AN EVALUATION OF THE COLD TOLERANCE OF SEVERAL SORGHUM VARIETIES AS MEASURED BY SEED VIGOR

By

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CHAPTER I

INTRODUCTION

Most sorghum varieties, Sorghum bicolor (L.) Moench, initially grown in the United States originated in tropical areas. This origin inhibited the movement of sorghums into areas with cool, early growing season temperatures. Cool soil temperatures delay seed germination and allow seed-borne or soil-borne pathogens to prevent emergence. World variety collections have been screened by workers to determine if genotypes exist that have superior ability to germinate under cool soil temperatures or have cold tolerance. Genotypes of this nature could be used to transfer cold tolerance to varieties with desirable agronomic characteristics. Varieties are needed that will germinate and produce vigorous seedlings under adverse conditions. This would allow early season plantings to be made and allow the crop to mature before frost. Full season varieties could be planted earlier to take advantage of a longer growing season. In some areas, it would be advantageous to plant early due to the likelihood of a shortage of soil moisture later in the season.

The purpose of this study was to evaluate several sorghum varieties for cold tolerance in laboratory and field studies by using several measures of seed vigor.

CHAPTER II

LITERATURE REVIEW

Seed germinination may be affected by many factors. Fox and Albretch (5) indicated that the factors influencing germination are (1) soil fertility and its influence upon the elemental composition of the seed produced; (2) the chemical and biochemical properties influencing the cellular metabolism of the germinating embryo; (3) the metabolic activity of the seed and the nutrients available to the germinating embryo.

The need to determine the germinative ability of seeds has been recognized. Sayers (27) stated that physiological evaluations of seed are referred to as vigor measurements. He indicated that seed vigor generally refers to the germination energy or power of a seed. Isely (10) defined vigor as the sum total of all seed attributes which favor stand establishment under unfavorable conditions. Delouche and Caldwell (4) defined vigor as the sum of all seed attributes which favor rapid and uniform establishment under field conditions.

Differences in vigor, as measured by rapidity of germination, may be found among varieties and among seed lots in the same variety. Schoorel (28) gave these reasons for lack of vigor: (1) unfavorable weather conditions ocurring prior to and at the time of seed harvest, (2) careless handling of the seeds during and after harvest, (3) prolonged storage under unfavorable conditions, (4) the presence or activity of parasitic organisms, (5) chemical treatments during storage, and (6) the genetic properties of the seed.

Investigations have shown that seeds with high vigor have a better chance to produce a stand under adverse conditions than nonvigorous seed (27). Standard germination tests or tests conducted at optimum temperatures may fail to predict field stands with sufficient accuracy. These tests produce total germination values, but they fail to detect weaknesses which may be present in the seed (10, 37). Woodstock and Combs (37) reported that standard germination tests sometimes rate the value of performance higher than can be expected in the field, especially under adverse conditions.

Sorghum is a typical warm-season crop having originated in the tropical areas near the equator (12, 36). This origin is probably the basis for problems of slow stand establishment in cold soil (29). Despite problems associated with early planting, it is very often desirable to do so. Maximum yields are most often obtained from late spring plantings, but early frost may result in inferior quality of the grain. Thomas and Cate (34) point out that early plantings are important in avoiding damage from the sorghum midge. Early plantings of sorghum may also be necessary to avoid chinch bugs (12). Bottrell (2) reported that early planting of sorghum may eliminate the need for insecticide or reduce the number of applications needed.

Often sorghums are planted in soils warm enough for germination, but prior to germination, colder weather lowers the seed-bed temperature and inhibits germination. Vigorous seed may survive until conditions improve and then still produce healthy seedlings and a good crop. Seeds are needed that will consistently survive to give uniform stands of vigorous plants (16).

Stoffer and Van Riper (30) indicated that a specific planting date can not be established in most areas due to high variability of the relationship of soil temperature to time of the year. They suggest that the minimum temperature for emergence in the field is 18°C at a 4-inch soil depth at sunrise. They also suggest that soil temperature would be a better criterion for determining the time to plant sorghum in the spring than a specific date, if soil moisture and other environmental conditions are favorable. Phillips and Youngman (19) explained the emergence response of sorghum seed or seedlings to date of planting and initial seed moisture on the basis of soil temperature. They observed that as soil temperature increased, the rate and percent emergence also increased. Adams (1) obtained a significant increase in grain sorghum yield when a clear plastic mulch was applied over the seed row. The increase was attributed to increased soil temperature during the first two months following planting.

Pinthus and Rosenblum (21) reported the minimum germination temperature for sorghum seed was between 8 and 10°C. They reported a temperature high than 10°C would be necessary for emergence in soil.

Cold tests or cold temperature tests have been used in predicting vigor of seeds or seedlings but these tests have not always given accurate measures of germination ability (16). Several workers have reviewed work done with cold tests and their value as tests for vigor (3, 9, 10, 15). They indicated the cold test has been difficult to standardize because of differences in temperature, soil conditions, and soil micro-organisms. All agree that a cold test is not a test for cold resistance but a test for resistance to seed rotting fungi which affect seeds germinating in cold soils. Isely (9) suggested that the usual mechanism of vigor in the field is the differential susceptibility of seeds and seedlings to attack of soil or seed-borne organisms. Adverse temperature and moisture relationships do not in themselves result in the lack of stand establishment, but allow micro-organisms to affect the seed. Some workers have indicated *Pythium spp.* are primarily responsible for rotting of seed corn, *Zea mays* (L.), under low temperature conditions (6, 7, 32).

Rice (22) recommended a cold test in a mixture of sand and *Pythium* infested soil at 10°C during part of the germination period followed by a warmer period. He also suggested that a cold test should be of value in evaluating the effectiveness of seed fungicides and seed processing methods.

Seedling vigor may be determined by speed of germination which is one of the oldest concepts of seedling vigor. Total emergence is not a good indicator of vigor as seed lots with similar total germination may vary in rate of seedling emergence and rate of growth (14). Maguire (14) modified a method originally used by Thorneberry and Smith (33) which was an evaluation of speed of germination as a function of vigor. The germination rate was calculated by dividing the number of normal seedlings per 100 seeds obtained at each counting in the germination test by the number of days seeds had been in the germinator. The values obtained at each count were then summed at the end of the germination test to obtain the germination rate:

$$\frac{\text{number of normal seedlings}}{\text{days to first count}} + \dots + \frac{\text{number of normal seedlings}}{\text{days to final count}}$$

Woodstock and Combs (37) studied corn germination in incubators and in the greenhouse. They studied a number of indices based on increases in length of shoot, root, and embryo axis, and on seedling fresh weight. All were compared for potential value in predicting growth. Of these, shoot growth was found to be best for predicting subsequent seedling performance.

The origin for the group of grain sorghum varieties called kaoliang, has been placed in Manchuria which has a cool climate (36). Because of their northerly origin, kaoliangs might germinate and grow at lower temperatures than varieties grown in the United States today. Nordquist (16) indicated that some kaoliangs have brown seed coats high in tannin. Tannins have been shown to have some fungicidal properties that may protect seedlings. Tannin is undersirable in human food since it produces an astringent taste and discolors the food. It is also undesirable in livestock feeds as it reduces feed intake. Nordquist (16) indicated that tannis inherited as a recessive would be desirable. It could be incorporated into female lines and have protective value to seedlings, but would not be in the grain to be harvested.

Stickler (29) tested several varieties of kaoliangs for emergence compared with standard varieties. The kaoliangs tested were all equal or superior to standard varieties regardless of seed color of the kaoliangs.

Pinnell (20) indicated a relationship between vigor and genetic composition in corn. He observed that the germination vigor of double cross hybrids was better than single cross hybrids and single cross hybrids were better than inbread lines.

Pesev (18) tested corn crosses and their parental inbread lines at 6 and 8°C and found that the degree of tolerance to low temperatures was strongly dependent on the germination ability of the maternal parent of the cross. He found the characteristics of the maternal parent were important in determining not only the percentage of germinated plants, but also the speed of germination and growth of the embryo root and stalk apex.

Many workers have studied the effect of seed moisture on germination (11, 17, 19, 23). Phillips and Youngman (19) studied emergence and yield of grain sorghum as affected by the moisture content of seeds at planting. They found seed planted at 8% moisture content emerged less than seed planted at either 11 or 14 percent moisture. They found a delay in the emergence of the radicle from the pericarp and a decrease in seed respiration during imbibition, when they had low initial seed moisture content and low substrate temperatures. They found the effects on emergence to be great enough to reduce grain yields when low initial seed moisture content and low substrate temperatures were combined.

Phillips and Youngman (19) stated that seeds must attain a certain moisture content before they can germinate. Kantor and Webster (11) studied the effect of freezing temperatures on the viability of sorghum seeds at different moisture levels and the damage to seed which may result from threshing. They found the viability of sorghum seed with a moisture content of less than 40 percent was not reduced when the seed was frozen for 12 hours at -1.7 to 0°C. Their results indicated that -4.4 to -3.3°C is the critical temperature for causing injury to seed with an excess of 20 percent moisture.

Robbins and Porter (23) found the viability of immature sorghum seeds was affected by the method of curing the seeds. Seed allowed to cure while in the panicle, germinated better than that which was threshed and cured in cloth sacks. They found mature seed with a moisture content of 15 percent or less was unaffected in viability by exposure to any temperature between 0.55 and -6.7°C. Sorghum seed with a moisture content of 16 to 19 percent was not seriously injured by exposure for 10 hours to a temperature of -6.7°C. Exposure for 10 hours at -6.7°C caused serious injury when moisture content was 22 percent or more.

Livingston (13) studied the effect of low temperatures on the germination of artifically dried seed corn and found seedling emergence had an inverse relationship to kernel moisture content at the time of harvest. Artifically drying of the seed intensified this effect, particularily in non-sterile soil.

Nutile and Woodstock (17) stated that the amount of soluble salts present adversely affects sorghum germination at cool temperatures and comfirmed this by germinating sorghum seed at three levels of salinity. They found soluble salts affected low temperature dormancy, but had little or no effect on seed germination at high temperatures.

It was suggested by Toole, <u>et al</u>. (35) that a favorable effect of non-constant temperatures may result from creation of a balance of the intermediate materials of respiration at the high temperature part of the cycle, which may be unfavorable for germination at that temperature, but may promote germination at a lower temperature.

Robbins and Porter (23) reported that freshly harvested, immature seed of sorghum appeared dormant and that dormancy was overcome by drying and prechilling, then germinating the seed at alternating temperatures of 20 and 30°C. Prechilling was accomplished by placing the seed in a 5 to 10°C environment for five days.

According to rules for testing seed (8, 24, 25, 26) germination is defined as the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under favorable conditions. Normal seedlings are those which possess those essential structures that are indicative of their ability to produce plants under favorable conditions. It is necessary for the plumule to have split the coleoptile for a seedling to be considered normal, or the plumule must be over one-half the length of the coleoptile. All seedlings that do not permit classification as normal seedlings are classified as abnormal. A seedling that has been seriously damaged by bacteria or fungi from any source other than the specific seed should be regarded as normal if all essential structures are present. If a chemical preparation is used to reduce the spread of micro-organisms, the results should be regarded as supplemental and reported as such.

CHAPTER III

MATERIALS AND METHODS

Laboratory Study

This study consisted of the laboratory germination of 11 varieties of sorghum at different temperatures to determine as measures of vigor the average percent normal germination, average speed of germination, and average length of shoot growth at 14 days. The varieties listed in Table I were tested.

TABLE I

SORGHUM VARIETIES STUDIED IN THE LABORATORY

Variety Number	Variety	Seed Color
1	White Kaoliang CI 792	White
2	Bonar Durra	White
3	White Kafir	White
4	Kalo CI 902	Red
5	Reliance	Red
6	Pink Kafir CI 432	White
7	Reed Kafir CI 628	White
8	Early Kalo CI 1009	Red
9	Improved Coes	White
10	Redlan	Red
11	Brown Kaoliang FPI 46677	Brown

The experimental design was a split-plot having three replications. Main plots were different temperature treatments and sub-plots were varieties. The treatments used were:

1. Uniformly placing the seeds in plastic germinating boxes on tissue moistened with 8 ml water and subjecting them to a temperature of 10°C for 10 days. The boxes were then transferred to an alternating environment of 20°C for 16 hours of night and 30°C for 8 hours of day for 10 days. This alternating environment was considered as the optimum germinating temperature condition. The seeds were treated with Captan. Fifty seeds per replication were used.
2. Treatment 2 differed from treatment 1 in that the seeds were germinated at 15°C for the first 10 days of the experiment.
3. Treatment 3 differed from treatment 1 in that the seeds were germinated at 20°C for the first 10 days of the experiment.
4. Treatment 4 differed from treatment 1 in that the seeds were germinated at 25°C for the first 10 days of the experiment.
5. Treatment 5 differed from treatment 1 in that the seeds were germinated at 30°C for the first 10 days of the experiment.

All treatments were placed in the germinators on the same day. Notes were taken at two day intervals on each treatment and variety by replication. Final germination percentages were recorded at 20 days following placement in the germinator. Data on the speed of germination were taken at the time of germination counts, and shoot growth was recorded at 14 days. Measurement of shoot growth at 20 days was impratical in treatments 4 and 5 due to the abundance of leaves;

therefore, for statistical purposes, shoot growth was analyzed at 14 days. A seedling was considered normal when, in addition to having normal structures, the plumule was over one-half the length of the coleoptile or the plumule had split the coleoptile. The distinction between a normal and an abnormal seedling was made following concepts of other workers (8, 24, 25, 26). The rate of germination was calculated by dividing the number of normal seedlings per 100 seeds obtained at each counting in the test by the number of days seeds had been in the germinator. The values obtained at each count were then summed at the end of the test to obtain the germination rate as suggested by Maguire (14). Shoot growth was measured in millimeters.

Field Study

A study was initiated in the spring of 1972 to determine under field conditions as measures of vigor, the percent emergence and average speed of emergence of 10 varieties of sorghum. Table II shows the varieties that were tested.

TABLE II

SORGHUM VARIETIES STUDIED IN THE FIELD

Variety Number	Variety	Seed Color
1	White Kaoliang CI 792	White
2	Bonar Durra	White
3	White Kafir	White
4	Kalo CI 902	Red
5	Reliance	Red
6	Pink Kafir CI 432	White
7	Reed Kafir CI 628	White
8	Early Kalo CI 1009	Red

Table II (Continued)

Variety Number	Variety	Seed Color
9	Improved Coes	White
10	Redlan	Red

The experimental design was a split-plot having three replications. Main plots were planting dates and sub-plots were varieties. The treatments consisted of:

TREATMENTS

Planting Date 1	April 24
Planting Date 2	May 10
Planting Date 3	May 22
Planting Date 4	June 5

Seeds were planted in rows 30 feet long spaced 40 inches apart. One hundred seeds were planted in each row. Notes were made at 2 day intervals for a period of 14 days following planting. Average percent emergence was determined for each treatment and variety at 14 days following planting. Average speed of emergence was calculated by dividing the number of seedlings per 100 seeds obtained at each counting in the study by the number of days seeds had been planted. The values obtained at each count were then summed at the end of the test to obtain the speed of emergence as suggested by Maguire (14).

Soil temperature at the 2-inch depth indicated the April 24 and May 10 plantings were sufficiently early to include suboptimum soil temperatures.

The data was statistically analyzed. In order to find if the difference among variety means within treatments was significant, error b mean square was used to compute the standard error to perform a Duncan's Multiple Range Test.

CHAPTER IV

RESULTS AND DISCUSSION

Laboratory Study

Significant differences were found among varieties and among treatments for percent normal germination, speed of germination, and shoot growth as indicated in Tables VIII, IX, and X. Significant treatment by variety interactions were also found for each of the three measures of vigor indicating the varieties did not have similar responses to treatments.

Normal Germination

In seed laboratory practice, a normal seedling is defined (8, 24, 25, 26) as the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the seeds ability to produce a normal plant under favorable conditions. For sorghum, seedlings must have well-developed roots and plumules to be considered normal. It is necessary for the plumule to have split the coleoptile for a seedling to be considered normal, or the plumule must be over one-half the length of the coleoptile.

The means of each treatment for percent normal germination showed a rank of 5, 4, 3, 1, 2. The germination percentages for the treatments were: treatment 1, 82.71 percent; treatment 2, 81.51 percent;

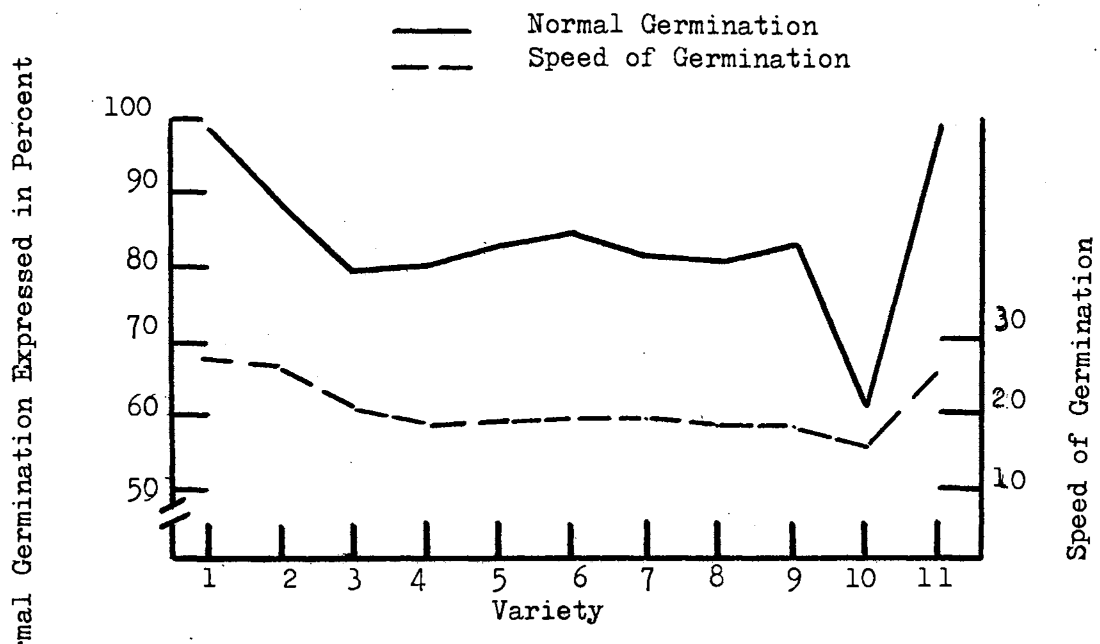

Figure 1. Relationship of Normal Germination to Speed of Germination in Treatment I (10°C) for 11 Varieties

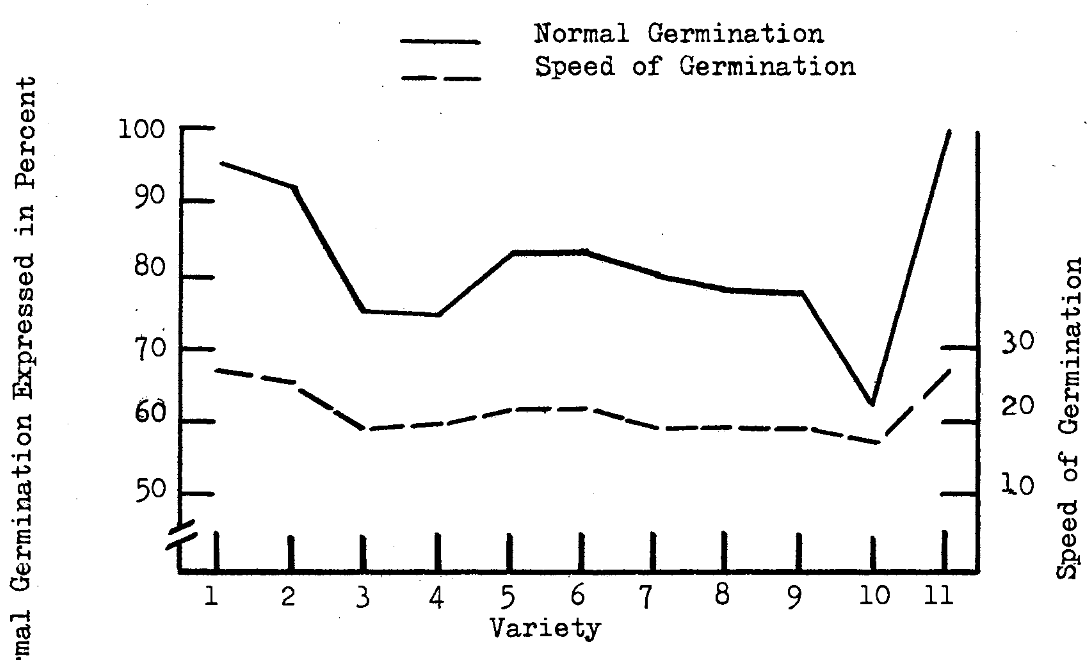

Figure 2. Relationship of Normal Germination to Speed of Germination in Treatment II (15°C) for 11 Varieties

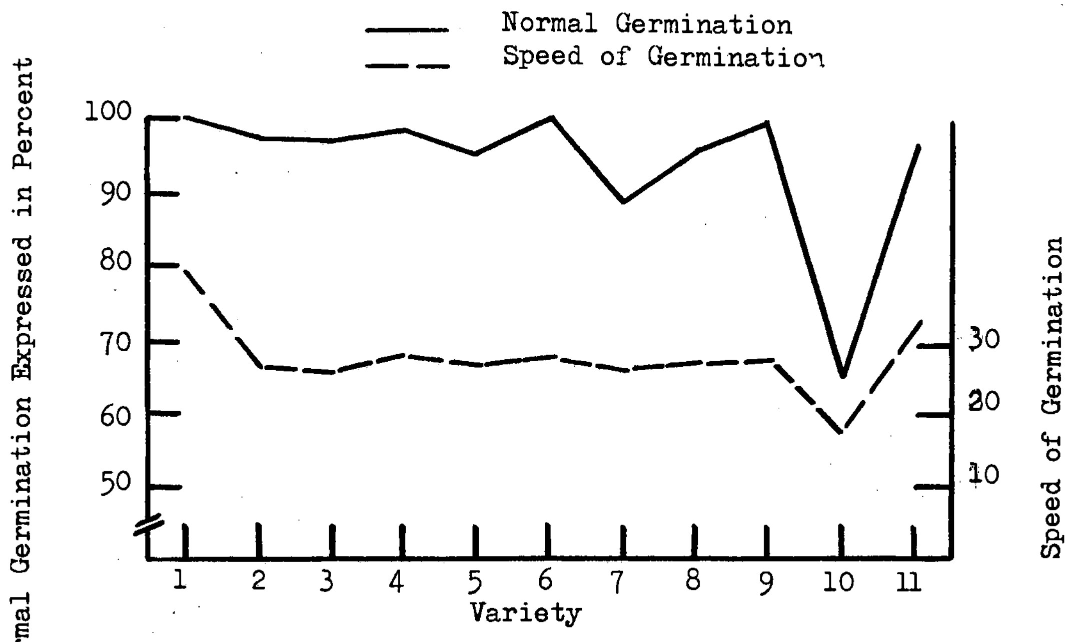

Figure 3. Relationship of Normal Germination to Speed of Germination in Treatment III (20°C) for 11 Varieties

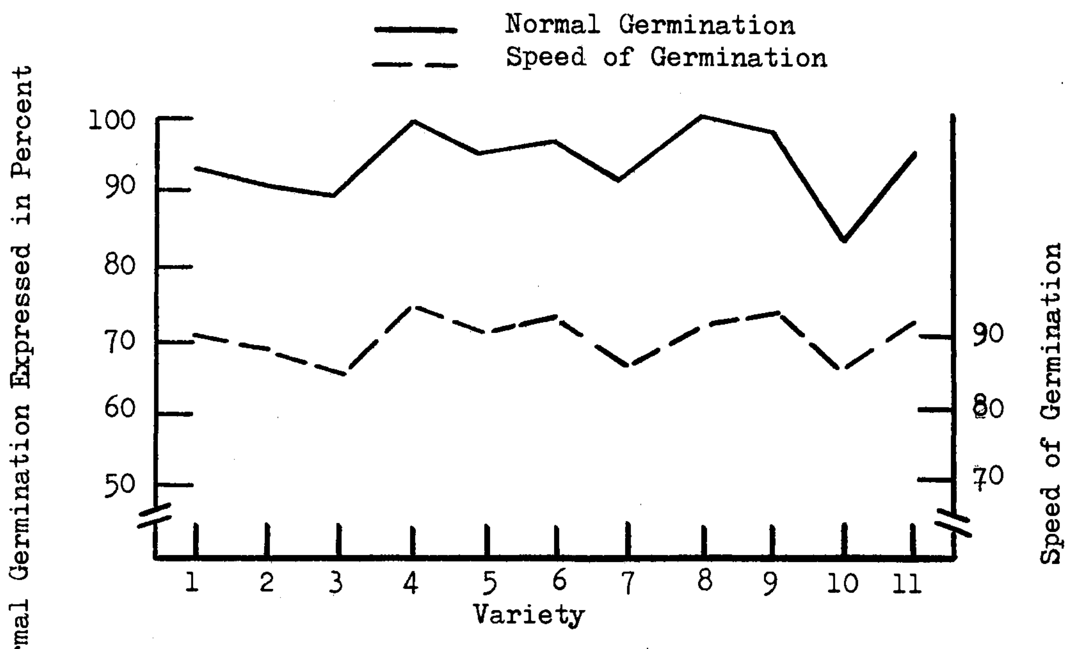

Figure 4. Relationship of Normal Germination to Speed of Germination in Treatment IV (25°C) for 11 Varieties

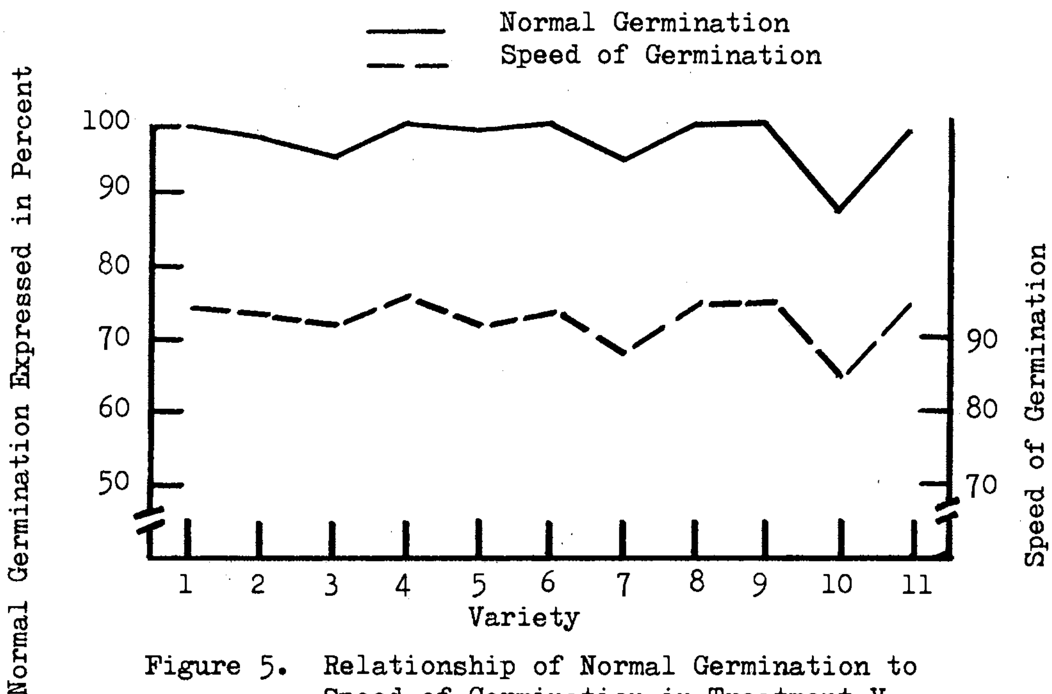

Figure 5. Relationship of Normal Germination to Speed of Germination in Treatment V (30°C) for 11 Varieties

treatment 3, 94.18 percent; treatment 4, 95.45 percent; and treatment 5, 98.00 percent (Table III). These data indicate that the initial 10 days of germination at 20°C in treatment 3 did not reduce final germination percentages as did the initial 10 days in treatments 1 and 2. In treatment 3, all varieties germinated 95.00 percent or better with the exceptions of Pink Kafir and Redlan which germinated 89.33 and 66.00 percent, respectively. In treatments 1 and 2, White Kaoliang, Bonar Durra, and Brown Kaoliang performed well with 89.33 the lowest percent germination and 98.66 the highest (Table III). White Kaoliang and Brown Kaoliang were significantly higher than all other varieties within treatment 1 and White Kaoliang, Brown Kaoliang, and Bonar Durra were significantly higher than all other varieties within treatment 2. Apparently the final germination percentages of other varieties were reduced due to the initial 10°C and 15°C temperatures of treatments 1 and 2. Redlan had a final germination percentage of 60.00 percent in treatment 1 and a final germination percentage of 62.00 percent in treatment 2. These values were the lowest within treatments 1 and 2.

<u>Speed of Germination</u>

The speed of germination is considered as a measure of vigor. It was calculated by dividing the number of seedlings per 100 seeds obtained at each counting in the study by the number of days seeds had been in the germinator. The values obtained at each count were then summed at the end of the test to obtain the speed of germination as suggested by Maguire (14).

The rank of means by treatment for speed of germination was 5, 4, 3, 2, 1. The speed of germination, when plotted by treatment and variety appeared similar to the curves for normal germination but on a lower scale (Table IV and figures 1, 2, 3, 4, 5). The speeds of germination for the treatments were: treatment 1, 20.87; treatment 2, 21.31; treatment 3, 27.97; treatment 4, 90.65; and treatment 5, 92.95. White Kaoliang, Brown Kaoliang, and Bonar Durra were significantly higher in speed of germination in treatment 1 than all other varieties within treatment 1. None of the varieties in treatments 1 and 2 germinated until they were moved to the alternating temperature environment. Normal germination for treatments 1 and 2 was first recorded 12 days after initial placement in the germinator. This length of time greatly reduced the speed of germination of treatments 1 and 2 as compared with other treatments. In treatment 3, White Kaoliang was significantly higher in speed of germination than all other varieties and Brown Kaoliang was significantly higher than all varieties with the exception of White Kaoliang. Many normal seedlings were present in the White Kaoliang and Brown Kaoliang varieties in treatment 3 at 10 days after placement in the germinator and high values were recorded for their speeds of germination at the end of the test. Other varieties had few or no normal seedlings until they were moved to the optimum temperature environment. When speed of germination was used as a measure of vigor, White Kaoliang performed better than other varieties at low temperatures. This is based on its performance at the 20°C temperature. The speed of germination for White Kaoliang in treatment 3 was 39.12 and Brown Kaoliang had a speed of germination of 31.91 (Table IV).

There were significant differences among varieties within treatment 4 and among varieties within treatment 5, but all values were high, ranging from 85.14 to 95.16 in treatment 4 and 84.71 to 96.09 in treatment 5.

Shoot Growth as a Measure of Vigor

Shoot length has been found to be a suitable index for predicting subsequent seedling performance.

There were highly significant differences among treatments and among varieties. The treatment by variety interaction was also highly significant. The rank of means by treatment for shoot growth was 5, 4, 3, 2, 1. White Kaoliang was significantly greater in shoot growth in all treatments than any other variety except in treatment 1 where it was not significantly greater than Brown Kaoliang (Table V and figures 6, 7, 8, 9, 10). Brown Kaoliang also performed well, being significantly greater in shoot growth in all treatments than any other variety except White Kaoliang in all treatments and Bonar Durra, Reliance, and Reed Kafir in treatment 1. The varieties responded similarly to temperature with regard to shoot growth; however, the two Kaoliangs were taller than other varieties.

Field Study

Significant differences among treatments and among varieties were found in measuring percent emergence but no significant variety and treatment interaction was measured (Table XI). Significant differences were found among varieties and among treatments and significant interactions were measured between varieties and treatments for speed of emergence (Table XII).

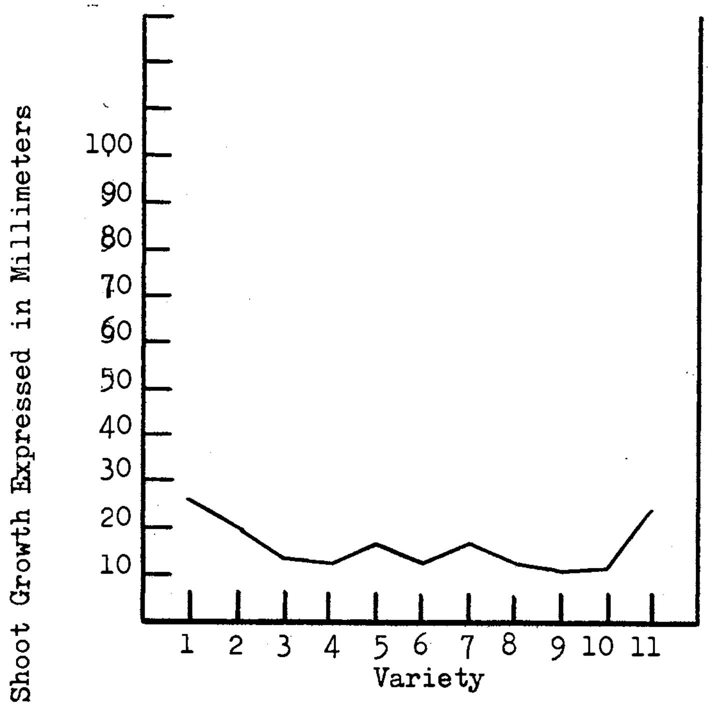

Figure 6. Shoot Growth in Treatment I (10°C) for 11 Varieties

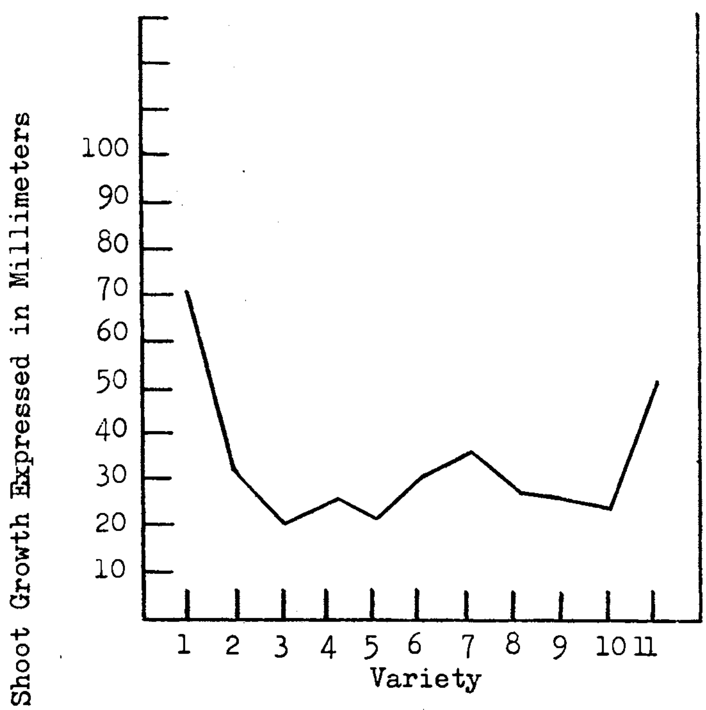

Figure 7. Shoot Growth in Treatment II (15°C) for 11 Varieties

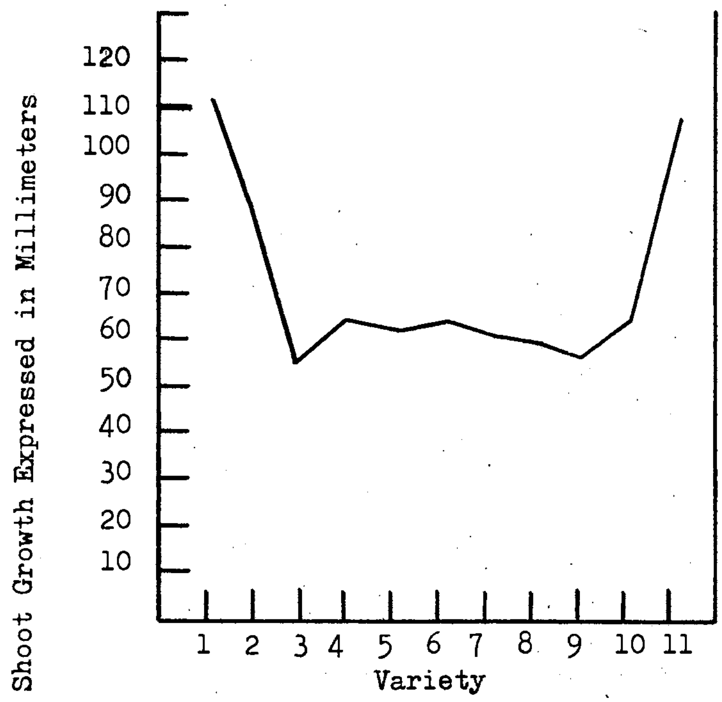

Figure 8. Shoot Growth in Treatment III (20°) for 11 Varieties

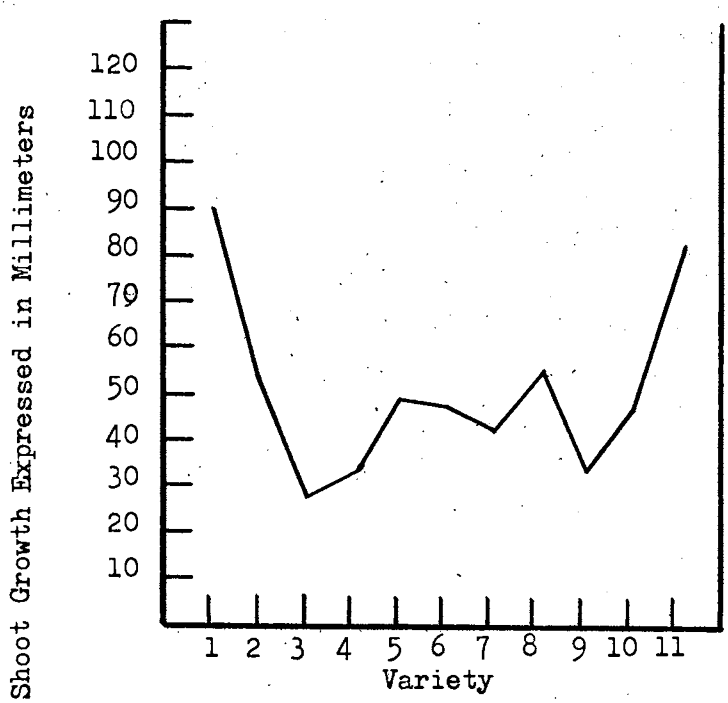

Figure 9. Shoot Growth in Treatment IV (25°C) for 11 Varieties

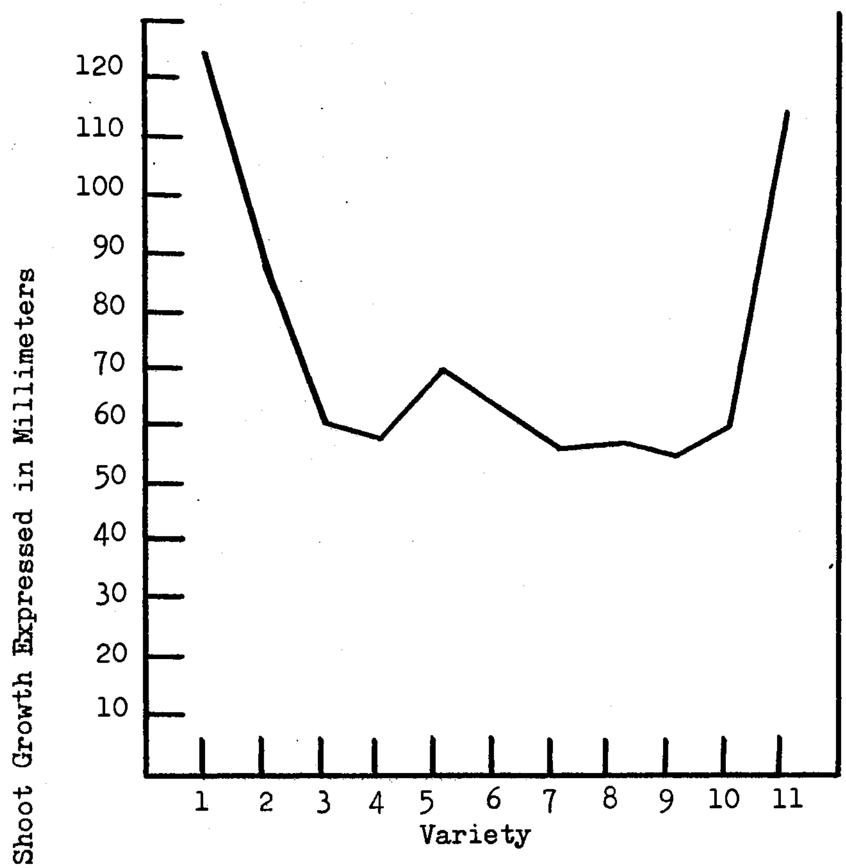

Figure 10. Shoot Growth in Treatment V (30°C) for 11 Varieties

Percent Emergence

The means of the treatments for percent emergence showed a rank of 1, 4, 3, 2 (Table VI). The April 24 planting date did not reduce emergence as had been expected (Table VI and Figure 11).

White Kaoliang had an equal or higher percentage emergence than any other variety within all treatments. Bonar Durra performed well in all treatments compared with other varieties within each treatment. White Kaoliang, Bonar Durra, White Kafir, Kalo, Reliance, Pink Kafir, and Reed Kafir were significantly higher in percent emergence than other varieties at the April 24 planting. Redlan had the lowest percent emergence at the April 24 planting, but produced stands similar to the other varieties in succeeding plantings.

Speed of Emergence

The speed of emergence is considered as a measure of vigor. It was calculated by dividing the number of seedlings per 100 seeds obtained at each counting in the study by the number of days seeds had been planted. The values obtained at each count were then summed at the end of the test to obtain the speed of evergence as suggested by Maguire (14).

The speed of emergence, when plotted by treatment and variety appeared similar to the curves for normal germination (Figures 11, 12, 13, 14).

There were significant differences among varieties for speed of emergence. White Kaoliang performed well consistently and had the highest speed of emergence in three treatments. It was surpassed in treatment 2 by Kalo but the difference was not significant. At the April 24 planting, only Kalo was not significantly below White Kaoliang in speed of emergence. Also at this planting date, Redlan had the slowest speed of emergence, but it was not significantly slower than White Kafir, Kalo, Reliance, Pink Kafir, Reed Kafir, Early Kalo, and Improved Coes.

There was a significant interaction between treatment and varieties. This indicated the varieties did not have a similar pattern of response to treatments.

From the measure of vigor as determined by speed of emergence, performance of White Kaoliang exceeded other varieties with the exception of Kalo in treatment 2. The differences between White Kaoliang and other varieties was not always significant, however.

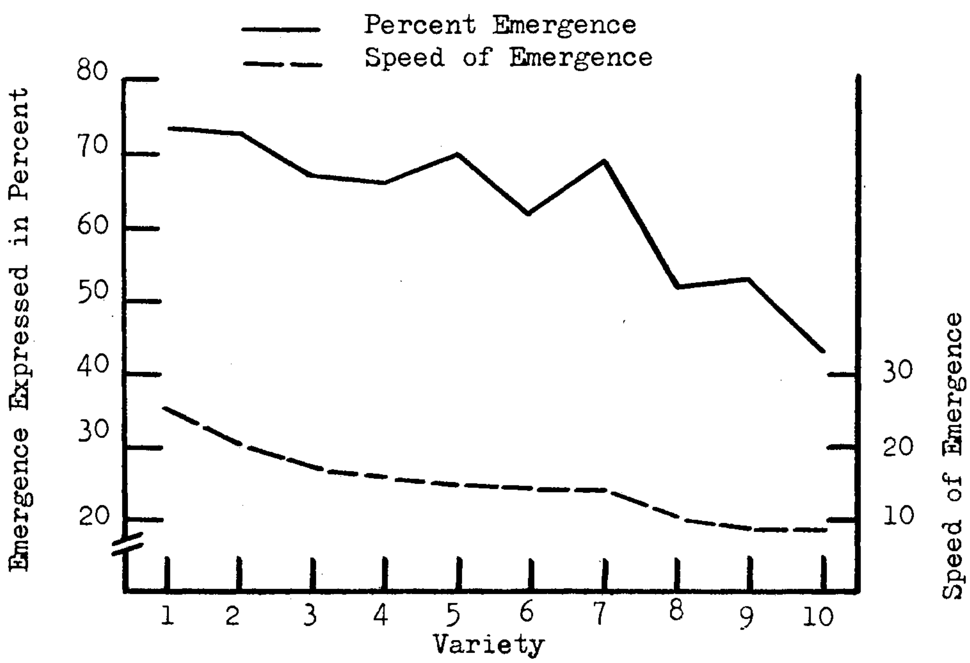

Figure 11. Relationship of Emergence to Speed of Emergence in Planting Date I (April 24) for 10 Varieties

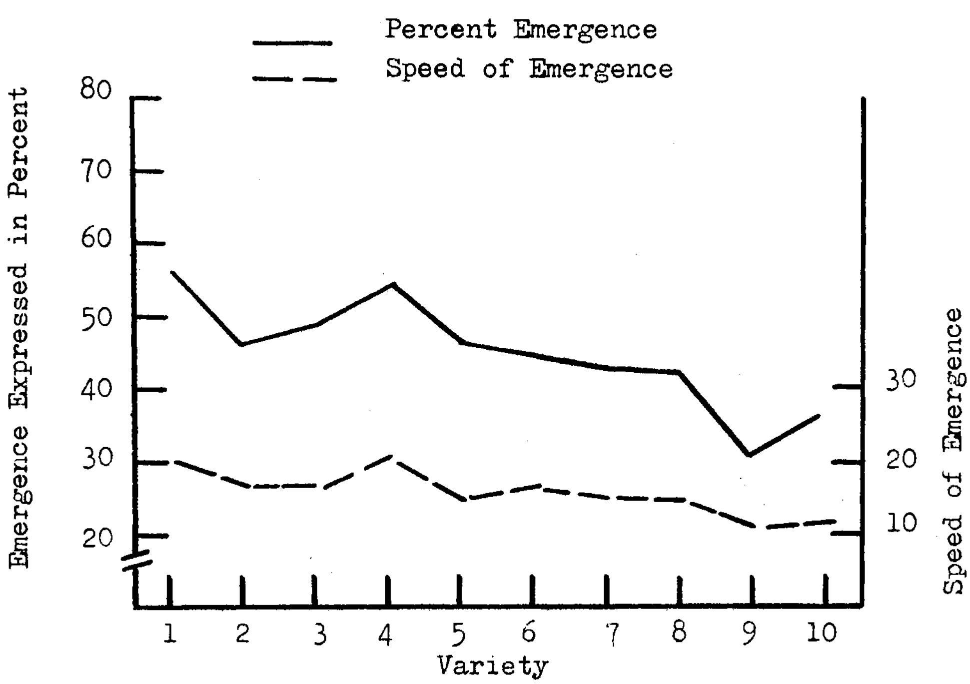

Figure 12. Relationship of Emergence to Speed of Emergence in Planting Date II (May 10) for 10 Varieties

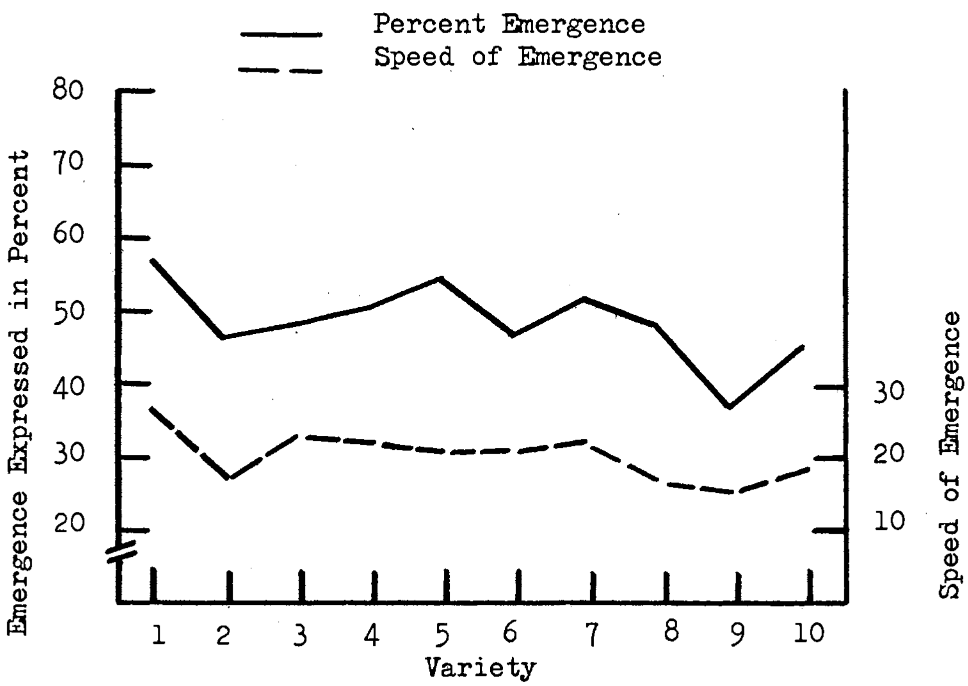

Figure 13. Relationship of Emergence to Speed of Emergence in Planting Date III (May 22) for 10 Varieties

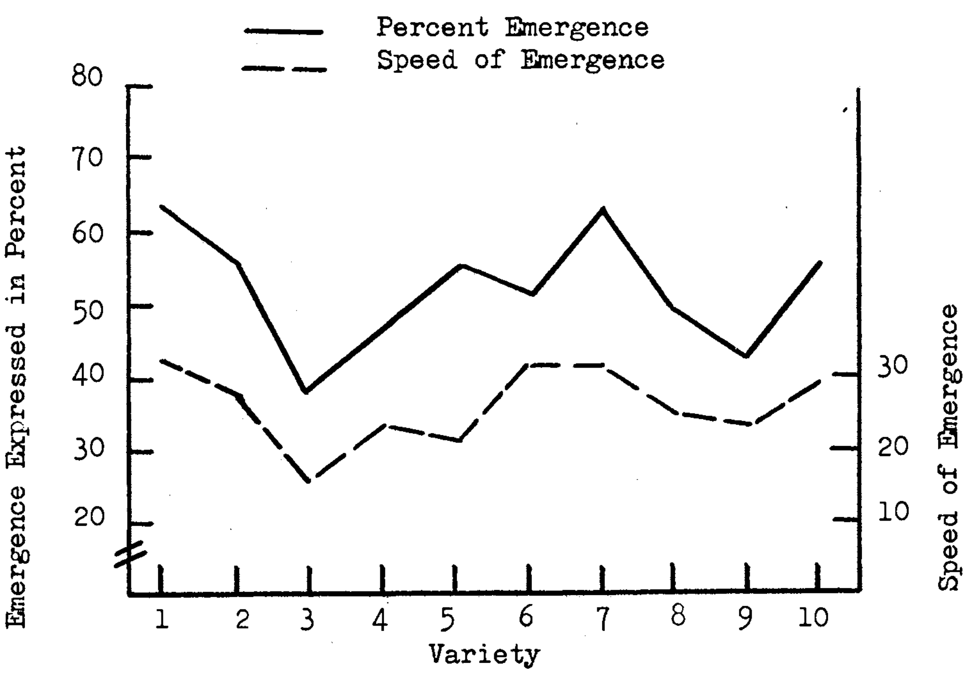

Figure 14: Relationship of Emergence to Speed of Emergence in Planting Date IV (June 5) for 10 Varieties

CHAPTER V

SUMMARY AND CONCLUSIONS

A laboratory study and a field study were conducted to determine by several measurements, the vigor of seedling emergence of different sorghum varieties as compared to a standard sorghum variety. Normal percent germination, speed of germination, and shoot growth were used to measure seed vigor in the laboratory. Percent emergence and speed of emergence were used to measure seed vigor under field conditions.

There is no standard laboratory vigor test recommended for sorghum; therefore, five treatments were included in this part of the study. Treatment 1 consisted of germination at 10°C for 10 days followed by an alternating environment of 20°C for 16 hours of night and 30°C for eight hours of day. Treatments 2, 3, 4, and 5 were conducted in the same manner as treatment 1 except the temperatures were 15°C, 20°C, 25°C, and 30°C respectively, for the initial 10 days of the germinating period.

None of the varieties in treatments 1 and 2 germinated until they were placed in the warm environment. Normal germination for treatments 1 and 2 was first recorded 12 days after initial placement in the germinator. This length of time greatly reduced the speed of germination of treatments 1 and 2 as compared with the other treatments. Many normal seedlings were present in the White Kaoliang and Brown Kaoliang varieties in treatment 3 at 10 days after placement in the germinator and high values were recorded for their speeds of germination. Other varieties had few or no normal seedlings until they were moved to the optimum temperature environment. At that time, White Kaoliang had germinated 80.00 percent and Brown Kaoliang had germinated 38.66 percent. Other varieties had germinated only a small percentage with the maximum being 8.66% for Bonar Durra. Final normal germination percentages and speeds of germination were similar for treatments 4 and 5.

By using speed of germination as a measure of vigor, White Kaoliang appeared to be the best variety at low temperatures. This is based on its performance at the 20°C temperature which is in the suboptimal germinating temperature range. The speed of germination for White Kaoliang in treatment 3 was 39.12 with Brown Kaoliang ranked second at 31.91

Shoot growth was statistically analyzed at 14 days following placement of the varieties in the germinating chambers. By this measurement of vigor, White Kaoliang appeared the best within all treatments. It was not significantly greater than Brown Kaoliang in treatment 1 but was significantly greater than all other varieties within all treatments. The varieties responded similarly to temperature with regard to shoot growth; however, the two kaoliangs were taller than other varieties.

In the field study, White Kaoliang had the greatest percent germination in planting dates 2 and 3. Its germination percentages were matched in planting date 1 by Bonar Durra and in treatment 4 by Reed Kafir. In the field study, White Kaoliang was significantly greater in speed of emergence at the April 24 planting date than all other varieties with the exception of Bonar Durra. White Kaoliang was superior to all varieties in speed of emergence within all other treatments except in treatment 2 where it was surpassed by Kalo but the difference was not significant.

Of the measures of vigor studied, White Kaoliang was superior in most cases to all other varieties studied. Brown Kaoliang also performed well compared with other varieties within each treatment. These two varieties should be considered as possibilities for producing cold tolerant sorghums through a breeding program.

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APPENDIX

TABLE III

AVERAGE PERCENT NORMAL GERMINATION BY TREATMENT AND VARIETY IN LABORATORY STUDY

	Treatment				
Variety	I $10^{o}C$	II $15^{o}C$	III $20^{o}C$	IV $25^{o}C$	V $30^{o}C$
1. White Kaoliang	98.67 a	95.33 ab	100.00 a	94.00 abcd	99.33 a
2. Bonar Durra	89.33 b	90.67 b	96.67 a	92.67 bcd	98.67 a
3. White Kafir	78.67 c	75.33 de	96.67 a	90.00 d	95.33 ab
4. Kalo	79.33 c	74.00 e	99.33 a	100.00 a	100.00 a
5. Reliance	81.33 c	82.67 c	95.33 a	96.00 abc	99.33 a
6. Pink Kafir	82.67 c	82.67 c	100.00 a	98.00 ab	100.00 a
7. Reed Kafir	80.67 c	80.00 cd	89.33 b	90.67 cd	94.00 ab
8. Early Kalo	80.00 c	78.00 cde	96.00 a	100.00 a	100.00 a
9. Improved Coes	80.67 c	77.33 cde	100.00 a	98.67 a	100.00 a
10. Redlan	60.00 d	62.00 f	66.00 b	94.67 abcd	92.67 b
11. Brown Kaoliang	98.67 a	98.67 a	96.67 a	95.33 abcd	98.67 a
Mean	82.73	81.52	94.18	95.45	98.00

Values within a treatment followed by the same letter are not significantly different from each other at the 0.05 level according to Duncan's Multiple Range Test

TABLE IV

AVERAGE SPEED OF GERMINATION BY TREATMENT AND VARIETY IN LABORATORY STUDY

Variety	Treatment I 10°C	II 15°C	III 20°C	IV 25°C	V 30°C
1. White Kaoliang	27.88 a	27.12 a	39.12 a	90.49 bcd	95.53 a
2. Bonar Durra	24.99 a	24.35 a	27.72 b	89.37 cd	95.16 a
3. White Kafir	20.43 b	19.10 bc	26.54 b	85.14 e	91.22 b
4. Kalo	18.66 b	19.23 bc	28.03 b	94.78 a	96.09 a
5. Reliance	19.03 b	20.70 b	27.52 b	90.37 bcd	92.56 ab
6. Pink Kafir	19.48 b	20.94 b	28.06 b	93.55 ab	94.28 ab
7. Reed Kafir	19.40 b	19.14 bc	25.96 b	87.28 de	87.83 c
8. Early Kalo	18.90 b	19.89 bc	27.00 b	93.28 ab	94.37 ab
9. Improved Coes	18.80 b	19.51 bc	27.47 b	95.16 a	95.81 a
10. Redlan	15.47 c	16.95 c	18.30 c	85.78 e	84.71 d
11. Brown Kaoliang	26.55 a	27.47 a	31.91 a	91.95 abc	94.89 a
Mean	20.87	21.31	27.97	90.65	92.95

Speed of Germination was calculated by dividing the number of normal seedlings per 100 seeds obtained at each counting in the germination test by the number of days seeds had been in the germinator. The values obtained at each count were then summed at the end of the test to obtain the speed of germination.

Values within a treatment followed by the same letter are not significantly different from each other at the 0.05 level according to Duncan's Multiple Range Test

TABLE V

AVERAGE SHOOT GROWTH IN MILLMETERS BY TREATMENT AND VARIETY IN LABORATORY STUDY

		Treatment				
Variety		I 10°C	II 15°C	III 20°C	25°C	V 30°C
1.	White Kaoliang	26.33 a	70.00 a	87.67 a	112.00 a	124.33 a
2.	Bonar Durra	20.67 b	30.67 b	50.67 cd	84.67 c	87.33 c
3.	White Kafir	14.00 c	20.67 d	26.67 h	55.00 f	59.33 ef
4.	Kale	12.67 c	25.67 bcd	32.67 g	64.00 d	57.00 f
5.	Reliance	17.00 bc	21.00 d	47.33 cde	62.00 d	69.33 d
6.	Pink Kafir	13.67 c	31.33 b	45.67 def	64.00 d	62.67 e
7.	Reed Kafir	17.33 bc	36.64 a	40.67 f	60.67 de	55.33 f
8.	Early Kalo	14.00 c	27.33 bc	52.67 c	59.00 def	56.33 f
9.	Improved Coes	12.00 c	26.67 bc	30.67 gh	56.00 ef	54.33 f
10.	Redlan	13.67 c	24.33 cd	45.00 ef	64.67 d	59.00 ef
11.	Brown Kaoliang	25.33 ab	50.67 a	79.00 b	105.67 b	112.00 b
	Mean	16.97	33.18	48.97	71.61	72.45

Values within a treatment followed by the same letter are not significantly different from each other at the 0.05 level according to Duncan's Multiple Range Test.

TABLE VI

AVERAGE PERCENT EMERGENCE BY TREATMENT AND VARIETY IN FIELD STUDY

Variety	Planting Date I April 24	II May 10	III May 22	IV June 5
1. White Kaoliang	73.33 a	56.33 a	58.66 a	63.00 a
2. Bonar Durra	73.33 a	46.33 abc	46.66 ab	58.33 ab
3. White Kafir	63.00 abc	49.33 ab	49.00 ab	38.00 c
4. Kalo	66.00 abc	55.00 a	51.66 ab	46.66 abc
5. Reliance	70.33 a	47.00 abc	54.33 ab	55.00 ab
6. Pink Kafir	61.00 abc	45.66 abc	47.33 ab	51.00 abc
7. Reed Kafir	69.00 ab	45.00 abc	52.33 ab	63.00 a
8. Early Kalo	52.00 cd	45.00 abc	49.33 b	49.66 abc
9. Improved Coes	53.00 cd	31.66 c	36.66 b	43.00 bc
10. Redlan	43.66 e	36.33 bc	45.66 ab	55.66 ab
Mean	62.53	45.77	49.17	52.33

Values within a planting date followed by the same letter are not significant different from each other at the 0.05 level according to Duncan's Multiple Range Test

TABLE VII

AVERAGE SPEED OF EMERGENCE BY TREATMENT AND VARIETY IN FIELD STUDY

Variety	Planting Date I April 24	II May 10	III May 22	IV June 5
1. White Kaoliang	24.83 a	21.04 a	26.76 a	32.29 a
2. Bonar Durra	21.09 ab	16.88 ab	18.91 ab	27.71 ab
3. White Kafir	16.67 bc	17.62 ab	22.35 ab	14.80 c
4. Kalo	15.85 bc	21.26 a	22.30 ab	23.57 b
5. Reliance	15.69 bc	15.82 ab	20.22 a	21.29 bc
6. Pink Kafir	14.67 bc	16.68 ab	20.57 ab	25.15 ab
7. Reed Kafir	14.39 bc	16.41 ab	22.00 ab	31.75 a
8. Early Kalo	10.31 c	15.76 ab	17.67 ab	24.47 ab
9. Improved Coes	9.83 c	11.53 b	15.76 b	22.56 b
10. Redlan	9.71 c	13.27 ab	19.41 ab	28.40 ab
Mean	15.30	16.63	20.69	25.20

Speed of Emergence was calculated by dividing the number of seedlings per 100 seeds obtained at each counting in the field test by the number of days seeds had been planted. The values obtained at each count were then summed at the end of the test to obtain the speed of emergence

Values withing a planting date followed by the same letter are not significantly different from each other at the 0.05 level according to Duncan's Multiple Range Test

TABLE VIII

ANALYSIS OF VARIANCE PERCENT NORMAL GERMINATION OF SORGHUM VARIETIES

Source	D.F.	M.S.
Treatment	4	1942.2061**
Error a	10	7.3697
Varieties	10	563.7770**
Treatment X Variety	40	110.7527**
Error b	100	10.3830
Total	164	115.5409

TABLE IX

ANALYSIS OF VARIANCE FOR SPEED OF GERMINATION OF SORGHUM VARIETIES

Source	D.F.	M.S.
Treatment	4	46625.2889**
Error a	10	7.6150
Varieties	10	152.6709**
Treatment X Variety	40	19.1991**
Error b	100	3.5436
Total	164	1153.8191

TABLE X

ANALYSIS OF VARIANCE OF SHOOT GROWTH OF SORGHUM VARIETIES

Source	D.F.	M.S.
Treatment	4	19277.3182**
Error a	10	15.5273
Variety	10	3913.0982**
Treatment X Variety	40	232.0815**
Error b	100	10.2139
Total	164	772.5621

TABLE XI

ANALYSIS OF VARIANCE OF PERCENT EMERGENCE OF SORGHUM VARIETIES

Source	D.F.	M.S.
Treatment	3	1571.344*
Error a	8	382.158
Variety	9	490.541**
Treatment X Variety	27	95.783 N.S.
Error b	72	82.436
Total	119	174.014

TABLE XII

ANALYSIS OF VARIANCE FOR SPEED OF EMERGENCE OF SORGHUM VARIETIES

Source	D. F.	M.S.
Treatment	3	597.7088*
Error a	8	82.7696
Variety	9	116.6323**
Treatment X Variety	27	30.5381*
Error b	72	18.3694
Total	119	47.4966

VITA

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