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Germination Studies in Grain Sorghum

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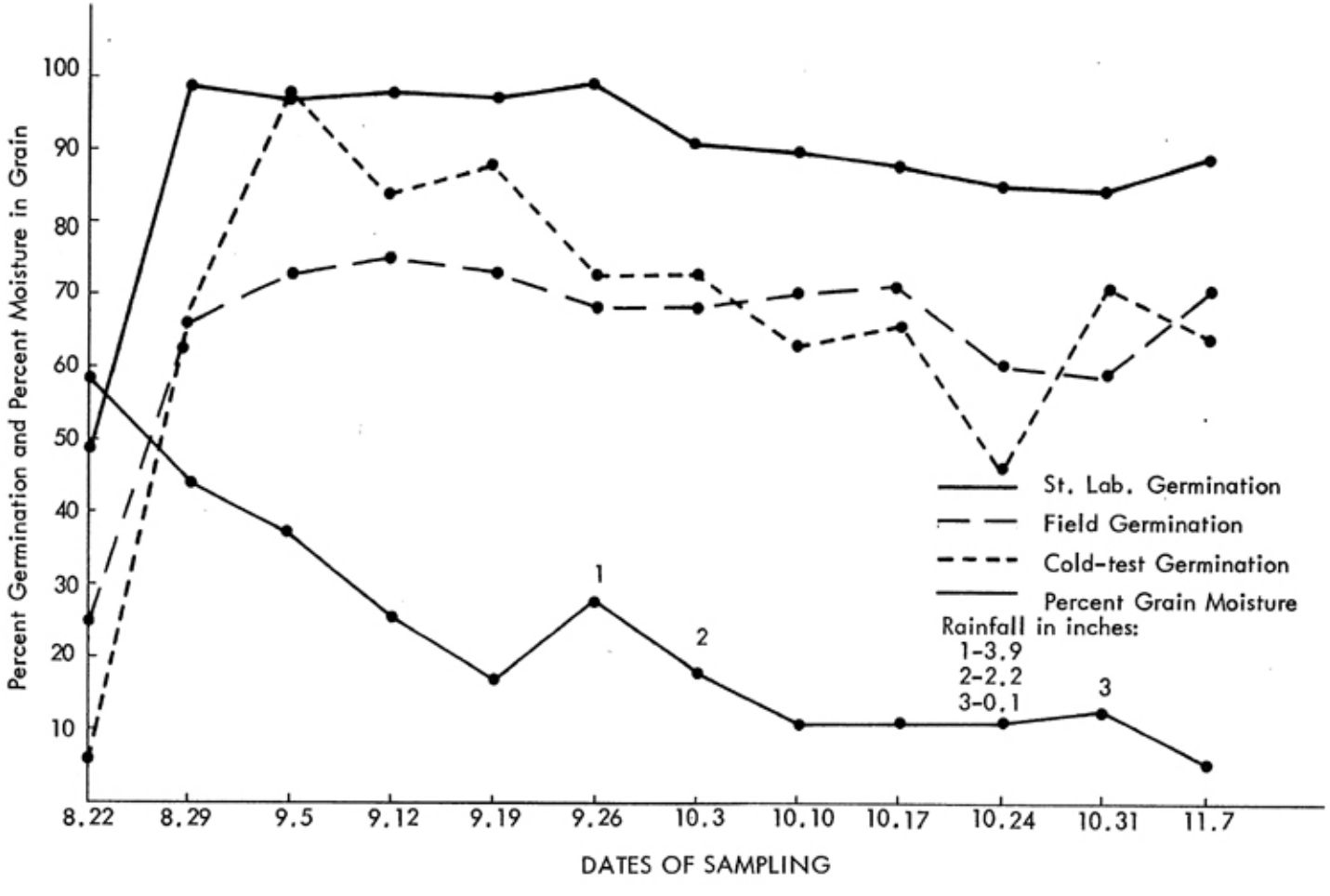

PLATE – I Percent moisture in sorghum grain at the time of harvest and laboratory, field, and cold test germination percentages of the grain, from a sampling study conducted at weekly intervals in 1959 at the University South Farm near Columbia, Missouri

SUMMARY

Investigations were conducted during 1959-61 on the germination of grain sorghum to determine: the minimum temperature for germination, a satisfactory temperature-time schedule for the rolled towel cold test, the effect of depth of planting on emergence, the behavior of different seed lots of the same hybrid or variety, the heritability of germination strength, and the effect of seed maturation on germination strength.

In germination trials of seven seed lots at 45, 50, and 55°F. for a ten day period, near normal germination as indicated by both plumule and radicle emergence occurred only at 55°F. However, since radicle emergence occurred at the lower temperatures, and germination is a function of time as well as temperature, the minimum temperature for sorghum germination is judged to be somewhat lower than 55°F.

Germinations from rolled towel cold tests at 8°, 12°, and 16°C. for time periods varying from 4 to 7 days were compared with standard laboratory germinations for predicting relative field stands in three dates of planting. As indicated by correlation coefficients the cold tests usually predicted relative field stands no better than did the standard laboratory test. This failure is attributed to the field tests rather than the cold tests. None of the field tests provided the combination of low soil temperature and high soil moisture content necessary for critical evaluation of different cold tests.

Sorghum seed planted two inches deep gave better field emergence as an average for three dates of planting than plantings one or three inches deep. In the third date where soil moisture conditions were ideal the one inch depth of planting gave the best stands. Fungicide treatment increased emergence only in the first and second dates of planting and in these dates only for the two and three inch depths of planting.

Commercial seed lots of 25 hybrids (or varieties) produced in 1957 and 1958 and tested in laboratory and field trials in 1959 demonstrated significantly lower germinations for the 1957 seed and no significant effect of "varieties" as indicated by the F value calculated from varieties/varieties x seed lots mean squares. When 1957, 1958, and 1959 seed lots of eight of the above hybrids were tested in field trials in 1960 a significant F value for varieties was obtained due largely to the rather good agreement between performance of the 1958 and 1959 seed lots of the same variety.

Estimates of the heritability of germination strength were made from the parental, F_1, and F_3 generation of four crosses. Seed lots of the same sexual generations produced in two different seasons gave widely different heritability values but the ranking of the crosses was in fair agreement.

Seed harvested from one hybrid at weekly intervals beginning 17 days after mid-bloom showed that maximum germination strength was reached 31 days ofter blooming and maintained for two more weeks after which there was a gradual decline in seed quality probably as a result of field weathering.

Germination Studies in Grain Sorghum[1]

D. P. Srivastava and E. L. Pinnell[2]

During the last sixty years a great deal of agronomic research on sorghums has been done by workers of the United States Department of Agriculture and state agricultural experiment stations, especially in the states of the Great Plains.

According to Quinby and Martin (13) the varieties that were first introduced into the United States were tall and late to mature. These produced satisfactory grain crops in the southern parts of the United States but could not be grown with much success any farther north than Kansas. The development of shorter and earlier maturing varieties extended the area of grain sorghum production north into Nebraska and higher altitudes of Kansas and Colorado. In South Dakota the breeding of adapted grain sorghums extended the area of grain sorghum still farther north.

The recent development of hybrid grain sorghum, government acreage control on corn and other crops, and a series of drought years in the 1950's stimulated an expansion of grain sorghum acreage eastward from the Great Plains into the western margin of the corn belt, especially Missouri. Grain sorghum production practices in Missouri are similar to those for corn but good stands, satisfactory control of weeds, and successful harvesting are all generally more difficult to achieve than with corn. In some years heavy lodging of the crop occurs before the grain is dry enough to store safely. Farmers who have equipment to dry the grain have less harvest loss because they can usually harvest before the onset of the cool, wet fall weather which is conducive to high moisture in the grain and heavy lodging. The general availability of sorghum seed with strong germinating power and the ability to produce a faster growing seedling would not only allow earlier planting and better weed control but should on the average make an earlier harvest possible.

Sorghums are generally known to require somewhat higher temperature than corn for germination. Recommendations that sorghums should be planted

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at least two weeks after corn, reflect this knowledge. However, little is known about some of the following:

1. Minimum germination temperature of sorghum compared with corn.

2. Variations among strains and hybrids of sorghum in vigor of germination under adverse conditions and in the minimum temperature required for germination.

3. The effect of maturation and the weather during and following maturation on the seed quality of the harvested crop.

The purpose of this research was to study the germination of grain sorghum under varying field and laboratory conditions. The investigations carried on during 1959-1961 may be grouped as follows:

Group 1. The germination of different seed lots of sorghum varieties and hybrids, under a range of environmental conditions, to obtain information on the effect of environment and heredity during the season of seed production.

Group 2. Determining the minimum temperature required for the near normal germination of grain sorghum.

Group 3. Development of a cold test technique for grain sorghum.

Group 4. Estimates of the heritability of germination power.

Group 5. Depth of planting sorghum in relation to stands obtained.

Group 6. The effects of seed maturity and environmental factors on the subsequent quality of sorghum grain.

MATERIALS AND METHODS

Group 1. Twenty-five varieties and hybrids of grain sorghum each with two seed lots (1957 and 1958) were studied for their laboratory germination and for their field germination at three different planting dates in 1959. These seed lots were collected from different commercial seed producers selling seed in Missouri. They were collected originally for use in the official Missouri yield trials of grain sorghum in 1958 and 1959, and thus were probably produced in the growing seasons of 1957 and 1958. This study was repeated in 1960 using only the eight hybrids for which three seed lots (1957, 1958, and 1959) were available.

All the seeds were treated uniformly with Arasan, and only good quality seeds apparently free from gross seed coat injury were used in the experiments.

Standard laboratory germination tests were made in the Seed Testing Laboratory of the University of Missouri, using automatically controlled refrigerator-type germinators, with alternating night-day temperatures of 20°-30°C. (68-86°F.). From each seed lot, four replicates of 100 seeds each were used for the germination tests. The seeds were spread evenly between moistened paper towels and kept in the germinator for ten days after which germination counts were made.

All field germination trials were conducted on the University of Missouri "South Farm" five miles south of Columbia, Missouri. One hundred seeds were planted in each of three replications for a single seed lot of each variety. A randomized block design was employed using single-row plots five feet in length for each replication. Seeds were drilled and covered by hand to a depth of approximately one inch. The purpose of the field germination trials was to obtain data on germination of grain sorghum under a range of conditions, from adverse to optimum.

The first planting in 1959 was made on April 23, a time presently considered too early for planting grain sorghum in Missouri. A second planting was made on May 5, and a third on June 2. Unfortunately, dry weather following the June 2 planting was so severe that this trial was abandoned because of poor stands. In late July, after light showers, another planting was made on July 24 to replace the one made on June 2.

The first field planting in 1960 was delayed by bad weather. The three plantings were made on May 14, May 31, and June 17.

Germination counts for each planting were made 15 to 20 days after emergence of the seedlings.

Group 2. Seeds of seven sorghum varieties which showed a range of germination in standard germination tests were used in an attempt to determine the minimum temperature for sorghum germination. The seeds were placed in "built-in" water cooled germinators maintained at 7.2°, 10.0°, and 12.8°C. (45°, 50°, and 55°F.). After ten days, germination percentages were recorded. This experiment was conducted as a four-replicate trial in a split-plot design.

Group 3. Seeds from five sorghum parents and F_1 and F_2 progenies from four crosses were used in these studies designed to develop a "cold test" technique. These consisted of bulked open-pollinated seeds harvested in 1959 from two replicated plots, one grown at the "Rollins Bottom" and the other at the "South Farm", both near Columbia, Missouri. The twenty-six seed lots thus obtained were germinated in standard laboratory, field, and cold test trials. Field germination tests were made at three planting dates on May 14, May 31, and June 17, 1960, after the method described in Group 1. The cold test germination trials were made at 8°, 12°, and 16°C. for four different durations at each temperature, i.e., 4, 5, 6, and 7 days. The method for cold testing was the "Rolled Towel Method", described by Hoppe (4) for corn. These two groups of seed lots were chosen for the study because those from the "South Farm" showed more or less uniform standard laboratory germination, all the values being above 91 percent, while those of the "Rollins Bottom" ranged from 76.5 to 98.5 percent.

Group 4. Five sorghum parents, four F_1 crosses, and the F_2 generations of the same crosses were grown at "Rollins Bottom" near Columbia, in 1959. Several heads of each were covered with paper bags to enforce selfing. These heads were harvested and threshed individually for use in field germination tests in 1960.

Seeds used for field germination were treated uniformly with Arasan. One hundred seeds from each head were divided into two replicates of 50 seeds each and planted in single-row plots five feet in length in May, 1960. Germination counts were made as described previously. Heritability values were calculated, but because they were unsatisfactory a new trial was planned as follows. The seedlings in one replication of the field germination trial were thinned to leave about five plants in each row. Twenty open-pollinated heads from each of the parents and seventy-five heads from each F_2 population were harvested in the fall of 1960. Each head was threshed individually and the seeds treated uniformly with Arasan. Cold testing was done by the "Rolled Towel Method" at 12°C. for four days. Heritability values were determined by the F_2 variance method described by Mahmud and Kramer (8).

Group 5. For the depth of planting study, seeds of three sorghum varieties were used, one high (above 90 percent), one medium (between 81-90 percent), and one low (between 71-80 percent) in standard laboratory germination. Both fungicide-treated and untreated seeds were used in a study of the interaction of seed treatments, seed lots, and depth of planting. One hundred seeds of each variety were planted in single-row plots five feet in length at depths of 1, 2, and 3 inches using three replications in a split-plot design. Depth of planting was used as the main plot, fungicide treatment as subplots, and varieties as sub-subplots. Three field plantings were made in 1960 on May 19, May 30, and June 18. Methods of counting seedlings were the same as described in Group 1.

Group 6. A six-head sample of sorghum hybrid Amak R12 was harvested at 7-day intervals on twelve different dates in 1959 by McBride, et al. (11). These samples were studied for standard laboratory, field, and cold test germination. The field plantings were made on May 14, May 31, and June 18, 1960, with 100 seeds in rows five feet long in a randomized block design with three replications. Cold testing was done at 12°C. for four days by the "Rolled Towel Method". Data on moisture content in the seed at each harvesting date were obtained from McBride, et al. (11). The three types of germinations stated above were studied in relation to the moisture content of the seeds at the time of harvest and also in relation to the date of blooming. The purpose was to determine the importance of seed maturity and environmental factors on the subsequent quality of the seed as measured by the above described tests.

EXPERIMENTAL RESULTS

Effect of Seed Lot and Variety on Germination

In the studies conducted in 1959 with the two seed lots of twenty-five hybrids and varieties of grain sorghum, the average standard laboratory germination percentages were 84.1 for 1958 seed lots and 78.9 for 1957 seed lots. In field trials, 1958 and 1957 seed lots averaged 63.4 and 59.4 percent respectively. These values were significantly different when tested by Duncan's Multiple Range Test.

There was, in general, no relationship between the stand performance of the two seed lots from the same variety as shown by analysis of variance and simply correlations. Table 1 gives the results of a combined analysis of variance for the three field germinations. F values for tests, varieties, and seed lots exceeded the 1 percent probability level. The interaction "variety x seed lot" was especially high indicating that environmental factors affecting seed quality were important. When the interaction sum of squares was used for the calculation of the F value for varieties no significant difference was demonstrated, showing that the environment under which the seed was produced and processed influenced the germination of the seed more than the genotype of the variety.

TABLE 1 -- COMBINED ANALYSIS OF VARIANCE FOR THREE FIELD GERMINATION TRIALS IN 1959 OF 25 VARIETIES OF GRAIN SORGHUM

Sources of Variation	Degrees of Freedom	Mean Square	F^1	F^2
Varieties	24	1833.70	54.92**	1.73
Seed lots	1	1720.90	51.54**	
Tests	2	8259.25	247.36**	
Replications within tests	6	78.81	2.36*	
Varieties X Seed lots	24	1063.30	31.85**	
Varieties X Tests	48	51.34	1.54*	
Seed lots X Tests	2	220.30	6.60*	
Varieties X Tests X Seed lots	48	59.88	1.79*	
Error	294	33.39		
Total	449			

F^1 values using residual error.
F^2 values using "Varieties X Seed lots" interaction as lesser mean square.
* Significant at the 5% probability level.
** Significant at the 1% probability level.

In the studies conducted in 1960 with three seed lots of eight hybrids, the 1959 seed lots germinated slightly better than the 1958 seed lots, and both germinated significantly better than 1957 seed lots in standard laboratory and field germination trials. The average standard laboratory germination percentages were 91.0, 90.1 and 77.9, while those for the three field trials were 78.2, 77.1 and 67.3 for the 1959, 1958, and 1957 seed lots, respectively. Table 2 gives the results of a combined analysis of variance for the three field germination trials of these hybrids. F values for tests, varieties, seed lots and the interaction of varieties x seed lots exceeded the 1 percent probability level. Unlike the previous test, use of the interaction varieties x seed lots in the F test for varieties demonstrated a significant difference among varieties indicating that seed germination was influenced by both the variety genotype and the environment under which the seed was produced and processed.

TABLE 2 -- COMBINED ANALYSIS OF VARIANCE FOR THREE FIELD GERMINATION TRIALS IN 1960 OF 8 HYBRIDS OF GRAIN SORGHUM.

Sources of Variation	Degrees of Freedom	Mean Square	F^1	F^2
Varieties	7	1938.71	46.23**	4.39**
Seed lots	2	2664.17	63.52**	
Tests	2	5606.19	133.67**	
Replications within tests	6	29.23	0.70	
Varieties X Seed lots	14	441.66	10.53**	
Varieties X Tests	14	66.04	1.58	
Seed lots X Tests	4	56.21	1.34	
Varieties X Tests X Seed lots	28	43.20	1.03	
Error	138	41.94		
Total	215			

F^1 values using residual error.
F^2 values using "Varieties X Seed lots" interaction as lesser mean square.
**Significant at the 1% probability level.

The relative germination values for the planting dates April 23, May 5, and July 24, 1959 are of interest. As shown in Table 3, these were 61.1, 68.6, and 54.1 for the early to late dates respectively. Soil moisture conditions were good for the first two dates but poor for the third. Soil temperatures at a depth of 1 inch, measured twice daily at 8:00 a.m. and 5:00 p.m., averaged 68.2°F. for the seven day period immediately following the April 23 planting and 71.0°F. for the seven day period following the May 5 planting. Soil temperatures were not measured after July 24 but as judged from air temperatures recorded at that time, must have been about 80°F.

TABLE 3 -- AVERAGE GERMINATION PERCENTAGES FOR 1957 AND 1958 SEED LOTS OF 25 SORGHUM VARIETIES IN THREE FIELD TRIALS IN 1959.

Seed lot	Field Germination Percentages			Average
	April 23	May 5	July 24	
1957	60.0a	67.1a	50.8a	59.4a
1958	62.2a	70.1a	57.3b	63.4b
Average	61.1	68.6	54.1	61.4

Entries in a column with the same letter are not significantly different according to Duncan's Multiple Range Test.

Minimum Temperature for Germination

Table 4 gives the germination of seven sorghum varieties and hybrids, at temperature of 7.2°C. (45°F.), 10°C. (50°F.), and 12.8°C. (55°F.). Their germination percentages in the standard laboratory test are given also. The data show that after 10 days at 7.2° and 10°C. there was no plumule emergence but considerable radicle emergence. Radicle emergence itself differed, Dekalb E56a being highest and Combine Kafir 60 lowest in the test. Germination at 12.8°C. (55°F.) and the standard germination percentages appeared to be correlated with the percent of radicle emergence at the lower temperatures.

TABLE 4 -- GERMINATION PERCENTAGES OF 7 SORGHUM VARIETIES AND HYBRIDS AFTER 10 DAYS EXPOSURE TO LOW TEMPERATURES WITHOUT SOIL.

Variety or Hybrid	45°F Percent Radicle Emergence	50°F Percent Radicle Emergence	55°F Percent Germination	68-86°F (Standard) Percent Germination
Northrup N.K. 230	60.0*	70.0*	72.0	96.3
R. S. 608	60.0*	72.0*	83.0	91.5
Northrup N.K. 140	14.0*	36.0*	80.0	96.0
Dekalb E56a	64.0*	75.0*	75.0	87.5
Martin	21.0*	25.0*	32.0	71.0
Westland	3.0*	9.0*	16.0	62.3
Combine Kafir 60	1.0*	4.0*	19.0	60.0

* Indicates emergence of radicle only.

Cold Tests Compared with Laboratory and Field Tests

The standard laboratory germination percentages averaged 94.9 for the seeds produced at the "South Farm" and 88.4% for those produced at "Rollins Bottom". More-over the "South Farm" seeds were more uniform in quality, all germinating above 91 percent, while the seeds from "Rollins Bottom" ranged from 76.5 to 98.5 percent in laboratory germination.

Similar differences were obtained in field trials as can be seen in Table 5. The "South Farm" seed averaged 73.5 percent for the three plantings while the "Rollins Bottom" seed averaged 69.7 percent. The three field plantings on May 14, May 31, and June 17 averaged respectively 72.3, 63.6, and 84.6 percent for the "South Farm" seed and 71.3, 56.3, and 81.6 percent for the "Rollins Bottom" seed. Low stands in the second date of planting were the result of poor soil moisture conditions immediately after planting. In the first and third dates soil moisture was considered satisfactory at the time of planting and light showers were obtained during the period of seedling emergence.

In cold test trials, however, the seeds from "Rollins Bottom" germinated better than those from the "South Farm", the germination percentages being

74.0 and 71.7 respectively. In both the cases the highest germination percentages were at 8°C. and the lowest at 12°C. These data appear in Tables 6 and 7.

The longer the exposure to a particular temperature the lower the germination percentage as shown by germinations of 82.5, 77.5, 64.9, and 61.7 percent for the periods of 4, 5, 6, and 7 days, respectively, for the seeds from "South Farm"; and 81.8, 76.7, 72.8, and 64.6 percent for these periods for the seeds from "Rollins Bottom".

TABLE 5 -- AVERAGE GERMINATION PERCENTAGES OF 13 SORGHUMS WITH TWO SEED LOTS IN THREE FIELD TRIALS IN 1960 AND IN A STANDARD LABORATORY TRIAL.

Seed Source	Field Germination Percentage			Average	Standard Laboratory Germination
	May 14	May 31	June 17		
South Farm	72.3	63.6	84.6	73.5	94.9
Rollins Bottom	71.3	56.3	81.6	69.7	88.4
Average	71.8	60.0	83.1	71.6	91.6

TABLE 6 -- AVERAGE COLD TEST GERMINATION PERCENTAGES OF 13 SORGHUMS (PRODUCED AT THE "SOUTH FARM ") WHEN EXPOSED TO THREE TEMPERATURES FOR PERIODS OF 4, 5, 6, AND 7 DAYS.

Temperature	Duration in days				Average %
	4	5	6	7	
8°C	85.2	86.8	86.2	81.4	84.9
12°C	78.2	73.2	51.2	51.4	63.5
16°C	84.0	72.6	57.3	52.4	66.6
Average	82.5	77.5	64.9	61.7	71.7

TABLE 7 -- AVERAGE COLD TEST GERMINATION PERCENTAGES OF 13 SORGHUMS (PRODUCED AT "ROLLINS BOTTOM") WHEN EXPOSED TO THREE TEMPERATURES FOR PERIODS OF 4, 5, 6, AND 7 DAYS.

Temperature	Duration in days				Average %
	4	5	6	7	
8°C	82.0	83.6	82.4	73.8	80.5
12°C	80.9	70.1	68.8	57.2	69.5
16°C	82.6	75.5	67.2	62.7	72.0
Average	81.8	76.7	72.8	64.6	74.0

Correlation coefficients were calculated among the laboratory, field, and cold test germination percentages of these sorghums. The results for the seeds of "South Farm" are presented in Table 8. As shown in this table, standard laboratory germination percentages were not significantly correlated with any of the field and cold test germination percentages. The first field germination percentages were not significantly correlated with the second and third field germination percentages nor with most of the cold test germination percentages. They were, however, significantly correlated with the cold test germination percentages at 12°C. and 16°C. for the 4 and 5 days exposure periods.

Correlation coefficients calculated among the standard laboratory, field, and cold test germination percentages for the seeds produced at "Rollins Bottom" are presented in Table 9. The standard laboratory germination percentages were correlated significantly with the first and third field germination percentages and with most of the cold test germination percentages. They were not significantly correlated with the second field germination percentages. The first field germination percentage correlated with the other two field germination percentages and with most of the cold test germination percentages.

As stated earlier, these seed lots ranged in their standard laboratory germinations from 77 to 99 percent. The correlation studies did not indicate any clear cut cold test temperature or exposure period as distinctly superior for the evaluation of seed lots for their expected performance under adverse field conditions. The 12°C. cold test trials did not correlate as well with all field tests as did those at 8° or 16°C. The standard laboratory tests were about equal to the cold tests in predicting relative field stands.

Soil temperatures were not taken in the 1960 field studies, but mean daily air temperatures (at Columbia, Missouri) for the seven days after planting were 68.1, 71.2, and 73.7°F. for the three field germination periods. Soil temperatures probably were higher than the air temperatures since this was true in comparisons of soil and air temperature fluctuations made in April and May of 1959. Air temperatures mentioned above are in the 20° to 23° range on the Centigrade scale. The average temperature in the standard laboratory test (alt. 20°-30°F.) is 74°F. Therefore it is quite likely that the average soil temperatures in the field tests were much nearer the standard laboratory temperatures than the cold test temperatures used. It is apparent that no prolonged period of cold, wet soil conditions occurred in any of the three field trials. Thus, it is not surprising that the cold tests failed to predict relative field stands any better than the standard laboratory tests.

Heritability Studies

In Table 10, data are presented for the 1960 field germination percentages of five sorghum parents and four advanced generation hybrids using selfed seed harvested in the fall of 1959. The mean field germination percentages of the five parents and the F_3 lines of the four hybrids were very low, because of the poor

TABLE 8 – SIMPLE CORRELATIONS (r VALUES) AMOUNG STANDARD, FIELD AND COLD TEST GERMINATIONS OF 13 SORGHUMS OF SOUTH FARM WHERE COLD TESTS VARIED IN DURATION FROM 4 TO 7 DAYS.

		Cold Tests														
	St. Lab Germ.	Field Germ.			8° C Days				12° C Days				16° C Days			
		1	11	111	4	5	6	7	4	5	6	7	4	5	6	7
St. Lab. Germ.	---	.07	.48	.50	÷42	÷05	.52	.30	.08	.54	÷13	÷08	.06	.12	.36	÷13
Field 1		---	.01	.11	.32	.42	.38	.54	.56*	.68*	.26	.21	.68*	.56*	.25	.08
Field 11			---	.27	.05	÷16	.45	.42	.51	.46	.10	.26	÷16	÷08	.47	.25
Field 111				---	÷27	÷08	÷04	.26	.30	.33	÷15	÷05	.12	.37	.26	.31
C. T. 8° 4 Days					---	.60*	.12	.47	.65*	.26	.38	.55	.36	÷13	.05	.21
C. T. 8° 5 Days						---	.23	.26	.46	.33	.56*	.28	.40	.12	.04	÷31
C. T. 8° 6 Days							---	.75**	.39	.65*	.47	.47	.47	.25	.68*	.01
C. T. 8° 7 Days								---	.76**	.79**	.40	.51	.73**	.36	.72**	÷12
C. T. 12° 4 Days									---	.73**	.47	.56**	.42	.22	.58*	.12
C. T. 12° 5 Days										---	.31	.25	.63*	.49	.65*	÷05
C. T. 12° 6 Days											---	.42	.30	.36	.64*	.36
C. T. 12° 7 Days												---	÷06	÷03	.42	÷27
C. T. 16° 4 Days													---	.61	.36	÷10
C. T. 16° 5 Days														---	.47	÷16
C. T. 16° 6 Days															---	.07
C. T. 16° 7 Days																---

* r value of 0.553 required for significance at the 5% level
** r value of 0.684 required for significance at the 1% level

TABLE 9 - SIMPLE CORRELATIONS (r VALUES) AMOUNG STANDARD, FIELD AND COLD TEST GERMINATIONS OF 13 SORGHUMS OF ROLLINS BOTTOM WHERE COLD TESTS VARIED IN DURATION FROM 4 TO 7 DAYS.

		Cold Tests														
	St. Lab Germ.	Field Germ.			8° C Days				12° C Days				14° C Days			
		1	11	111	4	5	6	7	4	5	6	7	4	5	6	7
St. Lab.	---	.57*	.40	.82**	.85**	.89**	.90**	.62*	.63*	.43	.58*	.65*	.79**	.74**	.73**	.69**
Field 1		---	.54	.78**	.46	.65*	.75**	.72**	.68*	.52	.05	.38	.41	.28	.61*	.75**
Field 11			---	.49	.55	.38	.48	.37	.40	.15	.00	.03	.35	.42	.55	.40
Field 111				---	.60*	.89**	.85**	.71**	.89**	.48	.34	.45	.71**	.62*	.86**	.91**
C. T. 8°c 4 Days					---	.69**	.83**	.60*	.46	.32	.37	.58*	.79**	.69**	.65*	.51
C. T. 8°c 5 Days						---	.83**	.67*	.83**	.55	.54	.63*	.72**	.68*	.75**	.77**
C. T. 8°c 6 Days							---	.76**	.72**	.47	.38	.62*	.86**	.67*	.79**	.79**
C. T. 8°c 7 Days								---	.74**	.77**	.35	.70**	.59*	.47	.77**	.69**
C. T. 12° 4 Days									---	.59*	.28	.45	.68*	.57*	.86**	.83**
C. T. 12° 5 Days										---	.61*	.74**	.28	.30	.61*	.47
C. T. 12° 6 Days											---	.76**	.40	.63*	.44	.22
C. T. 12° 7 Days												---	.58*	.57*	.49	.31
C. T. 16° 4 Days													---	.85**	.78**	.66*
C. T. 16° 5 Days														---	.76**	.56*
C. T. 16° 6 Days															---	.85**
C. T. 16° 7 Days																---

* r value of 0.553 required for significance at the 5% level
** r value of 0.684 required for significance at the 5% level

TABLE 10 - MEAN FIELD GERMINATION PERCENTAGES, VARIANCE, AND HERITABILITY VALUES DERIVED FROM PARENTS AND F_3 LINES OF FOUR SORGHUM HYBRIDS HARVESTED IN 1959.

Population		Number of plants	Mean Germination %	Variance	Heritability 1/ %
			(Combine Kafir 60 X Combine 7078)		
Combine Kafir 60	P_1	19	57.8	213.55	
Combine 7078	P_2	16	17.3	69.67	
(C.K.60 X Com. 7078)	F_3	21	53.0	155.25	22.43
			(Martin X Combine 7078)		
Martin	P_1	21	71.3	72.41	
Combine 7078	P_2	16	17.3	69.67	
(Martin X Com. 7078)	F_3	12	48.8	117.60	39.61
			(Combine Kafir 60 X Redbine 60)		
Combine Kafir 60	P_1	19	57.8	213.55	
Redbine 60	P_2	29	46.4	126.80	
(C.K.60 X R. 60)	F_3	19	55.7	219.76	25.12
			(Combine Kafir 60 X Plainsman)		
Combine Kafir 60	P_1	19	57.8	213.55	
Plainsman	P_2	16	29.3	231.03	
(C.K.60 X Plainsman	F_3	21	46.0	108.64	-104.0

1/ Calculated by the Mahmud and Kramer (5) formula:

$$H = \frac{VF_2 - \sqrt{VP_1 \times VP_2}}{VF_2} \times 100$$

quality of the seed produced in 1959. However, the mean field germination percentages of the F_3 lines were higher than the mid-parent value in each case. This may be due to hybrid vigor or to partial dominance of genes for germination capacity.

The heritability values for field germination were very low ranging from 22 to 40 percent for three of the crosses, and for C.K.60 X Plainsman the value was negative, which indicated that the character under study (germinability) is greatly influenced by environment.

Table 11 gives the data on the cold test germination of open-pollinated seed harvested in the fall of 1960 from individual plants of the five parents and F_2 populations of the four hybrids. In three of the hybrids, the mean cold test germination percentages of the seeds was less than the low parent, whereas in one hybrid it was approximately equal to the low parent. Heritability was found to be directly proportional to the total variance of the advanced generation. However, the total variance was inversely related to the mean germination. This would indicate that the higher variances in the advanced generation were contributed mostly by the inferior segregates.

These varying heritability values indicate that there is a variation in the extent to which the character "germinability" is transmitted from the parents to their progenies in different cross combinations.

Depth of Planting Studies

As shown in Table 12, the average percent germinations for the three plantings were 36.9, 38.3, and 66.0 percent in order of dates. In the first two plantings the highest germination was at the two inch depth with the germination at the one and three inch depth being essentially equal. In the third planting, however, the highest germination was at the one inch depth and the lowest at the three inch depth. These differences are a reflection of soil moisture conditions at different depths during these periods. There was a little moisture in the soil at the time of first planting, and still less at the time of second planting, with the result that the seed planted at the one inch depth suffered from a moisture shortage. Whereas during the third planting when there was adequate moisture in the soil, germination at the one inch depth was higher than that at the two or three inch depth. These data thus seem to indicate that planting two inches deep is quite satisfactory over a range of soil moisture conditions, but where soil moisture conditions are ideal the highest germination of sorghum can be obtained at shallower depths of planting.

An analysis of variance was calculated for each of the field plantings. There was no significant difference among the depths of plantings in the first and second plantings. But in the third planting, the depth of planting had a significant effect on germination. Seed treatment had a significant effect on germination of seeds in the first and second plantings, but not in the third planting, the main benefit being on improved emergence from the two and three inch depths. This

TABLE 11 - MEAN COLD TEST GERMINATION PERCENTAGES, VARIANCE, AND HERITABILITY VALUES DERIVED FROM PARENTS AND F_3 LINES OF FOUR SORGHUM HYBRIDS HARVESTED IN 1960.

Polulation		Number of plants	Mean Germination %	Variance	Heritability %
			(Combine Kafir 60 X Combine 7078)		
Combine Kafir 60	P_1	20	94.3	26.1	
Combine 7078	P_2	20	94.5	10.2	
(C.K.60 X Com. 7078)	F_3	75	87.6	61.5	73.5
			(Martin X Combine 7078)		
Martin	P_1	20	82.4	62.6	
Combine 7078	P_2	20	94.4	19.7	
(Martin X Com. 7078)	F_3	75	82.5	175.5	80.0
			(Combine Kafir 60 X Redbine 60)		
Combine Kafir 60	P_1	20	94.1	15.6	
Redbine 60	P_2	20	91.1	13.0	
(C.K.60 X R.60)	F_3	75	77.3	289.5	95.1
			(Combine Kafir 60 X Plainsman)		
Combine Kafir 60	P_1	20	95.4	13.4	
Plainsman	P_2	20	94.4	14.9	
(C.K.60 X Plainsman	F_3	75	92.7	29.7	52.5

TABLE 12 - AVERAGE PER CENT GERMINATION OF TREATED AND UNTREATED SEEDS OF 3 VARIETIES OF GRAIN SORGHUM PLANTED AT 3 DEPTHS IN 3 FIELD TRIALS IN 1960.

Planting I (May 19)

Type of Seed	Depth of Planting in inches 1	2	3	Average Germination Per Cent
Treated	37.0	48.3	40.3	41.9
Untreated	33.0	32.0	30.3	31.8
Average	35.0	40.2	35.3	36.9

Planting II (May 30)

Type of Seed	Depth of Planting in inches 1	2	3	Average Germination Per Cent
Treated	29.7	45.0	52.0	42.2
Untreated	40.0	41.0	22.3	34.4
Average	34.9	43.0	37.2	38.3

Planting III (June 18)

Type of Seed	Depth of Planting in inches 1	2	3	Average Germination Per Cent
Treated	75.0	64.0	57.7	65.6
Untreated	74.7	70.3	54.3	66.4
Average	74.9	67.2	56.0	66.0
Average of Three Plantings	48.2	50.1	42.8	47.1

was probably due to the fact that in the first two plantings the seeds were exposed to low temperature conditions in which germination was at a slow rate. Because of this, the untreated seed were exposed to the attacks of soil borne fungi and thus germination was hindered. In the third planting made in the middle of June, temperature and soil moisture conditions were ideal for germination. The rapidity of germination at these temperatures made it less likely that soil-borne fungi could invade the seed or seedling, and thus seed treatment did not have a significant effect on germination.

Time of Harvest and Seed Quality

The complete germination data of the twelve samples of sorghum hybrid Amak R 12 together with moisture percentage in the grain at the time of harvest are given in Table 13. As shown in Plate I, the moisture content of the grain decreased in general at each successive date of harvesting except for some slight increases in the moisture content as a response to periodic rains. The standard laboratory germination results show that the seeds were mature enough at approximately 24 days after blooming to germinate about 100 percent. Very high laboratory germination percentages were maintained up to 52 days after blooming, after which germination declined gradually to about 85 percent. Field germination reached its peak from seed harvested about 38 days after blooming. This quality was maintained up to about 73 days after blooming, beyond which there was a deterioration in seed quality. The cold test germination reached its top value when the seed was harvested about 31 days after blooming, after which there was a gradual but erratic decline of seed quality throughout the harvest period.

From the graph it appears that the seed reached approximate physiological maturity 31 days after blooming at a moisture percentage of about 37.2, when it showed on an average good laboratory, field, and cold test germinations. This quality of the seed was maintained for about two more weeks, beyond which the germination of the seed went down. This decrease in germination may have been due to the deterioration in seed quality as a result of weathering.

DISCUSSION

Early in these investigations an attempt was made to determine the approximate minimum temperature at which grain sorghum would germinate. The seven varieties and hybrids chosen for study had given standard laboratory germinations ranging from 60.0 to 96.3 percent. When the treated seeds were subjected to 10 days exposure at 45, 50, and 55 degrees F. on wet paper towels there was no plumule emergence at 45°F. (7.2°C.) or 50°F. (10°C.) but considerable at 55°F. (12.8°C.). Germination at 55°F. for the 10 days were rather well correlated with standard laboratory germinations although somewhat lower. Radicle emergence (not considered as normal germination) at 45° and 50°F. was well correlated with germination at the higher temperatures.

TABLE 13 - MOISTURE PERCENTAGE AND AVERAGE STANDARD LABORATORY, FIELD, AND COLD TEST GERMINATION PERCENTAGES AT 12°C. FOR 4 DAYS OF SORGHUM HYBRID AMAK R 12 HARVESTED AT 12 DATES IN 1959.

Date Harvested in 1959	Days After Mid-Bloom	Moisture Percent in Grain at Harvest **	Standard Laboratory Germination %	Field Germination (Avg. of 3 Plantings)	Cold Test Germination %
Aug. 22	17	58.4	48	24	6
Aug. 29	24	44.6	99	66	67
Sept. 5	31	37.2	97	73	98
Sept. 12	38	26.8	98	75	84
Sept. 19	45	16.9	97	74	88
Sept. 26*	52	28.3	99	69	73
Oct. 3*	59	18.2	91	69	73
Oct. 10	66	11.4	90	70	63
Oct. 17	73	11.5	88	72	66
Oct. 24	80	11.0	85	60	46
Oct. 31*	87	12.3	84	59	71
Nov. 7	94	5.4	88	70	64

* Rainfall for the week ending:
September 26, 1959 -- 3.9 inches
October 3, 1959 -- 2.2 inches.
October 31, 1959 -- 0.1 inch.

** Data for moisture per cent obtained from McBride et al. (8)

These results do not appear to agree with the report of Martin (9) who stated that germination occurs at 45° and 50°F., but did not reveal the source of the data. Leukel and Martin (7) present data on emergence of Kansas Orange sorgo from soil temperature tanks held at 12, 16, 20, 24, 28, and 32°C. Emergence at 12°C. (53.6°F.) occurred 30 days after planting and was 59 percent compared with 80 percent at the highest temperature, 32°C. Pinthus and Rosenblum (12) whose results were published after the termination of the studies reported here suggest that the minimum temperature for germination of sorghum seed is between 8° (46.4°F.) and 10° (50°F.). They determined radicle emergence of RS610 hybrid and the D. D. Yellow Sooner variety over a period of 55 days in a refrigerating germinator. They state however that "slow seedling growth at 10°C. indicates that somewhat higher temperatures are needed for emergence from the soil."

Since germination is obviously a function of both temperature and time it is quite possible that an extension of time beyond 10 days on the test at 45 and 50 degrees F would have revealed some plumule emergence. However, because an arbitrary limit of 10 days was used in these experiments the sole possible conclusion is that near normal germination occurred only at the 55°F. temperature. This is probably in rather good agreement with Pinthus and Rosenblum's conclusion that temperatures somewhat higher than 50°F. are needed for emergence from the soil.

The results of the minimum temperatures studies though interesting in themselves were the basis of the choice of 8, 12, and 16°C. for cold test studies. These temperatures were chosen to be respectively below, equal to, and above the requirements for near normal initiation of germination of sorghum.

Subsequent studies of grain sorghum in standard laboratory tests, early to late field plantings, and cold tests were aimed at developing a better understanding of all of the factors necessary to achieve adequate field stands as early in the season as possible.

Results of investigations carried on in 1959 with 25 commercial sorghum varieties and hybrids indicated that in seed lots from either year of production (1957 or 1958) varieties differed widely in ability to germinate in laboratory, field, and cold test germination trials. In all tests, in general, 1958 seed lots germinated significantly better than in 1957 seed lots. This would be expected since germination usually deteriorates with age of the seed. Correlation studies showed no significant relationship between the performance of 1957 and 1958 seed lots of the same variety grown and processed presumably by the same producer. There are, of course, many ways in which the environment of seed production could differ in two seasons to account for differences in laboratory germination of the same variety or even to account for different field emergence or cold test performance from seed lots of equal laboratory germination.

Studies continued in 1960 with only 8 hybrids for which 1957, 1958, and 1959 seed lots were available did, however, demonstrate a significant difference among varieties in both field emergence and cold tests. In most tests the 1959

and 1958 seed germinated much better than the 1957 seed. The 1959 and 1958 seed lots of the same varieties gave similar results in all tests as indicated by significant correlation coefficients but both were poorly correlated with results from the 1957 seed lots.[3] These correlation studies and the significant F value for varieties when tested by the "variety x seed lot" interaction mean square indicated that both the variety genotype and the environment of seed production were affecting the germination of a particular seed lot of a variety. Evans and Stickler (3) found varietal and seed lot effects on sorghum germination under simulated drouth.

Field emergence was found to be related to the general soil moisture conditions and to temperature of the soil during the period of germination and emergence. In a comparison of the three field plantings made in 1959, the May planting gave the highest percentage germination. The April planting, although producing stands lower than the May planting, did give stands which were much above the expected. Shallow planting of treated seeds and a soil temperature only 2.8 degrees lower than the May planting during the seven day period following seeding probably account for the unexpectedly good stands from the April planting.

In the depth of planting studies made in 1960 with three sorghum varieties, the highest germination of the first two plantings was obtained at the two inch depth. In the third planting the highest germination was at the one inch depth and the lowest at the three inch depth. These results appear to arise from differences in the moisture conditions of the soil at different depths during these periods as discussed in the experimental results. They indicate that under good soil moisture conditions, the highest germination of grain sorghum can be obtained at shallow depths of planting.

Seed treatment had a beneficial effect on germination, as on the average treated seed germinated better than untreated seed. Analysis of variance indicated that seed treatment had a significant effect on germination of seeds in the first and second plantings, but had no significant effect in the third planting. This was probably because of the fact that in the first two plantings the seeds were exposed to temperature conditions in which germination was at a slower rate. Because of this the untreated seeds were exposed for a longer time to the invasion of soil borne fungi and thus emergence was hindered. In the third planting during the middle of June soil temperatures and moisture conditions were more ideal. Rapid germination gave less opportunity for seed invasion by soil borne fungi resulting in no significant effect of seed treatment on germination.

That speed of germination declines with temperature has been found by Dickson and Holbert (2) in corn, and Martin, Taylor, and Leukel (10) in sorghum. Dickson and Holbert reported that corn emerges first at a soil temperature of 32°C., that the rate of emergence decreases gradually to a temperature of

[3]D. P. Srivastava. Germination Studies in Grain Sorghum. Unpublished Ph.D. Thesis, University of Missouri, June 1961.

24°C., and that the rate decreases sharply from 24°C. to 12°C. Martin, Taylor, and Leukel reported that percentage and rapidity of germination in sorghum are reduced by soil temperatures below 25°C. and slightly reduced by deep planting (2.5 inches). They report further that seedling development is retarded by the lower soil temperatures within the range 35°C. to 15°C. Development was also retarded by deep planting at 15°C. soil temperature but not at higher temperatures.

The cold test studies with different seed lots and varieties indicate that cold testing can be effective in sorghum as it has in corn in disclosing seed weaknesses that do not show up in the standard germination tests. Attempts to identify by correlation studies the best temperature and duration of exposure in the cold test were far from conclusive. Where the seed lots showed a range of viability in the standard germination test, e.g. the "Rollins Bottom" seed (Table 9), the 8° and 16°C. cold tests appeared to be slightly better than the 12° cold tests in predicting relative field stands. On the other hand, where seed lots with a narrow range in viability were used (South Farm seed—Table 8), the 12 and 16°C. cold tests appeared superior to the 8°C. test, at least in the cold tests of only 4 or 5 days duration.

Estimates of heritability calculated from the field emergence and cold test germinations of five sorghum parents and four of their advanced generation hybrids indicated that the character germinability is greatly influenced by environment since the values were low in one test and very high in the other. The two sets of heritability values for the four crosses were nevertheless in fair agreement. The same cross, Combine Kafir 60 x Plainsman, gave the lowest heritability values in both tests and other crosses were ranked in a similar manner in both tests.

Weekly sampling studies of sorghum hybrid Amak R12 indicated 99 percent laboratory germination for seed harvested 24 days after blooming when the moisture percentage was 44.6. The peak of germination strength as measured by the cold test was reached in seed harvested at 31 days after blooming. At this time the seed moisture level was 37.2. In general, high germination strength was maintained for two more weeks after which there was a gradual decline in seed quality. Freezing temperatures (14) were not a factor since temperatures did not drop below 32°F. until November 5. The deterioration was undoubtedly the result of weathering in which microorganisms play an important role. One may speculate that at 31 days after blooming the point of maximum germination strength in these data coincides with the time of physiological maturtiy. If so, the results differ slightly from those of Castro (1) whose studies of dry weight accumulation indicated that physiological maturity was reached 35 to 40 days after blooming.

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