THE DEVELOPMENT OF THE WHEAT KERNEL

by

GENE EDWARD SCOTT

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INTRODUCTION

The development of the wheat kernel has been of interest to farmers, agronomists, millers, and plant physiologists for many decades.

The farmers were interested because they wanted to know when the maximum monetary returns could be obtained for their wheat crop. They were also interested in how much loss in yield and test weight would be experienced if emergencies arose requiring wheat to be harvested early.

The agronomists were also interested in when the maximum yield could be attained from wheat, but they were also interested in what influence the environment had on the developing wheat kernel, and whether some stages of development were more susceptible to environmental influences. The agronomist would like to know how the wheat kernel develops; so that it might be possible to produce higher yielding varieties of wheat. Conditions often require that experimental seed be harvested before maturity, so it is important to know the earliest stage at which seed will germinate.

The millers were concerned about the milling and baking qualities of wheat harvested at various stages of maturity.

From the academic point of view the plant physiologists were interested in learning what changes take place within the developing wheat kernel, and what effect these changes have on the yield of grain and the following crop.

The Agronomy Department of Kansas State College has been studying this problem since 1948. In 1948 the first experiments were conducted at the Kansas Station to study the effect of date of cutting on quality of winter wheat. These experiments were continued through 1952. In 1951 a detailed study was conducted with Pawnee wheat to determine the effect of date of cutting on yield, test weight, moisture percentage, and germination and seedling vigor. In 1953 and 1954 the same type of experiments were conducted with the three varieties Triumph, Pawnee, and RedChief. In 1954 individual kernels were sampled. Data of these two years are presented in this thesis.

REVIEW OF LITERATURE

As early as 1879 Kedzie (1882) studied the daily development of the wheat kernel. He observed that the actual gluten content increased somewhat with maturity, but the percentage of gluten decreases. Starch accumulation was rapid and when the storage of the starch was completed the ripening of the grain was also complete.

Crozier and Briggs (1895) found that harvesting wheat at the "yellow ripe stage" gave higher yields than when harvested at the "milk stage, dough stage, or dead ripe stage." The germination of the seed was highest when harvested at the "yellow ripe stage."

Brenchley and Hall (1909) working with wheat, found that the relationship of green to dry weight has two definite breaks. The first break comes about twelve days after pollination indicating the final contraction and drying up of the pericarp, the second break occurs about six days before harvest indicating the beginning of desiccation and the conclusion of migration. They found the moisture content of ~~1,000~~ grains rose until about the twelfth day after pollination, ~~then it~~ remained approximately constant in amount until six days from cutting, at which time it decreased rapidly.

Thatcher (1913) gave the dry weight of Turkey wheat at 6.79 milligrams seven days after fertilization compared with 30.17 milligrams twenty-seven days after fertilization.

Thatcher (1915) also concluded that the amount of dry matter per 1,000 kernels and the volume occupied by 1,000 kernels naturally increased with each three day sampling period. This increase was not regular, however, the gain in dry matter during some periods being more than double that during other periods of the same length. He found no correlation between the amount of gain in dry matter per day and the stage of development, except that the most rapid gains occurred during the first three-day interval.

Kidd and West (1918) made an extensive literature review on the growth and yield from immature seeds. The authors concluded that the total yield from immature seeds are usually less than from mature seeds because a smaller percentage of the immature seeds germinate. If a comparison was made between yield per plant the plant from the immature seed yielded just as much and sometimes more than the plant from a mature seed. The immature seeds would not withstand storage as well as seed which was harvested when mature.

Woodman and Engledow (1924) noted a decrease in dry matter during the desiccation period. The authors attributed this loss of carbohydrates to respiration at a stage when no further nutrients were being moved into the grain.

Harlan (1920) studied Hanchen barley and made physical measurements at twelve-hour intervals. Growth was very rapid and the length was at a maximum on the seventh day after pollination. The width increased rather rapidly, but the kernel continued to increase in thickness quite steadily until near maturity.

Harlan and Pope (1923) noted that the dry matter ceased to increase when the average moisture content for all the barley kernels of a spike averaged approximately 42 percent.

Percival (1921) found an increase of dry matter during the entire developmental period. A decrease in weight and volume shortly after peak values were attained close to the final stage of development were recorded by this author. Individual grains also increased in weight until a few days before harvest, after which they decreased in weight rapidly through loss of water. This author found that the storage of the endosperm with reserves began when the tissue was completely formed which was 10 to 14 days after fertilization.

Percival (1921) also stated,

> These changes in developing grains exhibit the same general progression each season, but investigations carried on during several years show that they do not always proceed at the same rate, the loss of water and the accumulation of dry matter being accelerated or retarded by variations in the amount of sunlight, and the temperature and dryness of the atmosphere.

McGinnis and Taylor (1923) calculated the carbohydrate loss by respiration per 100 grams dry matter. The authors found that the loss changed from 1.759 milligrams when the moisture was at 45.73 percent to .170 milligrams at 14.44 percent moisture.

Olson (1923) concluded that apparently no food material is moved into the grain having a moisture content of 40 percent or less.

Kiesselbach (1925) found that wheat kernels ten days after fertilization contained 21 percent of the final dry matter; whereas 81 percent had accumulated by the end of 20 days. The maximum kernel size was attained 14 days after fertilization, at which time 46 percent of the mature dry matter had been acquired. Maximum dry weight was attained two days before dead ripe, at which time the grain contained an average of 29.9 percent moisture. Four days before dead ripe, when the grain contained 38.4 percent moisture, the kernel dry weight averaged as great as when dead ripe and for practical purposes should be regarded as mature. Premature harvesting gave a reduction of 2.3 and 7.7 bushels per acre for the "late dough" and "early dough" stages, respectively.

Whitcomb and Francis (1925) showed that wheat seeds harvested at various stages of maturity and then frozen differed in their ability to germinate. Kernels at the age of thirteen days after pollination gave 98 percent germination when not frozen, but those that were frozen only germinated 1 percent. At the age of 31 days the kernels germinated 84 and 100 percent for the frozen and non-frozen kernels, respectively.

Takasaki (1926) concluded that barley grains collected earlier than the seventeenth day after the appearance of the spike showed very low germination, and required a long time for germination, while those collected after the twenty-sixth day were comparable to ripe seeds in both respects.

Harlan and Pope (1922) found that barley seeds would germinate when harvested five and six days after pollination.

Alberts (1926) found that corn harvested in the early milk stage germinated poorly and gave weak seedlings, while those harvested in the dough stage gave germination and seedling vigor comparable to grain harvested at normal time.

Booth (1929) studied Gopher oats and concluded that growth of the kernel was at a maximum on the fifteenth day. Width and thickness increased rapidly during the first ten days and reached a maximum before growth in length ceased. The green weight increased rapidly for thirteen days, but there was a pronounced decrease after the fifteenth day. The dry weight increased rather uniformly until ripening began, on the fiftoenth day; but the loss of dry matter, when harvest was delayed two days, was 8.3 percent. This author found that the average laboratory germination percentage increased materially and that the increase in field germination was still greater with the accumulation of dry matter in the kernel. The field germination of immature kernels was low and the seedlings lacked vigor.

Bayles (1936) observed no difference in disease resistance due to difference in the stage of maturity at which wheat was harvested from eleven days after bloom until ripe.

Shirk (1942) determined the freezable water content and respiration of wheat and found that the respiratory activity was very high in the young grain with a peak eleven or twelve days after pollination, followed by a rather sharp decline which became more gradual as the grain matured. There was a close parallelism between the freezable water content and the respiration intensity, except during the earlier stages of growth. The freezable to unfreezable water ratio changed from 5.23 on the seventh day after fertilization to 0.50 on the thirtieth day. Shirk concluded that the tendency for one gram dry matter to associate less unfreezable water as ripening of the grain took place indicated either an increase of hydrophilic colloids or a higher water binding capacity of the colloids present in the grain immediately following their formation.

Harris, et al, (1943) found that the test weight of wheat increased to a maximum a few days before normal harvest, then tended to decrease slightly.

Hatcher and Purves (1945) working with wheat, rye, and barley found that very immature, medium mature, and mature seeds all gave quite high yields in the next generation, but yields tended to decrease with use of immature seed. The growth rate from immature seeds, however, was much higher than from mature grain.

McCammon (1951) concluded that the test weight, kernel weight, starch content, mixing time, and water absorption were all at a maximum for wheat harvested 1 to 2 weeks before ripe.

METHODS AND MATERIALS

The hard red winter wheats Triumph, CI No. 12132; Pawnee, CI No. 11669; and RedChief, CI No. 12502, were selected for this study.

Triumph is an early maturing, awned variety that has a test weight intermediate between the other two varieties.

Pawnee is a midseason maturing wheat that is grown extensively in Kansas. It is an awned variety that has a lower test weight than the other varieties and bleaches easily.

RedChief is a later maturing variety. It is noted for its superior test weight, and does not tend to bleach to the extent of the other two varieties. RedChief is an awnless variety that is difficult to thresh.

Samples for yield, test weight, moisture percentage, air dry weight of 100 kernels, and germination were taken on the eleventh day after 1/2 bloom, and thereafter on every other day until after normal harvest. The individual kernels were sampled on the day of pollination, daily for the following nine days, and then every second day.

The yield of grain was taken from the center two rows of a four-row eight-foot plot. The first harvested samples that had a high percentage of moisture in the straw and grain were spread on wire racks to dry. All samples were threshed after they were air dry.

The chaff was removed from the first four seed samples by using a South Dakoto Seed Blower. The other samples were cleaned sufficiently by the regular nursery thresher.

Samples for yield were taken from five replications at Hays, Kansas in 1953, and from six replications at Manhattan, Kansas, in 1953 and 1954.

Test weights were taken on a composite of all replications of each sampling period.

When the plots were blooming, tags were tied to the culms of heads that had approximately 1/2 of the florets extruding anthers.

Approximately 1650 heads of each variety were tagged within the border rows; so as not to influence the yield determinations.

On each sampling day 100 heads per variety were harvested. Thirty of these heads in groups of ten were threshed immediately and the grain weighed. This grain was later oven dried to determine moisture percentages. The remaining heads were threshed later, and eight 100 kernel air-dry samples were counted and weighed.

These 100 kernel samples were used for germination tests. Four of the samples for germination were planted in soil in greenhouse flats at Manhattan, Kansas, during the winter. Germination tests of the other four samples were conducted in the State Seed Laboratory at Topeka, Kansas.

The day a variety was flowering, individual florets near the center of the spike were marked with India ink. Only those florets with anthers shedding viable pollen were marked.

Commencing with the day of pollination, the heads with the marked florets were taken into the laboratory, and the marked kernels were threshed and weighed individually. Later these kernels were oven dried at approximately 115°F. until loss of weight ceased, and then weighed to determine the dry weight of the kernel.

RESULTS

Individual Kernels

The growth of the kernels was rapid and the increase in size was evident between samples taken at 24 hour intervals as shown by

Plates I, II, III, and IV.

Table 1 gives the average green weight, dry weight, moisture content, and the percent moisture of ten individual wheat kernels.

The green weight increased rather slowly for the first two or three days after pollination, and then at a greatly accelerated rate until the fifteenth day after pollination. From the fifteenth to the twenty-seventh day the green weight increased rather slowly, and after this period the rate became progressively slower as shown by Fig. 1.

During the first eight or nine days after pollination the rate of increase in dry matter was low, as illustrated by Fig. 2. From the ninth to the twenty-seventh day the dry matter per kernel increased rapidly. After the twenty-seventh day there was a decrease in dry matter.

The analysis of variance showed a highly significant difference among varieties, between dates of cutting, and the interaction for the first twenty-five days after pollination; which was all that could be compared between the three varieties.

The water content per kernel rose very rapidly until its peak on the thirteenth or fifteenth day after pollination, as shown by Fig. 3. From this time until the twenty-ninth day the amount of water per kernel remained approximately constant, but with a slight decrease during the later stages of this period. After the twenty-ninth day the water content decreased rapidly.

The water content per kernel showed highly significant differences between varieties, dates of cutting, and the interaction. The difference between varieties could be attributed to maturity

Table 1. The average weights of ten individual wheat kernels harvested from the day of pollination until maturity at Manhattan, Kansas, in 1954.

	Triumph				Pawnee				RedChief			
Days after pollination	Green weight mgs.	Dry weight mgs.	Moisture mgs.	Moisture %	Green weight mgs.	Dry weight mgs.	Moisture mgs.	Moisture %	Green weight mgs.	Dry weight mgs.	Moisture mgs.	Moisture %
0	2.06	0.55	1.51	73.3	2.66	0.56	2.10	78.9	1.92	0.56	1.36	70.8
1	2.71	0.61	2.11	77.8	2.74	0.64	2.10	76.6	3.38	0.87	2.51	74.3
2	2.96	0.75	2.21	74.6	4.21	1.19	3.02	71.7	4.77	1.23	3.54	74.2
3	4.93	1.15	3.78	76.7	6.78	1.70	5.08	74.9	6.46	1.22	5.24	81.1
4	6.75	1.53	5.22	77.3	8.71	1.78	6.93	79.6	10.30	2.01	8.29	80.5
5	8.75	1.80	6.85	78.3	10.83	2.53	8.30	76.6	13.48	2.57	10.81	80.2
6	11.39	2.26	9.13	80.2	15.36	3.79	11.57	75.3	15.61	3.47	12.14	77.8
7	14.48	2.63	11.85	81.8	17.06	4.14	12.92	75.7	17.40	3.79	13.61	78.2
8	18.44	3.89	14.55	78.9	17.62	4.05	13.57	77.0	22.68	4.57	18.11	79.9
9	21.34	4.53	16.81	78.8	22.62	5.18	17.44	77.1	28.33	6.22	22.11	78.0
11	26.96	5.41	21.55	79.9	30.45	7.83	22.62	74.3	32.33	8.35	23.98	74.2
13	35.90	7.52	28.38	79.1	34.68	10.33	24.35	70.2	44.01	13.15	30.86	70.1
15	47.33	12.99	34.34	72.6	43.60	14.95	28.65	65.7	48.75	16.99	31.76	65.1
17	49.83	15.83	34.03	68.3	45.05	17.52	27.53	61.1	49.57	18.61	30.96	62.5
19	54.21	19.59	34.62	63.9	48.80	19.87	28.93	59.3	55.53	23.31	32.12	58.0
21	56.19	22.66	33.53	59.7	54.35	25.13	29.22	53.8	56.23	26.32	29.91	53.2
23	58.15	26.31	31.84	54.8	57.31	29.21	28.10	49.0	58.54	32.31	26.23	44.8
25	61.43	28.52	32.91	53.6	59.75	33.89	25.86	43.3	60.57	34.55	26.02	43.0
27					63.26	38.13	26.13	41.3	68.78	40.57	28.21	41.0
29					59.32	35.56	23.76	40.1	65.27	38.24	27.03	41.4
31					44.26	34.30	9.96	22.5	50.39	35.97	14.42	28.6

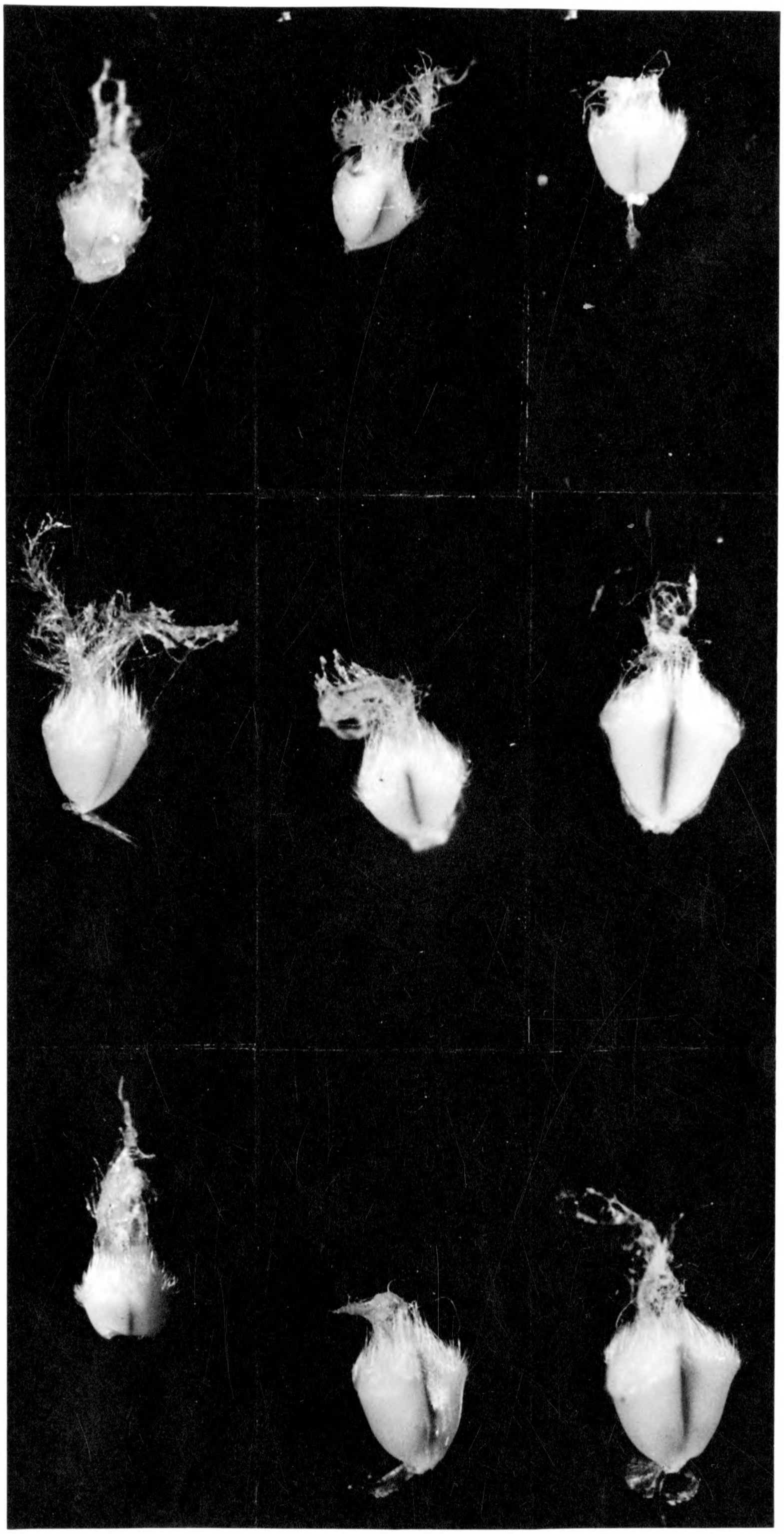
LSD for dry weight per kernel at the 5% level = 1.05

LSD for moisture content per kernel at the 5% level = 1.66

EXPLANATION OF PLATE I

Wheat kernels harvested 0, 1, and 2 days after pollination. The upper row is Triumph; center row Pawnee; and bottom row RedChief.

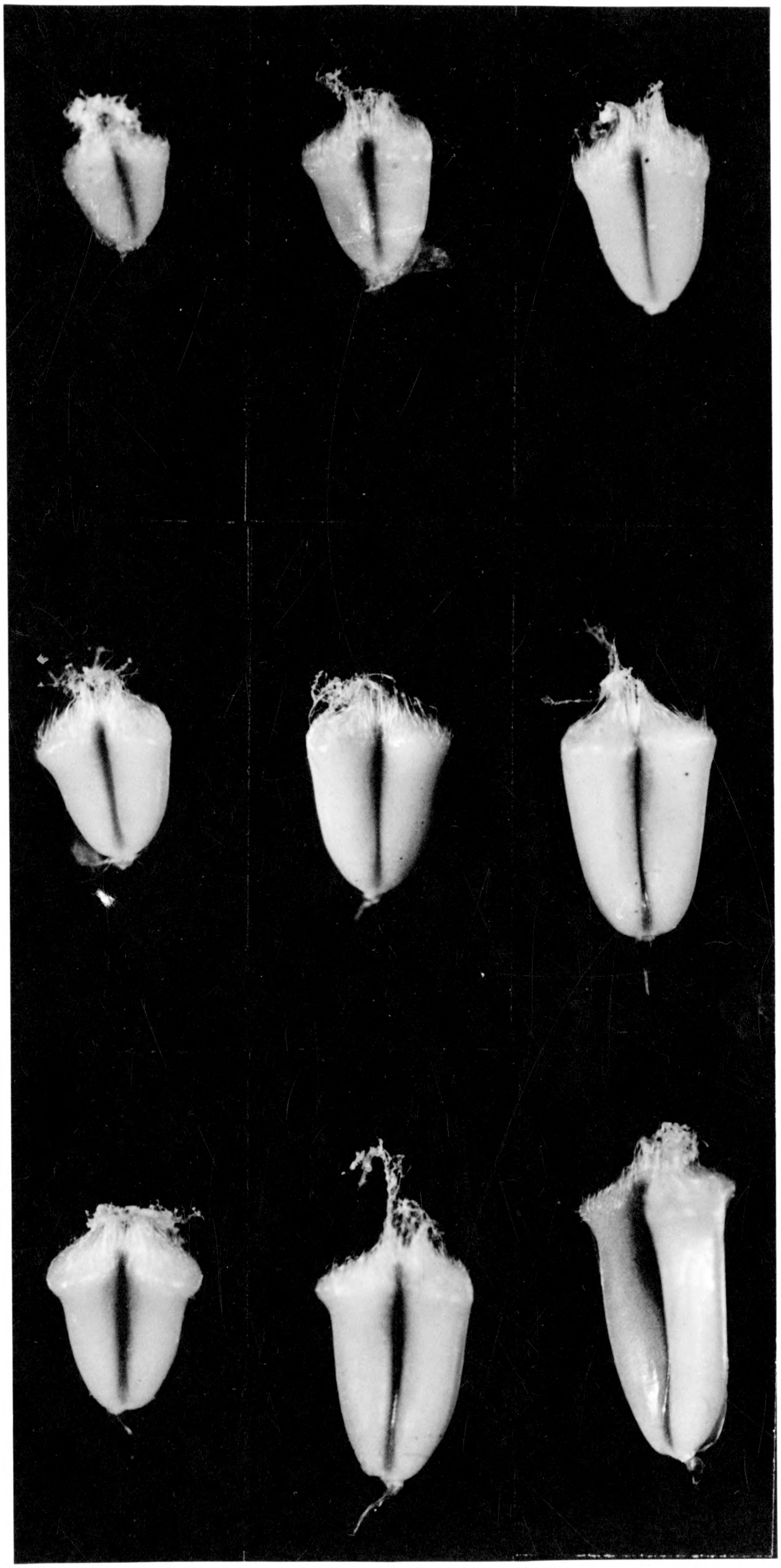
PLATE I



EXPLANATION OF PLATE II

Wheat kernels harvested 3, 4, and 5 days after pollination. The upper row is Triumph; center row Pawnee; and bottom row RedChief.

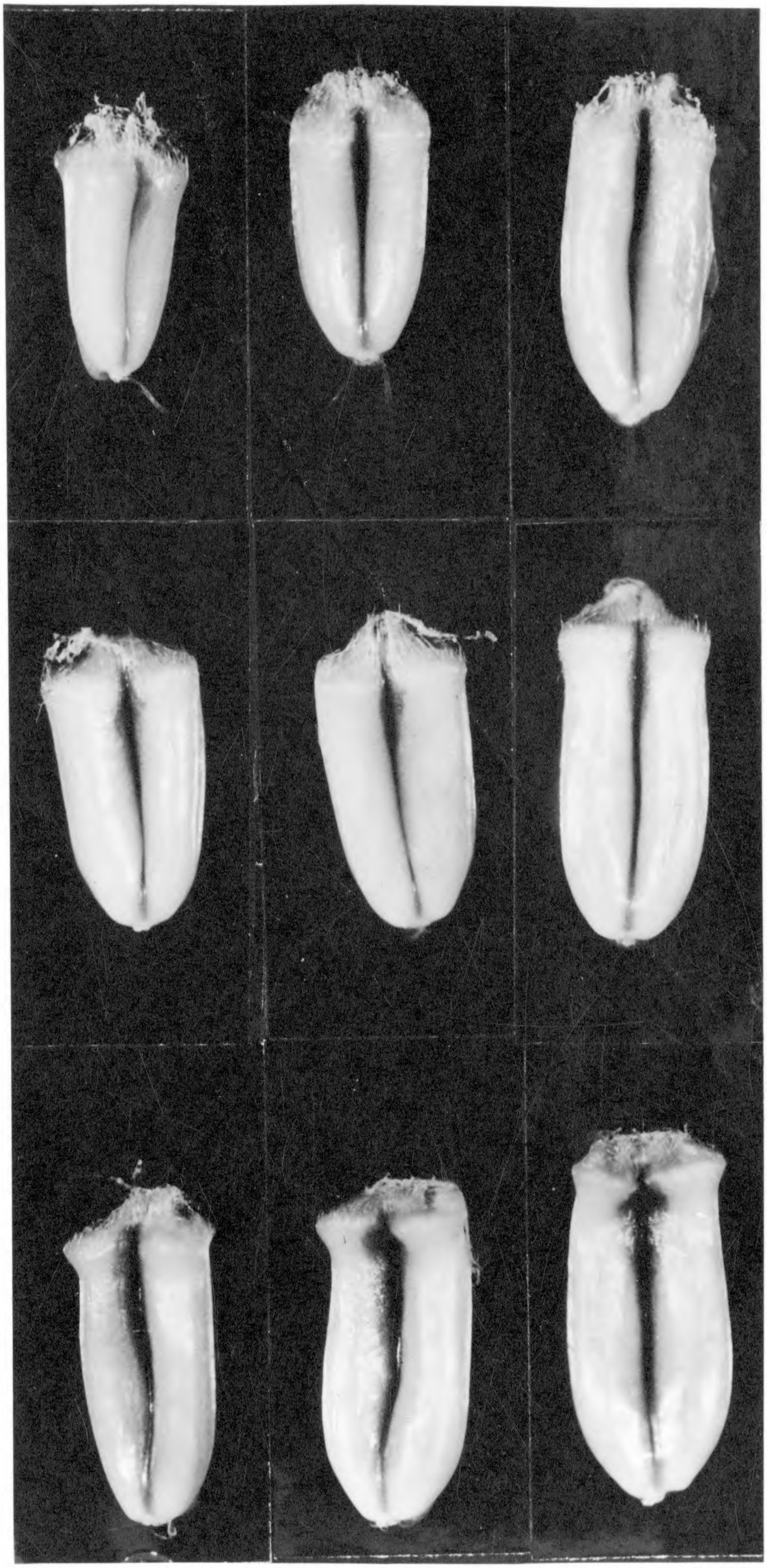
PLATE II



EXPLANATION OF PLATE III

Wheat kernels harvested 6, 7, and 8 days after pollination. The upper row is Triumph; center row Pawnee; and bottom row RedChief.

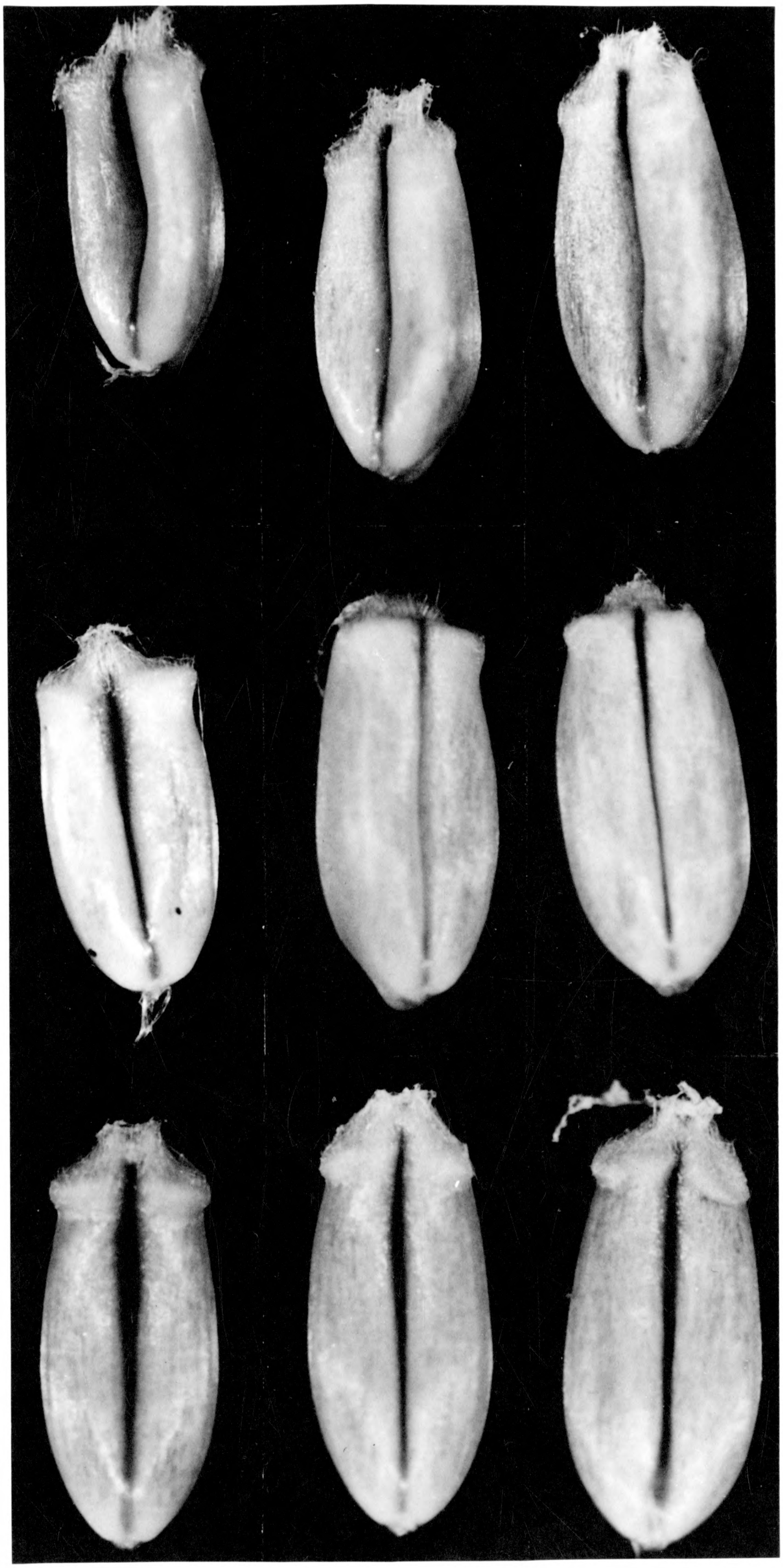
PLATE III



EXPLANATION OF PLATE IV

Wheat kernels harvested 9, 11, and 13 days after pollination. The upper row is Triumph; center row Pawnee; and bottom row RedChief.

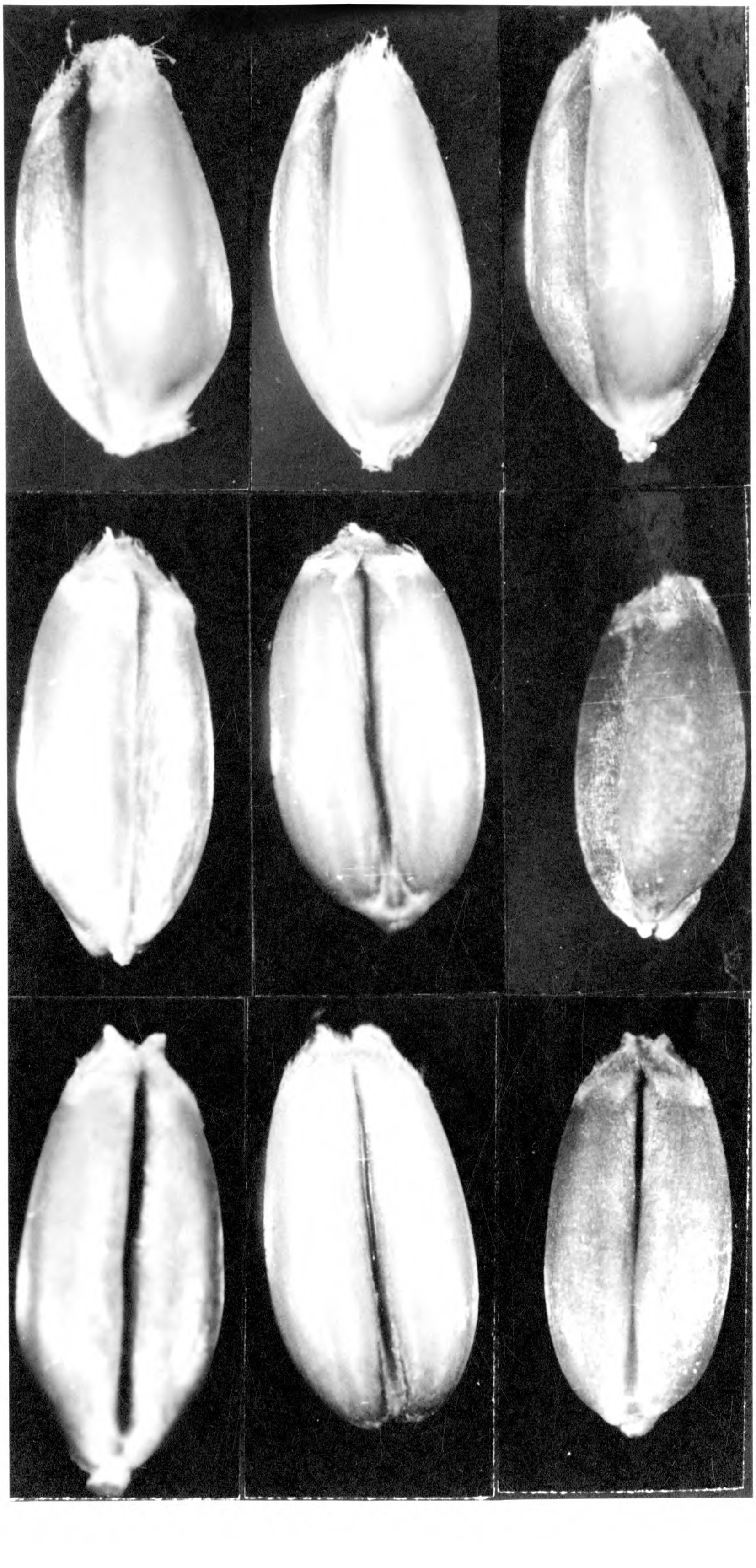
PLATE IV



EXPLANATION OF PLATE V

Wheat kernels harvested 19, 22, and 25 (Triumph) or 30 (Pawnee and RedChief) days after pollination. The upper row is Triumph; center row Pawnee; and bottom row RedChief.

PLATE V



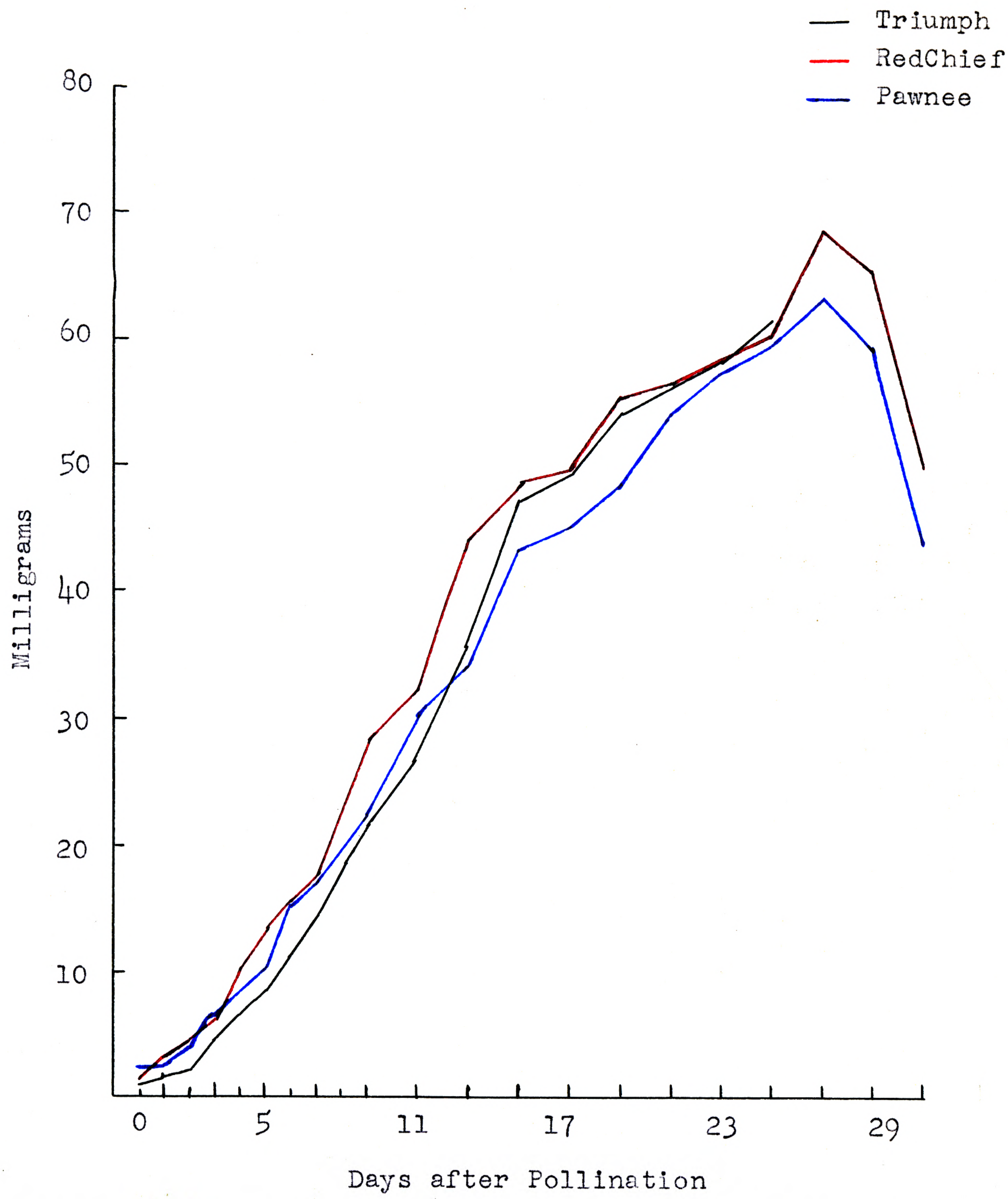


Fig. 1. The average green weight of ten individual wheat kernels harvested from the day of pollination until maturity at Manhattan, Kansas, in 1954.

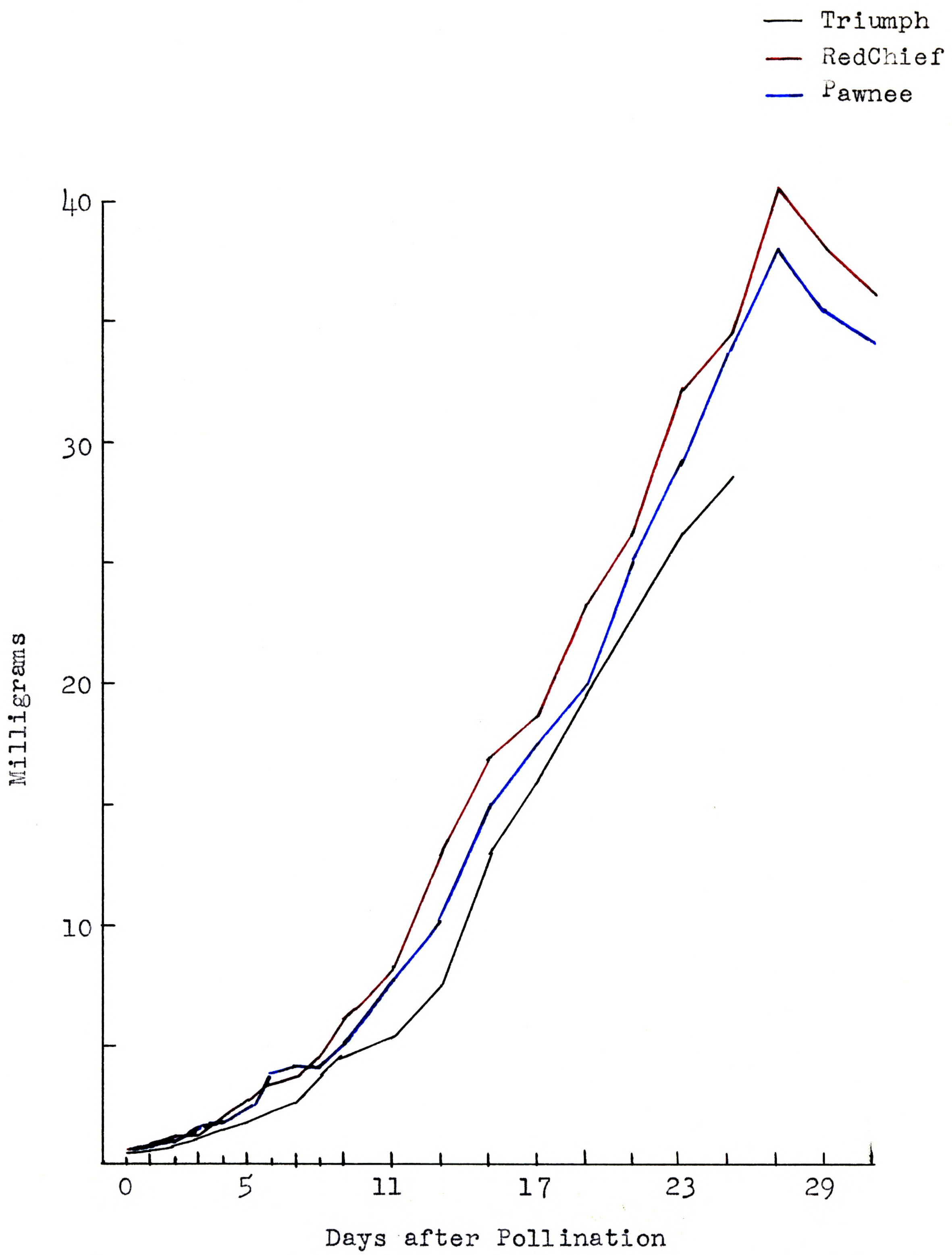


Fig. 2. The average dry weight of ten individual wheat kernels harvested from the day of pollination until maturity at Manhattan, Kansas, in 1954.

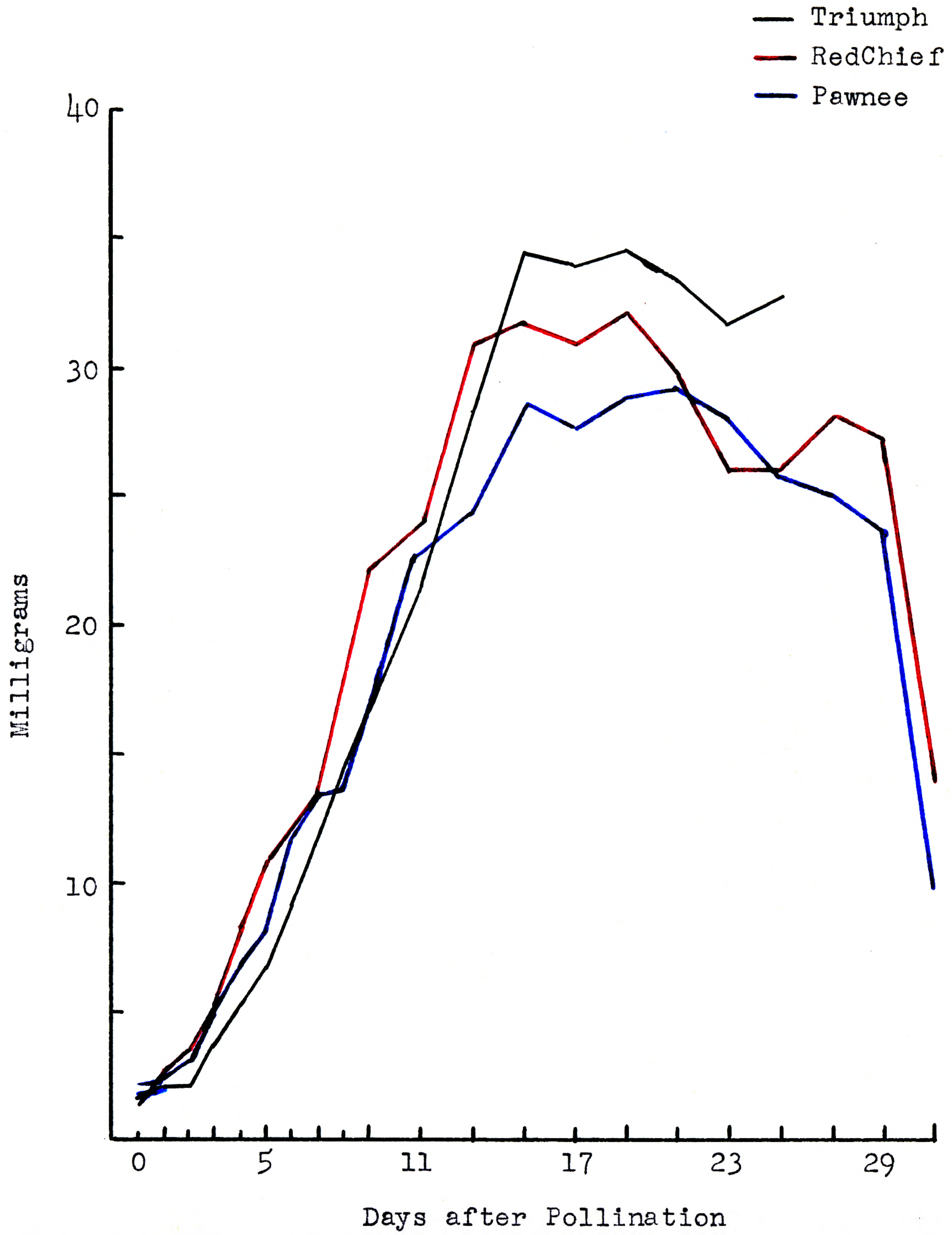


Fig. 3. The average water content of ten individual kernels harvested from the day of pollination until maturity at Manhattan, Kansas, in 1954.

dates of the varieties.

The percent moisture of the wheat kernels fluctuated considerably during the early stages of maturation as shown by Fig. 4. Triumph, the earliest maturing variety, retained a higher percent of moisture for a longer period of time. The percent moisture tended to decrease regularly from the ninth day after pollination until the period of desiccation. During the period of dessication the percent moisture decreased rapidly.

Air Dry Weight of 100 Kernels

The average air dry weight of eight 100 kernel samples are given in Tables 2, 3, and 4 and illustrated in Figs. 5, 6, and 7.

The sampling procedure prevented the use of the error to compute a least significant difference, and the error term for the interaction of dates time varieties would not give a comparable least significant difference.

The weight of 100 air dry kernels increased regularly during the earlier sampling periods, and apparently followed the general trend of the individual kernels.

Percival (1921) found that the development of the wheat berry can be accelerated or retarded by seasonal differences. The 1953 season was hot and dry after the blooming period, and the developmental period was accelerated. Thus, the average weight of 100 kernels for the three varieties was 2.03 grams at 13 days while for 1954 the average weight of 100 kernels was 0.9 grams. This difference in rate of development in 1953 and 1954 accounts for the difference expressed by the slope of the curve during the

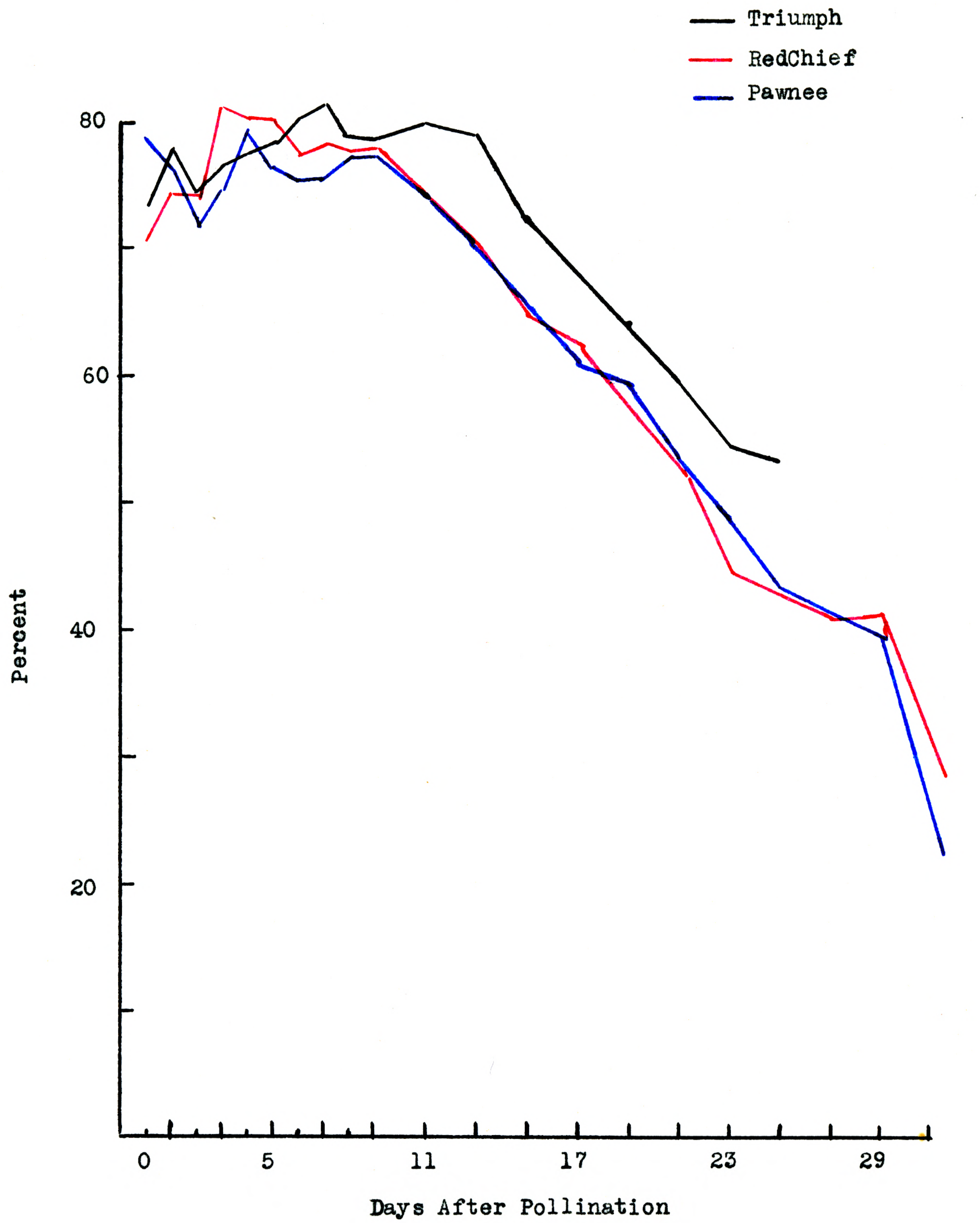


Figure 4 . The average percent moisture of ten individual wheat kernels harvested from the day of pollination until maturity at Manhattan, Kansas, in 1954.

Table 2. The average air dry weight of 100 wheat kernels harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1953.

Days after 1/2 bloom	Triumph Date cut	Triumph Weight Gms	Pawnee Date cut	Pawnee Weight Gms	RedChief Date cut	RedChief Weight Gms
11	June 5	1.67	June 9	1.55	June 9	1.51
13	" 7	1.94	" 11	1.97	" 11	2.19
15	" 9	3.06	" 13	2.25	" 13	2.41
17	" 11	2.91	" 15	2.26	" 15	2.61
19	" 13	2.48	" 17	2.56	" 17	2.67
21	" 15	2.94	" 19	2.05	" 19	2.73
23	" 17	2.91	" 21	2.53	" 21	2.52
25	" 19	3.06	" 23	2.32	" 23	2.67
27	" 21	3.26	" 25	2.45	" 25	2.73
29	" 23	3.02	" 27	2.60	" 27	2.81
31	" 25	3.16	" 29	2.35	" 29	2.58
33	" 27	3.18	July 1	2.60	July 1	2.73
35	" 29	2.94	" 3	2.47	" 3	2.65

Table 3. The average air dry weight of 100 wheat kernels harvested on alternate days beginning the eleventh day after 1/2 bloom at Hays, Kansas, in 1953.

Days after 1/2 bloom	Triumph Date cut	Triumph Weight Gms.	Pawnee Date cut	Pawnee Weight Gms.	RedChief Date cut	RedChief Weight Gms.
11	June 8	1.20	June 11	.70	June 12	1.23
13	" 10	1.57	" 13	1.03	" 14	1.44
15	" 12	1.88	" 15	1.22	" 16	1.79
17	" 14	2.15	" 17	1.36	" 18	1.92
19	" 16	2.39	" 19	1.50	" 20	1.90
21	" 18	2.45	" 21	1.48	" 22	2.11
23	" 20	2.40	" 23	1.62	" 24	2.09
25	" 22	2.47	" 25	1.41	" 26	2.08
27	" 24	2.54	" 27	1.51	" 28	2.00
29	" 26	2.46	" 29	1.53	" 30	2.04
31	" 28	2.37	July 1	1.48	July 2	1.97
33	" 30	2.24	" 3	1.55	" 4	1.97
35	July 2	2.42	" 5	1.38	" 6	2.04

Table 4. The average air dry weight of 100 wheat kernels harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhatten, Kansas, in 1954.

	Triumph		Pawnee		RedChief	
Days after: 1/2 bloom	Date cut	Weight: gms.	Date cut	Weight: gms.	Date cut	Weight gms
11	May 19	--	May 27	--	May 29	--
13	" 21	.67	" 29	.82	" 31	1.20
15	" 23	1.18	" 31	1.17	June 2	1.35
17	" 25	1.48	June 2	1.54	" 4	1.63
19	" 27	1.86	" 4	1.79	" 6	1.93
21	" 29	2.28	" 6	2.19	" 8	2.25
23	" 31	2.64	" 8	2.43	" 10	2.83
25	June 2	--	" 10	--	" 12	--
27	" 4	3.12	" 12	3.20	" 14	3.46
29	" 6	3.48	" 14	3.28	" 16	3.58
31	" 8	3.75	" 16	3.39	" 18	3.62
33	" 10	3.86	" 18	3.38	" 20	3.66
35	" 12	3.87	" 20	3.43	" 22	3.60
37	" 14	3.89	" 22	3.23	" 24	3.50

earlier sampling periods in Figs. 5 and 7, which show the accumulated dry weight of 100 kernels at Manhattan, Kansas.

Yield

The yields of the three varieties varied between the two years at Manhattan, Kansas, and the yields at Hays, Kansas, in 1953 were low. The average yields are tabulated in Tables 5, 6, and 7 and illustrated in Figs. 8, 9, and 10.

The stand of wheat at Hays, Kansas, in 1953 was not uniform, and wheat plants also were damaged by wind.

In 1953 at Manhattan, Kansas, the yields of Triumph and Red Chief were influenced by relatively late localized centers of stem rust infection; possibly altering some of the results.

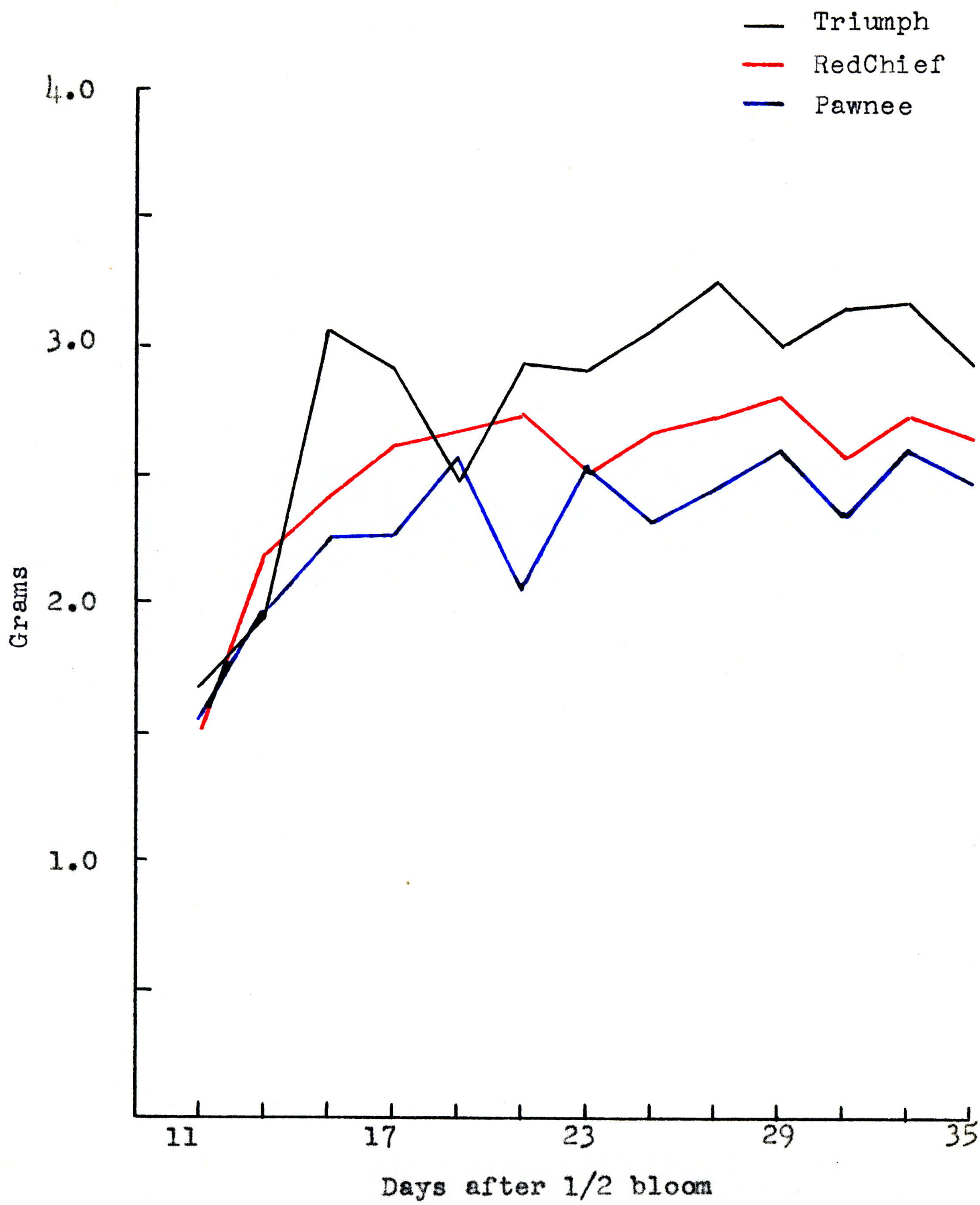


Fig. 5. The average air dry weight of 100 wheat kernels harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1953.

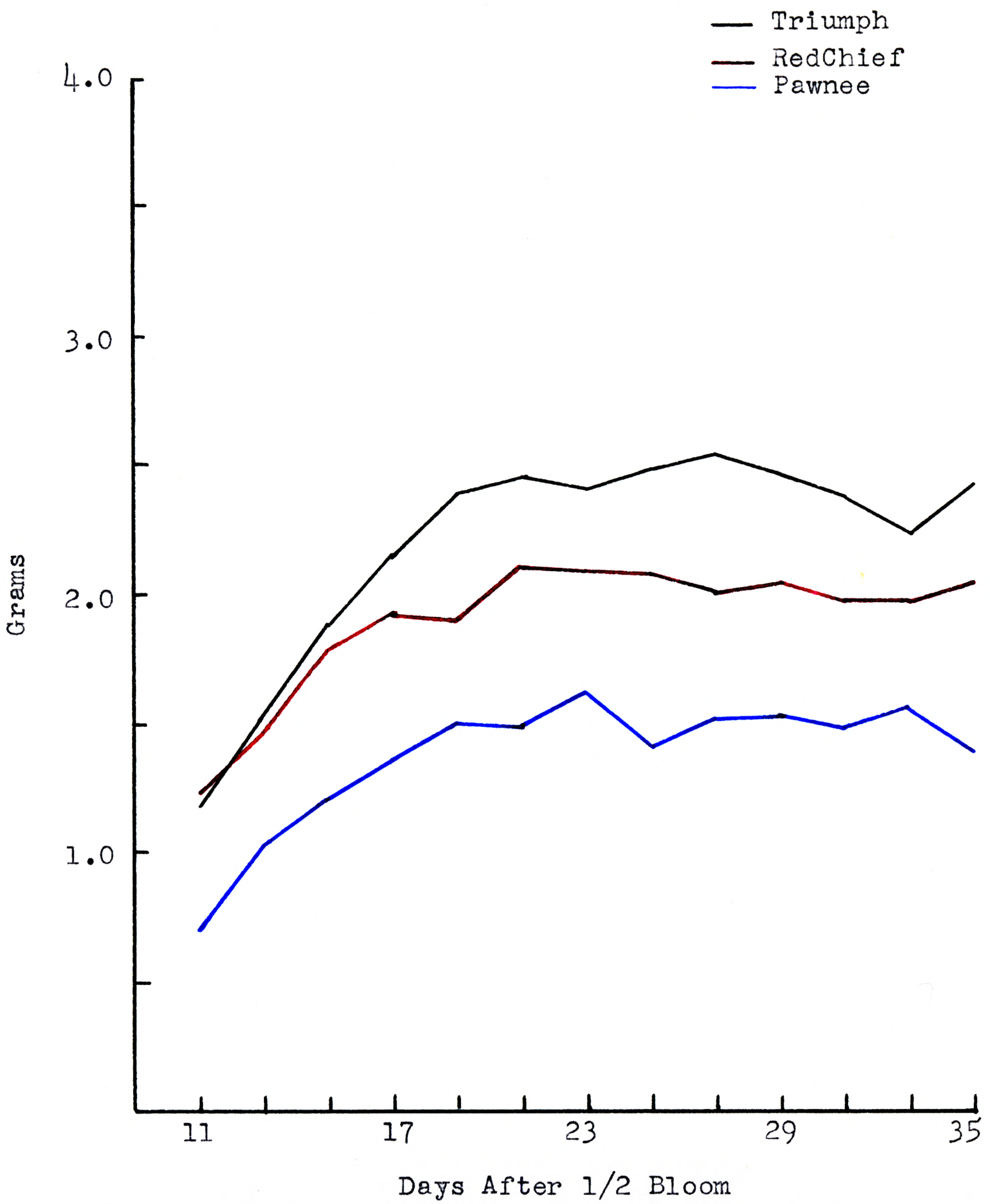


Fig. 6. The average air dry weight of 100 wheat kernels harvested on alternate days beginning the eleventh day after 1/2 bloom at Hays, Kansas, in 1953.

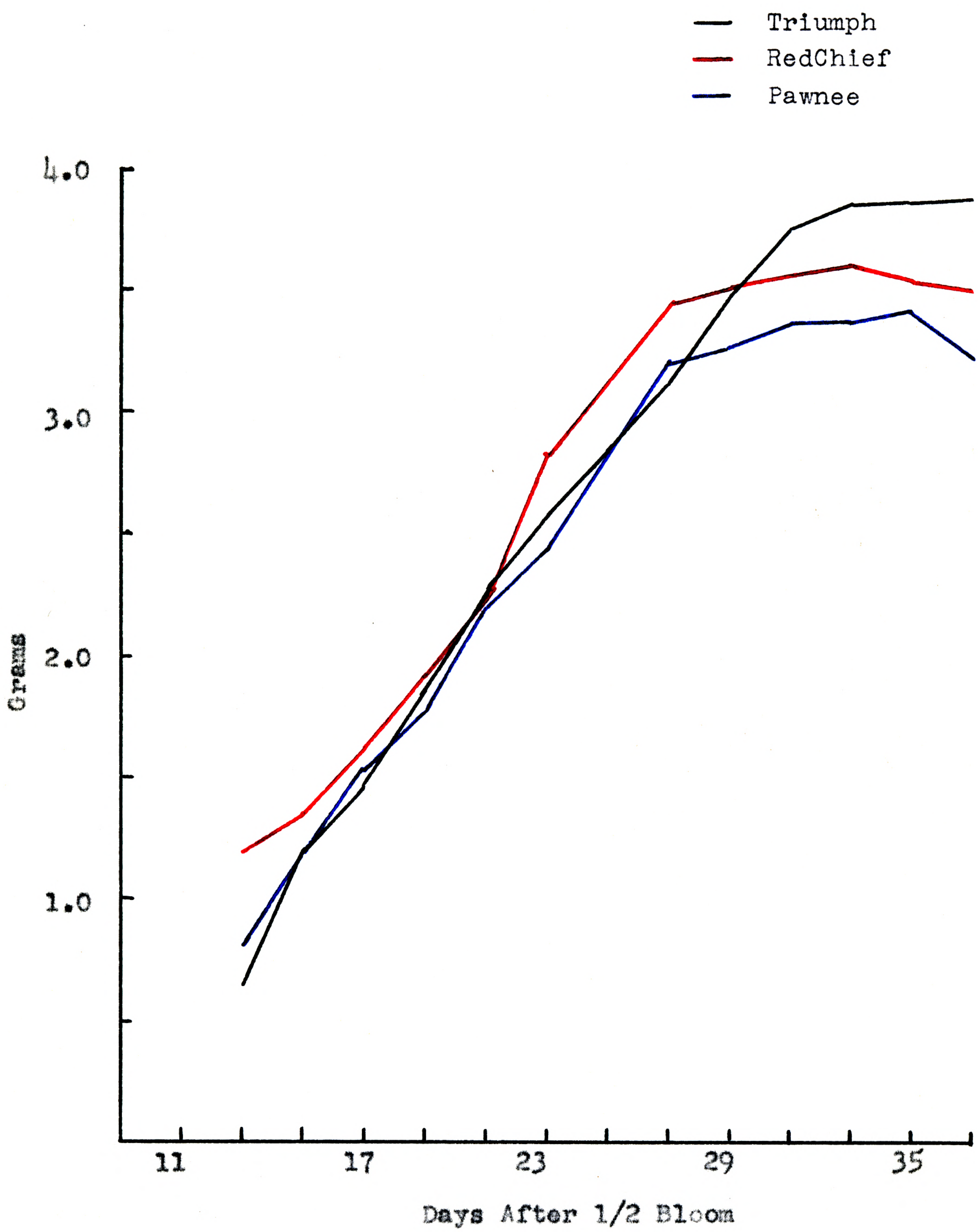


Fig. 7. The average air dry weight of 100 wheat kernels harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1954.

Table 5. The average yields of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1953.

	Triumph		Pawnee		RedChief	
Days after 1/2 bloom	Date cut	Yield Bu/acre	Date cut	Yield Bu/acre	Date cut	Yield Bu/acre
11	June 5	16.07	June 9	16.78	June 9	13.78
13	" 7	19.40	" 11	23.50	" 11	19.22
15	" 9	24.23	" 13	24.52	" 13	21.63
17	" 11	27.60	" 15	27.65	" 15	24.08
19	" 13	30.78	" 17	27.83	" 17	23.75
21	" 15	33.73	" 19	29.25	" 19	26.02
23	" 17	29.25	" 21	25.47	" 21	26.83
25	" 19	31.88	" 23	27.43	" 23	25.02
27	" 21	31.85	" 25	28.08	" 25	24.22
29	" 23	28.78	" 27	27.98	" 27	23.70
31	" 25	25.40	" 29	26.02	" 29	23.48
33	" 27	28.25	July 1	26.45	July 1	19.75
35	" 29	25.31	" 3	25.53	" 3	21.23
37	July 1	27.35	" 5	24.27	" 5	21.42
39	" 3	27.32	" 7	26.22	" 7	20.68
41	" 5	25.07	" 9	27.78	" 9	22.82
43	" 7	26.35	" 11	25.77	" 11	20.83
45	" 9	25.55	" 13	25.55	" 13	22.15

LSD between two dates for same variety = 3.46

LSD between two varieties at the same date of cutting = 3.71.

The analysis of variance showed that the dates of cutting were highly significant, and the varietal differences were significant at the five percent level in all cases. The least significant differences at the five percent level were computed to compare varieties at the same date, as well as, between dates of harvesting the same variety.

The different years and location do not give the same rate of maturity, but one method of comparing the three experiments was by the moisture percentage of the grain. The yields increased regularly until the moisture content ranged from 38 to 44 percent.

Table 6. The average yields of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Hays, Kansas, in 1953.

	Triumph		Pawnee		RedChief	
Days after 1/2 bloom	Date cut	Yield Bu/acre	Date cut	Yield Bu/acre	Date cut	Yield Bu/acre
11	June 8	5.34	June 11	5.62	June 12	8.20
13	" 10	5.24	" 13	8.34	" 14	9.40
15	" 12	11.02	" 15	8.78	" 16	8.94
17	" 14	12.70	" 17	10.06	" 18	14.32
19	" 16	16.08	" 19	12.18	" 20	11.76
21	" 18	16.78	" 21	11.40	" 22	10.98
23	" 20	12.70	" 23	10.20	" 24	10.84
25	" 22	17.68	" 25	13.24	" 26	14.38
27	" 24	18.30	" 27	13.38	" 28	15.44
29	" 26	17.44	" 29	12.40	" 30	16.32
31	" 28	17.62	July 1	13.02	July 2	11.80
33	" 30	19.56	" 3	12.76	" 4	14.10
35	July 2	19.38	" 5	10.72	" 6	14.26
37	" 4	17.92	" 7	13.58	" 8	12.12
39	" 6	17.56	" 9	14.44	" 10	11.58

LSD between two dates for same variety = 3.45

LSD between two varieties at the same date of cutting = 3.63

When the moisture percent of the grain of a plot was in this range the yield was at a maximum as far as could be determined by the least significant differences. Therefore, apparently the yield was at a maximum when the moisture percentage averaged approximately 40 percent.

The seasonal variations between 1953 and 1954, as pointed out in discussing the weight of 100 kernels, will also account for the differences at Manhattan in these two years in rate of yield increase during the early developmental stages.

The data collected in 1951 and not analyzed herein showed that the yield increased regularly until the maximum was attained

Table 7. The average yields of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1954.

Days after 1/2 bloom	Triumph Date cut	Triumph Yield Bu/acre	Pawnee Date cut	Pawnee Yield Bu/acre	RedChief Date cut	RedChief Yield Bu/acre
11	May 19	2.08	May 27	3.80	May 29	5.00
13	" 21	2.90	" 29	4.25	May 31	6.38
15	" 23	5.07	" 31	9.98	June 2	9.95
17	" 25	8.30	June 2	12.10	" 4	15.40
19	" 27	12.70	" 4	19.17	" 6	19.62
21	" 29	16.47	" 6	21.85	" 8	24.45
23	" 31	18.17	" 8	26.82	" 10	28.80
25	June 2	22.22	" 10	28.60	" 12	27.17
27	" 4	25.87	" 12	36.05	" 14	34.15
29	" 6	25.38	" 14	37.30	" 16	32.75
31	" 8	27.60	" 16	36.57	" 18	32.92
33	" 10	29.92	" 18	36.87	" 20	30.38
35	" 12	31.32	" 20	38.37	" 22	32.17
37	" 14	30.38	" 22	39.83	" 24	34.62
39	" 16	26.13	" 24	37.62	" 26	31.58
41	" 18	27.18	" 26	35.67	" 28	31.52
43	" 20	28.72	" 28	37.25	" 30	33.19

LSD between two dates for same variety = 3.93

LSD between two varieties at the same date of cutting = 5.33

approximately a week before normal harvest.

Test Weight

Only one test weight sample was taken for each sampling period; so it was not possible to compute analysis of variances for these samples. The test weights are listed in Table 8, and illustrated by Figs. 11, 12, and 13.

The rate of kernel development in 1953 was very rapid the first 11 days and consequently the test weight in that season was

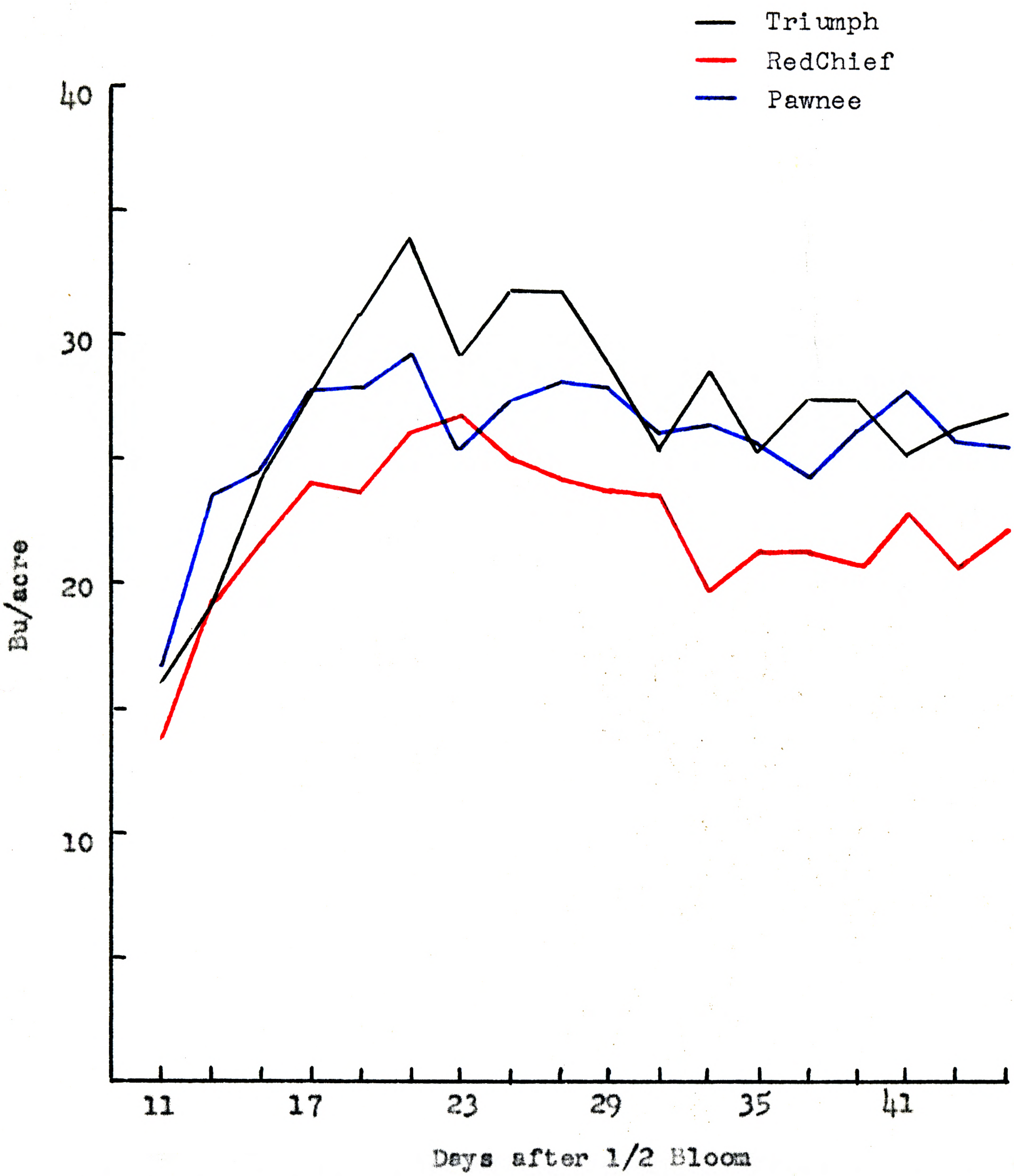


Fig. 8. The average yield of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1953.

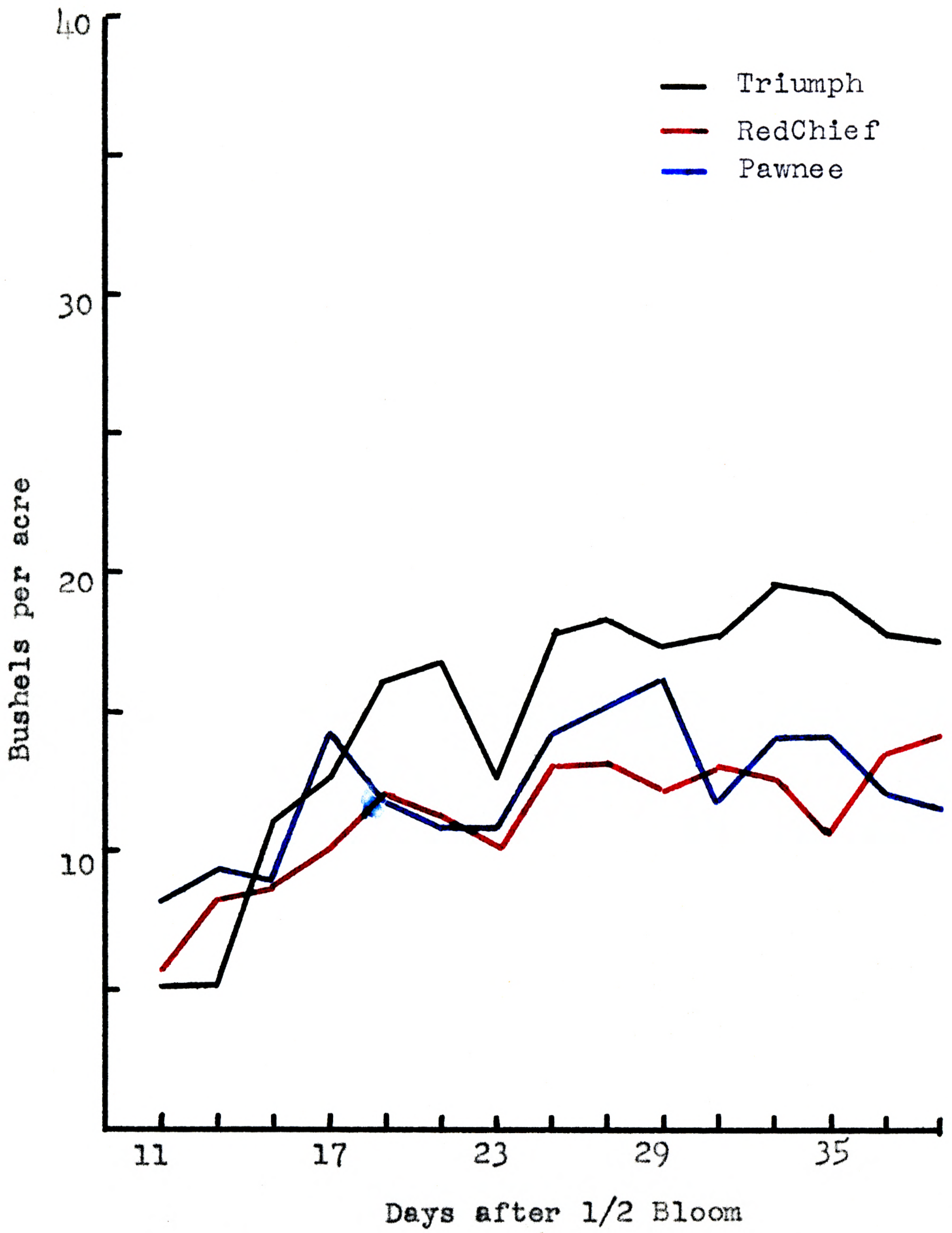


Fig. 9. The average yield of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Hays, Kansas, in 1953.

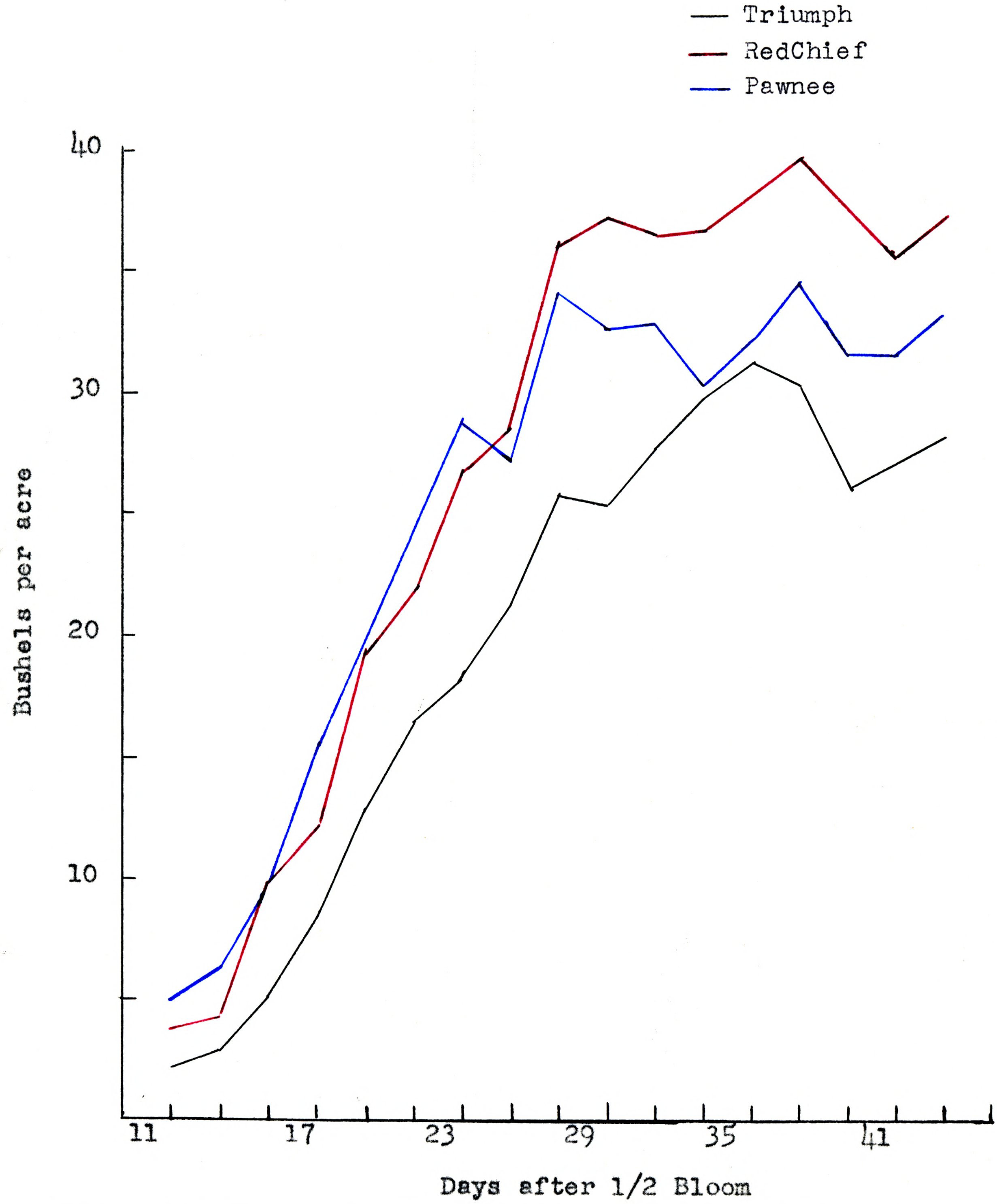


Fig. 10. The average yield of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1954.

Table 8. The test weight of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom.

Days after	Triumph			Pawnee			RedChief		
	Manhattan		Hays	Manhattan		Hays	Manhattan		Hays
1/2 bloom	1954	1953	1953	1954	1953	1953	1954	1953	1953
11	20.0	49.2	36	25.8	49.8	32	31.5	48.4	41
13	24.5	54.8	39	29.8	55.8	38	36.5	56.8	46
15	33.3	58.9	47	38.0	56.9	42	41.8	58.7	47
17	40.0	61.0	47	42.8	58.6	43	47.0	60.4	53
19	43.0	61.2	53	44.3	59.0	47	49.4	60.6	53
21	48.2	61.6	53	48.5	58.4	47	53.4	60.9	53
23	52.0	61.3	52	53.2	58.0	46	58.8	61.4	52
25	54.4	61.5	54	57.9	57.3	48	61.0	60.0	55
27	59.7	61.2	53	60.4	58.3	48	63.4	61.0	54
29	60.7	60.6	52	62.2	57.6	46	63.5	60.3	52
31	61.7	60.2	52	61.4	57.0	45	63.2	59.9	52
33	62.4	59.7	52	62.0	56.3	45	63.4	59.6	54
35	61.8	58.2	53	61.9	55.7	46	63.3	59.2	54
37	62.4	58.6	53	62.0	55.6	46	63.1	59.2	53
39	61.3	58.1	52	61.6	56.0	47	63.2	59.0	54
41	61.2	58.1		61.5	55.6		63.2	58.9	
43	61.1	58.2		62.0	55.5		63.2	58.3	
45	61.0	57.6		60.7	55.6		62.5	58.5	

much higher at the same stage of development than it was in 1954. The average test weight of the three varieties at Manhattan in 1953, 11 days after 1/2 bloom, was 49.3 pounds per bushel which compared to the test weight of the three varieties on or about the twenty-first day after 1/2 bloom in 1954.

The test weight increased regularly until approximately at the beginning of the desiccation period. During the period of desiccation the test weight remained more or less constant. Wetting and drying of the grain in the field will cause the test weight to decrease. This was shown by data collected in 1951 when considerable rain fell before and during the harvesting period. The test weight of Pawnee was 62.3 a week before harvest, but was

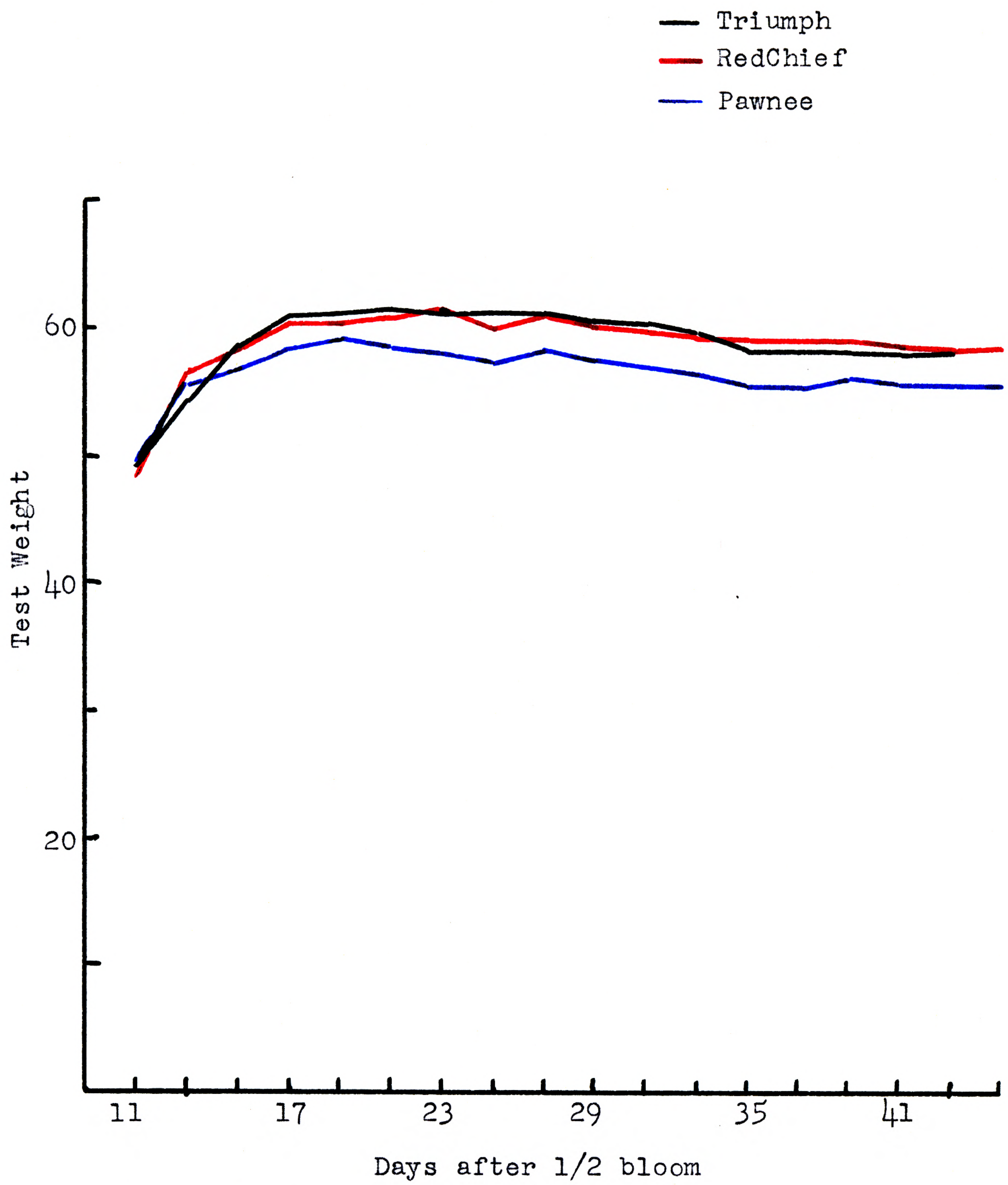


Fig. 11. The test weight of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1953.

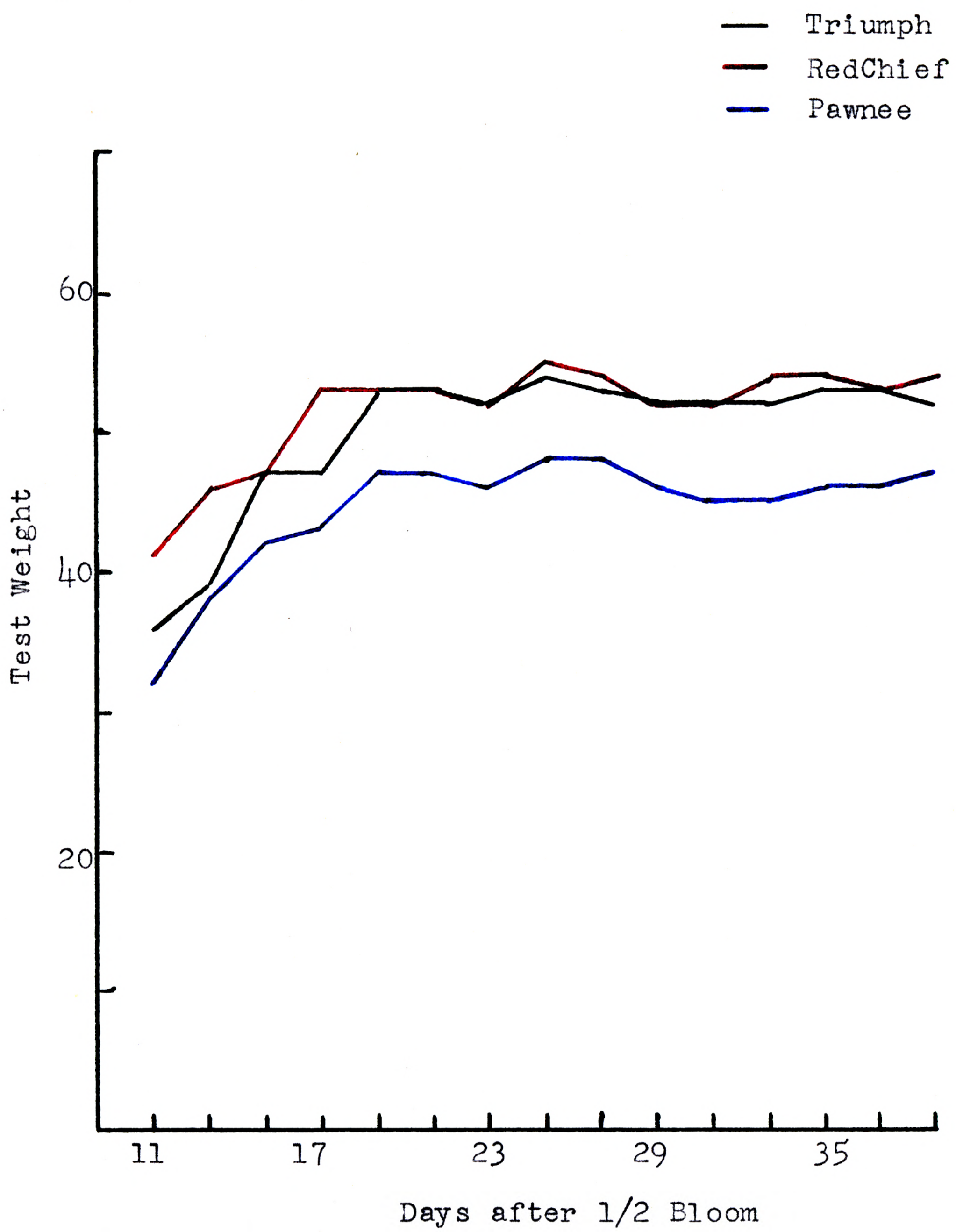


Fig. 12. The test weight of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Hays, Kansas, in 1953.

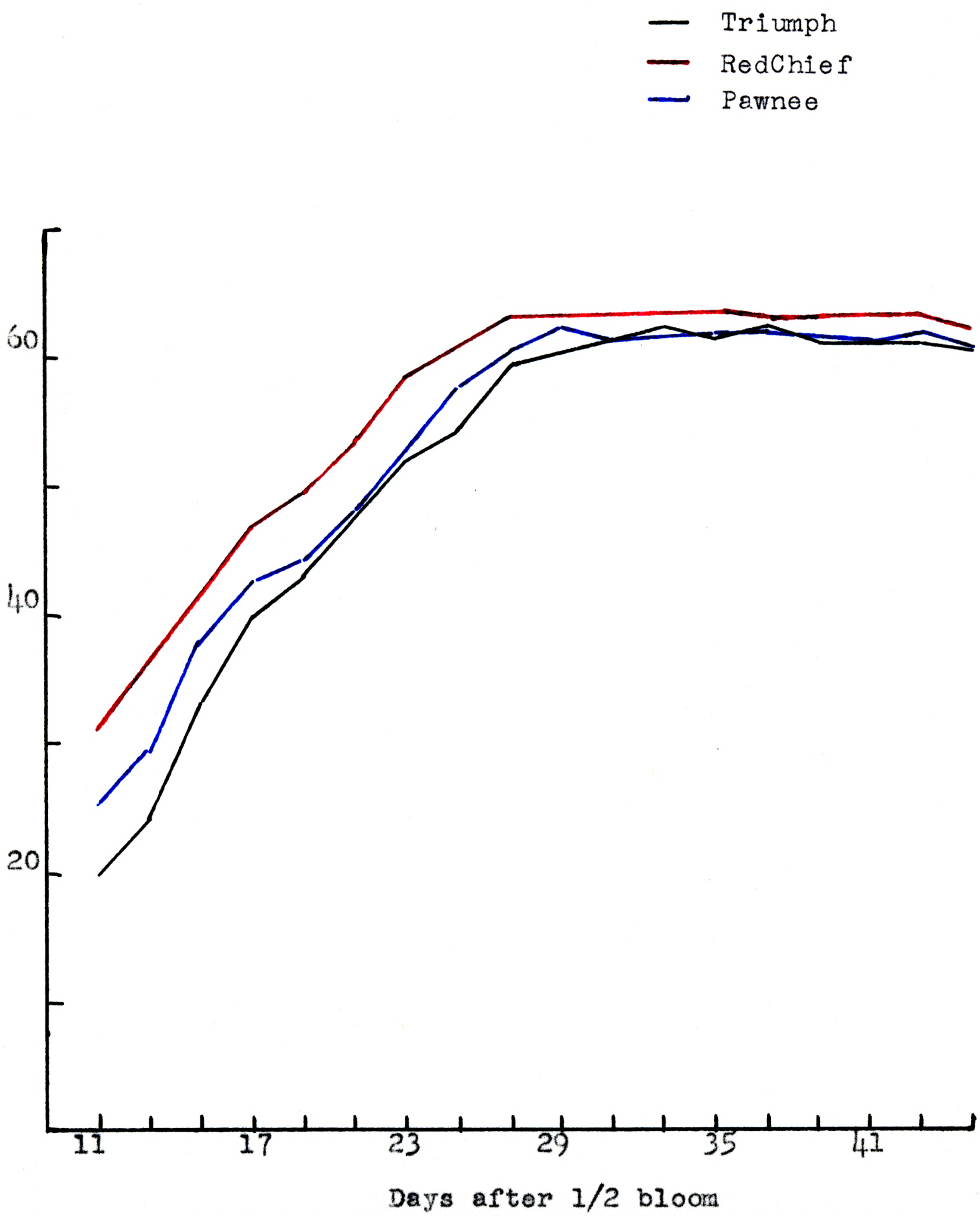


Fig. 13. The test weight of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1954.

58.5 at the time of harvest, and decreased even more when allowed to remain standing in the field.

Moisture Percentage

The average moisture percentage of the three varieties at the different dates of cutting are given in Tables 9, 10, and 11, and shown by Figs. 14, 15, and 16.

The highly significant differences between varieties was probably caused by the difference in maturity dates; because the later maturing variety invariably has a lower moisture percentage. The highly significant difference between dates of cutting was as expected because the moisture percentage decreased during the period. This decrease was rapid during the entire period from eleven days after bloom, with the greatest decrease during the period of desiccation.

The highly significant interaction between varieties and dates of cutting could be caused by environmental factors such as rainfall, temperature, and relative humidity.

The moisture percentage seemed to decrease regularly until it reached approximately 40 percent after which it fell off very rapidly. Following the four to six day period of desiccation, the moisture percentage did not remain constant, but fluctuated under the influence of the environment. Apparently this fluctuation was because the glume had become more loosely enclosed around the berry allowing atmospheric moisture to come in direct contact with the kernel.

The extremely low moisture percentages experienced must have

Table 9. The average percent moisture in the grain of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1953.

	Triumph		Pawnee		RedChief	
Days after 1/2 bloom	Date cut	Moisture %	Date cut	Moisture %	Date cut	Moisture %
11	June 5	62.12	June 9	58.67	June 9	58.07
13	" 7	61.46	" 11	49.10	" 11	50.43
15	" 9	52.86	" 13	41.45	" 13	44.43
17	" 11	46.73	" 15	40.83	" 15	39.71
19	" 13	38.55	" 17	35.53	" 17	39.05
21	" 15	33.53	" 19	18.42	" 19	30.30
23	" 17	28.44	" 21	9.96	" 21	19.71
25	" 19	7.82	" 23	9.99	" 23	12.39
27	" 21	7.71	" 25	10.15	" 25	9.31
29	" 23	8.32	" 27	13.36	" 27	11.45
31	" 25	9.41	" 29	15.10	" 29	13.79
33	" 27	12.58	July 1	9.50	July 1	9.68
35	" 29	14.90	" 3	13.66	" 3	12.66

LSD at 5% level = 2.276

Table 10. The average percent moisture in the grain of wheat harvested on alternate days beginning with the eleventh day after 1/2 bloom at Hays, Kansas, in 1953.

	Triumph		Pawnee		RedChief	
Days after 1/2 bloom	Date cut	Moisture %	Date cut	Moisture %	Date cut	Moisture %
11	June 8	66.86	June 11	66.77	June 12	59.71
13	" 10	61.13	" 13	60.27	" 14	54.29
15	" 12	52.53	" 15	51.72	" 16	48.69
17	" 14	48.29	" 17	49.44	" 18	45.62
19	" 16	44.57	" 19	43.16	" 20	38.37
21	" 18	44.22	" 21	32.97	" 22	33.72
23	" 20	30.43	" 23	20.81	" 24	17.75
25	" 22	8.72	" 25	5.95	" 26	7.86
27	" 24	8.69	" 27	5.52	" 28	9.63
29	" 26	5.93	" 29	9.55	" 30	7.36
31	" 28	9.80	July 1	5.83	July 2	4.49
33	" 30	7.35	" 3	4.10	" 4	6.68
35	July 2	4.56	" 5	10.15	" 6	11.10

LSD at 5% level = 1.55

Table 11. The average percent moisture in the grain of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1954.

Days after 1/2 bloom	Triumph Date cut	Triumph Moisture %	Pawnee Date cut	Pawnee Moisture %	RedChief Date cut	RedChief Moisture %
11	May 19	78.73	May 27	73.68	May 29	74.42
13	" 21	76.36	" 29	71.85	" 31	71.42
15	" 23	71.53	" 31	68.88	June 2	67.72
17	" 25	68.03	June 2	66.28	" 4	62.88
19	" 27	63.72	" 4	60.43	" 6	57.87
21	" 29	58.91	" 6	55.11	" 8	53.67
23	" 31	54.86	" 8	52.24	" 10	48.45
25	June 2	54.09	" 10	45.94	" 12	45.00
27	" 4	49.67	" 12	44.72	" 14	41.77
29	" 6	45.67	" 14	39.11	" 16	40.57
31	" 8	43.35	" 16	40.42	" 18	32.38
33	" 10	38.48	" 18	18.12	" 20	18.87
35	" 12	35.86	" 20	8.64	" 22	8.47
37	" 14	20.49	" 22	19.57	" 24	6.93
39	" 16	32.87	" 24	6.50	" 26	5.02

LSD at 5% level = 1.67

been the result of the extremely hot dry atmospheric conditions prevailing in Kansas during these two years.

Germination Percentage and Seedling Vigor

The results of the germination tests are recorded in Tables 12, 13, and 14.

No significant differences in germination of the 1953 material occurred in the soil germination tests. As far as this test could determine, seed harvested eleven days after 1/2 bloom germinated the same as seed harvested at normal time.

The greenhouse test for the 1954 material gave poor results

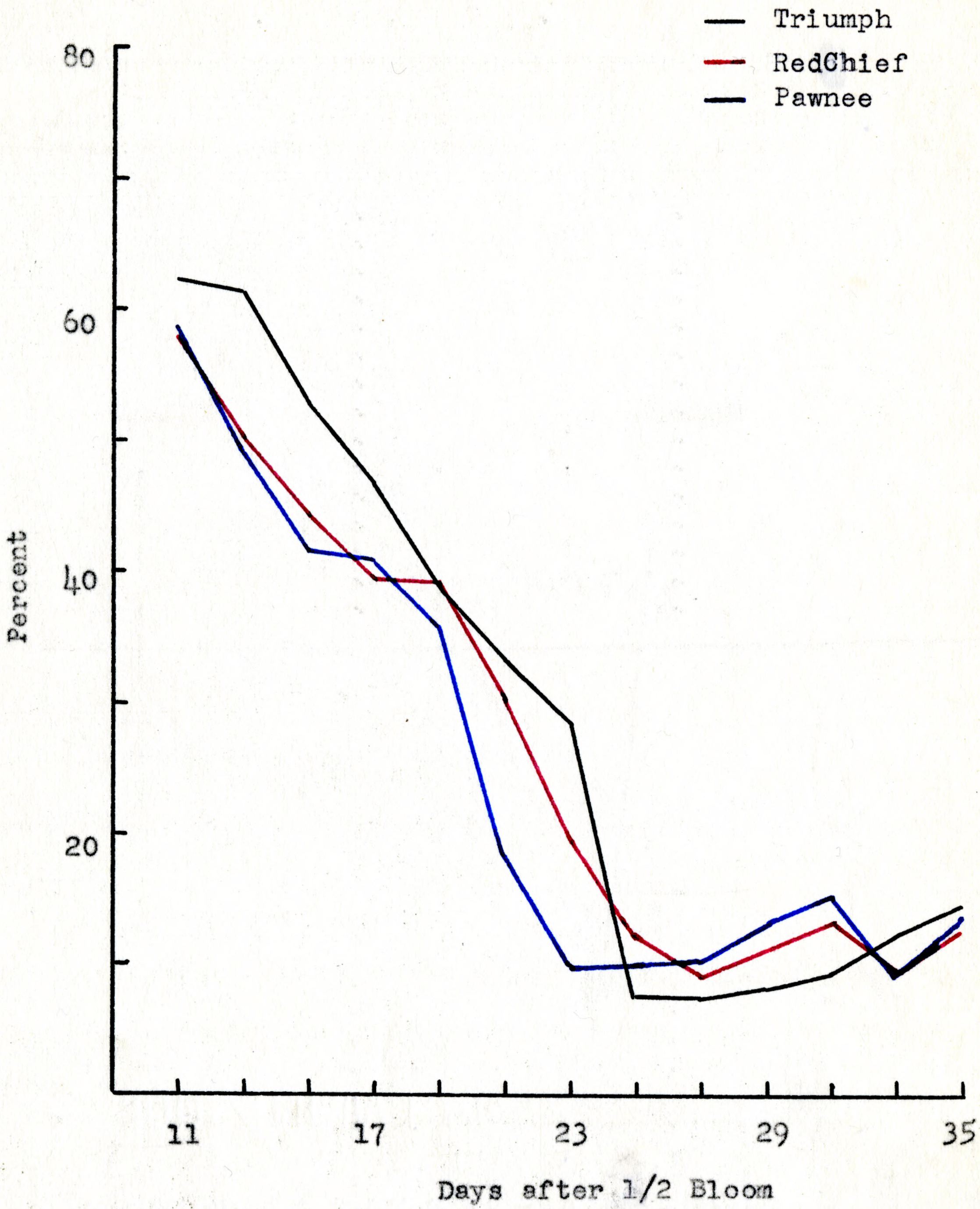


Fig. 14. The average percent moisture in the grain of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1953.

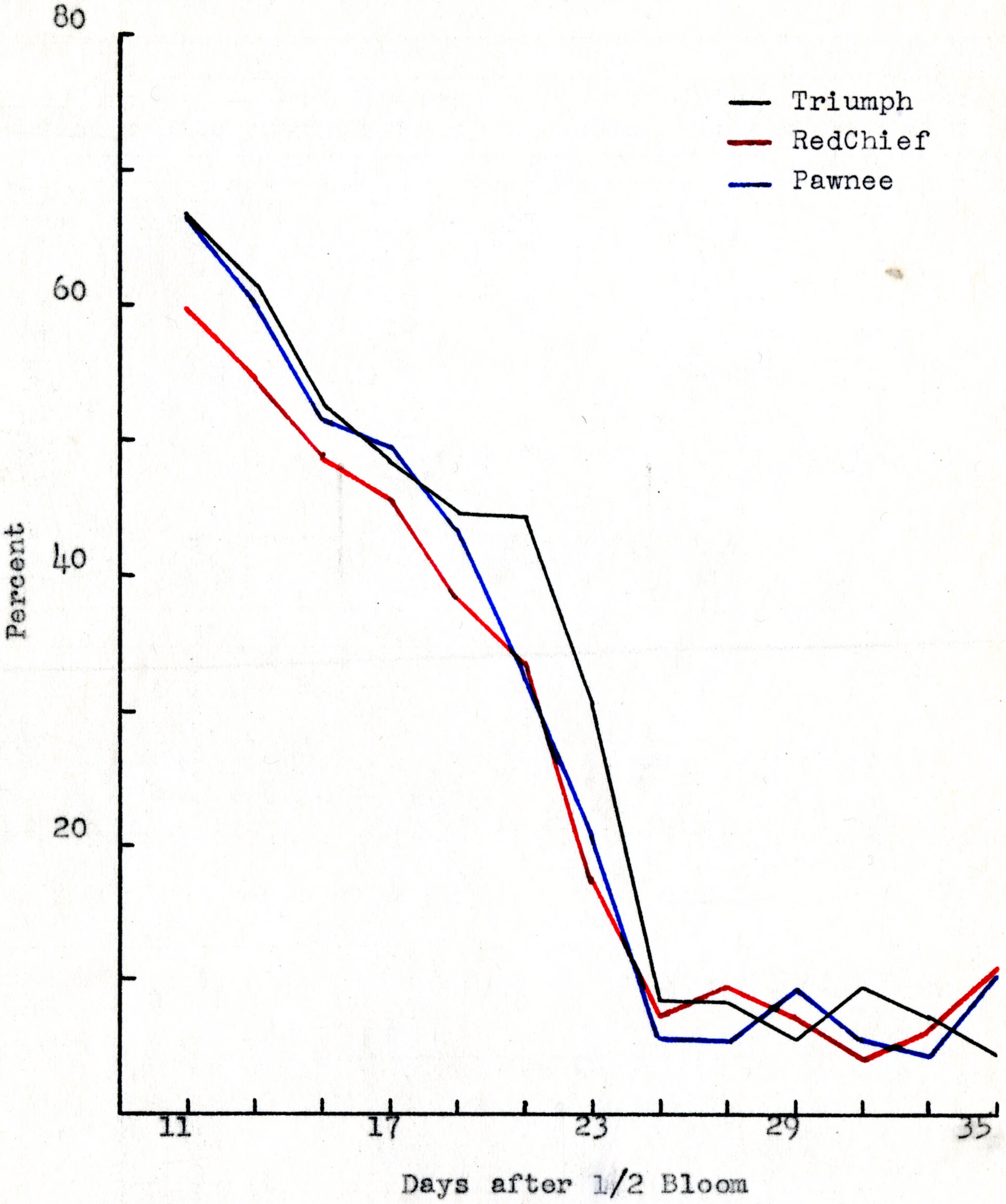


Fig. 15. The average percent moisture in the grain of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Hays, Kansas, in 1953.

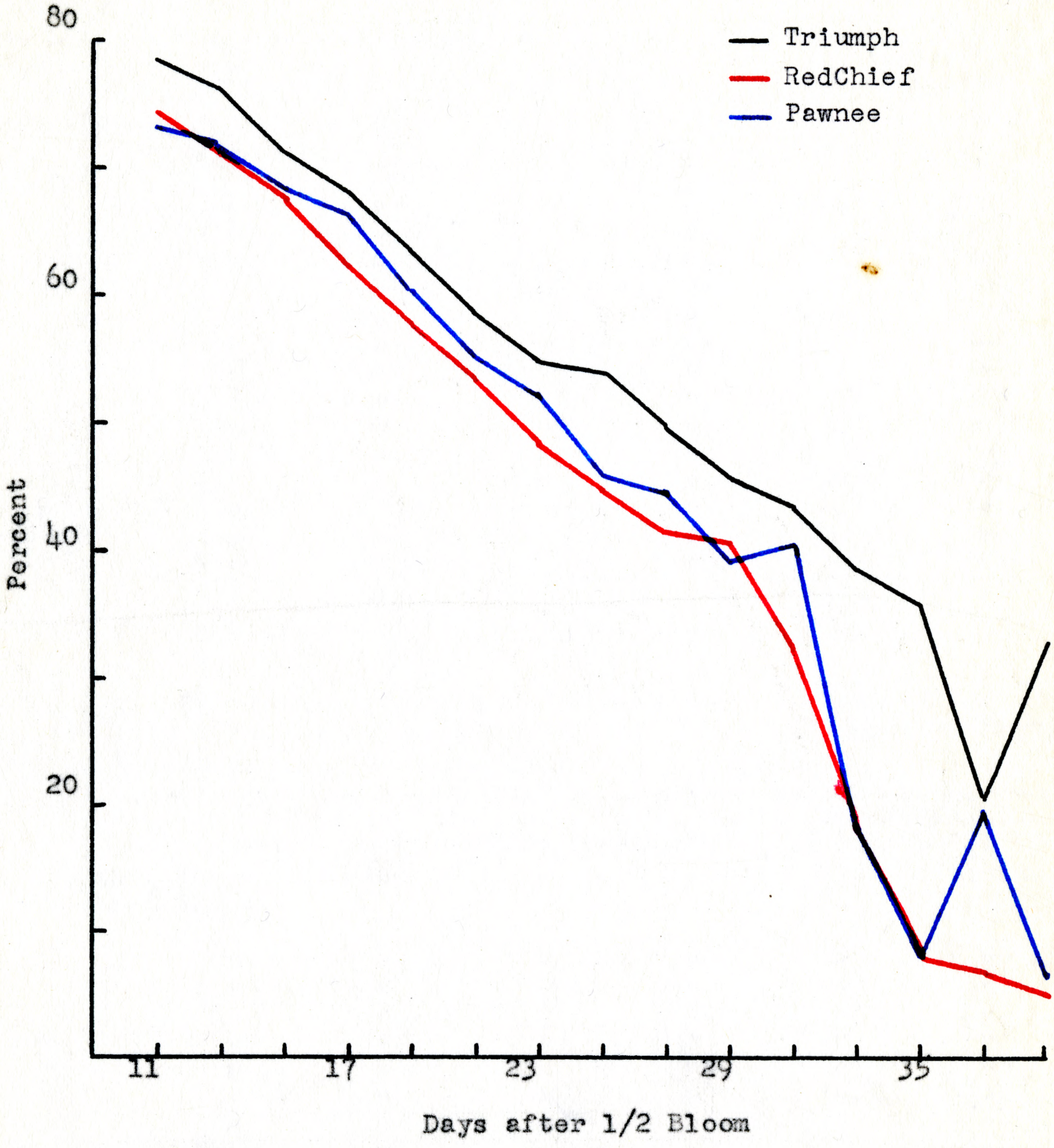


Fig. 16. The average percent moisture in the grain of wheat harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1954.

Table 12. The percent germination of wheat seeds harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1953.

	Triumph		Pawnee		RedChief	
	% Germination		% Germination		% Germination	
Days after 1/2 bloom	Greenhouse	Laboratory	Greenhouse	Laboratory	Greenhouse	Laboratory
11	96.0	97.3	93.0	93.0	91.8	92.5
13	97.5	96.0	92.5	93.8	88.8	95.5
15	96.3	93.5	92.8	95.5	89.5	70.5
17	89.8	94.5	94.5	95.0	90.3	87.5
19	94.0	95.3	93.8	93.8	90.5	89.8
21	95.0	94.5	95.3	95.8	87.3	94.0
23	91.8	94.3	93.3	95.8	83.0	89.8
25	94.8	94.8	91.0	95.0	87.8	85.0
27	91.0	93.8	90.8	93.0	90.5	93.5
29	94.5	94.8	93.5	90.3	89.5	94.8
31	94.5	96.5	88.8	90.5	87.0	92.3
33	94.0	95.5	93.0	91.3	95.0	97.0
35	95.0	94.8	91.3	86.0	92.0	93.8
Average	94.2	95.0	92.6	92.9	89.4	92.0

LSD for greenhouse test at 5% level = 5.67
LSD for laboratory test at 5% level = 3.01

Table 13. The percent germination of wheat seeds harvested on alternate days beginning the eleventh day after 1/2 bloom at Hays, Kansas, in 1953.

	Triumph		Pawnee		RedChief	
	% Germination		% Germination		% Germination	
Days after 1/2 bloom	Greenhouse	Laboratory	Greenhouse	Laboratory	Greenhouse	Laboratory
11	98.5	97.5	97.3	94.5	98.3	97.8
13	98.5	99.8	98.0	94.8	99.0	97.8
15	99.0	98.0	98.0	97.3	99.3	98.3
17	99.5	98.0	96.5	97.5	99.5	98.3
19	99.3	98.0	99.5	97.5	99.5	98.3
21	99.5	98.0	98.5	98.0	99.3	99.0
23	99.3	97.8	99.3	98.0	99.5	97.8
25	97.3	98.0	98.3	97.8	98.8	98.3
27	98.0	98.0	99.0	98.0	99.8	98.8
29	98.0	97.8	99.3	98.0	99.0	98.0
31	99.8	97.8	99.3	97.8	99.5	98.0
33	100.0	97.3	98.3	98.5	99.5	98.5
35	97.8	98.0	99.0	97.8	100.0	98.0
Average	98.8	97.9	98.5	97.3	99.3	98.2

LSD for greenhouse test at 5% level = 2.12
LSD for laboratory test at 5% level = 0.94

Table 14. The percent germination of wheat seeds harvested on alternate days beginning the eleventh day after 1/2 bloom at Manhattan, Kansas, in 1954.

	Triumph		Pawnee		RedChief	
	% Germination		% Germination		% Germination	
Days after 1/2 bloom	Green-house	Labora-tory	Green-house	Labora-tory	Green-house	Labora-tory
11	----	----	----	----	----	----
13	87.8	95.8	85.0	96.5	89.5	96.8
15	89.0	95.8	84.8	98.0	91.5	97.5
17	88.5	91.0	88.8	98.3	86.0	97.8
19	80.5	97.5	86.5	98.0	81.3	96.8
21	85.3	97.0	84.0	97.5	83.3	97.3
23	81.8	96.8	78.3	97.3	85.3	98.0
25	70.0	93.8	91.5	96.8	86.8	97.3
27	----	----	----	----	----	----
29	72.8	95.8	84.3	96.3	88.8	96.3
31	74.3	94.5	94.5	95.8	88.5	97.3
33	74.3	94.0	87.5	96.3	81.5	95.5
35	84.8	96.0	82.0	96.5	82.3	90.8
37	78.8	93.5	75.8	91.3	80.8	96.0
39	90.0	----	78.0		79.0	
Average	81.7	95.1	84.7	96.5	84.9	96.3

LSD for greenhouse tests at 5% level = 8.01
LSD for laboratory tests at 5% level = 2.17

throughout, but the seed harvested thirteen days after 1/2 bloom germinated as well as seed harvested at normal time. The samples taken eleven and twenty-seven days after 1/2 bloom were lost before percent germination could be determined.

The soil germination was lower than the laboratory germination in 1954, but the 1953 material germinated nearly as well, and sometimes better in soil in the greenhouse.

The soil germination in the greenhouse gave equal percent of germination for seeds harvested as early as eleven days after 1/2 bloom, but the seedling vigor was not equal. In 1953 the seedling vigor was not normal until the fifteenth day after 1/2 bloom; while in 1954 the seedling vigor was weak until the nineteenth or twenty-first day after 1/2 bloom. This difference in seedling vigor is illustrated by Plate VI.

The laboratory tests gave high percentage of germination for the 1953 Manhattan and Hays samples and for the 1954 Manhattan samples. In nearly all cases the percentage of germination for seed harvested eleven days after 1/2 bloom was equal to seed harvested at the normal time.

DISCUSSION

From the preceding results and the results of other workers, apparently the yield, test weight, and dry weight per kernel of wheat was at a maximum when the moisture percentage of the grain was approximately 40 percent. A search of the literature did not provide an explanation for this condition; nor was this experiment designed to answer the question.

Did the wheat plant maintain this moisture percentage of the grain until after photosynthesis in the plant had ceased? Photosynthesis may not have ceased completely at this time because there were still some green tissues in the plant.

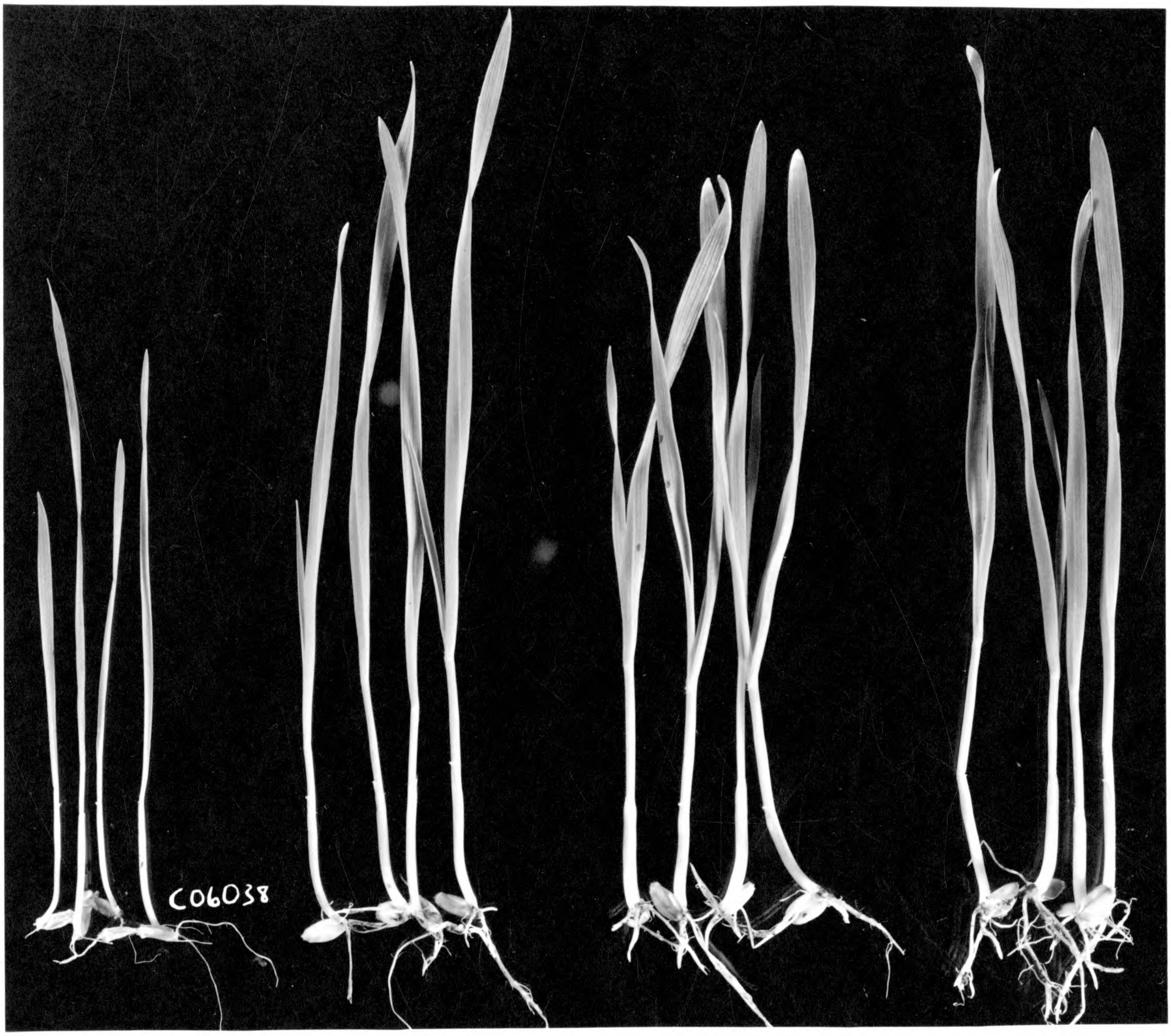
Has translocation of food material into the wheat kernel ceased at this time? Woodman and Engledow in wheat (1924), Harlan and Pope in barley (1923), and Olson in wheat (1923) concluded that apparently no food material was translocated into the grain after the moisture percentage was approximately 40 percent.

Did the enzymatic activity of the cells cease to change the

EXPLANATION OF PLATE VI

Illustration of the vigor of Pawnee wheat seedlings from kernels harvested 11, 21, 29, and 35 days after 1/2 bloom.

PLATE VI



sugars translocated into the kernel to starch grains? If this were true, the loss of dry matter by respiration during the period of dessication might be these sugars which have not been changed to starch. Whether these sugars were respired by both the endosperm and embryo, or the sugars from the endosperm were translocated into the embryo, and then respired, will have to be answered by future research. Dry and hot weather produces shrivelled seeds possibly because the moisture percentage of the kernel reaches too low a level to maintain the enzymatic activity for the change of sugars to starch. Therefore these shrivelled grains might not be the result of insufficient food material being produced by the plant for translocation into the kernel. Reserve sugars in the plant could also be lost by the plant through respiration, or a higher rate of respiration in the plant during drought stress could use up available sugars and leave none for translocation into the kernel.

What role does respiration have during the maturation of wheat? Apparently the wheat kernel used all of the carbonaceous food material which was translocated into the kernel during the earlier period for growth and energy. Percival (1921) and Brenchley (1909) found there was no starch deposited for the first ten to fourteen days after pollination. Therefore, this carbonaceous material must be used for the production of new protoplasm, and the energy required to produce this new protoplasm.

Shirk (1942) presented data on the rate of respiration of wheat kernels. The writer of this thesis used these data to calculate the milligrams of carbonaceous material loss per kernel per day. Results showed that the maximum loss of dry matter occurred on the fourteenth day after pollination, and from this day on the loss per day decreased uniformly until the moisture percentage of the kernel reached approximately 40 percent. At this time the respiration loss was above one milligram per kernel per day, and then the loss decreased as the moisture percentage decreased. McGinnis and Taylor (1923) had similar results on respiration losses, but they had an increase in dry matter until the end of their sampling period; probably because their results were based on a twenty-five gram sample rather than on a certain number of kernels.

The period of desiccation appears to be only a process of dehydration because the moisture percentage dropped from 40 percent to between 12 to 14 percent in a matter of four to eight days depending on the season with no increase in dry matter. In fact, as stated earlier, a decrease in dry matter actually occurred during this period of desiccation. At this time it will have to be left unanswered whether this loss was sugars that have accumulated after enzymatic activity had ceased, or starches.

The water content per kernel increased for approximately the first fourteen or fifteen days after pollination. Apparently this increase in moisture was necessary for the production of new protoplasm during the growth of the kernel. After the growth of the kernel ceased, the moisture content remained approximately constant until the desiccation period during which it decreased rapidly.

The germination potential of the wheat kernel must be high early in the developmental period because eleven days after 1/2 bloom the percentage germination was equal to kernels harvested at normal time. Apparently the only advantage of allowing seeds to become more mature was to increase seedling vigor and, according to Kidd and West (1918), to increase the storage life of the seed. Under field conditions the germination percentages would probably be decreased for the immature seeds because the depth of planting lacks uniformity, and thus many of the kernels that germinated would not have enough food reserves to facilitate emergence.

The higher growth rate of immature seeds observed by Hatcher and Purves (1945) was because the wheat kernel must reach a certain moisture percentage before it will germinate. The shrivelled seeds reached that percentage before plump seeds because of their smallness; thus enabling them to germinate in advance of the others. In soil germination test at Manhattan [illegible] plants from immature seeds emerged before plants from plump seeds, but the latter plants soon overtook the former in growth.

The moisture percentage of the grain was influenced by environmental conditions to a certain extent during the developmental period, but some varieties were influenced more during the period of desiccation. This was probably because during the developmental period, the glumes were more tightly closed around the berry, and moisture from the atmosphere would not come in contact with the kernel. As the wheat plant ripened the glumes tend to loosen and water can be absorbed by the kernels from the atmosphere. This was especially true of awned varieties that would give the wind a leverage to open the glumes.

The seasonal variation due to differences in available moisture and temperature materially changes the rate of development of the wheat kernel. It has generally been concluded that, on the average, the wheat kernel will be mature about 30 days after pollination (Kiesselbach, 1925). Information obtained during 1948-1952, when large samples of grain were harvested for quality studies, indicated that the maximum development of the kernel occurred about 24 days after 1/2 bloom and depending on the season required 4 to 9 days to dry out for harvest. This is an average of about 30 days from 1/2 bloom to ripe under Manhattan conditions. The 1953 season was hot and dry and this season greatly accelerated the rate of kernel development, while the 1954 season was more nearly an average season for rate of development of the wheat kernel for Pawnee and RedChief varieties but not for Triumph.

SUMMARY

The yield of grain, test weight, and dry weight per kernel were at a maximum when the moisture percentage was approximately 40 percent.

The water content increased until the fifteenth day after pollination, and then remained nearly constant until the period of desiccation during which it decreased rapidly. The moisture percentage decreased from the ninth day after pollination with the most rapid decrease during the period of desiccation.

The germination percentage was equal for seeds harvested eleven days after pollination and seeds harvested at maturity. The seedling vigor was not normal for seeds harvested until ap-

proximately seventeen days after 1/2 bloom.

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THE DEVELOPMENT OF THE WHEAT KERNEL

by

GENE EDWARD SCOTT

B. S., Kansas State College
of Agriculture and Applied Science, 1951

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These experiments were designed to determine the changes in size, dry and green weight, and moisture content and percentage of individual wheat kernels; and to determine how these changes were expressed by the more gross measurements of yield and test weight. It was also desired to determine the effect of immaturity on germination percentage and seedling vigor.

Individual florets were marked near the center of the spike with India ink on the day of flowering to permit the harvesting of kernels of known age; expressed as days after pollination.

The dry weight per kernel, yield and test weight increased steadily during the developmental period, and were at a maximum when the moisture percentage of the grain was approximately 40 percent. Respiration probably caused a loss of dry matter per kernel during the desiccation period.

The water content of individual kernels rose rapidly for the first fifteen days after pollination. From the fifteenth day until the twenty ninth day the water content remained more or less constant, and then decreased during the desiccation period. The moisture percentage rose a little after pollination and remained near 80 percent until the ninth day after pollination. Following the ninth day, it decreased uniformly until the period of desiccation during which it decreased rapidly.

The germination percentage was equal for seeds harvested eleven days after 1/2 bloom and seed harvested at normal time. The seedling vigor was less for the seedlings from seeds harvested as early as eleven days after 1/2 bloom.