach trees at southern locations in Illinois than at northern locations. Temperature fluctuations exceeding the basal temperature are presumed to be responsible for observations of reduced dormant flower bud hardiness of specific peach varieties when grown in warmer climatic regions.

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